Respiratory disease in the Middle Nile Valley:A bioarchaeological analysis of the impact of environmental and sociocultural change from the Neolithic to Medieval periods

DAVIES-BARRETT, ANNA,MYFANWY

Respiratory disease in the Middle Nile Valley:

A bioarchaeological analysis of the impact of environmental and sociocultural change from the Neolithic to Medieval periods

Anna Myfanwy Davies-Barrett

Thesis submitted for the degree of Doctor of Philosophy

Department of Archaeology,
Durham University
&
Department of Ancient Egypt and Sudan,
The British Museum

Submitted to Durham University

2018

Abstract

Respiratory disease in the Middle Nile Valley: a bioarchaeological analysis of the impact of environmental and sociocultural change from the Neolithic to Medieval periods.

Today, poor air quality is a major world-wide health burden, causing 4.2 million premature deaths per year globally, including from respiratory disease. Particulate pollution irritates and inflames the respiratory tract, increasing susceptibility to the development of respiratory conditions. Non-specific bone changes in the sinuses and on the visceral surfaces of the ribs have been linked to inflammation of the respiratory tract, caused by sinusitis and lower respiratory tract diseases. Analysis of these changes in archaeological populations is providing an historical perspective on the impact of environment, activities related to occupation, and associated socio-economic factors, such as poor ventilation in living and work spaces and low levels of hygiene, which potentially can all lead to exposure to poor air quality.

This study investigates the prevalence of abnormal bony changes to the sinuses and ribs in human skeletons from twelve Sudanese sites, ranging from the Neolithic to the Medieval periods (5000 BC – AD 1500), with a particular focus on the Fourth Nile Cataract area and comparative sites from other regions of the Nile Valley with differing sociocultural and environmental conditions. A total of 493 adults (aged 17+ years) were analysed. Changes in prevalence between sex, age, time period, and geographical region were examined. Prevalence rates of new bone formation on the visceral surfaces of the ribs displayed a general trend towards an increase in later time periods, while the frequency of bony changes associated with maxillary sinusitis remained remarkably consistent at around fifty percent in all Fourth Cataract sites. The data from the comparative sites displayed greater variation. The lowest prevalence rates for bony changes associated with respiratory disease were observed at the Neolithic site (R12) and the highest at the urban Medieval site (Soba East).

In Sudan increasing aridity from the Neolithic period until the modern day may have led to a growing exposure to environmental particulate matter from airborne dust and sand. The impact of increasing aridity, agricultural intensification, urbanisation, craft specialisation, and the emergence of visible signs of infectious diseases such as tuberculosis and leprosy, are all discussed in relation to the prevalence rates of respiratory disease between time periods and geographical regions. Changes in the environment in the Middle Nile Valley may have had a distinct effect on the presence of respiratory disease, in conjunction with exposure to other sources of particulate pollution and infectious diseases. This study of respiratory disease in Sudan provides a contextually driven perspective on a problem that is of increasing concern today across the world.

Table of contents

List of tables

Tables in main text

Tables in Appendices

List of figures

List of acronyms and abbreviations

ALRI	Acute lower respiratory tract infection
AMs	Alveolar macrophages
CDC	Centres for Disease Control and Prevention
CRIPEL	Cahir de Recherches de l'Institut de Papyrologie et d'Égyptologie de Lille
CT	Computed tomography
EF	Emission factor
FET	Fisher's Exact Test
FIRS	Forum of International Respiratory Societies
HAP	Household air pollution
HOA	Hypertrophic osteoarthropathy
IPR	Inflammatory periosteal reaction
NCAM	National Corporation for Antiquities and Museums of Sudan
NHS	National Health Service
PM	Particulate matter
SARS	Sudan Archaeological Research Society
SEM	Scanning electron microscope
TB	Tuberculosis
UFP	Ultrafine particles
UK	United Kingdom
USA	United States of America
WHO	World Health Organization

Statement of copyright

Acknowledgements

Firstly, I must thank my primary supervisors, Prof. Charlotte Roberts and Dr Daniel Antoine, who conceived of this project together and put their trust in me to undertake it. I could not have asked for a better, or a more complementary, pair of supervisors and I am deeply thankful for the support, advice, and feedback they have provided me with over the past three years. I would also like to thank my secondary supervisors, Dr Derek Welsby and Dr Penny Wilson, for taking the time to provide me with valuable feedback and answer my archaeology-based queries. I count myself very lucky to have had the expert advice of a wonderful team of supervisors.

Acknowledgements must go to the Arts and Humanities Research Council, who kindly funded this research as a Collaborative Doctoral Award (CDA). The excellent CDA scheme, both within the British Museum and consortium wide, has provided me with valuable information and training. I would also like to thank all the members of the Department of Ancient Egypt and Sudan, at the British Museum, who accepted me into the fold and have provided me with the dream workplace (and a plentiful supply of cake) for the last two and a half years. Aspects of this research would also not have been possible without the generous loan of an endoscope by the Department of Scientific Research at the British Museum, for which I am very thankful.

I have had the good fortune to share a lab with a number of wonderful people over the years, not only during my thesis but as an undergraduate and masters student also. To those from Kent, Sheffield, Durham, and the Museum, I cannot name you all, but our conversations have kept me curious and informed, broadening my perspective on bioarchaeology. I am so very grateful to all those who have shared their research and interests with me. A special thanks must go to Becka Whiting and Tatiana Vlemincq Mendieta, my dearest of lab-mates. I cannot put into words the appreciation I have for your continued friendship and support. I hope my incessant gifts of plants will say it for me. Moreover, this thesis would never have made it to existence if it weren't for the most generous loan of a laptop by Becka. I can always count on you to save the day.

To my family and friends, though you might not have always quite understood what I've been up to all this time, your words of encouragement and support have kept me going and left me feeling loved and for that I am eternally grateful. In particular, I would like to express my thanks to Shân and Jeff for kindly housing me when I first moved to London and to my mother for patiently listening to all my complaints. Finally, I must thank my one and only, Moose, who has been there for me from the start to the finish and every minute in between. I love you. But most importantly, thanks for all the tea.

Chapter 1: Introduction

1.1 Introduction

Respiratory disease is a major worldwide health burden today and has been linked to exposure to poor air quality from indoor and outdoor particulate pollution (e.g. Ferkol & Shraufnagel, 2014; FIRS, 2017). Particulate matter from a variety of sources, both human-made and natural, can cause irritation and inflammation of the respiratory tract, resulting in a greater susceptibility to respiratory diseases (e.g. Trevino, 1996; van Eeden et al., 2001; Jang, 2012; Lee et al., 2015; Rylance, Chimpini et al., 2015; Rylance, Fullerton, et al., 2015). Today, there is an increasing public concern about the effect of air pollution on health, particularly from industrial and vehicle emissions (Jiang et al., 2016:E31). A recent factsheet released by the World Health Organisation (WHO) (2018a) indicates that 4.2 million premature deaths per year globally, including from respiratory disease, are caused by poor outdoor air quality. In developing countries, the use of biomass fuels for cooking and heating also produces high concentrations of indoor air pollution, posing a considerable threat to respiratory health (e.g. Bruce et al., 2000, 2002; Amegah & Jaakkola, 2016). While the high burden of respiratory disease is often considered in a more recent context, particulate pollution was also likely to have been a common problem in the past.

In bioarchaeological studies of the human skeleton, bony changes within the maxillary sinuses and new bone formation on the visceral (inner) surfaces of the ribs are commonly observed. These changes are thought to be the result of chronic sinusitis, associated with inflammation of the upper respiratory tract (e.g. Lewis et al., 1995:497-498; Roberts, 2007:795), and inflammation of the lungs and pleura, commonly caused by lower respiratory tract diseases (e.g. Pfeiffer, 1991:197; Roberts, Boylston, et al., 1998:58; Nicklisch et al., 2012:401). This association is supported by clinical evidence (e.g. Tovi et al., 1992; Eyler et al., 1996; Perloff et al., 2000; Cho et al., 2006; Mafee et al., 2006; Porres et al., 2017). Thus, the prevalence of respiratory disease in past populations can be investigated by observing the frequency of bone changes in the sinuses and on the visceral surfaces of the ribs.

Bioarchaeological studies have suggested that there may be a relationship between the prevalence of respiratory disease in past populations and risk factors linked to exposure to poor air quality and infectious diseases, such as climate, socio-economic status, ventilation and sanitation within the living space, and activities related to occupation (e.g. Pfeiffer, 1991; Lewis et al., 1995; Merrett & Pfeiffer, 2000; Roberts, 2007, 2009; Bernofsky, 2010; Sundman & Kjellström, 2013). This is reinforced by a large body of evidence in the clinical literature supporting an association between exposure to poor air quality and an increased susceptibility to respiratory disease. Therefore, the study of respiratory disease in past populations can provide a valuable longterm historical perspective to a problem that is of increasing public concern today.

While there have been a number of bioarchaeological studies of respiratory disease, these have tended to be limited to investigations of populations from fairly temperate regions. Arid environmental conditions, including high levels of ambient particulate matter inherent in desert environments and dust storms, have been linked to increased rates of respiratory disease and hospital admissions (e.g. Hefflin et al., 1994; Meng & Lu, 2007; Bell et al., 2008; Lai & Cheng, 2008; de Longueville et al., 2013; Ebrahimi et al., 2014; Korzeniewski et al., 2015 Singh et al., 2016; Saers et al., 2017; Trianti et al., 2017). Therefore, a bioarchaeological study of the prevalence of bony changes in the sinuses and on the visceral surfaces of the ribs in people living in arid environments can contribute to a greater understanding of the impact of different environments on respiratory disease in the past. The current study considers evidence for respiratory disease in past people from the Middle Nile Valley, an environment that became increasingly arid from 5000 BC onwards.

1.2 The Middle Nile Valley

The Middle Nile Valley runs from the 1st Nile Cataract, just north of the Egypt-Sudan border, to the Khartoum region in the south of the Republic of the Sudan (Geus, 1986:7) (see Figure 4.1). Since the end of the African Humid Period, around the beginning of the Neolithic period (c. 5000 BC), this region has undergone a gradual increase in aridity over time, culminating in the desert and semi-desert conditions seen in Sudan today (Nicoll, 2004; Kuper & Kröpelin, 2006; Gatto & Zerboni, 2015). The increase in aridity and the encroachment of the desert is likely to have introduced higher concentrations of aeolian (windblown) dust and sand (Field et al., 2010:425; Ravi et al., 2011:7). A previous palaeopathological analysis of people buried at the Middle Nile Valley site of Amara West, dating between 1280 and 800 BC, found elevated prevalence rates of both maxillary sinusitis and new bone formation on the ribs (Binder, 2014:Tables 8.46 & 8.49). In the later phases of occupation at this site the advancing desert and aeolian sand caused a considerable problem for the inhabitants (Spencer et al., 2012:41-42; Spencer, 2015:195-196) and, alongside exposure to smoky environments from indoor fires and industrial kilns, may have increased susceptibility to respiratory disease (Binder, 2014:304-305). Therefore, aridity, alongside other factors, may have had a considerable impact on the prevalence of respiratory disease in people living in the Middle Nile Valley through time. This region has also undergone changes in subsistence strategies, types of housing, and practices related to occupation, religion, ideology, and trade that may have also affected exposure to particulate pollution or pathogens causing respiratory disease. This includes the development over time of more substantial but less ventilated housing, urban centres with industrial zones dedicated to metalworking and pottery, and the establishment of extensive trade networks.

Between 1995 and 2007 work was undertaken to salvage archaeological material from the Fourth Cataract region of the Middle Nile Valley before the construction of the Merowe Dam, which led to extensive flooding of the area. As part of this project the Sudan Archaeological Research Society (SARS) surveyed and excavated a 40km concession within this region, including numerous cemetery sites from different time periods (e.g. Welsby, 2000b, 2003b:26). Many of the human remains excavated by SARS from the Fourth Cataract region were generously donated to the British Museum by the National Corporation for Antiquities and Museums, Sudan (NCAM). This large collection of skeletons from a single region provides a rare opportunity to investigate changes in respiratory disease over a long period of time within a small geographical area, controlling for regional-based differences and climates. The British Museum also curates several sites from other regions of the Middle Nile Valley with different environments, cultural practices, and subsistence economies, which were available to analyse for comparative data.

1.3 Research questions

It was hypothesised that prevalence rates of respiratory disease in the Middle Nile Valley might increase over time, and correlate with increasing aridity and greater concentrations of dust and sand in the environment. However, a number of other risk factors during different time periods may have also to the exposure of people to poor air quality or pathogens causing respiratory disease, including sociocultural factors and activities related to occupation. The aim of the current research was to investigate changes in the prevalence of bony changes associated with respiratory disease in the Middle Nile Valley through time, in particular in the Fourth Cataract region, using associated archaeological, historical, and palaeoenvironmental data to explore the potential impact of environment and changing sociocultural factors.

A series of research questions were produced to guide this research:

1. How prevalent were bony changes associated with respiratory disease in populations living in the Fourth Cataract region of Sudan?

2. How do observed patterns compare with Middle Nile Valley sites outside the Fourth Cataract with differing practices and environments?

3. Did the prevalence of bony changes associated with respiratory disease change over time and correlate with differences in climate and environment, as well as changes in social, cultural and occupational practices?

4. Did evidence for respiratory disease vary according to sex and age?

These research questions were addressed by analysing skeletons dating from between the Neolithic and Medieval periods (5000 BC – AD 1500). In the Fourth Cataract eight cemetery sites, thought to represent rural agricultural communities, were analysed, and four comparative sites from different regions to the north and south of the Fourth Cataract were also investigated. These sites were chosen to represent different environments, cultural practices, and/or subsistence economies.

1.4 Thesis overview

This thesis contains nine chapters. Following on from an introduction in the current chapter, Chapter 2 contains a review of clinical data related to maxillary sinusitis and lower respiratory tract disease. This includes the aetiology and pathogenesis of these diseases and clinical studies linking inflammation of the respiratory tract to bony changes in the sinuses and on the visceral surfaces of the ribs. The clinical evidence for the effect of poor air quality on respiratory disease is also discussed. Chapter 3 provides a review of bioarchaeological studies which have explored the evidence for respiratory disease in human skeletal populations. The methods, results, and conclusions of these studies, particularly in relation to the potential aetiologies of respiratory disease in different populations, are discussed. Chapter 4 presents an archaeological and historical summary of the Middle Nile Valley during each time period represented in this study. Principally, factors that may have had an effect on respiratory disease during different time periods are discussed, including changes in the environment, habitation, ideology, subsistence economy, trade, and activities related to occupation. In Chapter 5 the different cemetery sites, from which the skeletons analysed derived, are presented alongside available archaeological data from the sites themselves and any nearby settlements, to provide further site-specific context. The methods developed and employed in this research are outlined in Chapter 6 and the results of the study are presented in Chapter 7. Chapter 8 discusses the results, including differences and similarities between sites and time periods, within the context of the archaeological, historical, and palaeoenvironmental data. This chapter also compares the data from the current research to those of other bioarchaeological studies of respiratory disease, to identify general differences or similarities between geographical regions, environments, and subsistence economies. Comparisons between sex and age groups are also made and several considerations for the bioarchaeological study of respiratory disease are discussed in relation to the results from this research, including the problems of identifying odontogenic sinusitis and differentiating possible causes of lower respiratory tract diseases. Finally, this chapter also presents the limitations of the current study and recommendations for future research. The findings of the thesis are briefly summarised in Chapter 9. The original research questions are revisited and the significance of the study for understanding respiratory disease in past populations is suggested.

Chapter 2: A clinical review of sinusitis and pleural disease

2.1 Introduction

Investigating the differences between prevalence rates of respiratory disease in archaeological populations cannot be undertaken without first having an understanding of current clinical data regarding sinusitis and pleural disease. The following chapter has three major sections. The first two sections present clinical data regarding sinusitis and pleural disease, respectively. Each section includes the anatomy of the organs and tissues affected by inflammation, their pathogenesis and aetiologies, and the clinical evidence for bony changes related to inflammation caused by disease or particulate pollution. The final section discusses the clinical evidence for one of the major factors leading to respiratory problems: poor air quality. This includes a review of epidemiological studies linking particulate matter to increased rates of respiratory disease and current understanding of the pathogenesis of inflammation caused by the inhalation of particulates.

2.2 Sinusitis

Sinusitis is generally described as inflammation of the mucous membrane that lines the paranasal sinuses, affecting one or more of the sinuses (Slavin et al., 2005:S16; Ah-See & Evans, 2007:358; Brook, 2009:126). Symptoms include nasal congestion, headache, cough, purulent nasal discharge, post-nasal drainage, fever, fatigue, dental pain, facial pressure or pain, ear pressure or ache, and halitosis (Slavin et al., 2005:S16; Steele, 2005:466-467; Brook, 2009: Table 3). Maxillary sinusitis, specifically, is often accompanied by pain in the cheeks (Brook, 2009:133). Incidences can be divided into acute sinusitis that lasts for up to four weeks, subacute sinusitis lasting between four to twelve weeks, and chronic sinusitis with symptoms lasting beyond twelve weeks (Slavin et al., 2005:S16; Brook, 2009:126). It is considered an extremely common disease and in the United States has been estimated to affect between 12 and 16% of the adult population annually (Slavin et al., 2005:S15; Brook, 2009:126; CDC, 2016). The following sections present information regarding the anatomy of the sinuses, the pathogenesis of sinusitis, the different aetiologies of the disease, the clinical evidence for bone changes related to sinusitis, and the potential complications if the disease is left untreated.

2.2.1 Anatomy of the sinuses

The paranasal sinuses consist of eight air-filled spaces, located bilaterally on either side of the facial region of the skull (Brook, 2009:126) (Figure 2.1). Comprising the maxillary, ethmoidal, frontal and sphenoidal sinuses, these cavities are lined by the mucosa: a layer of pseudostratified ciliated columnar epithelium, interspersed by goblet cells which produce mucus (Slavin et al., 2005:S22; Brook, 2009:126). Each sinus drains into the nasal cavity through an ostium, a small tubular opening (Brook, 2009:126). The ostia of the frontal, maxillary, and anterior ethmoidal sinuses all drain into an interconnected pathway, often referred to as the ostiomeatal complex, which drains into the middle meatus of the nasal cavity (Wald, 1995:341; N. Jones, 2001:16; Slavin et al., 2005:S22; Brook, 2009:126). The paranasal sinuses act as the first line of defence against potential pathogens from the external environment by trapping inhaled particulate matter within the mucus, while the cilia (tiny hair-like cellular structures) pulsate to sweep mucus towards the ostial opening and into the throat where it is then swallowed (N. Jones, 2001:8; Slavin et al., 2005:S22).

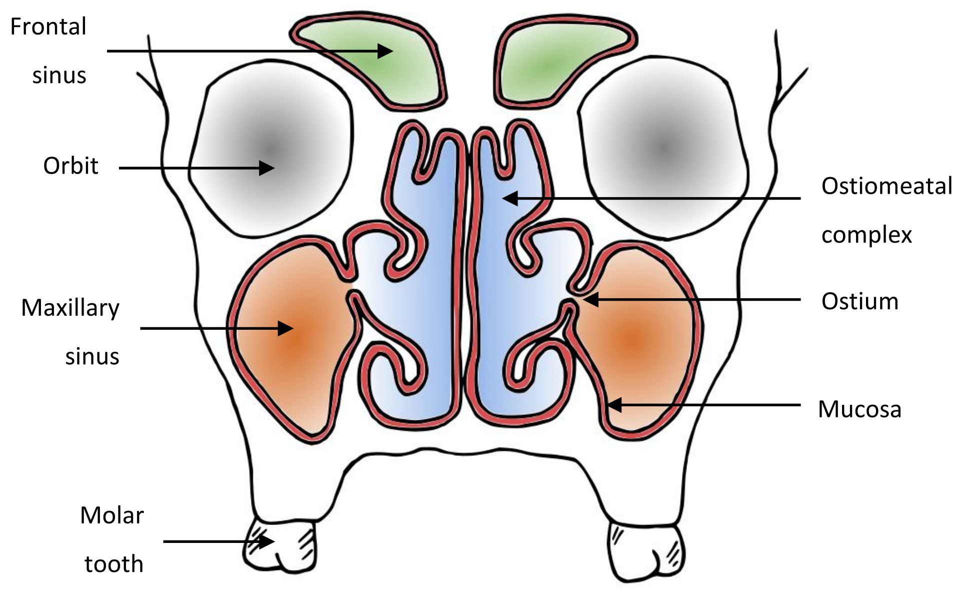


Figure 2.1 – A coronal section of the anterior portion of the cranium, demonstrating the bilateral position of the maxillary and frontal sinuses and the ostiomeatal complex.

The maxillary sinus, also referred to as the antrum, is the largest of the paranasal sinuses and is located on either side of the maxilla, which makes up the floor and walls of the sinus cavity, while the roof is formed by the floor of the orbit (Bolger, 2001:8; Slavin et al., 2005:S22). The ostium is located high on the supramedial aspect of the sinus wall and drains into the middle meatus through the ostiomeatal complex (Wald, 1995:339; Slavin et al., 2005:S22). The maxillary sinus first develops within the foetus during the third month of pregnancy (Brook, 2006:349). However, the final developmental stage does not occur until the ages of between 12 and 14 years, corresponding with the eruption of the majority of the permanent dentition and the growth of the maxillary alveolar process (Scuderi et al., 1993:1102; Brook, 2006:349; Mehra & Jeong, 2009:238). Although the average volume of the fully developed maxillary sinus reaches from between 15 to 20 mL (Brook, 2006:349; Mehra & Jeong, 2009:238), the size and shape of the sinus can vary considerably (Bolger, 2001:1) and remodelling and expansion of the sinus floor into the alveolar bone may continue following tooth loss (Brook, 2006:349-350).

2.2.2 Pathogenesis

A major factor in the pathogenesis of sinusitis is the blockage of the sinus ostium or the ostiomeatal complex (Wald, 1995:340; Hamilos, 2000:215; Slavin et al., 2005:S22; Ah-See & Evans, 2007:359; Brook, 2009:126). The sinus is reliant on the ostium for ventilation and drainage (Slavin et al., 2005:S22). Therefore, a blockage can lead to absorption of oxygen and changes in pressure within the sinus, and a decrease in mucociliary clearance leading to retention of secretions (Wald, 1995:341; Slavin et al., 2005:S22; Steele, 2005:466; Brook, 2009:126). The build-up of secretions, the lack of oxygen, and a lowering of the pH within the sinus can facilitate the growth of anaerobic bacteria and cause damage to the cilia, promoting purulent infection of the sinus (Wald, 1995:340; Nacleiro & Gungor, 2001:47; Slavin et al., 2005:S22; Brook, 2009:128). Most commonly prone to blockage are the narrow channels of the ostiomeatal complex, obstructing drainage into the middle meatus and leading to sinusitis within the connected maxillary, anterior ethmoid, and frontal sinuses (Bolger, 2001:7; Hamilos, 2000:215; Slavin et al., 2005:S22). The ostium of the maxillary sinus also seems to be commonly prone to blockage (Ah-See & Evans, 2007:359) and its position high on the medial wall, which restricts gravitational drainage, may also predispose to mucus accumulation and sinusitis (Wald, 1995:339).

2.2.3 Aetiology

The major cause of ostial blockage is inflammation of the mucosa, triggered by a viral upper respiratory tract infection or allergic reaction, leading to sinus ostial narrowing (Wald, 1995:341; Hamilos, 2000:213, 216; Nacleiro & Gungor, 2001:50; Ah-See & Evans, 2007:359; Brook, 2009:126). This is subsequently followed by bacterial infection, most commonly by *Streptococcus pneumoniae*, *Haemophilus influenzae*, *Moroxella catarrhalis*, and, in chronic sinusitis, also with *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and certain types of anaerobic bacteria (Hamilos, 2000:216;

Slavin et al., 2005:S16; Brook, 2009:127-128). Other factors predisposing to inflammation of the mucosa or blockage of the ostium include craniofacial anomalies (such as cleft palate), anatomical variations, nasal obstructions (such as nasal polyps, tumours, and foreign bodies within the sinus), trauma or fracture to the nose (including septal dislocation), cystic fibrosis, dental infection, congenital or acquired immunodeficiency, certain infectious diseases, conditions such as asthma or fungal allergies, and other environmental factors such as poor air quality (Hamilos, 2000:215; Nacleiro & Gungor, 2001:Table 4–1; Steele, 2005:Table 1; Brook, 2009:126). However, certain causes, such as congenital conditions or immunodeficiencies, may rarely be detected within the archaeological record. Individuals suffering from these conditions would have been unlikely to survive into adulthood and their remains may not be detectable in the archaeological record for various reasons (Lewis et al., 1995:498). Conversely, aetiologies, such as infectious disease, allergies, anatomical variation, dental infection, and poor air quality, may have been common during certain time periods in the past.

2.2.3.i Infectious disease

Infectious diseases such as leprosy and tuberculosis can predispose an individual to the development of sinusitis (Slavin et al., 2005:S29). For example, infection of the mucosa of the upper respiratory tract in lepromatous leprosy is a common occurrence, and the paranasal sinuses are often affected (Hauhnar et al., 1992:390; Sharma et al., 1998:201; Kiris et al., 2007:15). Leprosy-related infection of the sinuses can lead to mucosal thickening, inflammation and ulceration (Hauhnar et al., 1992:394), and the development of polyps (Sharma et al., 1998:202). It most commonly affects the maxillary sinuses and has been observed in clinical studies in 55-60% of patients with lepromatous leprosy (Hauhnar et al., 1992:393; Sharma et al., 1998:203), although one study has reported maxillary sinus involvement in 100% (16/16) of patients (Barton, 1979:597). Although rare, sinus involvement (particularly of the maxillary sinuses) has also been noted in tuberculosis, including the formation of polyps, obstruction of the middle meatus, mucosal thickening, or destructive loss of bone (Kant et al., 2013:175; Kim et al*.,* 2014:815; Upadhyay et al., 2014:2). Both tuberculosis and leprosy have been suggested as factors predisposing to high frequencies of sinusitis observed in archaeological populations (see Section 3.2.2.v).

2.2.3.ii Allergic sinusitis

Allergic reactions and asthma have been closely linked to a predisposition to sinusitis. Allergic rhinitis, caused by the inhalation of allergens, leads to inflammation of the mucosa and the formation of nasal polyps, which can both lead to ostial blockage. In clinical studies allergic rhinitis has been observed in association with chronic sinusitis in 36% to 60% of children and 40% to 84% of adults (Nacleiro & Gungor, 2001:51; Slavin et al., 2005:S30). A significant correlation between sinusitis and asthma has also been found (Wald, 1995:343; Nacleiro & Gungor, 2001:51; Slavin et al., 2005:S35), although the common causal factor between the two is as yet unknown (Slavin et al., 2005:S16). However, the fact that there exists a direct cause-and-effect relationship between asthma and sinusitis has been demonstrated by studies showing a significant improvement in asthma symptoms in individuals who have been treated for sinusitis (Slavin et al., 2005:S35; Ah-See & Evans, 2007:359). Asthma is known to cause nasal polyps, which may produce ostial blockage (Nacleiro & Gungor, 2001:49; Slavin et al., 2005:S35) and it has further been suggested that asthma and sinusitis may represent different reactions to the same inflammatory process occurring throughout the respiratory tract (Slavin et al., 2005:S35). For example, concurrent symptoms of asthma and sinusitis may both be linked to the development of allergic rhinitis (Ah-See & Evans, 2007:359).

A distinct form of sinusitis is caused by inflammatory allergic responses to certain fungal species or invasion of the sinus by fungi (deShazo et al., 1997:254; Hamilos, 2000:219; Dong & Lanza, 2001:179). Allergic fungal sinusitis is common in regions with hot humid weather and high mould spore counts, while invasive fungal sinusitis can occur in any region but is most commonly associated with already immunocompromised individuals (deShazo et al., 1997:257; Hamilos, 2000:219; Slavin et al., 2005:S16, S24). In surgical contexts allergic fungal sinusitis has been associated with a considerable degree of bone remodelling (Kennedy, 2001:202). Additionally, a form of fungal sinusitis named chronic granulomatous invasive fungal sinusitis, although rare in most parts of the world, has been most commonly found in Sudan (Milošev et al., 1969:137; Aribandi et al., 2007:1290). This form of sinusitis causes the formation of granulomas in the sinus tissues and can erode the walls of the sinus (Aribandi et al., 2007:1290).

2.2.3.iii Environmental factors

The environment in which a person lives is likely to have a major effect on an individual's predisposition to sinusitis. As the region of the body first exposed to inspired air, the nose and sinuses are most likely to be affected or damaged by environmental risk factors (Clerico, 2001:107). Particulates and pollutants in the air can cause irritation and stimulate inflammation of the mucosa (Clerico, 2001:108-109; Nacleiro & Gungor, 2001:47). Both indoor and outdoor air pollution, including that caused by chemicals and particulates from industrial activities, toxic gases from tobacco smoke, and the burning of biomass fuels, have been linked to nasal irritation and the development of sinusitis (Koltai, 1994:11; Trevino, 1996:239; Clerico, 2001:111-112; Nachman &

Parker, 2012:6). Environmental factors such as poor ventilation, overcrowding, decreased humidity, and poor levels of sanitation and hygiene will also lower host defence mechanisms and increase the likelihood of sinusitis due to exposure to viral and bacterial pathogens (e.g. Arundel et al., 1986:358; Lewis et al., 1995:499; Min et al., 1996:436-437; Aiello & Larson, 2002; Roberts, 2007:795; Wolkoff & Kjærgaard, 2007). Exposure to allergens, pollens, dust, animal hairs, and moulds within the environment are also likely to cause an inflammatory reaction within the sinuses (e.g. Zuskin, 1988, 1990, 1995; Lewis et al., 1995:499; Lombardi et al., 1996:145; Roberts, 2007:795; Gao et al., 2016:3) (see Section 2.4). The possible influence of these factors on prevalence rates of maxillary sinusitis in archaeological populations has been discussed extensively in bioarchaeological studies (see Section 3.2.2.i).

2.2.3.iv Anatomical variation

Anatomical variations in the sinuses or nasal bones that may cause blockage or impair ventilation and mucociliary clearance include concha bullosa (enlargement of the middle nasal conchae), septal deviations, uncinated process abnormalities, and infraorbital ethmoid cells (Bolger, 2001:10). However, anatomical variations rarely cause sinusitis and even those most commonly linked to the disease, such as extreme concha bullosa, are present in significantly high numbers without any proven association with sinus infection (Bolger, 2001:10; Nacleiro & Gungor, 2001:48). A correlation between the two may be even harder to determine in archaeological populations. An investigation into the frequency of maxillary sinusitis in individuals exhibiting nasal septal deviation in the medieval archaeological population of Wharram Percy, England, found no significant relationship between the two conditions (Mays, 2012). Mays et al. (2011:187) have also discussed the difficulty in identifying anatomical variations, such as concha bullosa, in relation to sinus disease in archaeological populations, where the delicate nasal and ethmoid bones are often not presevred or damaged during excavation, and where anatomical variations are often overlooked by bioarchaeologists. Nevertheless, a study of a small archaeological sample of skeletons, to investigate the relationship between anatomical variations in nasal height, width, or size and the presence of sinus infection, found no correlation between nasal index and the presence or absence of sinusitis (Bereza, 2016:74).

It is worth noting that the sinuses continue to expand (known as pneumatisation) with age, particularly with tooth loss, which is a common occurrence in older individuals (Brook, 2006:349-350; Mehra & Jeong, 2009:238). It has also been suggested that larger sinuses may increase susceptibility to sinusitis (Roberts, 2007:794). A clinical study by Sánchez Fernández et al. (2000:277) found that individuals suffering from chronic sinusitis on average had larger sinuses.

Therefore, this may be a factor in the increase in rates of sinusitis with age observed in some bioarchaeological studies (e.g. Panhuysen et al., 1997:Table 3; Merrett & Pfeiffer, 2000:Table 1; Liebe-Harkort, 2012:392). However, other clinical studies have found that individuals suffering from sinusitis have smaller sinuses than healthy individuals (e.g. Shin, 1986; Ikeda et al., 1998). For example, when investigating unilateral sinusitis, Shin (1996:69) found that the smaller of the two maxillary sinuses was involved approximately four times as frequently in sinusitis than the larger sinus. However, the difference in measured volume may be related to the inflammatory changes and thickening of the mucosa involved in sinusitis (Ikeda et al., 1998:151; Roberts, 2007:794).

2.2.3.v Odontogenic sinusitis

A common cause of maxillary sinusitis is the invasion of the sinus by pathogens related to dental infection, referred to as odontogenic sinusitis. The roots of the permanent maxillary molars and premolars are located just below the floor of the maxillary sinus, separated only by a thin layer of bone. Furthermore, the molar roots can occasionally perforate the sinus floor naturally and are then separated from the sinus cavity by only a layer of mucosa (Brook, 2006:350; Mehra & Jeong, 2009:238). The proximity of the roots to the sinus often facilitates the spread of dental infection into the sinus cavity, resulting in maxillary sinusitis (Brook, 2006:353). Odontogenic sinusitis is commonly thought to cause approximately 10 to 12% of incidences of maxillary sinusitis today (Brook, 2006:349; 2009:132; Mehra & Jeong, 2009:238; Patel & Fergusson, 2012:25). However, more recent studies have found that around 30 to 40% of chronic maxillary sinusitis may be caused by dental disease (Simuntis et al., 2014:42) and has been recorded as high as 51.8% (Maillet et al., 2011:756-757).

The majority of odontogenic sinus infections usually originate as dental caries, eventually infecting the dental pulp and leading to pulpitis (inflammation of the pulp) (Brook, 2006:350; Mehra & Jeong, 2009:239). This results in pus formation, spread of the infection into the dentoalveolar bone, and the development of a periapical abscess at the root of the tooth (Mehra & Jeong, 2009:239). Persistence of the abscess can lead to resorption of the maxillary bone between the tooth apex and the maxillary sinus, creating a direct channel for infection between the sinus and the oral cavity, called an oroantral fistula. If the tooth root already naturally perforates the sinus floor, infection can also spread easily into the sinus mucosa (Brook, 2006:350).

While perforation of the sinus by an oroantral fistula has been found to be the most common cause of odontogenic sinusitis (Akhlaghi et al., 2015:4), a direct connection between the oral cavity and the sinus may not necessarily be required for oral pathogens to cause infection. For example, a study of the causes of odontogenic sinusitis found that, while 95% of patients with sinusitis caused by dental disease had periapical lesions, only 24% had an oroantral fistula (Longhini & Ferguson, 2011:411). Additionally, a study of the presence of oral pathogens within the sinuses of people suffering from maxillary sinusitis, with no direct evidence for a related dental disease, found several oral species of bacteria present in the inflamed sinuses. It was suggested that the connection between the mouth and the maxillary sinuses, via the middle meatus, may provide a route for the infection of the sinuses by oral pathogens (Paju et al., 2006: 592; 596).

Current dental healthcare practices also cause a large proportion of odontogenic sinusitis, including the displacement of an infected tooth root during tooth extraction or the introduction of foreign bodies, such as dental fillings, into the sinus (Lopatin et al., 2002:Table 1; Brook, 2006:350; Mehra & Jeong, 2009:240; Arias-Irimia et al., 2010:e71; Lee & Lee, 2010:Fig. 2). A meta-analysis of the causes of odontogenic sinusitis found that 56% of incidences of the disease were caused by medical complications as a result of current dental healthcare practices (Arias-Irimia et al., 2010:e71). As there were less invasive medical treatments for dental disease in the past, this may have kept the prevalence of odontogenic sinusitis low. However, other causes of odontogenic sinusitis, such as caries, periapical abscesses, and oroantral fistulae, may have then been higher.

2.2.4 Complications

Although rare, if sinusitis is left untreated the infection can spread and, due to the proximity of the sinuses to the orbits, the anterior cranial fossa, and the intracranial venous sinuses, this can result in severe complications (Mafee et al*.,* 2006:168; Ah-See & Evans, 2007:36; Brook, 2009:136; Mehra & Jeong, 2009:239). Orbital involvement can lead to orbital cellulitis, periostitis, and abscess, alongside inflammatory oedema and subperiosteal abscess, and may even result in blindness (Mafee et al., 2006:168; Ah-See & Evans, 2007:360; Brook, 2009:136). The infection can also spread into the cranial cavity causing cavernous sinus thrombosis, epidural, subdural and brain abscesses, and meningitis (Mafee et al., 2006:168; Ah-See & Evans, 2007:361; Brook, 209:136). Other complications can also include osteomyelitis of the maxillary and frontal bones and sinusitis-induced bronchitis (Brook, 2009:136). Although rare, complications of sinusitis have been noted in the archaeological record, for example in an individual from Roman Lincoln, Lincolnshire, UK. In this instance, an extreme exostotic lesion (benign bony outgrowth) within the left maxillary sinus was observed as a result of odontogenic maxillary sinusitis, which was believed to have developed from a periapical infection and dento-alveolar abscess, eventually causing chronic osteomyelitis of the maxilla (Kendall et al., 2015).

2.2.5 Bone involvement

In the human skeleton, bone changes within the sinus as a result of a nonspecific inflammatory response are considered to be an indicator of sinusitis (e.g. Lewis et al., 1995:498). Although frequently overlooked in clinical contexts (Cho et al., 2006:404), changes to the underlying bone have been noted in several clinical studies of sinusitis (e.g. Zuckerkandl, 1893; Tovi et al., 1992; Hamilos, 2000; Perloff et al., 2000; Cho et al., 2006; Mafee et al., 2006). Inflammation within the sinuses has been linked to mucosal thickening and sclerosis (or hyperostosis) of the underlying bone (Perloff et al., 2000:2096; Cho et al., 2006:407; Mafee et al., 2006:176). Histological bone changes have further been observed in relation to sinusitis, including increased activity of osteoblasts and osteoclasts, new woven bone formation, marrow formation, and fibrosis (Hamilos, 2000:216; Cho et al., 2006:408). In an experimental study of induced sinusitis in rabbits, it was found that the involvement of bone played a major role in the spread of infection through enlarged Haversian canal systems within the sinus to non-infected areas of bone (Perloff et al., 2000:2097-2098). Tovi et al. (1992:429) also observed proliferative new bone formation within maxillary sinuses as a result of periosteal reaction to infection, resulting in localised deposits of thick lamellar bone. In this study, bone deposition was noted to occur predominantly on the posterior wall of the maxillary sinus and, if the infection continued, repeated bone deposition was observed to give the walls a sclerotic (thickened) appearance.

A lack of clinical reports on sinus related bone changes has been attributed to the inability of subtle bone deposits to be visible on radiographs (Lewis et al., 1995:498). Although hyperostosis of the sinus walls can be recognised within CT scans, this tends to be overlooked by clinicians, who concentrate on air-fluid levels and mucosal thickening to diagnose sinusitis (Okuyemi & Tsue, 2002:1883; Cho et al., 2006:407). The length of time needed to initiate bone changes within the sinus has led bioarchaeologists to conclude that the evidence for sinusitis within archaeological populations is representative of the chronic stages of the disease (Boocock et al., 1995:487; Roberts, 2007:795). This does, however, suggest that prevalence rates of sinusitis within archaeological populations may be underrepresented, as those suffering from acute sinusitis and recovering quickly may have no bony evidence of the disease (Jakob, 2004:326).

2.3 Pleural disease

Pleural disease is a common complication of lower respiratory tract infection. As the pleurae directly underlie the ribs, bioarchaeological studies have suggested that the spread of a lower respiratory tract infection from the lungs to the pleurae, causing pleural inflammation, may be responsible for stimulating the new bone formation on the ribs observed in some skeletal remains (Kelley & Micozzi, 1984:382; Pfeiffer, 1991:197; Roberts et al., 1994:178-179; Roberts, Boylston et al., 1998:56; Capasso, 2000:1774). There are many varieties of pleural disease, but major types include pleural effusion, pleurisy, and pleural empyema, which can all occur as a result of lower respiratory tract disease (Kroegel & Antony, 1997:2411; Rahman et al., 2004:31; Bourke, 2007:180; Light, 2013:14-15). However, determining the aetiology of rib lesions in archaeological populations is complicated by the wide range of causes of pleural disease that are unrelated to lower respiratory tract infection, including malignancy, heart and abdominal diseases (Rahman et al., 2004:31).

The following sections present information regarding the anatomy of the lower respiratory tract and pleurae, the pathogenesis of pleural disease, the different aetiologies of the disease including certain specific infectious causes and common non-pulmonary related causes, and the clinical evidence for bone changes related to pleural disease.

2.3.1 Anatomy of the lower respiratory tract and pleurae

The lower respiratory tract begins at the larynx and is followed by the trachea, which bifurcates to the left and right into the bronchi, supplying air to each lung (Bourke, 2007:3; Culver, 2012:20; Marieb, 2012:439-440). The airways then branch into smaller and smaller generations known as the 'respiratory tree', going from bronchi to bronchioles, then forming the respiratory zone known as the lung parenchyma, which contains the alveolar ducts and alveolar sacs, and finally terminates in the alveoli (Suki, 2011:1317; Culver, 2012:20; Marieb, 2012:443). Except for the mediastinum (the central cavity which houses all other organs in the thorax, such as the heart and oesophagus), the lungs themselves take up the entire thoracic cavity (Marieb, 2012:441). The superior apex of each lung lies deep to the clavicle, while the inferior broad base rests upon the diaphragm (Marieb, 2012:441).

The surface of each lung is closely lined by a serous membrane, the visceral pleura. Superficial and parallel to this membrane lies the parietal pleura, lining the inner aspects of each side of the chest cavity, including the mediastinum and the top of the diaphragm (Culver, 2012:19; Marieb, 2012:441; Wright & Churg, 2012:1; Light, 2013:1) (Figure 2.2). The parietal pleura is separated from the visceral surfaces of the ribs, internal intercostal muscles, and posterior surfaces of the costal cartilages and sternum only by a thin, loose connective tissue named the endothoracic fascia (O'Rahilly et al., 2004: Chapter 22) (Figure 2.3). The two pleurae meet at the lung root, forming an enclosed pleural space (also known as the pleural cavity) between the two layers, on either side of the chest (Light, 2013:1).

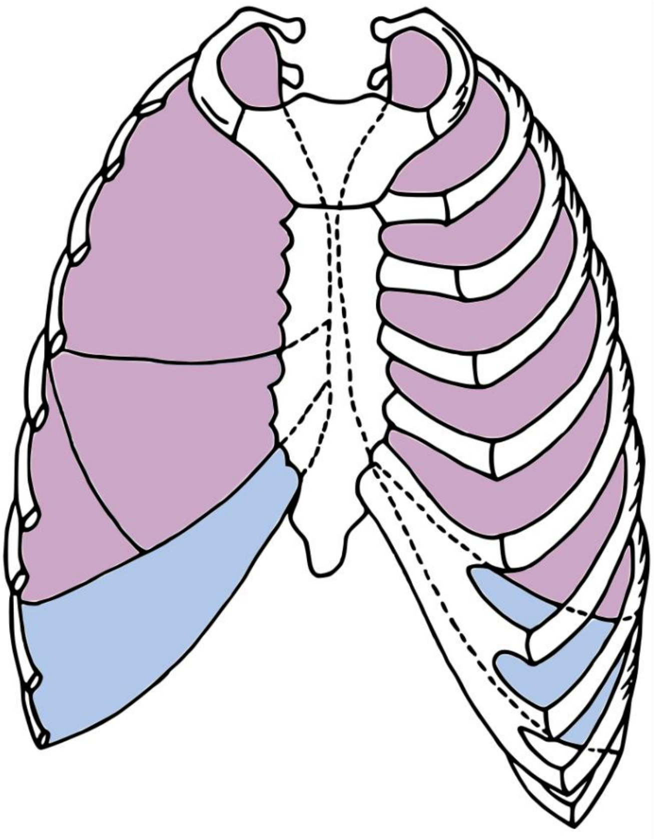


Figure 2.2 – Anatomy of the pleural cavity (blue) and underlying lungs (purple) in relation to the ribs. Note that the pleural cavity extends further than the lungs.

A thin layer of fluid within the cavity usually separates the two layers of pleura. This acts as a lubricant to allow the pleurae to slide against one another during the movement that occurs in respiration (Culver, 2012:19; Marieb, 2012:441; Light, 2013:1). These few millilitres of fluid help the pleurae to resist being pulled apart, anchoring the lungs to the thorax wall (Marieb, 2012:441; Ward et al., 2015:73). The tightly adhering pleurae are important in respiratory mechanics. The force produced by the movement of the chest wall and diaphragm during inspiration creates a negative pressure within the pleural space. The pleurae then resist being pulled apart, forcing the expansion of the lungs (Culver, 2012:23; Ward, 2015:73). Therefore, the maintenance of a regular pleural space is essential in sustaining normal breathing (Marieb, 2012:441).

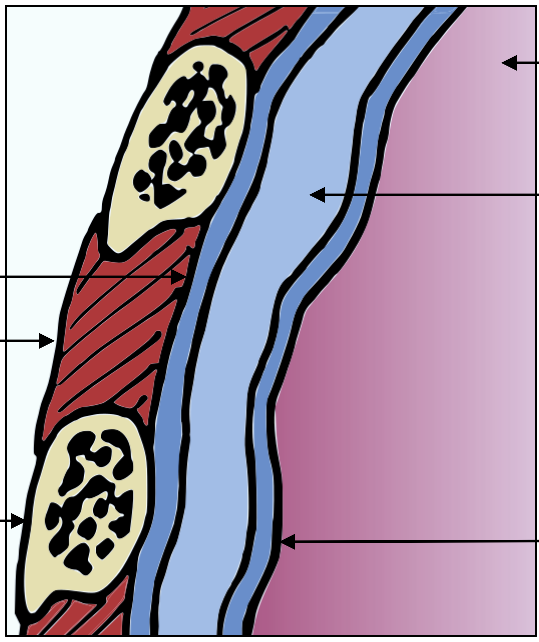


Figure 2.3 – Cross section of the thoracic wall demonstrating the anatomical relationships between the ribs, pleurae, and lungs.

2.3.2 Pathogenesis and aetiology

Pleural diseases are complex and can have a wide range of causes. Below, the pathogenesis and aetiology of the three most common forms of pleural disease, pleural effusion, pleurisy, and pleural empyema, are discussed.

2.3.2.i Pleural effusion

Fluid between the two layers of pleura is produced fairly rapidly but is quickly resorbed into the lymphatic channels to maintain equilibrium within the pleural space (Bourke, 2007:185-186; Wrightson et al., 2012:818). However, if a disease involves the lungs or adjacent tissues, the pleurae may also become affected (Kroegel and Antony, 1997:2411). Most commonly, this results in an upset in the maintenance of pleural fluid equilibrium and an accumulation of fluid within the pleural space, referred to as pleural effusion (Rahman et al., 2004:31; Porcel & Light, 2006:1211; Bourke, 2007:185; Ward et al., 2015:73). Several processes can lead to fluid accumulation, including an increase in capillary permeability as a result of infection, obstruction of lymphatic drainage, or increased capillary pressure, for example, through heart failure (Kroegel & Antony, 1997:2411; Rahman et al., 2004:31; Bourke, 2007:180; Light, 2013:14-15). Clinical manifestations of pleural effusion include cough and dyspnoea (difficulty in breathing) (Rahman et al., 2004:31; Porcel & Light, 2006:1211; Bourke, 2007:186; Wrightson et al., 2012:818; Light, 2013:86). In specific conditions, such as pleural malignancy or tuberculosis (TB), pleural effusion may cause other symptoms such as malaise, night sweats, weight loss, and anorexia (Rahman et al., 2004:32).

Table 2.1 – The causes of pleural effusion (Rahman et al., 2004: Table 1).

Transudative	Exudative
Common causes	
• Left ventricular failure • Cirrhotic liver disease • Hypoalbuminaemia • Atelectasis • Peritoneal dialysis	• Malignancy – Primary/secondary/mesothelioma • Parapneumonic effusion and empyema • Pulmonary embolus (with infarction) • Tuberculosis
Less common causes	
• Pulmonary embolus (10-20%) • Malignancy (5%) • Hypothyroidism • Mitral stenosis • Constrictive pericarditis • Urinothorax • Ovarian hyperstimulation • Meig's syndrome	• Rheumatoid arthritis • Systemic lupus erythematosus • Connective tissue diseases • Benign asbestos pleural effusion • Pancreatitis • Oesophageal rupture • Yellow nail syndrome • Drug abuse • Fungal infection • Chylothorax/pseudochylothorax • Hydatid disease (ruptured cyst)

A wide range of diseases can cause pleural effusion, which are commonly separated into two types: transudative and exudative (Bourke, 2007:187; Wrightson et al., 2012:818) (Table 2.1). Transudative effusions occur as a result of changes in hydrostatic pressure and are usually caused by cardiac or renal failure and liver cirrhosis, and are mostly bilateral (Bourke, 2007:187-188; Ward et al., 2015:73). Exudative effusions are the result of either obstruction of lymphatic drainage or increased capillary permeability and are often unilateral (Bourke, 2007:188; Wrightson et al., 2012:818). This type of effusion can be the result of a variety of pleural diseases, including metastatic malignancies that spread to the pleurae, infection of the lung, pleural cavity or neighbouring tissues, inflammatory diseases such as rheumatoid arthritis, and subdiaphragmatic diseases such as pancreatitis (Rahman et al., 2004:39-43; Bourke, 2007:188-190).

Most commonly, pleural effusions are the result of malignancy, tuberculosis, pneumonia, heart failure, and pulmonary embolism (Porcel & Light, 2006:1211; Light, 2013:128). Defining a specific aetiology is highly dependent on factors such as patient age, infectious disease prevalence, previous healthcare, and the geographic region or population studied (Marel et al., 1993:1488; Valdés et al., 1996:158; Wrightson et al., 2012:818). For example, in a study of the aetiology of pleural effusion over a five year period in two hospitals in Northwest Spain, it was found that the overall majority of pleural effusions within their sample were caused by tuberculosis (25%), which was in keeping with the high incidence of tuberculosis in this region at the time. However, whilst 69% of patients younger than 40 years suffered from pleural effusion due to tuberculosis, for patients older than 50 years malignancy was the most common cause (28.8%) (Valdéz et al., 1996:161). Similarly, the most common cause of pleural effusion in a more recent study of 199 incidences in Eastern Nigeria was that of tuberculosis (42.2%), a disease common to the region, followed equally by parapneumonic complications (14.07%), and cardiac failure (14.07%), whereas in higher income countries, with a lower rate of tuberculosis and greater access to antibiotics, malignancy or heart failure is often a more commonly recorded aetiology (Mbata et al., 2015:1). For example, in a study from central Bohemia of 142 people with pleural effusion, no instances were the result of tuberculosis, while cardiac failure was the most common cause, associated with 45.8% of patients, followed by malignancy (21.8%) and parapneumonic complications (17%) (Marel et al., 1993:Table 3).

2.3.2.ii Pleurisy

Pleural effusions often come accompanied by pleurisy, inflammation of the parietal pleura, which causes pleuritic pain (a sharp stabbing sensation in the chest when breathing) (Kass et al., 2007:1357, 1362; Marieb, 2012:443; Light, 2013:86). Although pleurisy can be caused by reduced secretion of pleural fluid and friction between the pleurae (Kass et al., 2007:1362; Marieb, 2012:443), it is regularly associated with, and can exacerbate further, pleural effusion (Kroegel & Antony, 1997; Kass et al., 2007: Tables 3 & 4; Light, 2013:86). The development of pleurisy is perhaps particularly important in relation to the formation of new bone on the visceral surfaces of the ribs as chronic inflammation of the pleura is likely to increase blood supply in this region and stimulate bone formation (Roberts, 1994:178; Eyler et al., 1996:925). Although pleurisy can occur during many of the same disease processes that cause pleural effusion, it is most common in pleural infection caused by pneumonia, tuberculosis, or viruses, or as a complication of malignancy or connective tissue and renal disorders (Kass et al., 2007:Table 1).

2.3.2.iii Pleural empyema

Pleural empyema, the accumulation of pus within the pleural cavity (Davies et al., 2010:ii42; Ward et al., 2015:73; Light, 2013:210-211), usually occurs when infectious pathogens, often originating from the lung, directly invade the pleural space (Weissberg & Rafaely, 1996:1027). For example, empyema may occur as a result of the formation of a bronchopleural fistula, providing a direct connection between the infected lungs and the pleural space. It can also be caused by spread of infection from the mediastinum, the diaphragm, or the spine or through penetrating trauma to the chest and the subsequent introduction of infective pathogens (Weissberg & Rafaely, 1996:1027; Light, 2013:Table 12.1). Empyema may form loculations (pleural effusions confined to pockets of pleural space), which inhibit drainage and cause chronic pleural infection and inflammation (Kroegel & Antony, 1997:2416; Porcel & Light, 2006:1211). Eventually, this may lead to the formation of fibrotic scar tissue, sometimes referred to as a pleural peel, which forms an inelastic membrane around the lungs and limits lung expansion and chest wall and diaphragm movement (Kroegel & Antony, 1997:2414; Rahman et al., 2004:39; Porcel, 2009:264). Additionally, diffuse pleural thickening (fibrothorax) can occur and has been recorded in up to 86 to 100% of patients with empyema (Wrightson et al., 2012:826).

2.3.3 Specific disease processes

Certain infectious pulmonary diseases commonly affect the pleurae. For example, pneumonia, pulmonary tuberculosis, and pulmonary actinomycosis have often been discussed in relation to new bone formation on the visceral surfaces of the ribs in bioarchaeological studies (e.g. Molto, 1990; Kelley et al., 1994; Roberts et al., 1994; Roberts, Boylston et al., 1998; Raff et al., 2006) and are likely to be the most common causes of pleural disease in many archaeological populations (Molto, 1990:446; Kelley et al., 1994:127). Therefore, the pathogenesis of these diseases and their effect on the pleurae are described below.

2.3.3.i Pneumonia and parapneumonic effusion

Pneumonia, the infection and inflammation of the lung parenchyma, is one of the most common and most deadly of lower respiratory tract infections today, particularly in infants under five and the elderly (Loebinger & Wilson, 2012:329; Troeger et al., 2017:1152; Van der Poll & Opal, 2009:1543). The mortality rate for pneumococcal pneumonia has ranged in various modern clinical studies from between 15% and 50% of all instances and, in particular, bacteremic (spread of infection to the blood) pneumococcal pneumonia has a high rate of mortality within the first 24 to 48 hours of hospital admission (Marrie, 1993:659). For example, one study recorded that 43% of all deaths related to bacteremic pneumococcal pneumonia occurred in the first 24 hours of hospital admission (Austrian & Gold, 1964:769). Unfortunately, there is very little data available for the mortality rate of pneumonia in instances untreated by antibiotics or modern healthcare practices.

Pneumonia is caused by invasion of microbes into the lower respiratory tract, often via inhalation, spread from other infected tissues, or through aspiration of gastric and nasopharyngeal microbes (Loebinger & Wilson, 2012:329). The most common invading organism is *Streptoccocus pneumoniae*, which is involved in approximately 39% of incidences (known as pneumococcal pneumonia), but other pathogens causing pneumonia can include *Chlamydia pneumoniae*, *Mycoplasma pneumoniae*, and other various infective organisms (Loebinger & Wilson, 2012: Table 1). Infection of the lower respiratory tract results in the production and accumulation of inflammatory cells and fluid within the alveoli (Wilkinson & Woodhead, 2004:129; van der Poll & Opal, 2009:1549; Loebinger & Wilson, 2012:329), causing fever, cough, dyspnoea, sputum production, and chest pain, and may also result in vomiting and diarrhoea (Wilkinson & Woodhead, 2004: Table 3; Bourke, 2007:56).

A common complication of pneumonia in over 50% of incidences is pleural effusion, referred to as parapneumonic effusion (Clouet et al., 2001:174; Rahman et al., 2004:39; Ward et al., 2012:73), although this term is also used to describe effusions caused by lung abscesses or bronchiectasis (Light, 2013:210). Spread of invading agents and inflammatory cells from the underlying lung tissues to the pleura stimulates inflammation and results in effusion (Kroegel & Antony, 1997:2413). Due to the fact that bacteria and bacterial degradation products cannot drain from the pleural space, if the pneumonia is not treated, the inflammation may exacerbate and empyema may occur (Kroegel & Antony, 1997:2414; Clouet et al., 2001:174; Rahman et al., 2004:39; Bourke, 2007:54; Ward et al., 2015:73). Eventually, fibrous scar tissue may develop, limiting movement of the chest wall and lungs (Kroegel & Antony, 1997:2414; Rahman et al., 2004:39; Davies et al., 2010: ii42; Light, 2013:211).

The development of pneumonia may be affected by a variety of factors, including the age of the patient, environmental and geographical factors, any concurrent diseases, the virulence of the microbe, immunity impairment, and the site of infection within the respiratory tract (Bourke, 2007:53-54; Berim & Sethi, 2012:296-297). Tobacco smoking, for example, is one of the greatest risk factors in increasing susceptibility to pneumonia today (Wilkinson & Woodhead, 2004:134).

Tuberculosis is also considered an important risk factor (Wilkinson & Woodhead, 2004:131), and, because both diseases are prevalent in areas of poverty and crowding, in certain regions the two conditions can often occur together (Van der Poll & Opal, 2009:1544). Other factors predisposing to pneumonia include malnutrition, alcohol abuse, diabetes, chronic obstructive pulmonary disease, and underlying cardiorespiratory disease (Bourke, 2007:55).

2.3.3.ii Pulmonary tuberculosis and tuberculous pleurisy

The bacterium *Mycobacterium tuberculosis* and various other *Mycobacterium* TB complex members, including *M. bovis* and *M. africanum*, cause tuberculosis, an infection which can target any organ of the body but most commonly involves the lungs (Bourke, 2007:63; Katalinić-Janković et al., 2012:2; Walter & Daley, 2012:383) and typically develops in the subpleural region of the parenchyma (Bourke, 2007:64). Today, tuberculosis is considered to be the leading cause of infectious death and one of the top ten overall causes of death, globally (WHO, 2018b:1). Untreated tuberculosis is fatal in approximately 70% of instances but the disease has a long duration of between 1 and 4 years, with an average length of around 3 years (Glaziou et al., 2018:Table 1; Tiemersma et al., 2011:10).

Infection with the human form is spread through the inhalation of infectious droplets, which may disperse through mechanisms such as talking, sneezing and coughing (D'ambrosio et al., 2012:16; Walter & Daley, 2012:385). Bovine tuberculosis can also be transmitted to humans through inhalation of infectious droplets or dust particles shed by the animal, but other forms of transmission include through cuts on the skin or from handing or consuming infected animal products (Cosivi et al., 1998:63; Ayele et al., 2004:927). Factors such as crowding, malnutrition, and poverty have all been argued to increase the prevalence of the disease today (Resnick, 2002:2525; Garg and Somvanshi, 2011:441).

Inhaled infectious droplets pass through the lower respiratory tract, adhering to alveolar cells, and disseminate into the lymphatic system and blood stream, triggering an immune response (D'ambrosio et al., 2012:16; Katalinić-Janković et al., 2012:2; Walter & Daley, 2012:385; Guirado & Schlesinger, 2013:1). Macrophages and other immune-response cells "wall off" mycobacterial foci within the alveoli, creating cell-masses known as granulomas (Walter & Daley, 2012:385; Guirado & Schlesinger, 2013:1). Within these granulomas, mycobacterial organisms are able survive for long periods of time (Guirado & Schlesinger, 2013:1). This initial infection is known as primary tuberculosis, which may then become clinically latent, reactivating as post-primary or reactivated tuberculosis decades later, usually as the result of weakened immunity (Bourke, 2007:64-65; Katalinić-Janković et al., 2012:6; Walter & Daley, 2012:385; Guirado & Schlesinger, 2013:1).

Acute inflammation of the pleura, leading to pleural effusion, as a result of either primary or post-primary tuberculosis is often referred to as tuberculous pleurisy (Berger & Mejia, 1973:88; Porcel, 2009:264; Walter & Daley, 2012:387). It is thought to be caused by the rupture of a subpleural granuloma into the pleural cavity, introducing tuberculous protein into the pleural space and triggering an inflammatory response (Berger & Mejia, 1973:89; Kroegel & Antony, 1997:2414; Rahman et al., 2004:42; Porcel, 2009:264; Walter & Daley, 2012:387; Light, 2013:247; Ward et al., 2015:73). It is a frequent complication of pulmonary tuberculosis, serving as the initial presentation in 25% of adult patients, and in regions with a high incidence of TB it is the most common cause of pleural effusion (Porcel, 2009:263; Light, 2013:249). Tuberculous pleurisy often affects young adults during the primary stages of infection, but can occur in older adults during reactivation of the disease (Valdés et al., 1996:161; Rahman et al., 2004:42; Porcel, 2009:264). Tuberculous pleurisy is most commonly unilateral (>95%), although bilateral effusions can occur in miliary tuberculosis (Kroegel & Antony, 1997:1414; Porcel, 2009:264). The clinical features of tuberculous pleurisy include pleuritic pain, fever, and dyspnoea (Ward et al., 2015:73), while other more general signs and symptoms of tuberculosis may include cough, sputum production, night sweats, weight loss, anorexia and malaise (Berger & Mejia, 1973:89; Bourke, 2007:66; Porcel, 2009:264).

If left untreated, tuberculous pleurisy will usually resolve spontaneously after two to four months, but in 65% of previous pleurisy sufferers some form of tuberculosis will reactivate within five years (Rahman et al., 2004:43; Walter & Daley, 2012:387; Wrightson et al., 2012:828; Light, 2013:250). A bronchopleural fistula may develop as a result of tuberculous pleurisy, providing a further direct route for bacteria to access the pleural space, causing pleural infection (Clouet et al., 2001:176; Light, 2013:257). Although rare in modern clinical contexts, this can lead to pleural empyema and the development of a fibrous pleural peel (Porcel, 2009:264; Light, 2013:258). Tuberculous pleurisy is also associated with diffuse pleural thickening (Wrightson et al., 2012:830; Light, 2013:441).

2.3.3.iii Actinomycosis

Actinomycosis is a chronic infection caused by anaerobic bacterial species from the genus *Actinomyces*, and is characterised by abscesses, the formation of draining sinuses, and tissue fibrosis (Smego & Foglia, 1998:1255; Chernihovski et al., 2007:686; Wong et al., 2011:1; Light, 2013:267). The most common pathogen responsible for actinomycosis in humans is *Actinomyces israelii*, although various other species may also cause the disease (Chernihovski et al., 2007:687;

Wong et al., 2011:1). These pathogens exist naturally within the human oropharynx, gastrointestinal tract, and urogenital tract and usually become pathogenic when a break in the mucosa of the gastrointestinal tract leads to invasion of the surrounding tissue and organs by bacteria. However, aspiration of oropharyngeal and gastrointestinal secretions into the respiratory tract is also a major cause, particularly in thoracic actinomycosis (Smego & Foglia, 1998:1256; Chernihovski et al., 2007:686-687; Wong et al., 2011:1). The most common manifestations of actinomycosis occur in the cervicofacial, thoracic, and abdominal regions of the body (Smego & Foglia, 1998:1256; Chernihovski et al., 2007:687; Wong et al., 2011:1-2).

Thoracic, or pulmonary, actinomycosis occurs in approximately 15 to 20% of all incidences of actinomycosis (Chernihovski et al., 2007:687; Wong et al., 2011:2), although some estimates claim up to 50% (Mabeza & Macfarlane, 2003:545). It often originates in the lungs and the infection may directly spread to involve the pleura, mediastinum, and chest wall (Smego & Foglia, 1998:1256; Chernihovski et al., 2007:687), with the pleura involved in over 50% of incidences (Light, 2013:267). Aspiration of oropharyngeal or gastrointestinal secretions is regarded as the most common cause of thoracic actinomycosis, although poor oral hygiene and dental disease, such as infected gums and carious teeth, may increase the risk by promoting the growth of *Actinomyces* species (Mabeza & Macfarlane, 2003:547; Chernihovski et al., 2007:687; Light, 2013:267). Although more rare, infection can also result from oesophageal perforation, haematogenous (via the blood) spread, or spread from cervicofacial or abdominal infections (Smego & Foglia, 1998:1256; Wong et al., 2011:2). Pleural effusion and marked pleural thickening can occur alongside chest wall abscesses and sinus tract formation extending to the skin, and the disease may result in chronic pneumonia, empyema, and destruction of the ribs and sternum (Smego & Foglia, 1998:1256; Wong et al., 2011:2; Light, 2013:267). The clinical manifestations of thoracic actinomycosis include cough, shortness of breath, chest pain, fever, and weight loss (Smego & Foglia, 1998:1256; Mabeza & Macfarlane, 2003:547; Wong et al., 2011:2).

The disease can occur at all ages, although children are very rarely affected, whilst men are estimated to be affected 2 to 4 times more frequently than women (Mabeza & Macfarlane, 2003:546; Chernihovski et al., 2007:687. In the last few decades, actinomycosis has declined and is now considered a rare disease, particularly in developed countries with a wide range of antibiotics and improved oral hygiene (Mabeza & Macfarlane, 2003:545; Chernihovski et al., 2007:686; Wong et al., 2011:1). Although extremely infrequent, actinomycosis has been reported in Sudan (Mahgoub, 1977:184). The prevalence of the disease in archaeological populations, however, may have been far greater (Molto, 1990:446).

2.3.4 Common non-respiratory causes of pleural effusion

The most common transudative pleural effusion worldwide is the result of congestive cardiac failure, which causes elevated pulmonary capillary pressure leading to the migration of pulmonary interstitial fluid into the pleural space, usually bilaterally (Wrightson et al., 2012:825; Light, 2013:140). Additionally, pleural effusion is likely to occur in up to 50% of patients affected by pulmonary embolism, as a result of increased permeability of lung capillaries, which, again, causes migration of fluids from the lungs to the pleura (Wrightson et al., 2012:829; Light, 2013:287). Although these conditions are often accompanied by pleuritic-like chest pain, this is not normally caused by pleurisy itself (Kass et al., 2007:1357).

Exudative pleural effusions due to malignancy are also frequent, accounting for 22% of all pleural effusions in modern clinical contexts (Wrightson et al., 2012:828), and it is the most common cause of exudative effusions in people over the age of 60 (Rahman et al., 2004:40). Effusions due to malignancy most commonly arise from metastases of lung, breast, gastrointestinal, and ovarian cancers and from lymphoma (Rahman et al., 2004:40-41; Bourke, 2007:188). Pleural effusion in these cases arises from the malignant involvement of parietal lymphatic channels, which causes reduced lymphatic drainage and increased production of pleural fluid (Wrightson et al., 2012:828). It may also increase the permeability of the pleurae and migration of non-pleural fluids into the cavity (Light, 2013:156). Effusions also develop as the result of abdominal disease, in particular severe pancreatitis, due to the transfer of fluid produced by acute pancreatic or diaphragmatic inflammation into the pleura (Bourke, 2007:190; Wrightson et al., 2012:829; Light, 2013:296). Effusions can further be a complication of rheumatoid arthritis, which can cause pleurisy in up to 5% of patients suffering from the disease (Rahman et al., 2004:43; Wrightson et al., 2012:828; Light, 2013:329).

2.3.5 Bone involvement

In clinical reports of lower respiratory tract and pleural disease, new bone formation on the surfaces of the ribs receives little attention. Certain studies have alluded to periostitis of the ribs in relation to lower respiratory tract and pleural disease, but the descriptions are brief and vague at best. For example, Asnis and Niegowska (1997:1018) state that 'tuberculosis is the most common cause of inflammatory lesions of the ribs' but fail to elaborate further. Simon (1973:162) notes that periostitis of the ribs may occur secondary to pleural infection, such as chronic empyema, and will usually involve neighbouring ribs but the paper does not provide any additional information. Guttentag and Salwen (1999:1138) also briefly state that chronic inflammation of the lungs or pleura can be associated with chronic reactive periostitis, causing enlargement of the ribs in radiographs.

In a rare clinical study, Eyler et al. (1996), after observing rib enlargement in association with pleural disease in radiographs for many years, investigated the statistical significance of this phenomenon. Using radiographs taken from patients with unilateral tuberculosis or pleural empyema, the study compared the thickness of ribs from the affected side of the thorax to thicknesses from the unaffected side and found a significant difference between the sizes of diseased and non-diseased ribs in both patients with tuberculosis and empyema. It was hypothesised that rib enlargement may be due to local hyperaemia (increased blood flow to a specific region) caused by an adjacent inflammatory process and that a greater thickness may be suggestive of greater chronicity of the disease. It was also noted that the ribs affected were likely to be located in the mid and lower part of the affected side of the chest, where the pleural disease was likely to be localised, and that the most common pleural disease associated with rib enlargement was pulmonary tuberculosis (Eyler et al., 1996:925-926). Following this, Porres et al. (2017:274-275) also noted rib thickening in patients with tuberculous lung destruction, which was attributed to chronic reactive periostitis caused by hyperaemia.

Skeletal involvement in pulmonary tuberculosis is reportedly uncommon. In modern clinical contexts it occurs in approximately 1 to 2% of all people with tuberculosis within the industrialised world, but may occur in up to 10 to 15% of people in non-industrialised regions (Resnick, 2002:2524; Talbot et al., 2007:405), likely due to a combination of factors, including lack of access to healthcare and antibiotics, and undernutrition. Skeletal involvement in extrapulmonary tuberculosis is slightly more common. Prior to the 1950s, skeletal changes related to extrapulmonary TB were recorded at around 30% (Resnick, 2002:2524), but today in industrialised regions it occurs in around 10 to 15% of people, most typically targeting the spine and major joints, such as the hip and knee (Talbot et al., 2007:405; Garg and Somvanshi, 2011:441). Osseous involvement of the ribs has been recorded in 7% of incidences of skeletal tuberculosis (Watts & Lifeso, 1996:289), although the type of bony involvement (proliferative or destructive) is not specified in this study.

Skeletal tuberculosis is most likely to occur through haematogenous spread from the initial site of infection, but may also take place due to direct invasion of tuberculous bacteria from surrounding tissues (Resnick, 2002:2525; Talbot et al., 2007:408). In the spine this results in destruction of the intervertebral disk space and adjacent vertebral bodies (Talbot et al., 2007:442), and in tuberculosis of the joints results in circumscribed lytic lesions in the bone, sometimes accompanied by reactive periostitis (Resnick, 2002:2536). In clinical contexts, tuberculosis of the rib has been recorded as either osteochondritis of the costochondral junction or osteomyelitis of the rib shaft, both resulting in destructive lesions on the bone (Asnis & Niegowska, 1997:1018). However, lesions of the ribs, either destructive or proliferative, as a result of pleural TB are rarely reported in the clinical literature, partially due to the failure for bony changes on the ribs to be easily detected on radiographs (Ip et al., 1989:243; Asnis & Niegowska, 1997:1019).

Proliferative new bone formation on the ribs is mentioned most frequently in relation to actinomycosis, often in conjunction with rib destruction (e.g. Thompson & Carty, 1979; Resnick, 2002:2563-2564; Guttentag & Salwen, 1999:1138; Jeung et al., 1999:625; Light, 2013:267). Resnick (2002:2563) notes that in actinomycosis proliferative bone growth may be extensive, while Jeung et al. (1999:624-625) describe rib destruction and periostitis caused by empyema, as a result of the spread of actinomycosis from pulmonary or pleural lesions. Pleural empyema is known to cause osteomyelitis of the ribs (Jeung et al., 1999:621) and may cause destructive lesions as a complication of other diseases such as pneumonic or tuberculous empyema (Madeo et al., 2013).

It should be noted, however, that non-respiratory related processes may also involve destruction or new bone formation of the ribs. Periostitis and destructive lesions on the ribs, usually associated with osteomyelitis, may occur as a result of trauma to the chest (Guttentag & Salwen, 1999:1138). Primary tumours may also invade the chest wall and cause destruction of the ribs (Guttentag & Salwen, 1999:1133). Additionally, rib enlargement can be seen on radiographs in 1 to 4% of patients suffering from Paget's disease (Levine et al., 2009:6) and in 30% of incidences of fibrous dysplasia (Guttentag & Salwen, 1999:1139-1141; Jeung et al., 1999:633). This could cause some confusion with rib thickening as a result of pleural disease.

2.4 The effect of air quality on respiratory health

A large quantity of air is inhaled into the lungs every day. As the primary barrier between environmental air and the internal body, the lining of the respiratory tract frequently comes into contact with pollutants present in the environment, such as particulate matter (PM), toxic gases, and pathogens (Clerico, 2001:107; Antunes & Cohen, 2007:5; Marino et al., 2015:286). Therefore, the respiratory tract is likely to be one of the first sites of the body directly at risk of injury from toxic and damaging pollutants in the air (Clerico, 2001:107; Marino et al., 2015:286). Although the nasal cavity and sinuses function to remove PM and pathogens from the air before they can reach the lungs, this mechanism is not always successful. Air pollutants can concentrate in the nasal mucus, causing localised inflammation (Trevino, 1996:239), and PM of a certain size can penetrate further into the lower respiratory tract, which has been closely associated with the development of respiratory problems (Li et al., 2003:455; Jang, 2012:154; Hiraiwa & van Eeden, 2013:1). The following section discusses the effect of different types of PM, in particular from household air pollution, on respiratory health. The epidemiological studies linking exposure to PM to increased prevalence rates of respiratory disease and the mechanisms by which PM causes inflammation of the respiratory tract are also presented.

2.4.1 Particulate matter and household air pollution

PM larger than 10µm in diameter is removed from the airstream within the nasal cavity (Clerico, 2001:108). However, particulates smaller than this are able to penetrate into the lower respiratory system (Brunekreef & Holgate, 2002:1235; Sood, 2012:650; Marino et al., 2015:286). In studies of its effect on respiratory health, PM tends to be discussed in three categories of size: PM_{10} (<10µm in diameter), which can penetrate the lower respiratory system; $PM_{2.5}$ (<2.5µm in diameter), which can penetrate further into the parenchyma of the lungs; and ultrafine particles (UFP or $PM_{0.1}$) (<1µm in diameter), which have a large surface area, a high particle concentration, and can travel from the alveoli into the blood stream (Bruce et al., 2000:1079; Brunekreef & Holgate, 2002:1235; Li et al., 2003:455; Perez-Padilla et al., 2010:1081). The molecular composition of PM is directly related to the source of production and can be made up of a complex mixture of components containing metals, nitrates, sulfates, and polycyclic aromatic hydrocarbons (Morales-Bárcenas et al., 2015:167). There are many types of PM within the environment, including pollen, plant and animal debris, spores, dust particles, industrial emissions, cigarette smoke, and smoke from the combustion of fuel products (Breysse et al., 2010:102).

Recent studies have been addressing the impact of smoke from biomass fuels used within the home, often referred to as household air pollution (HAP), on respiratory health (e.g. Bruce et al., 2000, 2002; Dherani et al., 2008; Fullerton et al., 2008; Ingale et al., 2011; Gurley et al., 2013; Kelly et al., 2015; Amegah & Jaakkola, 2016; Jary et al., 2017). The use of biomass fuels, such as wood, animal dung, and crop residues, to heat homes and cook food is relied on by approximately 2.8 billion people worldwide (Pope et al., 2015:285; Amegah & Jaakkola, 2016:215; WHO, 2018a). The majority of these people live in rural households in developing countries (Bruce et al., 2000:1078). The burning of biomass fuels can produce high concentrations of PM within the household environment, particularly in homes where ventilation is limited, stoves and fire pits are poorly designed and, therefore, combustion of fuel is inefficient (Bruce et al., 2000:1079; Fullerton et al., 2008: 844; Perez-Padilla et al., 2010:1081). Biomass fuels can also produce a wide variety of toxic molecules, such as carbon dioxide, carbon monoxide, formaldehyde, nitrogen oxides, and sulphur oxides, which are harmful in certain concentrations to humans and can cause irritation of the respiratory tract (A.P. Jones, 1999:4536; Bruce et al., 2000:1079; Smith et al., 2000:521; Bernstein et al., 2008:586; Fullerton et al., 2008:844; Sood, 2012:650).

Individual exposure to HAP is highly variable and depends on a number of factors, such as the rate of production of the pollutant, the volume of air and extent of ventilation within the indoor space, the extent of infiltration of outside pollutants, and the activity patterns and behaviours of the individual (A. P. Jones, 1999:4536; Clerico, 2001:Table 9-1; Nazaroff, 2013:3). Additionally, whether HAP may negatively affect an individual's health is complicated by factors such as the frequency and duration of exposure, the concentration of the pollutant, an individual's sensitivity to certain pollutants, and their current state of health (A. P. Jones, 1999:4537; Perez-Padilla et al*.,* 2010:1080). In particular, women and children are thought to have the highest exposure to HAP. Traditionally, women are likely to spend the longest amount of time cooking over open fires, often accompanied by their young children (Bruce et al., 2000:1080; Fullerton et al., 2008:845; Perez-Padilla et al., 2010:1081; Sood, 2012:651; Amegah & Jaakkola, 2016:215).

Therefore, in households reliant on biomass fuels, exposure to HAP may be lifelong, starting from birth and continuing throughout life, and this can have a negative effect on lung growth and development (Bruce et al., 2000:1082; Gauderman et al., 2004:1063; Sood, 2012:651). For example, in a study of the effect of ambient air pollution on lung development between the ages of 10 and 18 years, it was found that $PM_{2.5}$, among various other pollutants, significantly reduced the development of the lungs and could lead to an increased risk of developing a respiratory condition (Gauderman et al., 2004:1063). It has also been suggested that exposure of pregnant women to biomass fuel smoke may lead to low birthweight of their babies and that young children exposed to smoke are more likely to develop deficiencies such as anaemia and stunted growth. This is thought to occur through a complex interplay of factors that includes inhalation of high levels of carbon monoxide, leading to a reduction in the oxygen content of the blood (Smith et al., 2000:529; Mishra & Retherford, 2007:118; Fullerton et al., 2008:845, Fig. 2). For example, a study of women and new born children in rural Guatemala found a highly significant difference between the birth weight of children whose mothers used cleaner burning fuels and those whose mothers used wood fires, with a mean birthweight of 63g less in wood users (Boy et al., 2002:110-111).

Furthermore, different types of biomass fuel, which can create different sizes and concentrations of particulates when burnt, can have varying degrees of effect on the respiratory system. The concentration of particulates produced by a fuel can be measured as the weight in grams of particulates produced per one kilogram of fuel burned, known as the Emission Factor (EF). Certain fuels have a higher emission factor, such as untreated wood (average EF = 10.5) when compared to charcoal (EF = 0.9) (Amaral et al., 2016:Table 10). A higher emission factor and, therefore, exposure to a higher concentration of particulates can negatively affect respiratory health. For example, in testing the pulmonary function of different fuel users (agricultural waste, wood, or gas fuels) from the Jalgoan district of Maharashtra, India, it was found that lung function was impaired to a greater extent in women exposed to smoke from agricultural waste, which has a higher EF of PM_{10}, causing more frequent complaints of chest pain, coughing, and throat irritation (Ingale et al., 2011:467). The use of animal dung as a fuel produces a significantly higher EF than other fuels (Amaral et al., 206:14) and has a high metal content, which can be highly oxidative (Mudway et al., 2005) and damaging to the immune response and regulation of inflammation in the lungs (e.g. Becker, 2002; Lee et al., 2015) (see Section 2.4.3.i). Studies of people using mainly dung as fuel have found a higher risk of developing pulmonary diseases compared to those using cleaner burning fuels (e.g. Turaclar et al., 1999:123; Balcan et al., 2016:1619).

2.4.2 Epidemiological studies

Many epidemiological studies are now investigating the connection between particulate matter and the development of lower respiratory tract diseases. An association between $PM_{2.5}$ concentrations and hospitalisations, including due to respiratory health problems, has been found across the USA (Dominici et al., 2006:1133). For example, significant reductions in lung function during episodes of elevated ambient PM_{10} in people in Utah Valley, USA, have been found, accompanied by an increase in reported symptoms of respiratory disease (Pope et al., 1991:672). Furthermore, Guatemalan women have been found to have greater levels of HAP exposure, associated with reduced lung function and increases in respiratory symptoms suggestive of airway inflammation (e.g. coughing, wheezing, phlegm production, and chest tightness) (Pope et al., 2015:290-291). Additionally, in a study of acute respiratory infection in Kenya, an increase in the frequency of respiratory infections with greater exposure to PM_{10} from biomass fuel was observed (Ezzati & Kammen, 2001:623).

Although indoor air pollutants are also thought to irritate the mucosal lining of the sinuses (Koltai, 1994:11; Trevino, 1996:240; Shusterman, 2011:103-104), leading to ostiomeatal blockage and sinusitis (Holt, 1996:203) and although several papers have discussed the potential effect of air quality on the upper respiratory tract and sinuses (e.g. Koltai, 1994; Holt, 1996; Trevino, 1996; Clerico, 2001; Shusterman, 2011), very few epidemiological studies have attempted to quantify this hypothesis (Riechelmann et al., 2003:59; Bhattacharyya, 2009:433). In a rare cross-sectional study of the adult population in the USA over 10 years a significant association between concentrations of PM, sulphur dioxide, carbon monoxide, and nitrogen dioxide, and the prevalence of sinusitis was found. However, the study was unable to separate chronic from acute sinusitis to investigate the effect air quality may have had on the longevity of the disease (Bhattacharyya, 2009:Fig. 2, 433). An increase in $PM_{2.5}$ was also significantly correlated with an increase in reports of sinusitis in adults in a separate national USA study (Nachman & Parker, 2012:5).

While the effect of PM on susceptibility to respiratory diseases is likely to be markedly affected by interindividual variability, it has been suggested that genetic predisposition and epigenetic changes associated with air pollution are likely to play a part (Hiraiwa & van Eeden, 2013:6). For example, in a study of $PM_{2.5}$ concentrations and self-reported respiratory conditions in adults from the USA, Nachman and Parker (2012:8, 9) found a racial disparity in reports of asthma, with a greater number of black adults reporting asthma related problems with exposure to higher levels of PM. Although this may be due to genetic differences in physiological reactions to PM, a variety of other confounding factors and the fact that respiratory problems were self-reported may have affected this outcome (Nachman & Parker, 2012:7-8). Additionally, investigations of respiratory illness in relation to HAP in developing countries are impeded by the lack of data about the extent and duration of exposure to particulates and the subsequent respiratory response, by the use of indirect measures of exposure, and also by the number of confounding factors that can affect exposure to HAP and illness outcome (Smith et al., 2000:530; Ezzati & Kammen, 2001:619; Kelly et al., 2015:354).

While it is evident that general exposure to PM is related to an overall decrease in respiratory health and function, exposure to particulates from specific environments or the effect PM has on specific diseases have also been investigated. A large number of these epidemiological studies have concentrated on acute lower respiratory tract infection (ALRI) in children, which is summarised in the section below. Additionally, epidemiological studies of the effect of exposure to particulate matter from certain climates and occupations, as well as the effect of PM on tuberculosis, are also presented, because these were likely to have been factors affecting the prevalence of respiratory disease in archaeological populations.

2.4.2.i Acute lower respiratory tract infection in children

Epidemiological studies are finding a positive correlation particularly between the use of biomass fuels and the development of ALRI in children, including serious infections of the lungs such as pneumonia (e.g. de Francisco et al., 1993; Smith et al., 2000; Rehfuess et al., 2009; Ramesh Bhat et al., 2012; Sood, 2012:656; Bates et al., 2013; Gurley et al., 2013). The World Health Organisation (WHO) (2018a) estimates that today half of all deaths from pneumonia in children under 5 years are caused by HAP. For example, it was found that the use of biomass fuels increased the hazard risk of ALRI in children under five in Africa by an odds ratio of 2.35 and there was a particularly strong association between the effective use of ventilation in cooking practices and a reduced risk (Rehfuess et al., 2009:889).

In a study in Santa Dominigo, the Dominican Republic, the relationship between ALRI in children and the use of charcoal was investigated. Charcoal was chosen because it is thought to produce lower levels of pollutant emissions than other types of biomass fuel and has been suggested as a less damaging alternative. However, results suggested that children living in households that used charcoal were still exposed to higher levels of PM and were at a significantly greater risk of ALRI than those from households using propane gas, which produces very low particulate emissions (Bautista et al., 2009:577). In a meta-analysis of previous epidemiological studies from around the world, Dherani et al. (2008:392) concluded that the risk of pneumonia in young children is increased by a factor of 1.79 with the use of biomass fuels and coal for fires. It has also been found that exposure to biomass HAP is associated with an almost 50% increase in the risk of failure to effectively treat pneumonia within 48 hours in children under the age of two, suggesting that exposure to HAP might increase lung injury and the persistence of inflammation (Kelly et al., 2015:351). Other factors that are likely to affect a child's risk of ALRI include parental (passive) smoking, previous healthcare treatment, malnutrition, socioeconomic status, and poor parental education (Dherani et al., 2008:392; Rhamesh Bhat et al., 2012:133-134; Kelly et al., 2015:353).

2.4.2.ii Tuberculosis

An association between the indoor use of biomass fuels and the prevalence of tuberculosis has been found in several epidemiological studies (Bruce et al., 2000:1084; Lin et al., 2007:0183; Fullerton et al., 2008:846; Perez-Padilla et al., 2010; Sood, 2012:657; Öztürk et al., 2014) and a meta-analysis of thirteen studies found an overall strong association between TB and HAP (Sumpter & Chandramohan, 2013:105). For example, the use of biomass fuels in cooking has been positively correlated with the presence of pulmonary tuberculosis in adult women in Chandigarh, Northern India, although confounding factors such as level of income and education, area of residence, and age may also play a part in susceptibility to the disease (Lakshmi et al., 2012:458-459). Similarly, an association between the prevalence of tuberculosis and the use of biomass fuel was found in adult women in Pokhara, Nepal. In this case fuel was mainly used for heating the home, rather than for cooking, suggesting that at certain times of the year using biomass fuel for heating, with minimal ventilation and deliberate prolonged exposure, may constitute a higher risk for tuberculosis than exposure to smoke during cooking, which may be intermittent (Pokhrel et al., 2010:561-562).

In a large-scale study of tuberculosis in Tamilnadu, India, exposure to biomass smoke also had a stronger association with tuberculosis than smoking, which is known to be a risk factor for the disease (Kolappan and Subramani, 2009:707). A similar study in Istanbul, Turkey, found a greater association between smoking and TB, with a fivefold increase in the likelihood of having active tuberculosis compared to non-smokers, but it was also found that using coal or wood for indoor heating increased the likelihood of having TB by 1.6 fold (Öztürk et al., 2014:5). In a rare study of the relationship between TB and outdoor air pollution in different regions of the city of Tehran, Iran, a significant association was found between the disease and regions which had a higher concentration of $PM_{2.5}$, with a 10-fold increase (Rajael et al., 2018:42). A very similar study of outdoor air pollution in Seoul, South Korea, only found an increase in tuberculosis in males with exposure to sulphur dioxide (Hwang et al., 2014:187). However, clinical studies on the relationship between particulate pollution and tuberculosis are rare and there are a large number of confounding factors involved in the development of the disease (Cohen & Mehta, 2007:0600; Perez-Padilla et al., 2010:1083; Jindal, 2014:168). It has been suggested that a greater number of high-quality studies are required before a positive association between them can be proven (Sumpter & Chandramohan, 2013:107; Jindal, 2014:168; Lin et al., 2014:620).

2.4.2.iii Occupation

Activities that are regularly undertaken as part of an occupation and involve exposure to particulate matter for extended periods of time can have an adverse impact on respiratory health. Exposure to particles within the workplace can occur from a wide range of sources, such as mineral, metallic, chemical, and organic dusts, and biohazards including animal allergens, moulds, and spores (WHO, 1999:2). For example, occupational exposure to particulate matter in organic dust has been closely associated with sinusitis (Shusterman, 2011:103). In a series of studies of respiratory illness in different occupational groups, self-reported sinusitis and other respiratory symptoms were found to significantly increase in furriers, hemp workers, vegetable picklers, in people working with woollen and synthetic textiles, and in paper-recycling and pharmaceutical workers, as opposed to control-groups (Zuskin et al., 1988, 1990, 1993, 1995, 2004; Zuskin, Mustajbegovic, Schacter, Kanceljak et al., 1998; Zuskin, Mustajbegovic, Schacter, Kern et al., 1998). These occupations involve exposure to organic matter and irritant chemicals and dusts, which are likely to cause sensitisation and inflammation of the sinus mucosa, leading to an increased susceptibility to sinusitis (Hox et al., 2014:282). The inhalation of organic matter, from chemical, fungal, animal, and bacterial sources, can also affect the lower respiratory tract, resulting in interstitial lung disease (affecting the interstitium - the tissues and space surrounding the alveoli), granulomatous tissue formation, and eventual lung fibrosis (Patel et al., 2001:661; Sirajuddin & Kanne*,* 2009:315). Known as hypersensitivity pneumonitis, this disease was first associated with farmers and bird breeders, but occupational exposure to various microbial and animal antigens have further been associated with the disease (Sirajuddin & Kanne*,* 2009:315).

Non-organic matter, particularly silica (including quartz), asbestos, and coal dust particles, have been closely associated with the development of pneumoconiosis, an interstitial lung disease that causes inflammation and fibrosis of the lung parenchyma, resulting in dyspnoea and low transfer of oxygen into the blood stream (Rom et al., 1987:1429). Pneumoconiosis is particularly likely to affect industrial workers who are exposed to a variety of dusts during their work for long periods of time, often in confined or poorly ventilated spaces, such as miners. For example, inhalation of dust from asbestos mining often leads to a type of pneumoconiosis named asbestosis, which can also cause pleural plaques (diffuse fibrosis of the pleura that can eventually calcify) and malignant diseases, such as mesothelioma (Mossman & Churg, 1998:1666-1667; Ross & Murray, 2004:305).

Pneumoconiosis as a result of silica inhalation is referred to as silicosis and is characterised by extensive lung fibrosis (Mossman & Churg, 1998:1667; Sirajuddin & Kanne*,* 2009:310). In addition to mining, workers in occupations such as quarrying, sandblasting, drilling, and foundry working, and in ceramic, pottery, brick, concrete, and glass manufacturing, are also likely to be exposed to high levels of silica dust (Robert et al., 2008:652; Sirajuddin & Kanne*,* 2009:310). In a study of construction workers exposed to quartz dust from grinding, drilling, cutting, sawing, polishing, and hammering materials such as stone, brick, cement, and concrete, it was found that there was an increased risk of radiographic abnormalities of the lung, indicative of mixed dust pneumoconiosis. An increase in this risk was also found with greater duration of exposure (Tjoe Nij et al., 2003:415, Fig. 1). People working in pottery manufacturing are also likely to be exposed to dust containing a high concentration of quartz particles, increasing the risk of developing silicosis (e.g. Rees et al., 1992; Forastiere et al., 2002; Tsao et al., 2017). For example, in a survey of female ceramic manufacturers from Civitacastellana, Italy, a positive correlation was found between exposure to silica dust and the development of silicosis and a decline in lung function, particularly after longer periods of exposure (Forastiere et al., 2002:855). An association between exposure to silica dust and an increased risk of chronic interstitial pneumonia and tuberculosis has also been established (Calvert et al., 2003:126; Ross & Murray, 2004:307; Sirajuddin & Kanne*,* 2009:311). For example, an increase of 2.8 fold in the risk of contracting tuberculosis was found in South African goldminers with silicosis (Cowie, 1994:1469).

Domestic related occupations may also cause a type of interstitial lung disease often referred to as "hut lung", which is characterised by carbon and dust particle deposits in the lungs and fibrosis of the parenchymal lung tissue (Grobbelaar & Bateman, 1991:340; Gold et al., 2000:315; Fullerton et al., 2008:845; Sood, 2012:10). In lung biopsy samples from 25 women with pneumoconiosis from the Transkei district of South Africa, anthracosis (carbon pigment deposits) and mixed dust fibrosis were observed. Within this region it is traditional for women to grind maize for forty-five minutes a day from the age of ten onwards by crushing the maize using grinding rocks, which produces an inhalable fine maize and stone dust that is likely to contribute towards fibrosis of the lung. However, the study also found that the greatest contributor to pneumoconiosis in these women was likely to be from exposure to smoke from biomass fuels (Grobbelaar & Bateman, 1991). Other researchers have also suggested that hut lung is caused by exposure to biomass smoke, describing the condition as domestically acquired particulate lung disease (e.g. Gold et al., 2000:315; Asaad et al., 2018:74). As discussed above, in developing countries, women are likely to traditionally take on the role of family cook and will spend long hours exposed to smoke from biomass fuelled cooking fires and are, therefore, most commonly discussed in relation to this condition (e.g. Grobbelaar & Bateman, 1991; Fullerton et al., 2008:845; Sood, 2012:10). However, a case of domestically acquired particulate lung disease has been described in a man from Sudan, who had been exposed to smoke within the small and poorly ventilated kitchen of his home whilst his wife baked (Asaad et al., 2018), suggesting that men can be similarly exposed.

Other occupations involving exposure to PM, such as farming, metalworking, and even outdoor work in heavily polluted areas, have demonstrated adverse effects on respiratory health. Metalworkers involved in casting and forging steel in northern India, who did not always wear protective masks, were found to have a significant reduction in lung function compared to a control group, likely due to occupation-related dust inhalation (Singh et al., 2013:5). A study of traffic-police officers working outside in the metropolitan area of Bogotá, Colombia, found a higher prevalence of respiratory symptoms, including sinusitis, in those working in traffic roles and exposed to vehicle exhaust emissions compared to those working in administration roles within the office, although the differences were not statistically significant (Estévez-García et al., 2013:897-898).

In particular, farming has been closely linked to adverse effects on respiratory health as the activities related to this occupation often involve exposure to mixed organic and inorganic dusts when dealing with animals, and ploughing, tilling, harvesting, and winnowing crops (e.g. Kirkhorn & Garry, 2000; Schenker, 2000:664, 2010:109; Boxall et al., 2009:511). One of the greatest risks comes from regions with a dry climate, where inorganic mineral dust can be easily suspended in the air during agricultural activities (Schenker, 2010:110). For example, a study of lung biopsies of people from California, USA, which has a fairly arid climate, demonstrated significantly higher rates of pneumoconiosis and interstitial fibrosis in the lungs of agricultural workers compared to nonagricultural workers, which was attributed to greater occupational exposure to dust (Schenker et al., 2009:992). Inhalation of dusts, allergens, and endotoxins shed by animals, particularly in poorly ventilated buildings, is also an occupational hazard of farming and has been found to impair lung function (e.g. Iversen et al., 2000; Radon et al., 2001; Pfister et al., 2018:291).

It should also be noted that poor air quality can have a general effect on people living in proximity to industrial areas. This has been demonstrated in a community from Chilanga, Zambia, who were located 1km from a cement factory producing considerable amounts of dust, and had higher levels of exposure to particulate matter than a similar community located 18km away. This higher concentration of PM was significantly associated with reduced lung function and increased respiratory symptoms (Nkhama et al., 2017:10-11).

2.4.2.iv Climate

Extremes in climate and related environmental events have also been linked to an increased susceptibility to respiratory diseases. For example, it has been noted that infections acquired via the respiratory tract in tropical Africa, such as lobar pneumonia, occurred in much higher frequencies during the dry season. It was suggested that this may have been due to reduced humidity and the consequent drying out of the mucosa of the respiratory tract, leading to impaired resistance to infection (Waddy, 1952:677). A more recent study of hospital admissions rates for respiratory disease during high temperature events in New York City found that morbidity rates increased with temperature. However, a higher humidity actually interacted with higher temperatures to increase morbidity, whereas lower humidity acted as a buffer against the effect of high temperatures (Lin et al., 2009:742, 744). Studies have found that that a relative humidity range of between 40% and 60% is required for optimal upper respiratory tract health and extremes in humidity, both higher and lower than this, can lead to upper respiratory symptoms and infection (e.g. Arundel et al., 1986:358; Wolkoff & Kjærgaard, 2007:854). Additionally, changes in climate and temperature can lead to an increase in allergen matter in the air, including a rise in pollen and mould spores, which can cause allergic inflammation and increased susceptibility to other respiratory diseases (Ayers et al., 2009:297; Bernstein & Rice, 2013:1456; D'Amato et al., 2015:2; Yusa et al., 2015:8372).

High temperatures and resulting increased drought and aridity can lead to dust storms (Meng & Lu, 2007:7048; Ebrahimi et al., 2014:1; Yusa et al., 2015:8372). These storms are the result of winds blowing over vegetation and soil that lack moisture, subsequently picking up and transporting airborne particles (Meng & Lu, 2007:7049; Ebrahimi et al., 2014:1; Middleton & Kang, 2017). During dust storms there is an increased level of PM in the ambient air, which can lead to adverse health effects (Uduma & Jimoh, 2013:175; Esmaeil et al., 2014:20; Yusa et al., 2015:8372). This is supported by a number of studies that document rises in hospital admissions for respiratory disease during and after dust "events" (e.g. Hefflin et al., 1994; Meng & Lu, 2007; Bell et al., 2008; Lai & Cheng, 2008; de Longueville et al., 2013; Ebrahimi et al., 2014; Trianti et al., 2017). For example, a positive association between dust events and hospitalisation for respiratory problems and hypertension was found in people admitted to hospital during and after major dust storms in Minqin County, China (Meng & Lu, 2007:7055). In a similar study in Athens, Greece, that investigated hospital visits during days of high dust concentration transported from the Sahara, a significant increase of approximately 50% in admissions for respiratory disease, including asthma and infection, was observed (Trianti et al., 2017:4). A significant rise in hospital emergency room visits for sinusitis after increases in PM_{10} concentrations caused by natural dust storms in Washington State, U.S., has also been noted (Hefflin et al., 1994:173).

A high prevalence of silicosis associated with frequent dust storms in two villages in a Himalayan area also appeared to be related to progressive and extensive fibrosis of the lungs in older individuals. In this study, a higher association in women was attributed to exposure to environmental dust during farming and sweeping, which women traditionally undertook (Norboo et al., 1991:341, 343). A similar study of pneumoconiosis in a Bedouin population from the Negev Desert, Israel, suggested that the preponderance for silicosis in women may have been due to their role in cleaning dust from inside the tents and processing wool, among other activities (Hirsch et al., 1974:510). Additionally, a higher prevalence of tuberculosis in desert dwellers in the Thar Desert, India, compared to nearby non-desert populations has been suggested to be the result of damage to the lungs caused by desert dust inhalation (Mathur & Choudhary, 1997:561).

Studies of soldiers deployed to desert environments have also reported an increased prevalence of respiratory symptoms and disease, for which desert dust inhalation has been suggested to play a major role, among other factors such as exposure to particulates from fires and vehicle exhaust emissions, and psychological stress (e.g. Richards et al., 1993; Lange et al., 2003; Miller, 2013; Morris et al., 2014; Korzeniewski et al., 2015; Singh et al., 2016; Harrington et al., 2017; Saers et al., 2017). For example, it has been reported that 40 to 70% of soldiers deployed to Iraq and Afghanistan seek out treatment for upper respiratory tract infections (Korzeniewski et al., 2015:79). Other respiratory symptoms, such as wheeze or cough, were reported at a much higher rate in Swedish soldiers deployed to Kosovo and Afghanistan compared to a control group of Swedish civilians (Saers et al., 2017:5). The hot and dry environment of the desert has also been found to reduce mucociliary function in soldiers (Singh et al., 2016:1487), which can lead to inflammation of the sinuses.

Much of Sudan has consisted of a semi-desert or desert environment from around at least 2000 BC (see Chapter 4). Dust storms, known as *haboobs*, are common in the region and today, near Khartoum, an average of twenty dust storms occur per year, for the most part between May and July (Idso, 1976:109; Goudie & Middleton, 2001:Table 5; Nicholson, 2011:305). While there remain very few epidemiological studies of respiratory disease in Sudan, the examples above from similar environments demonstrate that the deserts and dust storms of Sudan may have had an adverse impact on respiratory health in people living in the Middle Nile Valley for much of its history.

2.4.3 Pathogenesis

Despite the many epidemiological studies that have demonstrated a link between an increase in exposure to particulate pollution and a rise in respiratory-related morbidity and mortality, the mechanisms responsible for this increase remain unclear (van Eeden et al., 2001:826; Rylance, Chimpini et al., 2015:2; Rylance, Fullerton et al., 2015: 585). Several suggestions have been put forward for the processes by which particulate matter causes increased susceptibility to respiratory disease. These mainly centre on the immune response within the lungs triggered by PM, but this can be dependent on the size and composition of particulates, factors which are discussed below. The mechanisms by which PM can affect mucociliary clearance and the relationship between lung inflammation and the development of other non-respiratory related diseases are also presented.

2.4.3.i Alveolar macrophage function

The lungs contain several defence mechanisms that protect the tissue from invading pathogens, but the majority of studies in relation to PM have focussed on alveolar macrophages (AMs) (Lee et al., 2015:369). AMs function is to remove infectious, allergic, or toxic particles and pathogens from the alveoli through the process of phagocytosis (ingestion of particles) (Rubins, 2003:10; Hiraiwa & van Eeden, 2013:4). Once particles are phagocytosed, AMs produce reactive oxygen species, in a process known as oxidative (or respiratory) burst, which aids in the break-down of ingested particles or pathogens (Rylance, Chimpini et al., 2015:2; Rylance, Fullerton, et al., 2015:590). AMs also release cytokines, cell-to-cell signals, which recruit neutrophils (inflammatory cells), causing immune responsive inflammation of the local tissue (Rubins, 2003: 103; Lee et al., 2015:370). Once an infectious challenge has been dealt with, neutrophils are phagocytosed by AMs, reducing any further inflammation (Rubins, 2003:103). Excessive inflammation can cause damage to the epithelial barriers, promoting lung tissue injury and susceptibility to further infections or pulmonary disease (Lee et al., 2015:369; Morales-Bárcenas et al., 2015:168). Therefore, AMs are important in the regulation of inflammatory responses within the alveoli and in the maintenance of healthy lung tissue and function (Rubins, 2003:104).

Several studies have suggested that the interaction between inhaled particulates and AMs may affect the immune response of the lungs to invading pathogens (van Eeden et al., 2001:828; Jang, 2012:154; Lee et al., 2015:370; Rylance, Chimpini et al., 2015:2; Rylance, Fullerton et al., 2015:585). In a meta-analysis of clinical studies investigating the effects of PM exposure on respiratory inflammation and immune response it was suggested that PM stimulates the release of cytokines by AMs, which attracts neutrophils to the airspace, causing inflammation, and that a high level of particulate loading (number of particulates phagocytosed) induces apoptosis (self-destruction) of AMs. This then further exacerbates inflammation and compromises host resistance to infection. It has also been suggested that PM impairs the ability for AMs to phagocytose and kill pathogens and alters the regulation of receptors involved in pathogen invasion, increasing susceptibility to bacterial infection (Lee et al*.,* 2015:370).

In a study of adults exposed to HAP from biomass fuel in Malawi it was found that people with chronic exposure displayed altered macrophage function. In particular, macrophages showed reduced cytokine production and diminished oxidative burst response (Rylance, Chimpini et al., 2015:11). A similar study in the same region, using human alveolar macrophages taken from healthy adults, found that, when exposed to acute levels of wood smoke *in vitro,* AMs demonstrated an impaired ability to phagocytose *S. pneumoniae* and *M. tuberculosis* pathogens. AMs which had a high level of particulate loading also displayed a reduction in oxidative burst, which is required for the breakdown of particulates or pathogens (Rylance, Fullerton et al., 2015:591).

2.4.3.ii PM size and composition

The gaseous and particulate composition of PM, which can vary considerably depending on the source of pollution, may also have an effect on the type of inflammatory response (Schlesinger, 1995:315; Li et al., 2003:455; Jang, 2012:161; Hiraiwa & van Eeden, 2013:2). Toxic gases, such as nitrogen dioxide (NO_2), ozone (O_3), and formaldehyde (CH_2O), are highly irritant to lung tissue but are usually removed from inhaled air within the upper respiratory tract, before they can cause damage to tissue in the lower airways (Schlesinger, 1995:317). However, carbon particles, which constitute a large component of smoke and are inert when inhaled alone, provide a surface onto which these gases can adhere and penetrate into the lower respiratory tract, causing damage to the tissue (Schlesinger, 1995:317; Seaton et al., 1995:177). One study of AM response to different types of air pollution found that the chemical composition of PM may be particularly important in determining the level of oxidative burst response. During a period of exposure to certain particles an inflamed lung may be in a constant state of oxidative stress, which can lead to AM apoptosis. It was also noted that the oxidative response of AMs to naturally occurring dusts was far less than to other particles and was suggested to be the result of an adaptation of macrophages to dusty environments (Becker et al., 2002:216-217).

Although some studies have found no correlation between different particle sizes of 10µm or less and the extent of inflammatory response (e.g. van Eeden et al., 2001:830, Becker et al., 2001:216), a review of studies on PM size concluded that UFP caused a greater inflammatory response by mass than $PM_{2.5}$ (Oberdörster, 2001:7). Li et al. (2003:459) also found that UFP was more potent than PM_{10} and $PM_{2.5}$ in inducing oxidative stress. Ultrafine particles are formed during incomplete fuel combustion. They have a high number concentration and, therefore, a large surface area per unit mass, with an increased ability to adsorb organic molecules and penetrate cellular structures (Li et al., 2003:455). It has been suggested that the greater impact of ultrafine particles may be due to the higher percentage of organic content (particularly of polycyclic aromatic hydrocarbons, which can induce oxidative burst), to the enhanced penetration of interstitial tissue by these particles, and to their surface chemistry, which dictates the toxicity of UFP (Oberdörster, 2001:7; Li et al., 2003:459).

2.4.3.iii Mucociliary clearance

In addition to inflammation, it has also been proposed that pollutants in the air affect the functioning of mucociliary clearance, which is the primary defence mechanism against inhaled particulate matter, allergens, and pathogens in the respiratory tract (Antunes & Cohen, 2007:5; Johnson et al., 2011:30). It is also particularly important in regulating the environment within the sinuses (Birdi et al., 1998:15; Antunes & Cohen, 2007:5). Individual cilia move in coordination, in waves of activity called ciliary beat frequencies, to propel mucus, trapped matter, and pathogens along the epithelial surface to the oropharynx, where they are swallowed (Goto et al., 2011:665; Johnson et al., 2011:30; Tilley et al., 2014:380). A reduction in mucociliary clearance, by disruption of the ciliary beat frequency, interruption of the coordination of ciliary activity, or changes to the composition of the mucus, impairs lung function and immune defences and leads to a build-up of trapped matter, which can result in increased susceptibility to respiratory tract infections (Leopold et al., 2009:1; Antunes & Cohen, 2007:5; Goto et al., 2011:665; Johnson et al., 2011:30). In particular, disruption of mucociliary clearance is thought to cause stasis of sinonasal secretions, bacterial overgrowth, and infection and inflammation of the sinuses and nasal cavity (Johnson et al., 2011:31).

Environmental pollutants such as sulphur dioxide, nitrogen dioxide, formaldehyde, and ozone are all known to affect mucociliary clearance by reducing ciliary beat frequency (Houtmeyers et al., 1999:1182-1183; Tilley et al., 2014:393). Leopold et al. (2009:7) suggest that tobacco smoke, which contains many of the same components of biomass smoke including particulate matter, can reduce cilia length by 10%, affecting the ability of the cilia to effectively propel mucus. Additionally, tobacco smoking has been shown to produce atypical epithelial cells and missing cilia, increasingly exacerbated by longer exposure to smoke, and it may also cause reduced ciliary beat frequency (Houtmeyers et al., 1998:1183; Tilley et al., 2014:392).

A study of the effect of biomass smoke on nasal mucociliary clearance in women from Chennai, India, found that nasal mucociliary clearance was significantly altered in those using biomass fuels, leading to longer mucus clearing times (Johnson et al., 2011:31). In a similar study of the daily biomass burning of sugarcane on a Brazilian farm, as part of the harvest, an 80% reduction in nasal mucociliary clearance of farm workers during the harvest was found. It was also noted that $PM_{2.5}$ concentrations were significantly higher on the farm during the period of burning (Goto et al., 2011:666). Unfortunately, there have been very few other studies on the effect of biomass smoke and particulate matter on mucociliary function (Johnson et al., 2011:32).

2.4.3.iv Lung inflammation and non-respiratory diseases

Epidemiological studies have also shown an increase in admittance to hospitals for cardiovascular diseases during high pollution "events" (van Eeden et al., 2001:826). Seaton et al. (1995:178) hypothesised that alveolar inflammation caused by PM creates changes to blood coagulability, increasing susceptibility to cardiovascular disease. However, more recent research suggests that the proinflammatory cytokines released as a result of the phagocytosis of PM stimulates bone marrow to release leukocytes and platelets (van Eeden et al., 2001:828; Hiraiwa & van Eeden, 2013:6). This, in turn, may cause atherosclerotic plaques to destabilise, causing rupture and thrombosis (local clotting of the blood), which can lead to a cardiovascular event (Hiraiwa & van Eeden, 2013:6). PM may also play a part in the development of lung cancer by altering epithelial cells and increasing the invasiveness of cancer cells, working in conjunction with localised inflammation in the airways to increase susceptibility to cancer development (Morales-Bárcenas et al., 2015:172). Mutagens in biomass smoke have also been suggested to mutate cells and cause the development of cancer (Nabi et al., 2015:142).

2.5 Summary

While the development of sinusitis is relatively simple, most commonly caused by inflammation of the mucosa and blockage of the ostium or ostiomeatal complex, the pathogenesis and manifestations of pleural disease can be complex, caused by numerous diseases, including tuberculosis, pneumonia, and actinomycosis. In particular, a wide range of non-pulmonary diseases can result in pleural disease and may serve as a differential diagnosis for new bone formation on the visceral surfaces of the ribs in archaeological populations. Nevertheless, it is evident that particulate matter plays an important role in triggering inflammation within the respiratory tract, resulting in sinusitis and lower respiratory tract conditions leading to pleural disease. Exposure to Particulate matter can be from a wide range of sources, including from the general environment, the burning of biomass fuels, and from various occupational hazards. As well as causing inflammation and tissue damage, particulate matter can also increase susceptibility to other infectious diseases, such as tuberculosis. A greater understanding of the pathogenesis of respiratory disease and its relationship to exposure to particulate matter ultimately aids in the interpretation of prevalence rates of bony changes associated with respiratory disease in archaeological populations, which will be further discussed in the following chapter.

Chapter 3: A bioarchaeological review of respiratory disease

3.1 Introduction

Bony changes in the sinuses and on the visceral surfaces of the ribs in human skeletal remains have been used to investigate the prevalence of upper and lower respiratory tract disease, respectively. Differences in the prevalence of respiratory disease among populations can give an indication of the presence of risk factors affecting respiratory health. The following chapter contains two separate sections that review the available bioarchaeological studies of maxillary sinusitis and inflammatory periosteal reaction (IPR) on the visceral surfaces of the ribs. This includes available prevalence rates for different populations in various regions, a discussion of the potential aetiological factors involved in susceptibility to respiratory disease in the past, and a review of the methods used by different studies.

3.2 Maxillary sinusitis

The clinical text by Zuckerkandl (1893:317-318) was one of the first to describe proliferative new bone formation within the maxillary sinuses, including thickening, pitting, thin spicules, and protuberances on the sinus walls. It was suggested that this represented a reaction to periostitis and osteitis. However, it was not until 1977 that the first prevalence study of maxillary sinusitis, in British archaeological populations, was undertaken (Wells, 1977:174). This study suggested that an inflammatory reaction to pus accumulation on the antral floor resulted in spicules and exostoses (bony outgrowths) extending from the antral floor and a granular or rugose surface with extensive pitting. It was noted that factors such as living conditions, urban or rural environment, occupation, climate, and anatomical variation would need to be investigated in further bioarchaeological studies of sinusitis to explore potential aetiologies (Wells, 1977:177-178). It was not until much later that diagnostic criteria for bone changes related to maxillary sinusitis were established, through the study of a cemetery population from the Medieval hospital of St. James and St. Mary Magdalene (12^{th} to 17^{th} C.), in Chichester, England (Boocock et al., 1995). This study has provided the framework for all subsequent prevalence studies. The criteria identified as evidence for bony involvement in sinusitis were pitting of the bone surface, thickening of the sinus walls, white-pitted bone deposits, and bone spicules with subsequent remodelling (Figure 3.1). The following sections will review the bioarchaeological studies of maxillary sinusitis conducted using these criteria, including the potential aetiological factors involved and the different methods employed.

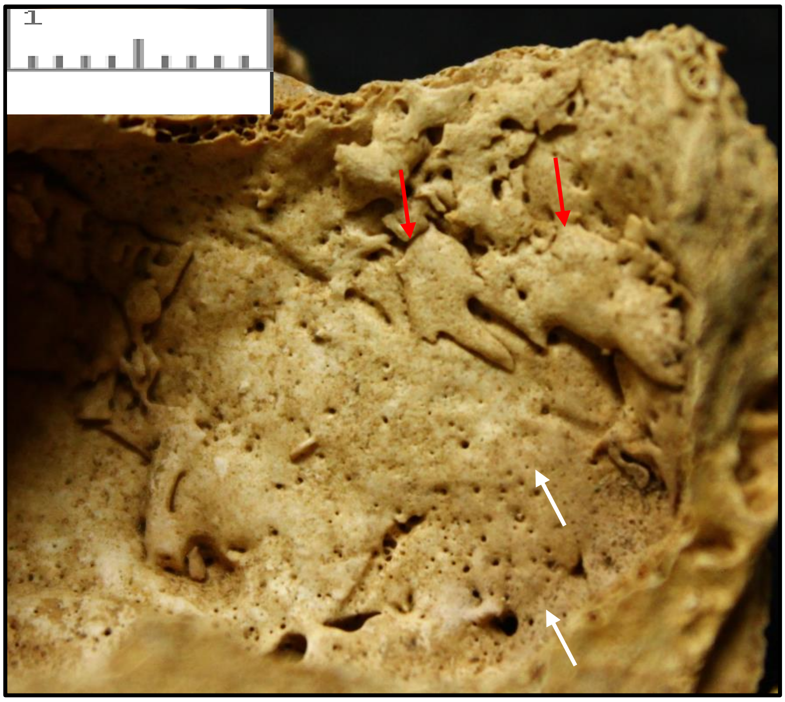


Figure 3.1 – Bony changes within the maxillary sinus related to sinusitis (red arrows = remodelled spicules; white arrows = white pitted bone) (site Soba East, UA3, Sk45H, right maxillary sinus).
Image courtesy of the Trustees of the British Museum

3.2.1 Prevalence rates in bioarchaeological studies

The majority of prevalence studies of maxillary sinusitis have focussed on skeletal populations from England. However, there have also been several studies from mainland Europe, North America, and Sudan (Figure 3.2). While only the occasional chance find of sinusitis in skeletons was reported before 1977 (e.g. Leigh, 1928:417; Wells, 1964), the initial true prevalence studies of maxillary sinusitis by Wells (1977) and Gregg and Gregg (1987) revealed low prevalence rates, indicating that perhaps sinusitis was not a common condition (Lewis et al., 1995:497). However, later studies have revealed that sinusitis was in fact a common disease affecting large proportions of populations in the past, as Figure 3.2 demonstrates. It has been suggested that the disparity between initial low prevalence rates provided by Wells (1977:Table 1 – 3.6% Medieval Britain; 6.8% Anglo-Saxon Britain) and Gregg and Gregg (1987:Table 3.2 – 3.9% Crow Creek, Dakota, USA) and the considerably higher rates reported in later studies may have been due to subsequent methodological developments, following the publication of Boocock et al. (1995). In particular, due to improvements in the consistency of morphological descriptions of the bone changes related to maxillary sinusitis and in the development of palaeopathology as a discipline (Merrett & Pfeiffer, 2000:302). For this reason, studies conducted before the publication of standard diagnostic criteria by Boocock et al. (1995), such as Wells (1977), Gregg and Gregg (1987), and Lilley et al. (1994), have been omitted from Figure 3.2.

Additionally, the majority of studies to date have excluded non-adults from their analyses. Hence, in order to maintain consistency between studies, wherever possible only prevalence rates for adults have been calculated from the data provided in publications. Therefore, prevalence rates presented in the figures that follow may not match the overall frequencies provided in the publications themselves, some of which may include non-adults. Furthermore, it should be noted that the frequencies for non-adults and adults in certain studies could not be separated and have been noted as such in Figure 3.2.

Prevalence rates of maxillary sinusitis demonstrate a considerable degree of variation, both within and between geographical regions and across time. This could be due to a wide range of temporal-, regional-, or site-specific factors. The aim of many bioarchaeological studies of maxillary sinusitis was to investigate the potential effect of various aetiological factors on susceptibility to sinusitis.

3.2.2 Aetiological factors

The following sections present a review of the main aetiological factors that have been discussed in relation to maxillary sinusitis. These include air quality, living environment and subsistence economy, socio-economic status, climate, infectious disease, the role of dental disease in the development of sinusitis, and potential aetiological differences between the sexes.

3.2.2.i Air quality, living environment, and subsistence economy

The clinical importance of poor air quality and particulate matter on susceptibility to maxillary sinusitis has been demonstrated in Section 2.4. Many bioarchaeological studies have also noted the possible relationship of particulate pollution, from indoor fires, industrial emissions, and other activities related to occupation and subsistence economy, to elevated frequencies of maxillary sinusitis (e.g. Wells, 1977:174; Lewis et al., 1995:499; Merrett & Pfeiffer, 2000:314-315; Roberts, 2007:792-793; Sundman & Kjellström, 2013:455). Additionally, the wider living environment, including the quality of hygiene and sanitation and levels of crowding within houses and workplaces, has also been suggested as a factor in the transmission of infectious airborne droplets and, therefore, in the development of sinusitis (Wells, 1977:174; Boocock et al., 1995:492; Lewis et al., 1995:499).

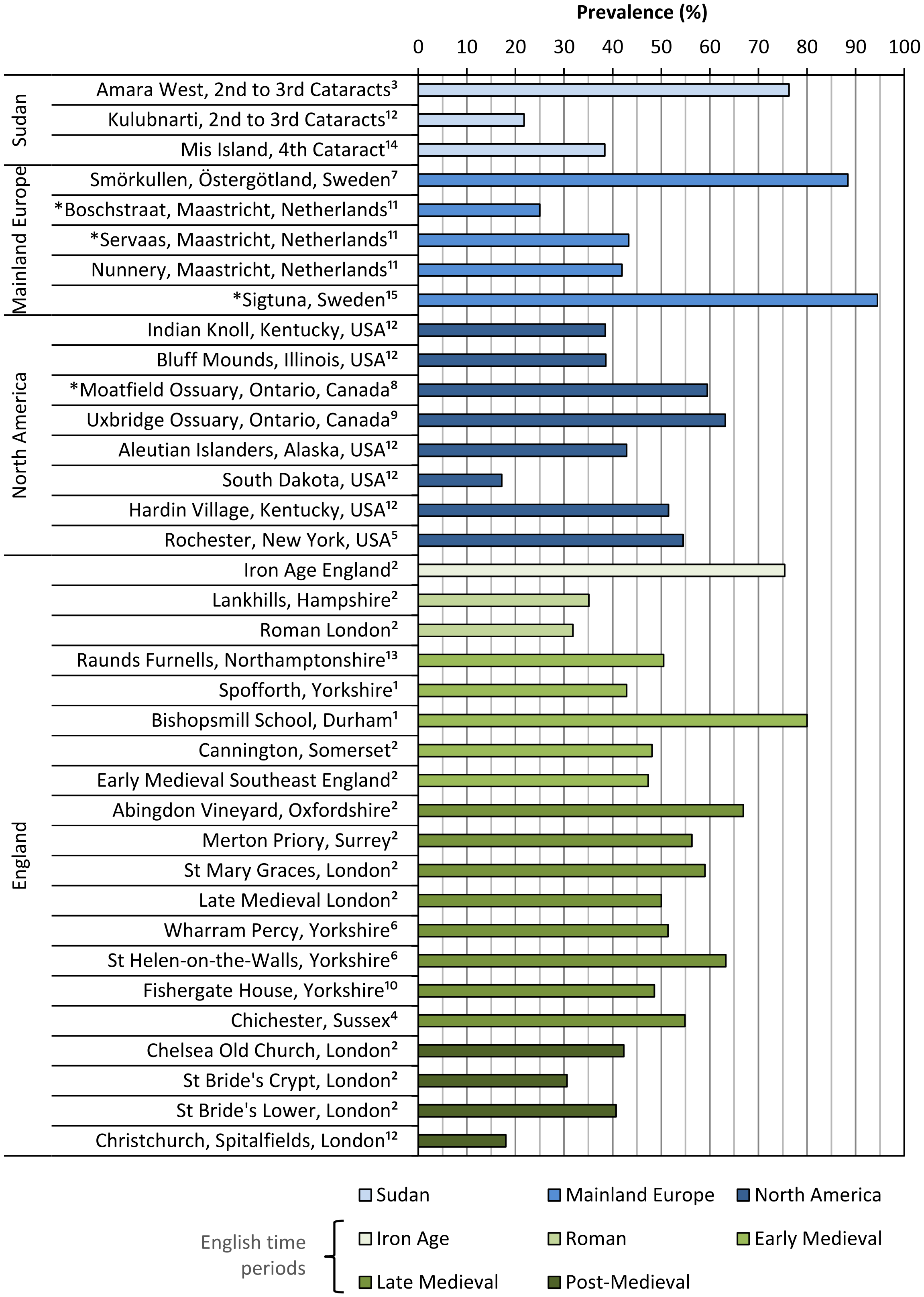


Figure 3.2 – A comparison of the prevalence rates of maxillary sinusitis in adults from various studies, ordered according to geographical region and approximate time period (* = mixed adult and non-adult population). Data from each study, consisting of percentage and frequency of maxillary sinusitis, time period, and subsistence economy in each population, can be found in Table A.1 in Appendix A.

[1]Bernofsky (2006); [2]Bernofsky (2010); [3]Binder (2014); [4]Boocock et al. (1995); [5]DiGangi and Sirianni (2017); [6]Lewis et al. (1995); [7]Liebe-Harkort (2012); [8]Merrett (2003); [9]Merrett and Pfeiffer (2000); [10]Papapelekanos (2003); [11]Panhuysen et al. (1997); [12]Roberts (2007); [13]Roberts, Lewis, & Boocock (1998); [14]Soler (2012); [15]Sundman & Kjellström (2013)

To investigate potential differences based on living environment and occupational activities, another early study of sinusitis considered rates between the Medieval urban population of St Helen-on-the-Walls, York, England, and the nearby contemporaneous rural agricultural population at Wharram Percy, in the Yorkshire Wolds. The population from St Helen-on-the-Walls displayed a significantly higher prevalence of maxillary sinusitis (at $p = <0.1$) when compared to Wharram Percy (Lewis et al. 1995:502). Additionally, there was a significant difference (at $p = <0.1$) between the males from the urban (75%) and rural (44%) sites, while there was no significant difference between females from either site. It was suggested that air pollution resulting from industrial related activities within York may have predisposed individuals from St Helen-on-the-Walls to higher rates of sinusitis. Males in the parish may have been more likely to develop sinusitis than their counterparts at Wharram Percy due to occupational exposure to toxic fumes and dust particles from industrial activties, such as the tanning, founding, working in the apothecary business, and making lime in lime kilns, which were all evident in neighbouring Bedern in York (Lewis et al., 1995:503-504).

In an extensive study of the prevalence of maxillary sinusitis in skeletons from various archaeological sites across the world, with different subsistence economies and living environments, overall, people who lived in the urban sites demonstrated the highest frequencies of maxillary sinusitis, followed by rural agricultural sites. Hunter-gatherer populations exhibited the lowest frequencies of sinusitis. However, it was also found that rural sites were more consistently affected than urban sites, which demonstrated a greater range of frequencies (Roberts, 2007:798-799). The differences between the subsistence groups may have been the result of variations in environmental exposures to particulates within the indoor and outdoor air in the different subsistence economies.

In an urban setting, industrial activity and related pollution, poor sanitary conditions, and closely packed housing may have led to an equal susceptibility to sinusitis in populations (Lewis et al., 1995:504; Roberts, 2009:313; DiGangi & Sirianni, 2017:163). In rural agricultural sites, other particulates in the air such as pollen, fungal spores, moulds, dust produced by agricultural activities, and exposure to pathogens through contact with animals may have all led to inflammation in the sinuses that predisposed to sinusitis (Lewis et al., 1995:504; Roberts, Lewis, & Boocock, 1998:106; Roberts, 2007:803). Hunter-gatherers, on the other hand, were likely to have spent the majority of their time hunting and foraging outside, would not have been exposed to poor air quality as the result of urban industrial activities, and the healthier lifestyle was likely to have reduced susceptibility to sinusitis (Roberts, 2007:799). However, a study of frequencies of maxillary sinusitis in populations from rural, semi-urban, and urban environments, using the defined area of southeast

England to control for climate and other regional factors, found no consistent differences between these populations (Bernofsky, 2010:236, 263). It was suggested that variations in the lifestyle and environment of these populations were not varied enough to produce statistically significant differences in the frequency of sinusitis. While subsistence economy is likely to have had an impact on the type and extent of exposure to particulate matter, other factors, such as socio-economic status, may have also affected the living environment and, therefore, are likely to confound the results.

3.2.2.ii Socioeconomic status

In the study of different subsistence economies and environments from around the world, despite finding a higher prevalence of sinusitis in urban populations overall, the relatively high status people (described as the "middling sort") buried at the urban site of Christchurch, Spitalfields, London, had a particularly low frequency of sinusitis (18%) compared to contemporaneous sites (Roberts, 2007:Table 3). This suggested that the higher status of the people who lived in the area, including better house ventilation and sanitation, may have acted as a buffer against exposure to air pollution and reduced susceptibility to sinusitis in this population (Roberts, 2007:803; 2009:313-314). Similarly, the urban site of Jewbury in York (Lilley et al., 1994), roughly contemporaneous with the nearby site of St Helen-on-the-Walls, had a lower prevalence rate. Again, this has been suggested to reflect the higher status of the Jewish people buried at Jewbury, including better quality housing and different occupations (Roberts, 2007:802, 803; 2009:313). It should be noted, however, that sinusitis in the people buried at Jewbury was investigated prior to the publication of the diagnostic criteria established by Boocock et al. (1995), and this may have had some impact on the data recorded in the skeletal remains at this site. Bernofsky (2010:164, 216) also compared prevalence rates in British populations with different socio-economic status and found that the frequency of sinusitis in the population buried in St Bride's Crypt (high status) in London was significantly lower than in the contemporaneous population of St Bride's Lower (low status), although both cemeteries were located close to one another and served the same parish. This, again, suggested that higher status populations could afford better ventilated homes and cleaner burning fuel, such as higher quality coal, to prevent poor air quality in the home, and higher levels of sanitation to prevent the spread of infection, thus reducing susceptibility to sinusitis. Bernofsky (2010:226) also noted that British high-status populations tend to consistently have among the lowest prevalence rates. While the type of housing and occupation a person has, according to their socioeconomic status, can lead to different exposures to risk factors for sinusitis, certain factors, such as climate and weather patterns, can consistently affect the entire population.

3.2.2.iii Climate

As discussed in Section 2.4.2.iv, climate and related weather patterns can contribute to drying of the respiratory tract mucosa and can have an impact on the types and concentrations of particulates in the environment, affecting susceptibility to sinusitis (e.g. Arundel et al., 1986; Wolkoff & Kjærgaard, 2007; Esmaeil et al., 2014; Yusa et al., 2015; Middleton & Kang, 2017). Wells (1977:174, 178) noted that climate, particularly that related to cold damp weather, may affect susceptibility to sinusitis and that future studies would need to explore prevalence rates in relation to changes in climate during different time periods. This relationship was investigated by Bernofsky (2010:Figs. 6.31 & 6.32, 255) using maxillary sinusitis frequency rates in British populations from different time periods, but no relationship was found between warmer or cooler time periods and changes in prevalence rates. Additionally, North American populations were investigated in relation to latitude and again no distinctive differences in frequencies were found between more northern (colder) and southern (warmer) latitudes (Bernofsky, 2010:Fig. 2.7, 47). It was suggested that the high prevalence rate of sinusitis in people buried at the Iron Age site of Smörkullen, Östergötland, in Sweden, may have been the result of a cooler and rainier climate during the Iron Age in northern Europe (Liebe-Harkort, 2012:394). However, a very high frequency of maxillary sinusitis was also found in people buried at the site of Amara West, Sudan (76.3% in adults). This was suggested to likely be the result of recurring dust and sandstorms in the desert climate (for which there was archaeological evidence at the site), in conjunction with air pollution from cooking fires and kilns in confined spaces (Binder, 2014:304-305). Thus, high frequencies of maxillary sinusitis may develop in different climates due to a range of different risk factors operating at any one location.

3.2.2.iv Differences between the sexes

It has been suggested that similar frequencies of maxillary sinusitis between men and women from the same population may indicate general environmental exposure to factors that may predispose to sinusitis, both outdoors and indoors (Boocock et al., 1995:493; Lewis et al., 1995:502). Conversely, the differences in the roles and cultural practices of men and women in different societies have been used to explain variation in frequencies between the sexes in specific populations (e.g. Panhuysen, 1997; Roberts, 2007; Sundman & Kjellström, 2013:448). Figure 3.3 summarises frequencies of maxillary sinusitis for males and females from various studies, with populations producing statistically significant differences between the sexes indicated within the figure.

Roberts, Lewis, and Boocock (1998) investigated the rates of sinusitis in males and females from four English Medieval skeletal populations to determine if both sexes were equally susceptible to infection. Only at one rural site (Wharram Percy, North Yorkshire) was there a weak statistical significance between the sexes (p = <0.1), with 58.3% of females but only 44.3% of males affected, which may have reflected differences in occupation and other everyday activities (Roberts, Lewis, & Boocock, 1998:105, 108). In a study of populations from Medieval Maastricht, in the Netherlands, it was also found that, when individuals with dental pathology were removed from the dataset, females had a significantly greater prevalence of maxillary sinusitis than males (females: 51.6%; males: 20%) (Panhuysen et al., 1997:612, 613-614). It was suggested that women may have been more exposed to smoke from fires, and could have been more likely to contract infection while caring for sick individuals.

In many societies today the role of women in the preparation of food within the home, including prolonged proximity to cooking fires, has proved a serious factor in the sex-biased development of respiratory disease (e.g. Bruce et al., 2000:1080; Perez-Padilla et al., 2010:1081; Amegah & Jaakkola, 2016:215) (see Section 2.4.1), and it is possible that similar gender roles within populations in the past are responsible for variations in frequencies of sinusitis. For example, Roberts (2007:798, 801, 802) found that, while at urban Medieval sites males and females had similar frequencies of sinusitis, women appeared to be more affected at rural agricultural and hunter-gatherer sites. However, only the two sites of Hardin Village, Kentucky (agricultural) and Bluff Mounds, Illinois (hunter-gatherer and early agricultural) had significantly higher frequencies for females. This was attributed to the greater exposure of females to indoor air pollutants following the development of permanent housing, including smoke inhalation from cooking fires during the preparation of food and the tending of fires.

Conversely, higher rates of sinusitis were recorded in men (97.3% in males; 89.2% in females) buried at the Medieval site of Sigtuna, Sweden, which may have been due to particulate inhalation while men worked as bronze casters and ironsmiths. This is supported by archaeological evidence for industrial workshops within the town (Sundman & Kjellström, 2013:455). Another study, found that males at the Late Medieval site of St Mary Graces, London, had a significantly higher frequency of sinusitis when compared to females (Bernofsky, 2010:155). Although no reason for this disparity is given, it might be reasonable to suggest differences in occupation or other daily activities may have been a factor in these results. The majority of studies, however, have demonstrated relatively equal frequencies of maxillary sinusitis between males and females (see Figure 3.3).

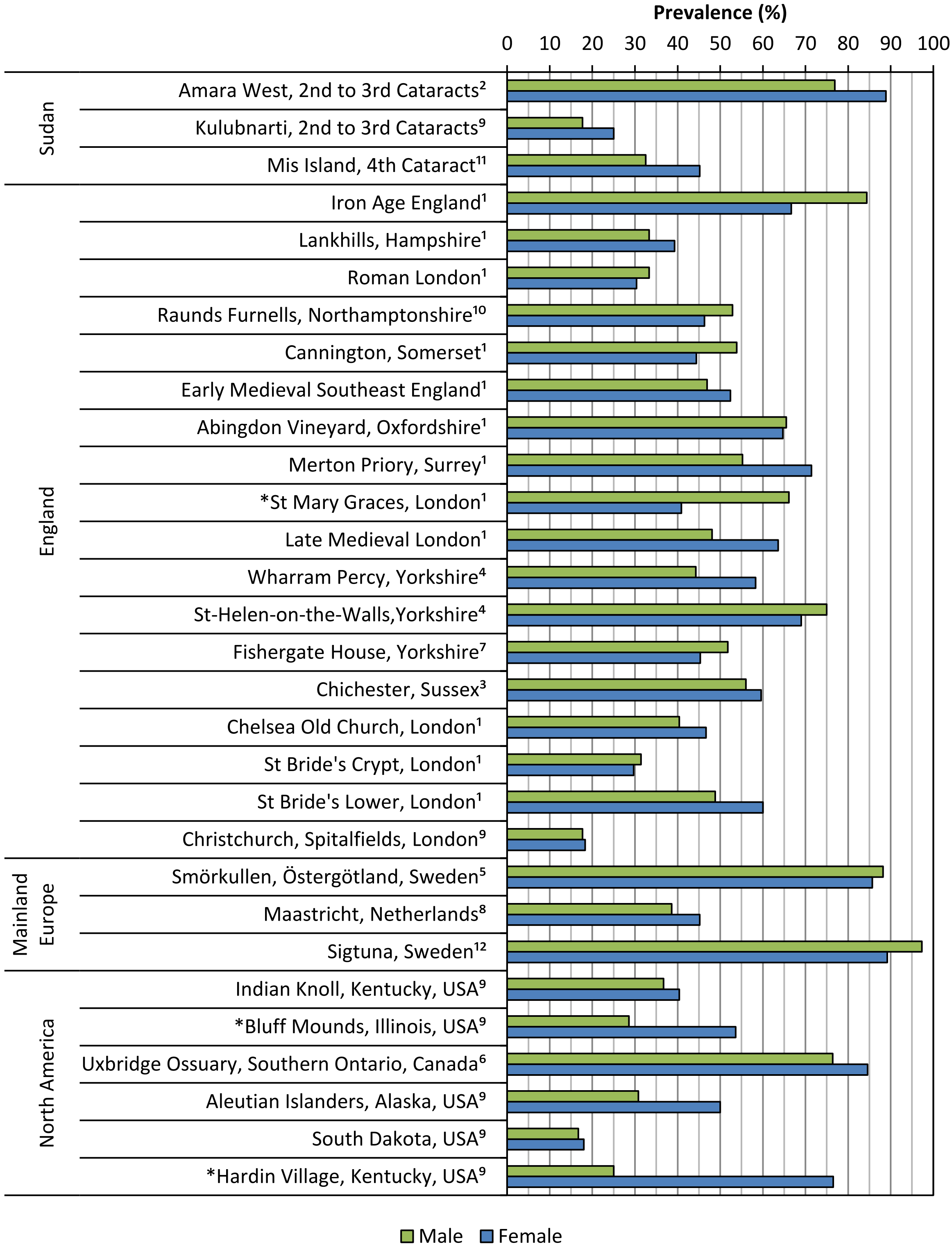


Figure 3.3 – A comparison of the prevalence rates of maxillary sinusitis in males and females from various studies (* = significant difference between males and females, p = <0.05). Data from each study, consisting of percentages and frequencies of maxillary sinusitis in males and females, can be found in Table A.2 in Appendix A.

[1]Bernofsky (2010); [2]Binder (2014); [3]Boocock et al. (1995); [4]Lewis et al. (1995); [5]Liebe-Harkort (2012); [6]Merrett and Pfeiffer (2000); [7]Papapelekanos (2003); [8]Panhuysen et al. (1997); [9]Roberts (2007); [10]Roberts, Lewis, & Boocock (1998); [11]Soler (2012); [12]Sundman & Kjellström (2013)

3.2.2.v Infectious disease

Infectious diseases, like tuberculosis and, in particular leprosy, have been linked to an increased susceptibility to sinusitis (e.g. Hauhnar et al., 1992; Sharma et al., 1998; Kiris et al., 2007; Kant et al., 2013; Kim et al., 2014; Upadhyay et al., 2014) (see Section 2.2.3.i). A study of the frequency of maxillary sinusitis among people with and without evidence for skeletal leprosy buried at the Medieval hospital of St James and St Mary Magdalene, Chichester, UK, is one of the few studies that has attempted to link a specific infectious disease to maxillary sinusitis (Boocock et al., 1995). However, no significant difference in the rates of sinusitis between the two groups was found, suggesting that universal environmental factors, such as poor air quality, may have influenced a predisposition to sinusitis among the entire population (Boocock et al., 1995:493). When comparing frequencies of sinusitis from different sites in late Medieval Britain, the higher prevalence of sinusitis seen at Chichester has been suggested to be likely due to the influence of leprosy as a predisposing factor in this population (Roberts, 2009:313). Additionally, in a study of child morbidity in two Medieval cemeteries from Denmark, a significantly higher prevalence of maxillary sinusitis was found in children displaying skeletal lesions related to leprosy than those without, suggesting that the higher rates of sinusitis in this group were a direct consequence of secondary infection linked to leprosy (Bennike et al., 2005:739, 741). Additionally, Boocock et al. (1995:487) demonstrated that white pitted bone within the sinuses appeared to have a high frequency among leprous individuals. This may indicate that certain pathogens can lead to the formation of distinctive bone changes in sinusitis (Merrett & Pfeiffer, 2000:313). However, the different types of bone formed in the sinuses need to be investigated clinically before they can provide any specific diagnostic value (Boocock et al., 1995:493).

In the population represented by disarticulated bones in the Uxbridge Ossuary, Ontario, Canada, skeletal evidence for tuberculosis was frequently recorded, which may have been a factor responsible for the high prevalence of maxillary sinusitis in this population (see Section 2.2.3.i). In this study 88% of people were observed to have lytic lesions within the sinuses, characterised as 'pits'. It was suggested that the destructive response (i.e. pitting) within the sinsues may have been caused by mycobacterial infection (Merrett & Pfeiffer, 2000:313). However, due to the disarticulated nature of the Uxbridge skeletal remains, the correlation between tuberculous lesions of the long bones and vertebrae and evidence for maxillary sinusitis within discrete individual burials could not be investigated (Merrett & Pfeiffer, 2000:316). Unfortunately, there still remain very few studies of the relationship between infectious diseases and maxillary sinusitis, which makes conclusions about their aetiological impact unreliable.

3.2.2.vi Odontogenic maxillary sinusitis

The link between sinusitis and its infectious origin is particularly important because it has relevance to the potential range of aetiological factors that may increase susceptibility to sinusitis within a population. One of the major causes of maxillary sinusitis is spread of infection from dental disease into the sinus (e.g. Brook, 2006; Mehra & Jeong, 2009; Simuntis et al., 2014). In order to differentiate between rhinogenic (transmitted by way of the nose) and odontogenic (transmitted by way of the mouth) infectious origins for sinusitis, bioarchaeological studies have employed several different criteria. For example, an odontogenic cause of sinusitis is often attributed to individuals who display an obvious antemortem oro-antral fistula alongside advanced dental disease (Boocock et al., 1995:485). The fistula represents an opening into the maxillary sinus from a periapical infection and, therefore, a direct route for oral infection to spread into the antrum (Liebe-Harkort, 2012:389). Oroantral fistulae can be differentiated from post-mortem damage or holes caused by the perforation of the antral floor by healthy tooth roots by the presence of a clearly rounded and remodelled rim, which can often be surrounded by a chimney-like wall of new bone formation (Lewis et al., 1995:502; Sundman & Kjellström, 2013:450-451) (Figure 3.4).

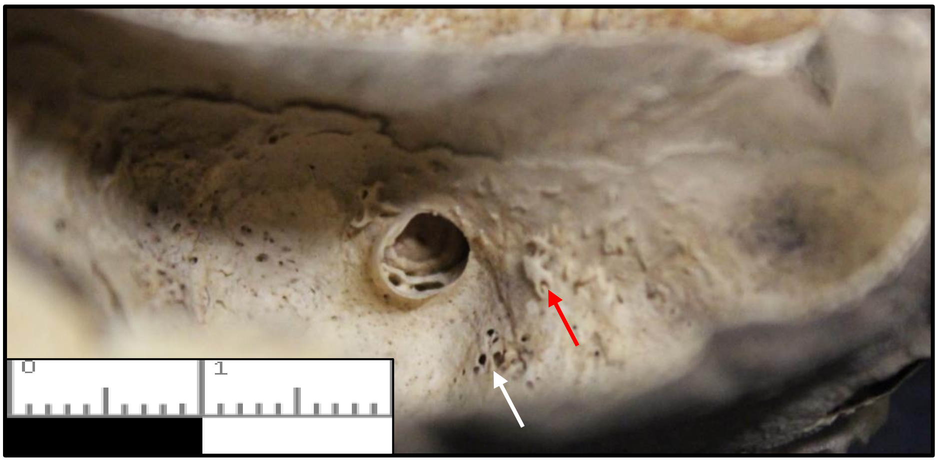


Figure 3.4 – An oroantral fistula in the maxillary sinus, with remodelled margins in the form of chimney-like new bone formation. Spicules (red arrow) and pitting (white arrow) indicate the presence of maxillary sinusitis (site 3-J-18, Sk4154, left maxillary sinus).

Image courtesy of the Trustees of the British Museum

Many studies have argued that a direct connection between the dentition and the antrum, in the form of an oro-antral fistula, must be observed alongside bone changes to the surfaces of the sinuses for odontogenic sinusitis to be recorded as present (e.g. Roberts, 2007; Liebe-Harkort, 2012; Sundman & Kjellström, 2013). However, other studies have used less direct evidence to imply an odontogenic origin. For example, alongside oroantral fistulae, Merrett and Pfeiffer (2000: 309-310) also assigned a dental source of infection to individuals who displayed buccal or lingual cloacae related to dental abscesses and to any ante-mortem tooth loss that did not display subsequent complete in-filling/remodelling of the tooth socket. Panhuysen et al. (1997:612-613) recorded a range of dental pathologies: periapical abscesses, oroantral fistulae, periodontitis, and antemortem tooth loss. It was suggested that a correlation between an increase in both dental pathology and sinusitis within older adult skeletons was indicative of an odontogenic origin as the dominant cause of sinusitis. However, dental diseases other than oroantral fistulae, do not provide direct evidence for an oral route of infection. This is also complicated by the fact that sinusitis and dental disease can co-occur without being related.

Figure 3.5 displays the proportion of instances of maxillary sinusitis attributed to a rhinogenic or odontogenic route of infection in different studies. It is possible that differences in the criteria used by studies to attribute an odontogenic origin of sinusitis are responsible for the variation in frequencies of odontogenic sinusitis (Jakob, 2004:323). For example, while Panhuysen et al. (1997) employ the broadest criteria in assigning an odontogenic aetiology, they also report the highest rates of sinusitis stemming from an odontogenic origin, with 56.8% of individuals with sinusitis also displaying dental pathology. It was noted within a study from Smörkullen, Sweden, that only 16.7% of individuals with sinusitis had an odontogenic route of infection, by demonstrating a direct link between the sinus and dental infection in the form of an oroantral fistula. However, 56.7% of the adults with maxillary sinusitis also had periapical lesions that could suggest an indirect link between sinusitis and dental infection (Liebe-Harkort, 2012:392, 394). A significant co-occurrence was found between maxillary sinusitis and periapical lesions, leading to the suggestion that poor dental health may have been a more significant factor in the development of maxillary sinusitis at Smörkullen than was directly observable (Liebe-Harkort, 2012:392). If periapical lesions had been included in this study as evidence for odontogenic sinusitis, the prevalence rate for an oral origin of sinusitis would have been considerably higher. Bernofsky (2010:171) also found a similar significant association between maxillary sinusitis and periapical abscesses. However, other bioarchaeological studies have found no relationship between the co-occurrence of dental disease and maxillary sinusitis (e.g. DiGangi & Sirianni, 2017:160).

The problem confronted by bioarchaeologists in assessing relevant aetiological factors for sinusitis is that rhinogenic and odontogenic sinusitis are not mutually exclusive, nor is it easy to determine which one may have played a role in the development of sinusitis (Wells, 1977:175; Merrett & Pfeiffer, 2000:312; Sundman & Kjellström, 2013:448). For example, an oro-antral fistula may develop after a rhinogenic form of sinusitis has already caused new bone formation in the antrum.

Therefore, determining the proportion of a population affected by odontogenic or rhinogenic sinusitis will always be problematic. The issues related to the comparability of odontogenic sinusitis between studies demonstrate how vital the methods employed by different researchers can be for the interpretation of results.

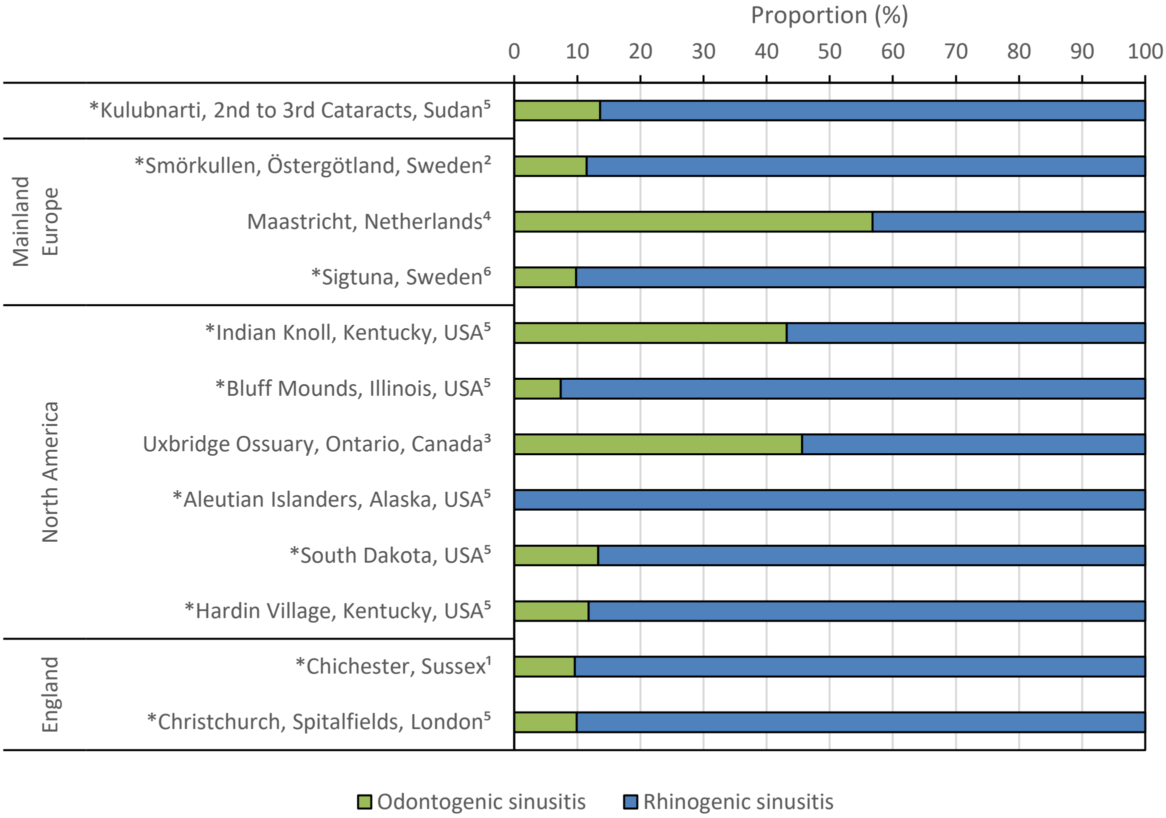


Figure 3.5 – A comparison of the proportion of odontogenic and rhinogenic sinusitis observed at various sites (* = only the presence of an oroantral fistula considered to be evidence for odontogenic sinusitis). Data from each study, consisting of percentages and frequencies of rhinogenic and odontogenic sinusitis, can be found in Table A.3 in Appendix A.

[1]Boocock et al. (1995); [2]Liebe-Harkort (2012); [3]Merrett & Pfeiffer (2000); [4]Panhuysen et al. (1997); [5]Roberts (2007); [6]Sundman & Kjellström (2013)

3.2.3 Methods

The criteria for recognising the bone changes in the maxillary sinuses set out by Boocock et al. (1995) have been recommended as the standard diagnostic criteria for future studies of maxillary sinusitis. This enables the comparison of data between studies (Sundman & Kjellström, 2013: 456). Fortunately, these criteria have been employed in the majority of major studies of maxillary sinusitis since its publication (e.g. Merrett & Pfeiffer, 2000; Bennike et al., 2005; Roberts, 2007; Liebe-

Harkort, 2012; Sundman & Kjellström, 2013). However, methods have still varied, including minor adjustments and additions to the criteria. Furthermore, methods for overcoming extremes of preservation have also been developed, as well as scoring systems for bony changes, as discussed below.

3.2.3.i Diagnostic criteria

Boocock et al. (1995) identified four categories of bone change in the maxillary sinus that are likely to be indicative of inflammation and subsequent periosteal reaction and, therefore, maxillary sinusitis (Table 3.1). Additionally, three further categories have been used to describe bone changes found within the sinuses (Merrett & Pfeiffer, 2000:307-308) (Table 3.2). Both Boocock et al. (1995:486) and Sundman and Kjellström (2013:450) also describe thickening and porosity of the walls of the sinuses as a possible indicator of maxillary sinusitis, but they did not assign this bone change its own category. It may be that thickening of the sinus walls simply represents an extreme example of white pitted bone or remodelled spicule formation. It should also be noted that antemortem loss of teeth can lead to thickening and irregularity of the alveolar surface of the sinus as the dental alveoli become remodelled, and this can be confused with thickening of the sinus walls caused by inflammation (Lewis et al., 1995:501-502).

The maxillary sinuses of young non-adult skeletons often display porosity and large pits, which are believed to represent normal growth and development of the sinuses (Lewis et al., 1995:501). Therefore, in order to avoid confusion with pitting caused by sinusitis, several studies of maxillary sinusitis in non-adults have excluded individuals under the age of 2.6 years (M. E. Lewis, 2002; Jakob, 2004; Bennike et al., 2005). The development of the permanent dentition can also produce changes to the bony surfaces of the maxillary sinus and the development of the first molar inhibits the use of an endoscope for observing intact sinuses because it blocks the posterior wall of the maxilla (Lewis et al., 1995:501; Sundman & Kjellström, 2013:449). For this reason, Lewis et al. (1995:501) only included non-adults over the age of seven and did not drill sinuses for endoscopy in non-adults, while Sundman and Kjellström (2013:449) excluded all non-adults whose second molars had not fully erupted. However, differences in the inclusion of individuals and the diagnostic criteria used in studies of maxillary sinusitis may lead to inconsistent frequencies that are not comparable (Jakob, 2004:322; Sundman & Kjellström, 2013:456).

Table 3.1 – Categories for bone changes related to maxillary sinusitis, as established by Boocock et al. (1995:486) and described in greater detail by Merrett & Pfeiffer (2000:307-308).

Bone Change	Description
Pitting	Fine pits seen in association with other types of bone change. These pits represent bone resorption and can range from 1 mm in diameter to, at higher densities, fused pits of between 3 to 5 mm in diameter.
Spicules of New Bone	Thin spicules of bone that appear to have been applied to the original periosteal surface of the bone. These bone spicules take the form of 2 to 4 mm projections of bone. Groups of spicules can form bridging, creating small stellate plates of bone. In their most extreme form, spicules can form multiple, partially overlaying plates with extensive bridging.
Remodelled Spicules	Remodelling of spicules into the walls of the sinus. Spicules may merge to become plaque-like or take on the appearance of molten wax
White Pitted Bone	Highly pitted discrete areas of bone that appear white in comparison to the surrounding bone.

Table 3.2 – Additional categories for bone changes related to maxillary sinusitis, as described by Merrett and Pfeiffer (2000:307-308).

Bone Change	Description
Plaque	The deposition of plaque on the sinus walls can consist of smooth or dense and porous bone, and can vary in thickness from less than 1mm to greater than 1 mm.
Lobules	Rounded masses of bone on the periosteal surfaces of the sinus.
Cysts	Hemispherical depressions in the bone, with a smooth interior surface and no bony projections into the area of the cyst. The margin of the cyst is surrounded by a smooth rim of bone deposition.

3.2.3.ii Preservation

Due to the variable preservation of skeletons from archaeological sites, studying maxillary sinusitis in bioarchaeology has proved challenging. In a complete well-preserved skull, the sinus is an enclosed structure within the facial bones and is difficult to access for observation (Wells, 1977:176; Merrett & Pfeiffer, 2000:302). This may be a reason for the lack of studies of maxillary sinusitis, particularly prior to 1995 (Lewis et al., 1995:497). Wells (1977:176) was the first to employ the use of endoscopy to view the interior of the maxillary sinuses to record bone changes and this method has since been used by several researchers (e.g. Boocock et al., 1995:485; Lewis et al., 1995:501; Panhuysen, 1997:611; Merrett & Pfeiffer, 2000:309; Roberts, 2007:797; Bernofsky, 2010:128; Binder, 2014:157). However, in order to access completely intact sinuses using a traditional endoscopic tube, a hole must be drilled into the maxilla, often in the posterior wall (Wells, 1977:176; Boocock et al., 1995:487). Permission to employ this destructive method may not always be given, depending upon the skeletal collection being investigated and the policies of the curators (Merrett & Pfeiffer, 2000:302). The use of radiography to view bone formation in intact sinuses has also been investigated (Wells, 1977:176; Boocock et al., 1995:485). However, even in individuals where obvious bone formation in the sinuses has already been observed macroscopically, the use of radiography does not always show these lesions (Boocock et al., 1995:485; Lewis et al., 1995:498; Roberts, Lewis, & Boocock, 1998:97). For this reason, several studies of the prevalence of sinusitis have not included skeletons where the sinuses were preserved intact (e.g. Liebe-Harkort, 2012:389; Sundman & Kjellström, 2013:449). Therefore, the number of instances of sinusitis recorded in these studies is only the minimum number present within these populations (i.e. the prevalence may be an under-representation of the potential frequency).

While only fragmented or partially preserved sinuses have been used in certain studies, this may also have had an impact on the prevalence of sinusitis recorded for a population. Partially preserved sinuses are not completely observable and could be missing areas which may have displayed evidence for sinusitis. In a study to investigate the bias that fragmented sinuses may have on sinusitis frequencies, the presence or absence of sinusitis based on the percentage of the sinus still preserved for observation was recorded into different preservation groups (1-25%, 26-50%, 51-75%, or 76-100% of the sinus preserved) (Sundman & Kjellström, 2013:451). The results indicated that there was a significant relationship between the level of preservation and the frequency with which sinusitis was identified, with sinusitis detected less frequently in sinuses which were more poorly preserved (Sundman and Kjellström, 2013:454).

Additionally, the majority of studies have recorded the presence or absence of sinusitis in an individual based on the presence of only one sinus (e.g. Boocock et al., 1995:485; Roberts, 2007:797; Liebe-Harkort, 2010:389). While the presence of bone changes related to sinusitis in an individual with only one preserved sinus demonstrates definitively that the individual had sinusitis, the absence of bone changes within a single sinus does not tell us that the individual did not suffer from sinusitis. This is because it is impossible to tell whether the absent sinus was affected or not (Jakob, 2004:322). For this reason, some studies have only considered individuals with both sinuses preserved (e.g. Jakob, 2004) or have presented the prevalence of sinusitis based on the total number of sinuses present in addition to prevalence according to the total number of individuals analysed (e.g. Bernofsky, 2010). However, the exclusion of individuals with only one sinus preserved can greatly reduce the sample size, which in bioarchaeological studies is often already limited. By excluding individuals from a population based on either too incomplete a skull (only one sinus) or too complete a skull (sinuses unobservable without destructive methods), the number of individuals within a sample group may become very limited. This has been suggested as a reason for the lack of studies of maxillary sinusitis prior to 1995 (Lewis et al., 1995:497). As the majority of studies have also included skeletons with only one sinus preserved, for comparability purposes this approach is preferable, but other ways of presenting prevalence data can also be utilised.

While the main objective of studies of maxillary sinusitis has been to establish accurate frequency rates, some researchers have also scored the extent or severity of bony changes within the sinus.

3.2.3.iii Scoring

In an attempt to measure the 'severity' of bone changes within the sinuses, two studies have both employed the use of a scoring/grading system (Merrett & Pfeiffer, 2000; Sundman & Kjellström, 2013). Merrett and Pfeiffer (2000:308) scored pits and spicules using four grades of severity. Sinuses attributed a score of 0 or 1 were considered to represent an absence of sinusitis, but no clear indication of the criteria used to score further changes was given. Sundman and Kjellström (2013:450, Fig. 2) also described the severity of changes to each individual surface of the sinus (e.g. roof, floor, medial wall) in four grades, using a score of 0 for absence of bone change to a score of 3 for severe changes. Scores for each category of bone change were attributed based on the extent of the affected bone surface area. A score of 1 was accorded to limited change affecting only 1.5 cm^2 of the bone surface, a score of 2 to moderate change affecting 1.5 to 2.5 cm^2, and a score of 3 for severe changes affecting more than half of the wall or floor of the sinus.

Using this scoring system, a significant relationship was found between age groups and the degree of bone change within a Swedish population, with older individuals often displaying more severe bone changes. This was suggested to be due to bone modifications accumulating throughout adult life (Sundman & Kjellström, 2013:454, 455). However, there is no formal established criteria for the grading of sinusitis and the majority of studies have simply recorded the presence or absence of sinusitis based on the observation of any of the four main categories of bone change (e.g. Boocock et al., 1995; Lewis et al., 1995; Panhuysen et al., 1997; Roberts, Lewis, & Boocock, 1998; Roberts, 2007; Bernofsky, 2010; Liebe-Harkort, 2012). It is also worth noting that while more proliferative and extensive bone changes are assumed to be associated with prolonged or repeated suffering of sinusitis, i.e. increased severity, a lack of clinical studies on the varying characteristics of the bone changes and their extent means that this assumption cannot be supported (Boocock et al., 1995:493). For example, in clinical studies of osteoarthritis, the severity of symptoms of the disease reported by patients do not always correlate with the changes to the bone observed using radiography (Rogers et al., 2004:456; Litwic et al., 2013:2).

3.3 Inflammatory periosteal reaction (IPR) on the ribs

Unlike bony changes within the sinuses, which are likely related specifically to sinusitis, new bone formation on the visceral surfaces of the ribs caused by inflammation can be the result of a number of causes. Several bioarchaeological studies have attempted to narrow the scope of the causes of this new bone formation and this is discussed in the following sections. These studies often refer to new bone on the ribs as 'rib lesions'. However, a 'lesion' can be any pathological abnormality caused by a disease or trauma (Manchester et al., 2016:22), including bone destruction. Therefore, to avoid confusion with other types of bony changes to the ribs, new bone formation on the visceral surfaces, likely caused by periosteal reaction to inflammation, will henceforth be referred to as 'inflammatory periosteal reaction (IPR)' in the current study. It should be noted, however, that some studies do not differentiate between new bone formation and bone destruction on the ribs and this can have implications for the comparability of results and the interpretation of potential causes. The methods used by different researchers to record IPR and destructive lesions on the ribs are also discussed below. Firstly, however, it is important to consider the mechanisms behind periosteal reaction that result in IPR.

3.3.1 Periosteal new bone formation

The periosteum is a layer of fibrous connective tissue that surrounds the outer surfaces of all bones, excluding the joints, and can produce bone-forming cells (osteoblasts). It therefore plays an important role in the formation and remodelling of bone (Waldron, 2009:115; Kini & Nandeesh, 2012:29). Periosteal layers of new bone on the outer cortical surface of bones, referred to as periosteal reaction or periostitis, are a commonly reported pathological lesion in bioarchaeological studies and are produced when the periosteum reacts to pathological stimuli (Waldron, 2009:115; Weston, 2012:492). Although many bioarchaeological studies consider periosteal reactions to be the result of infectious inflammation of the surrounding tissue, a variety of other causes can trigger new bone formation including trauma, haemorrhage, overlying soft tissue lesions, tumours, and certain metabolic diseases (e.g. Ortner, 2003:88; Rana et al., 2009; Waldron, 2009:Table 6.7; Weston, 2012:493-494).

Inflammation of the periosteum often, although not always, occurs in relation to these pathological stimuli, triggering a sequence of events that causes new bone formation (Weston, 2008:49). The processes involved in inflammation, including the enlargement of blood vessels and the development of oedema (fluid collection), cause changes to blood oxygen levels and stimulate osteoclast (bone resorbing cell) and osteoblast (bone forming cell) function (Weston, 2008:49; 2012:494). This results in a mass of dead cells and lost bone tissue, which is repaired by the formation of granulation tissue. In turn, this develops into woven bone and is gradually, over a period of months, remodelled into lamellar bone (Weston, 2008:49; 2012:494; Ortner, 2012:255).

Figure 3.6 – Typical woven bone formation (IPR) on the neck and angle of the visceral surface of the rib (arrows) (site 3-J-23, Sk132, left 11th rib).

Image courtesy of the Trustees of the British Museum

On the ribs periosteal reaction has been described as multiple fine pits on the surface, as layers of 'plaque-like' new bone formation, or as dense smooth bone merging with the original cortical surface (Roberts et al., 1994:172; Raff et al., 2006:25). The new bone can range from woven in nature, suggesting active bone formation and an acute condition at the time of death, to thick remodelled lamellar bone, possibly representing a long-term chronic inflammatory condition (Roberts et al., 1994:172; Matos & Santos, 2006:196; Raff et al., 2006:25; Ortner, 2012:255) (Figure 3.6). By observing these bone changes, the prevalence of IPR on the visceral surfaces of the ribs has been systematically recorded in a number of studies of both documented and archaeological skeletons.

3.3.2 Prevalence rates in bioarchaeological studies

Figure 3.7 displays the prevalence rates for rib IPR recorded in various bioarchaeological studies. To maintain consistency between studies, whenever possible, only frequencies for adults are presented here. Therefore, prevalence rates in the figure may not match the overall frequencies presented by the studies themselves, which may include data from non-adults. Furthermore, the results for non-adults and adults in some studies could not be separated and these are indicated within the figure.

The vast majority of studies have been undertaken on skeletons from English sites, while a small number of studies have been conducted on populations from mainland Europe, North and South America, and Sudan. There are sufficient studies of skeletons from different sites in England to make it possible to begin to identify potential differences in frequency during different time periods, which might give an indication of changes in exposure to risk factors over time. In general, however, prevalence rates remain fairly low across all geographic regions studied, except in the Sudanese population buried at Amara West, which presented the only prevalence rate over 30% (at 46.7%) (Binder, 2014: Table 8.49). A greater number of studies from Sudan will help to identify if this study is anomalous for the region or if risk factors for lower respiratory tract disease were, in general, higher than in other parts of the world. The majority of bioarchaeological studies of rib IPR have focussed on identifying the potential aetiologies and risk factors involved in inflammation of the tissues underlying the ribs, including pleural and lower respiratory tract diseases.

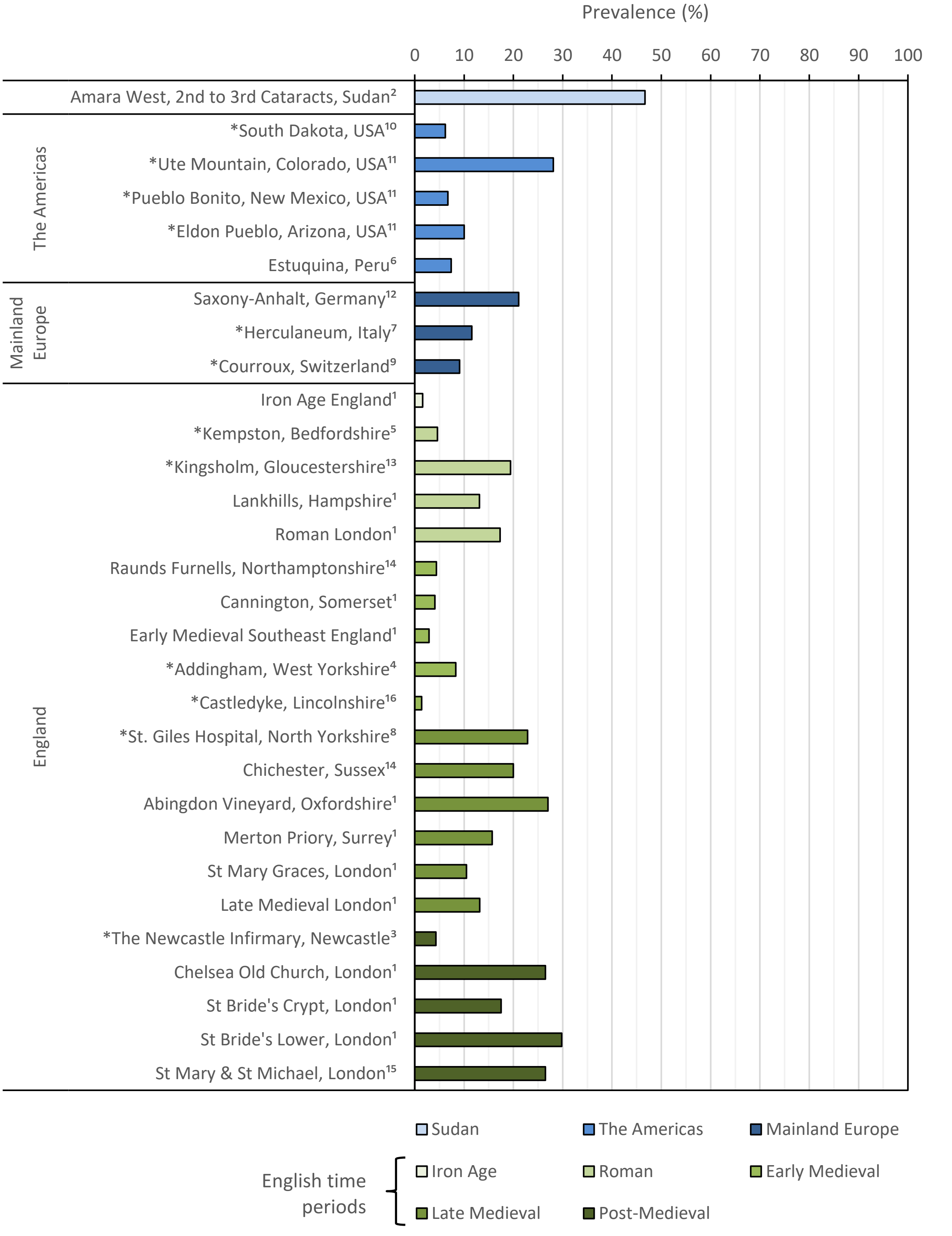


Figure 3.7 – A comparison of the prevalence rates of rib IPR in adults from various studies, ordered according to geographical region and approximate time period (* = mixed adult and non-adult population). Data from each study, consisting of percentage and frequency of rib IPR, time period, and subsistence economy in each population, can be found in Table A.4 in Appendix A.

[1]Bernofsky (2010); [2]Binder (2014); [3]Boulter et al. (1998); [4]Boylston (1991); [5]Boylston & Roberts (1996); [6]Buikstra & Williams (1991); [7]Capasso (2000); [8]Chundun (1992); [9]Cooper et al. (2016); [10]Kelley et al. (1994); [11]Lambert (2002); [12]Nicklisch et al. (2012); [13]Roberts (1989); [14]Roberts, Lewis, & Boocock (1998); [15]Walker & Henderson (2010); [16]Wiggins et al. (1993)

3.3.3 Aetiological factors

Although periosteal new bone formation has often been referred to as evidence for non-specific inflammation in bioarchaeology (e.g. M. E. Lewis, 2007:134; Weston, 2008:48; Roberts & Manchester, 2010:172; Larsen, 2015:86), the unique position of rib IPR in relation to other organs and anatomical features has led to several investigations into possible specific diseases causing the bone changes. In particular, a number of human identified skeletal collections have been used to investigate the relationship between the presence of rib IPR and the recorded cause of death, especially lower respiratory tract diseases such as tuberculosis. Studies of skeletons from archaeological sites have also discussed rib IPR in relation to infectious diseases including tuberculosis, pleurisy, and actinomycosis and in relation to risk factors such as air quality in the lived environment. The type of lesions (e.g. bone destruction or bone formation) and their position within the rib cage have also been suggested to potentially indicate different pathological causes. These factors are all discussed in the following sections.

3.3.3.i Human identified skeletal collections

Human identified skeletal collections have biographical data associated with the individual skeletons, including age, sex, and cause of death, and tend to derive from the late 19th and early 20th Centuries. These collections are valuable for developing and testing methods on identified individuals with biographical information to determine their reliability and applicability on unknown skeletal remains, for example from archaeological sites or forensic contexts (Belcastro et al., 2017:913). Research on rib IPR in relation to cause of death have been undertaken on the Hamann-Todd, Robert J. Terry, Coimbra, Luís Lopes (or Lisbon), and Certosa Cemetery Collections (Hunt & Albanese, 2005; Cardoso, 2006; Cunha & Wasterlain, 2007; Belcastro et al., 2017).

The first study that focused on the causes of rib IPR was undertaken by Kelley and Micozzi (1984) using skeletons from the Hamann-Todd Osteological Collection, curated at the Natural History Museum in Cleveland, Ohia, USA. The correlation between rib IPR and tuberculosis was investigated by examining a total of 445 individuals, who were recorded to have died from some form of tuberculosis. Of all the tuberculous individuals within the collection, a total of 8.8% (39/445) displayed some form of lesion on the ribs, although destruction and new bone formation were not separated. It was noted that of the 39 individuals displaying rib lesions, 31 were recorded to have died specifically from pulmonary tuberculosis, suggesting that IPR was caused by the spread of tuberculous infection from the lungs or pleura (Kelley & Micozzi, 1984:382; 386). However, although the presence of IPR in individuals dying from a pulmonary condition unrelated to tuberculosis, in this case pneumonia, was also investigated and only two individuals (2/385) were found to have inflammatory lesions on the ribs, the lack of investigation into the frequency of rib IPR within the entire collection as a whole means that other alternative causes for IPR were not considered (Roberts, 1999:313).

Later, the frequency of rib IPR was considered within the Robert J. Terry Collection, curated at the Department of Anthropology, Smithsonian Institution, Washington DC, USA (Roberts et al., 1994). This collection consists of 1,728 morgue cadavers with associated biographical information (Hunt & Albanese, 2005). Of the 1,718 individuals viable for examination, 24.2% (413/1718) displayed some form of inflammatory lesion of the ribs. Dividing individuals into groups based on the cause of death, it was found that 61.6% (157/255) of individuals dying from pulmonary tuberculosis displayed rib IPR. This was the case for 22.2% (51/230) of individuals with a pulmonary disease unrelated to tuberculosis as a cause of death, including pneumonia, bronchitis, emphysema, and pleurisy, and 15.2% (165/1086) of individuals with a non-pulmonary cause of death. The frequencies revealed a highly significant association between rib IPR and those who died from pulmonary tuberculosis (Roberts et al., 1994:172, Table 1.).

Further investigations of rib IPR using identified skeletal collections have analysed the Coimbra Collection curated by the Anthropological Museum at the University of Coimbra (Santos & Roberts, 2001; 2006) and the Luís Lopes Collection curated by the Bocage Museum in Lisbon (Matos & Santos, 2006), both in Portugal. In Italy the identified skeletal collection from Certosa Cemetery, curated at the Anthropology Museum, University of Bologna, has also been investigated (Mariotti et al., 2015). All four studies found that rib IPR was significantly more common in individuals who had died from pulmonary tuberculosis when compared to other diseases (Santos & Roberts, 2001:41; 2006:42; Matos & Santos, 2006:193; Mariotti et al., 2015:394). Additionally, 83.3% (15/18) of all adult individuals in the Coimbra Collection who died from extrapulmonary TB also displayed rib IPR (Santos & Roberts, 2006:Table 1). A high association between rib IPR and individuals with tuberculosis has also been recorded in a combined study of the Pretoria Bone (University of Pretoria) and the Raymond A. Dart (University of the Witwatersrand) identified collections, both in South Africa, although a prevalence rate for the total sample was not provided (Steyn et al., 2013:470).

In the Luís Lopes Collection rib IPR was also present in 36.7% (18/49) of individuals dying from pulmonary disease unrelated to tuberculosis, including pneumonia and bronchitis, and in 25.0% (16/64) of individuals with a cause of death of a non-pulmonary disease, with 43.7% of the individuals from this group having died from some form of heart disease (Matos & Santos, 2006:Table 4). Nevertheless, the consensus of studies of identified skeletal collections is that rib IPR in these collections is most frequently related to pulmonary tuberculosis. Figure 3.8 displays the prevalence rates of rib IPR in categories organised according to cause of death, demonstrating a high prevalence of IPR in individuals who died from pulmonary tuberculosis in the majority of these studies. It has been suggested that the anomalous result from the Hamann-Todd Collection (Kelley & Micozzi, 1984), which presents a surprisingly low prevalence rate of rib IPR in individuals who died from tuberculosis compared to other studies, may be due to differences in recording methods (Mariotti et al., 2015:398). This study was, after all, the first to record rib IPR in a systematic manner and the methods for identifying bony changes have developed since that time.

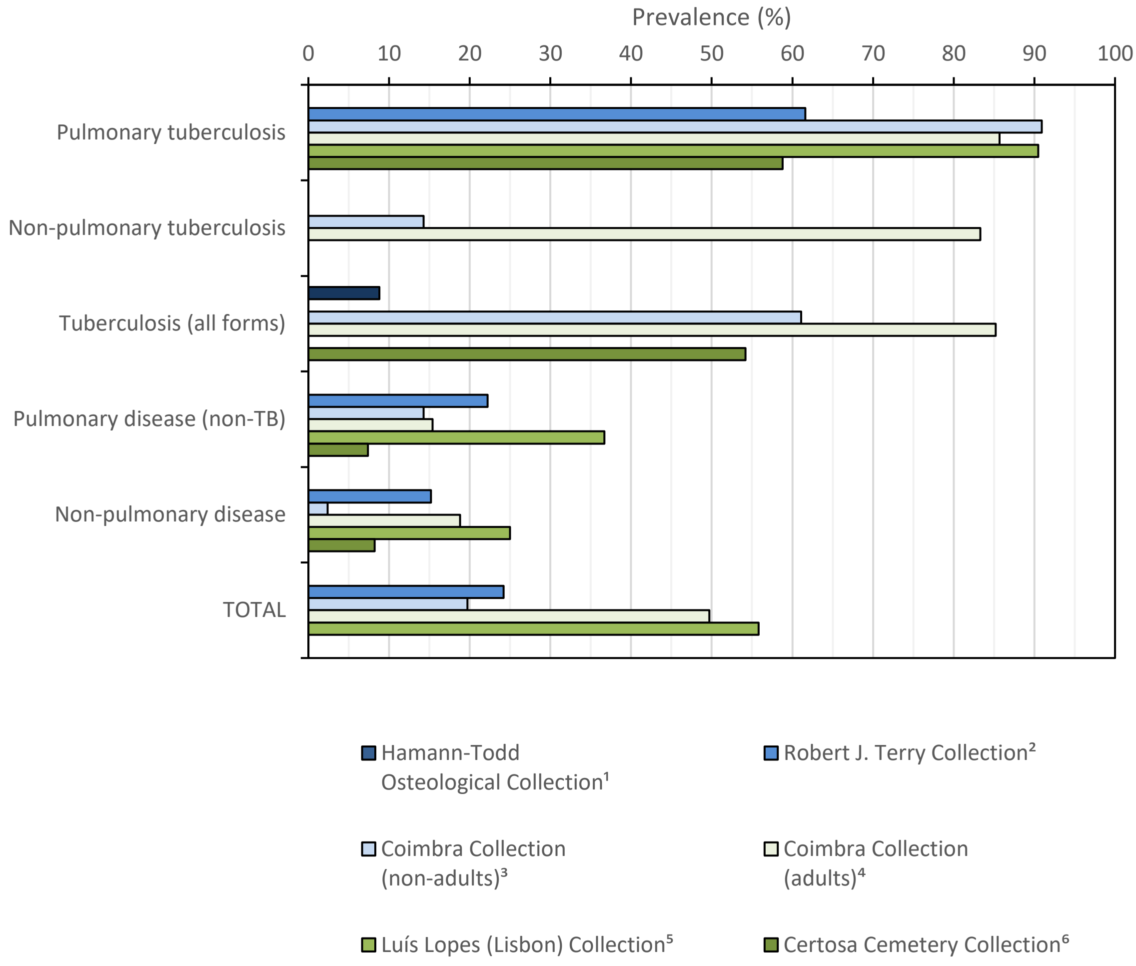


Figure 3.8 – Prevalence of rib IPR from human identified skeletal collections, categorised according to cause of death. Data from each study, consisting of percentages and frequencies of rib IPR according to cause of death, can be found in Table A.6 in Appendix A.

[1]Kelley & Micozzi (1984); [2]Roberts et al. (1994); [3]Santos & Roberts (2001); [4]Santos & Roberts (2006); [5]Matos & Santos (2006); [6]Mariotti et al. (2015)

A high prevalence of rib IPR in people dying from pulmonary tuberculosis does not, however, rule out other causes (Santos & Roberts, 2001:48). A number of factors can confound these results and human identified skeletal collections are faced with some limitations. Importantly, the associated biographical data, including cause of death, may not always be reliable (Ferreira et al., 2014:202.e1). For example, in the Robert J. Terry Collection age at death was not always accurately documented (Hunt & Albanese, 2005:411-412). Similarly, the cause of death in identified skeletal collections could have been incorrectly diagnosed or misclassified and co-morbidities at the time of death may not have been recorded, resulting in an incomplete understanding of the pathological processes that caused rib IPR. Additionally, an individual may have had a lower respiratory tract disease earlier in life, resulting in the formation of rib IPR, but this could have been resolved and as such would not have been recorded in medical data at the time of death (Roberts, Boylston et al., 1998:57; Santos & Roberts, 2001:46). Therefore, a direct correlation between the recorded cause of death and the cause of inflammatory lesions should be approached with caution (Santos & Roberts, 2001:48; 2006:47).

When comparing prevalence rates of rib IPR between archaeological skeletons and identified skeletal collections, frequencies reported from archaeological populations are, overall, much lower. This is likely due to the poorer preservation of archaeological skeletal remains, particularly of the ribs (Santos & Roberts, 2006:47). Many studies of rib IPR in human identified skeletal collections are also inherently biased towards a higher prevalence as the major part of their samples are often selected to contain individuals who died from tuberculosis or other lower respiratory tract diseases, and are, thus, more likely to demonstrate a higher frequency of rib IPR. Despite the lower prevalence rates, studies of archaeological skeletal remains have also attempted to investigate the potential aetiologies of rib IPR.

3.3.3.ii Pulmonary tuberculosis

Based on the findings of identified skeletal collections, many bioarchaeological studies of archaeological skeletons suggest that the most likely cause of rib IPR is the spread of tuberculous infection from the lungs and the subsequent inflammation of the pleura (e.g. Pfeiffer, 1991:197; Kelley et al., 1994:129; Lambert, 2002:287-288; Raff et al., 2006:27; Nicklisch et al., 2012:401). Evidence from archaeological skeletal remains has been used to support this. For example, individuals found to have new bone formation on the ribs in conjunction with skeletal lesions or calcifications associated with tuberculosis have been presented as further evidence of a correlation between the disease and the formation of rib IPR (Roberts, 1999:314). In a study of an individual from 18th to 19th century Connecticut, USA, the presence of rib IPR was used in conjunction with folklore, historical data, and evidence for the post-mortem rearrangement of the skeleton to suggest that the person may have suffered from tuberculosis and was, therefore, subject to "anti-vampiric" cultural practices after death (Sledzik & Bellantoni, 1994). Using the specific location of lesions within the rib cage, the age distribution of affected individuals, and a review of clinical literature on the pathogenesis of various pulmonary illnesses, it has been further concluded that the most likely cause of rib IPR in post-contact populations buried in South Dakota sites, USA, was pulmonary tuberculosis (Kelley et al., 1994:129).

More recently, DNA samples from individuals with rib IPR have been used to test for an association with tuberculosis. *Mycobacterium tuberculosis* complex DNA has been demonstrated to survive for several millennia within the skeletal remains of infected individuals (Mays et al., 2002:28-29). An attempt was made to extract and amplify this DNA from the ribs of seven individuals from the Medieval population from Wharram Percy, England, all of whom had rib IPR. Only one tested positive for the presence of *Mycobacterium tuberculosis* complex DNA, while two individuals from the control sample, displaying no rib IPR or skeletal signs of infection, tested positive for the infection. Interestingly, the skeleton testing positive from the rib IPR group was the only individual to display erosive lesions in other bones of the skeleton that are more commonly associated with tuberculosis (Mays et al., 2002:32-33, Table 2).

However, ribs from five individuals all with IPR from the prehistoric Schild population, Greene County, Illinois, USA, all tested positive for the presence of tuberculosis (Raff et al., 2006:26), while all control samples and a skeleton with rib lesions typically associated with trauma tested negative. Additionally, in a study of *M. tuberculosis* complex DNA in early Neolithic individuals from three sites in Saxony-Anhalt, Germany, samples from the long bones and vertebrae of several individuals, who also displayed new bone formation on the visceral surfaces of their ribs, tested positive for tuberculous DNA (Nicklisch et al., 2012: Table 5). Although, only one rib sample produced a positive result, the presence of tuberculous DNA within other skeletal elements was used to suggest that the high frequency of rib IPR in their study was most likely the result of tuberculous infection (Nicklisch et al., 2012:396, 399). However, even the presence of *M. tuberculosis* complex DNA cannot be used as direct evidence that rib IPR was caused specifically by tuberculosis (Roberts, Boylston et al., 1998:57; Roberts, 1999:314). An individual may have also had another disease that resulted in new bone formation on the ribs.

3.3.3.iii Pleurisy, actinomycosis, and pneumonia

Histological analysis, micro-CT scanning, and scanning electron microscopy (SEM) have all been used to investigate rib IPR. SEM and thin sections of ribs with IPR on the visceral surfaces have revealed multiple layers of new bone formed on top of the original cortical surface, providing further evidence that new bone formation is a reaction of the periosteum to a stimulus such as inflammation (Wakely et al., 1991:186; Wiltschke-Schrotta & Berner, 1999: 546; Schultz, 2001: 123; Nicklisch et al., 2012:396). SEM reveals a process of increased vascularity and the development of vascular grooves, which are eventually covered by layers of new woven bone (Wakely et al., 1991:186). Micro-CT scans demonstrate that new bone formation does not infiltrate or destroy the original bone surface, ruling out diseases such as osteomyelitis or osteoclastic cancer (Nicklisch et al., 2012:396). In some samples the remodelling of inner layers into lamellar bone has been identified, while outer layers can remain of unstructured woven bone, implying in these instances a prolonged or recurring disease process (Wakely et al., 1991:186; Roberts et al., 1994:172; Nicklisch et al., 2012:396). These methods indicate that bone formation on the surface of the periosteum on ribs is the result of chronic inflammation of the surrounding soft tissue due to pleurisy (Wakely et al., 1991:187; Roberts, Boylston et al., 1998:57; Schultz, 2001: 123; Nicklisch et al., 2012:396).

Although pleurisy can be caused by tuberculosis (See Section 2.3.3.ii), other respiratory conditions that have been hypothesised by bioarchaeologists to cause rib IPR include pneumonia, actinomycosis, and chronic bronchitis (although pleural disease is not commonly caused by bronchitis, but the two may share risk factors). Additionally, peritonitis, metastatic carcinoma, non-specific osteomyelitis, syphilis, trauma, and heart and renal diseases may also lead to pleural disease or periosteal reaction, and have been suggested as differential diagnoses (Molto, 1990:444; Sledzik & Bellantoni, 1994:271; Roberts, Boylston et al., 1998:58; Roberts, 1999:315; Raff et al., 2006:25; Santos & Roberts, 2006:46; Nicklisch et al., 2012:396). For example, extensive periosteal reaction and destruction, remodelling, and thickening of the bone of the visceral surfaces of all twelve ribs of the right thorax of an individual from the LeVesconte Burial Mound (c. A.D. 230; southeastern Ontario, Canada) have been attributed to pulmonary infection due to actinomycosis (Molto, 1990:440, 446). However, it has been argued that actinomycosis is not a common disease, with the thorax affected in only 5 to 20% of individuals. Furthermore, when unaccompanied by the cranial and vertebral lesions more commonly associated with actinomycosis, it is believed to be unlikely that a high frequency of rib IPR within a population is caused by this disease (Lambert, 2002:283).

Pneumonia has also been suggested as one of the only pulmonary diseases to have affected large enough frequencies of the population to account for a high prevalence of rib IPR in the preantibiotic era (Kelley et al., 1994:127). Although a study of 385 individuals who died from pneumonia only recorded one instance of clear periosteal reaction and one individual exhibiting only slight reaction on two ribs (Kelley and Micozzi, 1984:383-383), other studies have found that 22.2% to 25.0% of all individuals dying from a pulmonary disease other than tuberculosis, most commonly pneumonia, displayed rib IPR (Roberts et al., 1994: Table 1; Matos & Santos, 2006:Table 4). However, Roberts et al. (1994:181) have noted that people recorded as dying from pneumonia may have been misdiagnosed due to the development of acute pneumonia as a result of pulmonary tuberculosis. Therefore, identifying which of these two diseases may have ultimately caused the rib IPR is not always possible. Molto (1990:444) also suggested that it is likely that the acute pathogenesis of untreated pneumonia leads to either death or recovery before the underlying bone can become affected.

It should also be noted that Capasso (1999:Table 5) observed a high correspondence between vertebral lesions associated with brucellosis and what was believed to be periosteal reaction on the visceral surfaces of the ribs in skeletons from Herculaneum, Italy. However, pulmonary involvement in brucellosis is extremely rare, affecting less than 1% to 5% of infected people (Uluğ & Can-Uluğ, 2012:e13), and the bone changes on the ribs reported by Capasso (1999:282, Fig.10) are not morphologically consistent with periosteal reaction observed in other bioarchaeological studies. This new bone may instead represent surface irregularities produced by muscle attachments or normal variation (Anson et al., 2012:61) (see Section 6.6.2.ii). Additionally, the vertebral bone changes involved in brucellosis can be similar to those of tuberculosis (e.g. Waldron, 2009:96-97) and rib IPR in some instances could be related to misdiagnosis of TB as brucellosis.

3.3.3.iv Air quality and living environment

The effect of the living environment and air quality on lower respiratory tract disease and, therefore, on the prevalence of rib IPR has been noted by several authors (Pfeiffer, 1991:196; Capasso, 2000:1774; Lambert, 2002:288; Roberts, 2007:795; 2009:314; Nicklisch et al., 2012:400). For example, high levels of indoor particulate pollution predisposing the population to developing respiratory disease as a result of burning animal and vegetable oils in lamps and vegetal materials in fires has been used explain the prevalence of rib IPR (11.6%) among the Roman population from Herculaneum, Italy (Capasso, 2000). No differences in prevalence between sex and age groups were noted, suggesting that the population was uniformly affected within their everyday living environment.

Pfeiffer (1991:196-197) also emphasised the role that living environment is likely to play in the development of rib IPR, noting the adverse effects that smoke-producing fires in badly ventilated longhouses may have had on the respiratory health of the Uxbridge population, Ontario, Canada. Stressors, such as undernourishment and warfare, were also suggested as factors exacerbating a predisposition to infectious pulmonary diseases, including tuberculosis (Pfeiffer, 1991:197). Similar stressors were cited in a study of skeletons from Cowboy Wash, Colorado, USA, which suggested that famine and warfare in the pre-contact population were responsible for the high visibility of respiratory infections such as tuberculosis, as evidenced by rib IPR. This study also noted that the cramped living quarters and dust and pollen produced in the arid environment may also have predisposed the population to developing respiratory diseases (Lambert, 2002:288, 290). In particular, particulates produced in an arid environment are known to have an impact on respiratory disease (see Section 2.4.2.iv). In a study of skeletal remains from Amara West, Sudan, dating from between 1300 and 800 BC, 46.7% (49/105) of adults displayed new bone formation on their ribs (Binder, 2014:Table 8.49). This is extremely high when compared to other archaeological studies (see Figure 3.7). It was suggested that the high prevalence may have been due to dust and sand in the desert environment and from exposure to smoke in poorly ventilated rooms and courtyards (Binder, 2014:303-305).

In a study of respiratory disease through time in southeast England a significant difference in the prevalence of rib IPR was found between the higher and lower status burials of the parish of St Bride's (post-Medieval London). A significant difference was also found between these populations for maxillary sinusitis, suggesting that different lifestyles and occupations may have led to a greater exposure to particulate pollution in the lower status population (Bernofsky, 2010:164, 216, 244). However, in general, any significant differences between the prevalence of rib IPR during different periods or in people from different urban and rural sites, where there may have been different levels of particulate pollution, were not found. Instead, it was suggested that a variety of other factors were likely to affect the development of respiratory disease within a population (Bernofsky, 2010:242, 263).

In a study of direct and indirect evidence for smoking within a 19th Century population from St Mary and St Michael churchyard, Whitechapel, London, the frequency of rib IPR in the adult population was 26.5% (71/268). However, when only looking at individuals displaying direct evidence for smoking, using the presence of lingual enamel staining (from tobacco) and/or pipe-stem facets on the teeth, a higher prevalence rate (40.9%) was found (Walker & Henderson, 2010:214, 215). Males within the age groups of 18 to 25 and 26 to 35 years were more frequently affected by rib IPR than females, which corresponded to the findings that men within the 26 to 35 age group most commonly displayed direct evidence for smoking. It was suggested that the high age-specific prevalence of rib IPR within early to early-mid adulthood in smokers may indicate a strong relationship between smoking and periosteal reaction on the ribs. Although it was noted that the local environment and occupations may have affected rates of lower respiratory disease and, therefore, the prevalence of rib IPR, it was suggested that smoking may have played a large part in increasing susceptibility to, or aggravating pre-existing, pulmonary diseases, such as tuberculosis (Walker & Henderson, 2010:215, 218, 219). While the environment and air quality, including exposure to particulates from cultural activities such as smoking, may have led to a general susceptibility to lower respiratory tract diseases, the type and position of rib IPR within the rib cage may provide a more specific indication of the disease responsible.

3.3.3.v Type and position of lesion

The type of lesion (i.e. new bone formation or destruction) affecting the rib and the position of the lesion within the rib cage have both been discussed in relation to potential differentiation of the responsible disease (e.g. Pfeiffer, 1991:197; Matos & Santos, 2006:198; Santos & Roberts, 2006:47; Waldron, 2009:117).

Lesion type

Kelley and Micozzi (1984:383) noted two types of lesions affecting the rib: mild periosteal reaction seen as new bone formation and, in a small number of individuals, sharply circumscribed lytic (destructive) lesions penetrating the cortex. Matos and Santos (2006:192) noted that only 4.6% (9/197) of all individuals within their sample displayed lytic lesions, commonly affecting the visceral surface of shaft of the ribs, but the lesions were randomly distributed in terms of the side of the rib cage or the specific rib (e.g. 7th rib, 12th rib) affected. Lytic lesions were found in two individuals who died from uterine cancer and breast cancer, suggesting a metastatic origin, while four individuals displaying lytic lesions were recorded as dying from pulmonary TB and may represent the haematogenous spread of tuberculous infection into the bone (Matos & Santos, 2006:195-196).

The destructive form of rib involvement is most commonly described in the clinical literature in relation to tuberculosis (e.g. Asnis & Niegowska, 1997:1018; Talbot et al., 2007:40). Due to this fact, it has been argued that lytic lesions of the ribs may be considered potentially diagnostic of tuberculosis, while new bone formation can only be interpreted as a non-specific inflammatory periosteal reaction to underlying inflammation (Pfeiffer, 1991:197). However, it should also be noted that the involvement of rib destruction in other diseases, such as metastases from primary tumours, reduces the reliability of using this type of bony change as a diagnostic indicator of tuberculosis. Mays et al. (2002:27-28) stated that direct extension of tuberculous spinal foci and haematogenous spread of the infection are likely to result in destructive lesions on the ribs, but tuberculous infection of the lungs, pleura, or lymphatic system will most likely result in inflammatory new bone formation. What is not mentioned by these studies is that skeletal tuberculosis (i.e. resulting in lytic lesions) is more commonly the result of tuberculous infection that does not involve the lungs and is only rarely caused by pulmonary TB (Resnick, 2002:2524; Talbot et al., 2007:405). Therefore, lytic changes cannot be reliably used as evidence for lower respiratory tract disease.

In studies of human identified skeletal collections and archaeological skeletons the most common form of lesion reported is IPR (Mays et al., 2002:28). Matos and Santos (2006:196) noted that the majority of rib IPR in people who have died from pulmonary tuberculosis consisted of lamellar bone and this is consistent with the prolonged survival time of around 2.5 years for people with untreated tuberculosis, while rib IPR in people dying from pulmonary diseases other than TB more commonly consisted of woven bone, suggesting an acute infection such as pneumonia. Similarly, lamellar bone has been noted as more common in individuals dying from tuberculosis, while woven bone was more often observed in individuals with a non-pulmonary disease (Roberts et al., 1994:176). However, in non-adults with a cause of death of pulmonary tuberculosis the majority of lesions were of woven bone (Santos & Roberts, 2001:46), and this may represent the shorter survival period of children with this disease.

The ribs can also appear to be expanded or enlarged, as the result of layers of remodelled new bone on top of the original surface (Pfeiffer, 1991:193; Roberts, Boylston et al., 1998:57; Matos & Santos, 2006:194-195). Thickening of the ribs is the only bony change to be noted in clinical studies that appears to correlate with what is seen archaeologically (Eyler et al., 1996). This is because very thick layers of new bone formation may be visualised on radiographs, unlike the more subtle lesions noted in the majority of bioarchaeological studies (Roberts, Boylston et al., 1998:58; Santos & Roberts, 2006:44; Nicklisch et al., 2012:391). On the other hand, plaque-like new bone formation may represent an initial acute reaction to inflammation, whereas thickening of the rib may represent a more chronic form of the disease (Pfeiffer, 1991:197). The thickening of ribs in association with mixed osteolytic and proliferative lesions, in particular, has been argued to represent a reaction to actinomycotic infection (Molto, 1990:446; Buikstra & Williams, 1991:167).

Location of lesion

The position of rib IPR in relation to the rib cage, and on the rib itself, has also been used to discuss differential diagnoses. The data on the location of rib IPR within the rib cage from various studies has been summarised in Table 3.3, although not all data are directly comparable. Kelley and Micozzi (1984:382) first noted that, when laying out the ribs in the correct anatomical position, the region of the rib cage affected often appeared to conform to an oval-shaped area across several ribs, most frequently affecting the fourth to eighth ribs. This led to the suggestion that infection of the pleura or lung tissue, which lies adjacent to this area, may be involved in the development of rib IPR (Kelley & Micozzi, 1984:382). This region of the affected rib cage has been noted in other archaeological studies (e.g. Sledzik & Bellantoni, 1994:271; Kelley et al., 1994:125). Other researchers have also observed the involvement of multiple ribs and more frequent or advanced involvement of the middle region of the rib cage (Molto, 1990:441; Kelley et al., 1994:126; Roberts et al., 1994: Fig. 8; Santos & Roberts, 2001:41, 2006:40, 42; Lambert, 2002:284; Matos & Santos, 2006:193; Nicklisch et al., 2014:397-398). This suggests that the pervasive spread of IPR throughout the rib cage may be indicative of diffuse pleural inflammation, for example through pleural effusion (Pfeiffer. 1991:197).

While Kelley and Micozzi (1984:383) noted that periosteal lesions involved the central part of the rib shaft, and not the head and neck of the rib, the majority of authors have observed IPR also localised in the head or neck region, or spread across the entire rib (e.g., Pfeiffer, 1991:192; Kelley et al., 1994:125; Roberts et al., 1994:176; Lambert, 2002:284; Santos & Roberts, 2001:41, 2006:40; Matos & Santos, 2006:193-194; Nicklisch et al., 2012:395-296). Many have found a greater frequency of rib head and neck involvement compared to shaft involvement in their samples (Pfeiffer, 1991:192; Lambert, 2002:284; Nicklisch et al., 2014:395-396). Kelley and Micozzi (1984:383) argue that, when the head and neck of the rib are involved, this represents direct extension of infection from the spine to the ribs. Erosive lesions on the ribs, representing the extension of tuberculous lesions from the spine, have further been noted in archaeological populations (e.g., Baker, 1999:303-304; Capasso & Di Tota, 1999:464; Ortner, 2003:246). However, the claim that proliferative new bone formation on the ribs also represents such an extension has been disputed as ribs with lesions on the head or neck of the rib are not often accompanied by skeletal involvement of the spine (Roberts et al., 1994:177).

Table 3.3 - Data for rib IPR distribution within the rib cage from various studies of identified skeletal collections and archaeological human remains.
(+) = most frequent; (n) = number of ribs affected; (n*) = number of individuals affected

[1]Kelley & Micozzi (1984); [2]Roberts et al. (1994); [3]Santos & Roberts (2001); [4]Santos & Roberts (2006); [5]Matos & Santos (2006); [6]Mariotti et al. (2015); [7]Kelley et al. (1994); [8]Lambert (2002); [9]Nicklisch et al. (2012); [10]Pfeiffer (1991); [11]Bernofsky (2010)

Collection/ Site	Cause of death	Side affected (proportion of affected individuals)			Most commonly affected ribs	Zone affected on rib (percent of affected ribs)			
		Left	Right	Bilateral		Neck	Angle	Shaft	Sternal
Hamann-Todd Collection[1]	Tuberculosis	2 : 1		-	4th to 8th			(+)	
Robert J. Terry Collection[2]	Tuberculosis	25%	30%	45%	5th to 8th	25%	28%	20%	-
	Pulmonary disease (non-TB)	37%	37%	26%	-	-	-	-	-
	Non-pulmonary disease	20%	30%	50%	5th to 8th	23%	24%	29%	-
Coimbra Collection (non-adults)[3]	Pulmonary tuberculosis	40% (4/10)	20% (2/10)	40% (4/10)	4th to 6th	40 (n)	-	10 (n)	5 (n)
Coimbra Collection (adults)[4]	Pulmonary tuberculosis	34.4% (22/64)	21.9% (14/64)	43.7% (28/64)	4th to 6th	275 (n)	-	61 (n)	63 (n)
Luís Lopes (Lisbon) Collection[5]	Tuberculosis	17.1% (13/76)	23.7% (18/84)	59.2% (45/84)	3rd to 7th	85.6% (477/557)	-	37.5% (208/555)	32.2% (494/159)
	Pulmonary disease (non-TB)	33.3% (6/18)	33.3% (6/18)	33.3% (6/18)	8th	52% (39/75)	-	42.7% (32/75)	59.4% (41/69)
	Extrapulmonary disease (non-TB)	31.3% (5/16)	25.0% (4/16)	43.8% (7/16)	4th to 8th	81.3% (100/123)	-	54.0% (67/124)	42.7% (41/96)
Certosa Cemetery Collection[6]	Various	20% (6/30)	40% (12/30)	40% (12/30)	2nd to 10th	126 (n)	-	4 (n)	47 (n)
South Dakota, USA[7]	-	Fairly equal		13.0% (6/46)	Upper and middle ribs	-	-	-	-
Ute Mountain, Colorado, USA[8]	-	Left < Right		-	6th to 10th	(+)	(+)		
Saxony-Anhalt, Germany[9]	-	46%	54%	-	Middle ribs	(+)			
Uxbridge Ossuary, Ontario, Canada[10]	-	136 (n)	123 (n)	-	3rd to 10th	(+)			
Southeast England[11]	-	90 (n*)	79 (n*)	-	4th and 8th	39 (n*)	-	140 (n*)	8 (n*)

However, Roberts et al. (1994:176) did find a greater association between involvement of the head and neck in individuals dying from tuberculosis, while individuals suffering from a non-pulmonary cause of death more commonly displayed lesions on the anterior part of the rib shaft. This finding is supported by Santos and Roberts (2006:40), who found that 69.5% of the people who died from pulmonary tuberculosis had lesions affecting the vertebral end of the rib, while only around 15% of tuberculous individuals had involvement of the shaft or sternal ends. Matos and Santos (2006: Table 5) also report an 85.6% involvement of the vertebral ends of the ribs in individuals with pulmonary tuberculosis, and that individuals suffering from non-tuberculous pulmonary disease were more likely to have sternal end involvement (59.4% compared to 32.2% of TB sufferers).

In particular, it has been argued that the location of IPR and the type of bone formed may be indicative of the type of disease experienced by the individual. In the Luís Lopes Collection it was noted that individuals dying from pulmonary tuberculosis were more likely to display lesions on ribs from the middle of the rib cage, whilst individuals suffering from peritonitis showed more severe periosteal reaction on the lower ribs (Santos & Roberts, 2006:47). Waldron (2009:117) hypothesised that pleural effusion may be expected to gravitate towards the bottom of the chest and affect the lower ribs, while lesions restricted to a region of the ribs corresponding to the anatomical position of a specific lobe of the lung may indicate lobar pneumonia as a cause. It is also suggested that infection or effusion causing an individual to become bed-ridden may settle towards the back of the chest (Waldron, 2009:117), which could explain the higher prevalence of rib IPR found at the vertebral end of the ribs.

The frequency of unilateral and bilateral lesions, and the frequency of left and right side involvement have also been investigated with results varying in the side, position, and number of ribs affected between studies (Roberts et al., 1999:Table 1; Matos & Santos, 2006:Table 7; Santos & Roberts, 2006: Table 4). For example, Matos and Santos (2006:193) found a significantly higher proportion of bilateral lesions (59.2%) in individuals suffering from pulmonary TB. Both Kelley and Micozzi (1984:382) and Santos and Roberts (2006:43) also found that unilateral lesions in tuberculous individuals were more likely to affect the left side with a ratio of approximately 2:1. A closer examination of clinical studies may help to provide further diagnostic value in differentiating the potential aetiologies of rib IPR. However, in archaeological populations, where ribs are often fragmented and incomplete, it may be more difficult to accurately determine the distribution of lesions and differentiate between pathological causes (Roberts, Boylston et al., 1998:58). Table 3.3 also demonstrates the inconsistencies among studies in the recording methods and the presentation of prevalence data for rib IPR in different regions of the rib cage. Therefore, a careful consideration of the methods for recording rib IPR is important for comparability with other studies.

3.3.4 Methods

As it has been suggested that the position of IPR within the rib cage may aid in the differential diagnosis of the disease causing the lesions, in many studies, where possible, ribs are sided and seriated and the position of IPR on the rib is recorded, for example at the sternal end, vertebral end, shaft, neck, or angle, and on the visceral or external surface (e.g. Pfeiffer, 1991; Kelley et al., 1994; Lambert, 2002; Bernofsky, 2010; Nicklisch et al., 2012). The type of bone involvement (bone destruction or formation) and the status of bone remodelling (woven, remodelling, or lamellar bone) is also recorded in many studies (e.g. Lambert, 2002, Bernofsky, 2010; Binder, 2014). Although the majority of studies have recorded rib IPR as either present or absent, Nicklisch et al. (2012:393) also attempted to grade lesions into five grades (0 to 4), with new bone formation increasing in severity from absent (grade 0) to severe (grade 3). A grade of 4 was restricted to ribs displaying lytic lesions alongside extensive new bone formation. While the grading of bone changes might give an indication of the chronicity of the disease, too little is yet known about the processes of bone formation on the ribs from clinical contexts for this to be reliable.

Additionally, the observation of new bone formation on the ribs can often be problematic. The formation of plaque-like bone can be delicate and may easily become detached, making new bone unobservable and leading to underestimations in prevalence (Pfeiffer, 1991:193; Matos & Santos, 2006:198; Santos & Roberts, 2006:47). The fragmentation of ribs in many archaeological contexts makes it difficult to side and seriate the ribs and can hinder the identification of lesions (Roberts, Boylston et al., 1998:58; Santos & Roberts, 2006:47; Anson et al., 2012:62), while taphonomic factors can prevent identification, for example by creating discolouration or pseudopathologies that inhibit actual observation of lesions (Capasso, 2000:1774; Santos & Roberts, 2006:47). The repeatability of a study's results may also be affected by intra- and inter-observer error (Santos & Roberts, 2006:47) and the distinction between different types or stages of new bone formation (e.g. woven or lamellar) can be problematic (Matos & Santos, 2006:198). Therefore, observer error testing is essential to evaluate the effectiveness of different methods, but most studies of rib IPR do not appear to have conducted such tests.

A frequently discussed problem in relation to rib IPR is the disparity in reports of bony changes on the ribs in clinical contexts as opposed to the relatively common rates seen in the bioarchaeological record (e.g. Roberts, Boylston et al., 1998:56; Santos & Roberts, 2001:48, 2006:47; Mays et al., 2002:28; Matos & Santos, 2006:190; Bernofsky, 2010:33; Nicklisch et al., 2012:391). Clinical studies often rely on radiography or more advanced methods of imaging, such as CT scanning, to observe pathological changes to the bone, but the subtle bone formation seen on the ribs of skeletons is often invisible using these imaging techniques. In clinical contexts IPR, therefore, goes unnoticed, except in cases where the rib has become extremely thickened (Eyler et al., 1996; Roberts, Boylston et al., 1998:58; Lambert, 2002:281; Nicklisch et al., 2012:391; Porres et al., 2017:274-275). Additionally, routine autopsies do not normally investigate the visceral surface of the ribs and are, therefore, unlikely to note new bone formation (Kelley et al., 1994:129; Santos & Roberts, 2001:46, 2006:42; Matos & Santos, 2006:190; Nicklisch et al., 2014:391).

While lesions of the ribs are difficult to detect, they may also be overlooked because they do not provide any diagnostic value (Santos & Roberts, 2001:48, 2006:42; Nicklisch et al., 2012:391). The different methods used by clinicians to observe pathological changes (i.e. radiography, CT scanning) have resulted in a lack in diagnostic protocol related to rib IPR and its association with lower respiratory tract disease (Roberts et al., 1994:177; Santos & Roberts, 2001:48). The absence of a clinical base to work from is perhaps partly responsible for the lack of research into rib IPR in bioarchaeological contexts, among other factors, such as poor preservation and fragmentation of archaeological skeletal remains.

3.4 Summary

Both maxillary sinusitis and rib IPR occur fairly often in archaeological populations. However, bioarchaeological studies of respiratory disease are scarce compared to other types of studies, and have mainly centred on populations from England. This has limited investigations into a host of risk factors, such as variations in prevalence related to the environment, climate, and socio-cultural activities and behaviours. Additionally, while a fairly standardised method for identifying bony changes related to maxillary sinusitis has been established for some time, approaches to identifying and recording rib IPR can vary considerably and this is reflected in the lack of comparability of data between studies, such as for the location of IPR within the rib cage. Despite these limitations, a number of researchers have attempted to investigate the aetiologies involved in the formation of bony changes in the sinuses and on the visceral surfaces of the ribs. A variety of factors may affect susceptibility, including the living environment, climate, socioeconomic status, subsistence economy, and activities related to occupation, which can all affect exposure to particulate matter and pathogens. Specific infectious diseases, such as tuberculosis and leprosy, are also likely to have had an impact on the prevalence of respiratory disease in past populations and, in particular, tuberculosis appears to have a close association with the development of rib IPR. Bioarchaeological studies of respiratory disease have demonstrated the potential risk factors and causes of respiratory disease in different populations. In the next chapter the archaeological evidence for risk factors that may have affected respiratory disease through time in the Middle Nile Valley are presented.

Chapter 4: Archaeological context

4.1 Introduction

Details of the archaeological context related to the human remains analysed in the current research are focussed specifically on factors that may have affected exposure of the people studied to particulate matter or increased their susceptibility to respiratory disease. This includes factors such as the environment in which they lived, their subsistence economy, trade, activities related to specific occupations, living conditions and housing, social structure, and ideology. For example, the environment in the Middle Nile Valley varies according to region, and changes through time may have had an effect on the density of particulate matter (PM) in the air, such as sand or dust (Field et al., 2010:425; Ravi et al., 2011:7). In terms of subsistence economy, activities related to agriculture could have affected exposure to PM through ploughing, harvesting, threshing, winnowing, the burning of crops, or the grinding of grain (Grobbelaar & Bateman, 1991; Kirkhorn & Garry, 2000:706; Schenker, 2000:664; Boxall et al., 2009:511; Goto et al., 2011). Certain subsistence strategies could also have introduced infectious diseases and allergens via contact with animals (Kirkhorn & Garry, 2000:707), and could have affected dietary quality and quantity, ultimately impacting the strength of the immune system and subsequent health. Trade and the movement of people, both within the Nile Valley and on an international scale, may also have had an effect on the spread of infectious pathogens that could have led to respiratory disease (e.g. Tatem et al., 2006; Yue et al., 2017).

Occupations that involved fire, such as metalworking or pottery manufacture, or exposure to other forms of particulate matter, could have increased susceptibility to respiratory disease (e.g. Robert et al., 2008:652; Sirajuddin & Kanne, 2009:310; Shusterman, 2011:103). The structure and plans of housing or workplaces, and the location of open fires in particular, are likely to have had an impact on exposure to PM on a daily basis (Bruce et al., 2000:1079; Fullerton et al., 2008:844; Perez-Padilla et al., 2010:1081). The building materials used and the size of habitation areas would have dictated the amount of ventilation a house and its occupants experienced, and archaeological evidence can also provide an indication of levels of sanitation within homes, such as the means for waste disposal or the proximity of animals to the house. Ideological and socio-economic factors such as social stratification and the division of labour by sex or age may also have affected the likelihood of certain individuals being exposed to particulate pollution (e.g. Bruce et al., 2000:1080; Fullerton et al., 2008:845; Perez-Padilla et al., 2010:1081; Sood, 2012:651; Amegah & Jaakkola, 2016:215). The archaeological evidence pertaining to these factors during different time periods is discussed below as thoroughly as possible, although this relied on the extent of excavation and the amount of extant archaeological data made available, which is limited for certain sites or time periods.

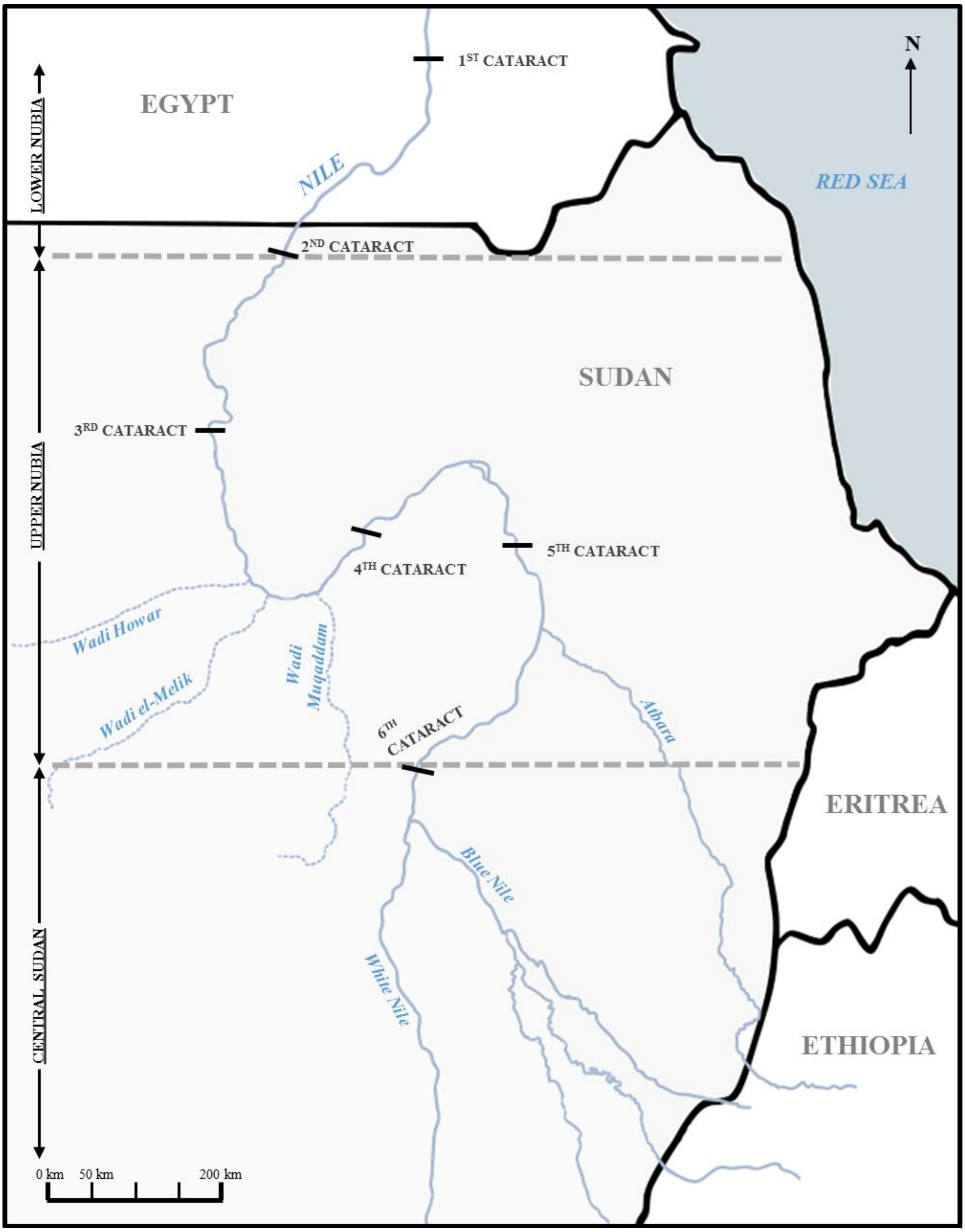


Figure 4.1 – Map of the Middle Nile Valley marking the geographical regions of Lower Nubia, Upper Nubia, and Central Sudan

The study of Sudan's archaeology contains a great deal of variation in the attribution of names to specific time periods, sites, and geographic regions. In general, sites in the Middle Nile Valley have been discussed in relation to three regions: Lower Nubia (located mostly in Egypt between the First and Second Cataracts), Upper Nubia (between the Second and Sixth Cataracts), and Central Sudan (south of the Sixth Cataract) (Figure 4.1). On the whole, discussion of sites in this chapter has been limited to the geographic regions that display the characteristic material culture of these distinct time periods. For example, sites displaying material culture related to the Kerma period are limited to Upper and Lower Nubia.

The human remains studied in this research belong to the time periods of the Neolithic, Kerma, Meroitic (Kushite), Post-Meroitic, and Medieval periods (Table 4.1). Therefore, the following chapter contains a discussion of the archaeological context of these specific time periods, with only a brief discussion of other periods where appropriate.

Table 4.1 – Approximate dates for each time period of the Sudanese Nile Valley. Time periods specific to the current study are highlighted in grey. See tables in individual sections below for phases within each time period.

Approximate Dates	Time Period
8000 – 6000/5000 BC	Mesolithic
6000/5000 – 3100 BC	Neolithic
3100 – 2500 BC	Pre-Kerma
2500 – 1500 BC	Kerma
1500 – 1069 BC	New Kingdom Egyptian control
1096 – 800 BC	? (Early Kushite)
800 BC – AD 350	Kushite
AD 350 – 550	Post-Meroitic
AD 550 – 1500	Medieval
AD 1500 – 1820	Islamic

4.2 The Neolithic period

Conventionally, in archaeology the Neolithic is characterised by the adoption of agriculture and animal husbandry (Sadig, 2013:23). Neolithic sites in Sudan have been identified by the style of pottery present and characteristic lithics (Hassan, 1986:84; Honegger, 2014:22). Evidence for the cultivation of plants and livestock may be present, but not necessarily (Hassan, 1986:84). The attribution of dates and the phasing of the Neolithic in Sudan is complex, differing between Upper Nubia and Central Sudan. This has been further complicated by the use of various names for different phases of the Neolithic (e.g. Hassan, 1986; Salvatori & Usai, 2007; Sadig, 2013).

The majority of Neolithic sites investigated in Sudan are situated in two regions: between the Second and Fourth Cataracts and south of the Fifth Cataract in the Khartoum region. Sites from the former region are referred to as Upper Nubian and the latter region, although containing sites north of Khartoum in what is conventionally defined as Upper Nubia, have been categorised into a Central Sudanese Neolithic group (e.g. Honegger & Williams, 2015:Fig. 1) (Figure 4.2).

Within Upper Nubia the Early Neolithic is attested by the site of el-Barga, dating to between 6000 and 5500 BC, which contains the oldest evidence for domesticated livestock in Sudan. A gap in any archaeological data of 500 years is then present, before the commencement of the Middle Neolithic, spanning from approximately 5000 to 4000 BC and evidenced by numerous cemeteries in this region (Usai, 2016:15). The Neolithic of Central Sudan follows later, with a period referred to as the Khartoum Neolithic or Early Neolithic, which spans from approximately 5000 to 4000 BC. This is followed by a Late Neolithic period from approximately 4000 to 3100 BC, attested by the site of el-Kadada, a phase for which, in Upper Nubia, there is no archaeological evidence (Salvatori & Usai, 2007:Fig. 4) (Table 4.2).

4.2.1 Environment

Geochemical, geomorphological, sedimentological, palaeontological, biomolecular, palynological, isotopic, and faunal analysis provide a detailed understanding of the environment in Sudan leading up to and during the Neolithic (e.g. Lario et al., 1997; Nicoll, 2004; Buckley et al., 2014; Gatto & Zerboni, 2015; Honegger & Williams, 2015; Woodward et al., 2015). The early Holocene (*c.* 8000 – 5000 BC), following on from the hyper-arid Pleistocene era, was characterised by the start of far wetter and humid conditions in Egypt and Sudan (Nicoll, 2004:565), sometimes referred to as the African Humid Period (Honegger & Williams, 2015:141; Usai, 2016:5). An increase in precipitation

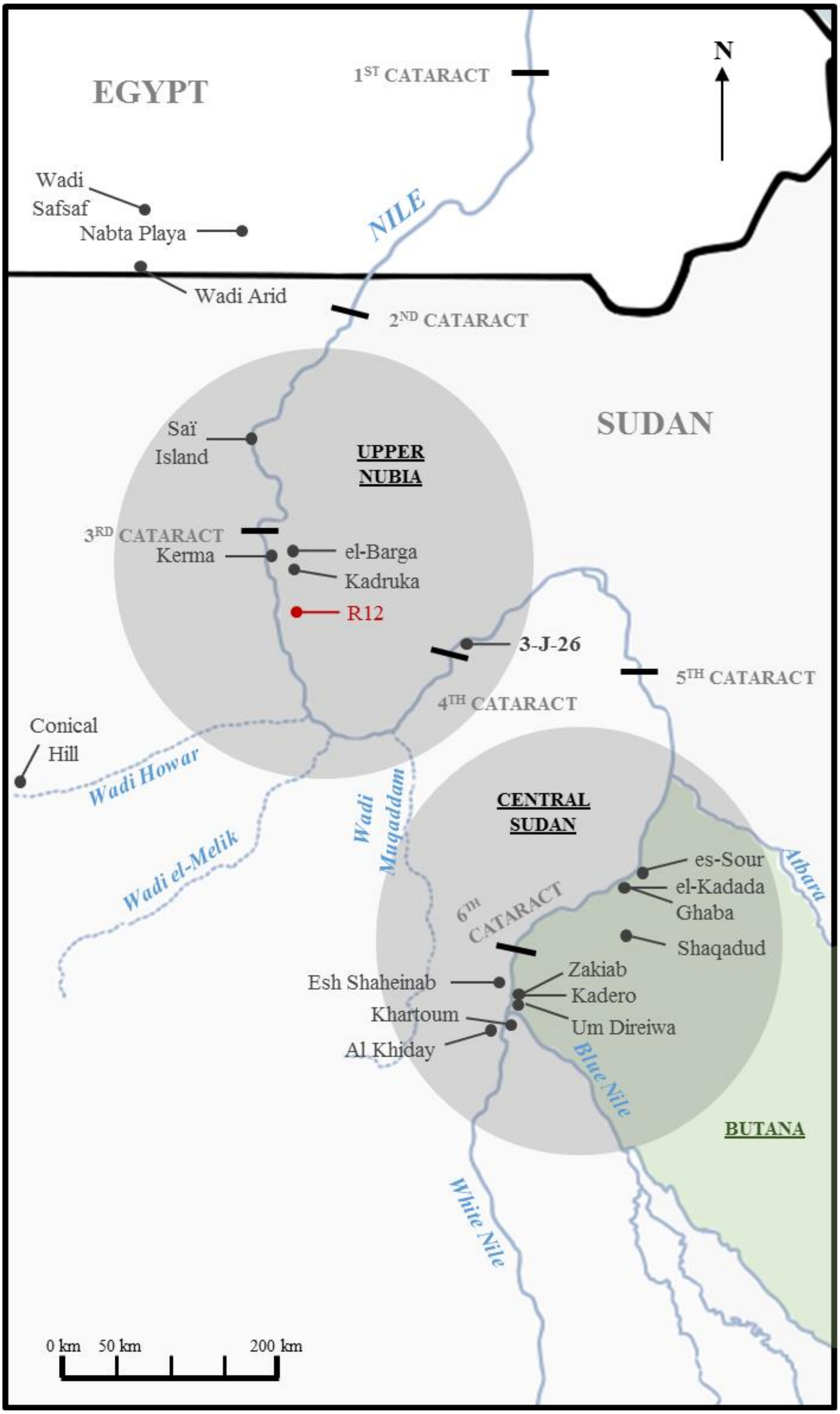


Figure 4.2 – Map of the Middle Nile Valley marking the location of all sites and geographical features mentioned in the Neolithic section of this text. Site marked in red is that included in the current study.

Table 4.2 – Time periods, with approximate dates, between 8000 and 2600 BC in the regions of Upper Nubia and Central Sudan (Salvatori & Usai, 2007: Fig. 4).

<table>
<tr><th>Approximate dates (BC)</th><th>Upper Nubia</th><th>Central Sudan</th></tr>
<tr><td>8000 – 6000</td><td>Mesolithic</td><td rowspan="2">Mesolithic</td></tr>
<tr><td>6000 – 5500</td><td>Early Neolithic</td></tr>
<tr><td>5500 – 5000</td><td>?</td><td>Late Mesolithic</td></tr>
<tr><td>5000 – 4500</td><td rowspan="2">Middle Neolithic</td><td rowspan="2">Early Neolithic</td></tr>
<tr><td>4500 – 4000</td></tr>
<tr><td>4000 – 3100</td><td>?</td><td>Late Neolithic</td></tr>
<tr><td>3100 – 2600</td><td>Pre-Kerma</td><td>?</td></tr>
</table>

and a rising water table caused lakes and wetlands to form (Nicoll, 2004:568; L. Krzyżaniak, 2011:21; Gatto & Zerboni, 2015:308). Northern Sudan typically supported a savannah-like environment (Kuper & Kröpelin, 2006:805; Out et al., 2016:37; Usai, 2016:6). Areas such as the Wadis Howar and el-Melik, which contained tributaries of the Nile, were actively flowing into the Nile Valley (Nicoll, 2004:568; Usai, 2016:5) and, at least in the case of Wadi Howar, supported dense savannah woodland vegetation and a swampy environment (Neumann, 1989:110). These humid conditions provided an ideal environment for expansion of populations from the Nile Valley into what had been desert regions, which could now sustain seasonal occupation (Gatto & Zerboni. 2015:313-314).

During the Middle Holocene (c. 5000 – 3000 BC) drier conditions began to develop (Nicoll, 2004:569), causing the shrinking of some lakes (Nicoll, 2004:570; Gatto and Zerboni, 2015:311). The region receiving the greatest rainfall also moved to the south, with a consequent shift of the vegetation belt (Kuper & Kröpelin, 2006:807; Gatto & Zerboni, 2015:311-312; Out et al., 2016:37). This is attested by a change in faunal assemblages between the Mesolithic and Neolithic. At Esh Shaheinab, the disappearance of swamp adapted animals (e.g. water mongoose, reed rat) and the appearance of savannah species (e.g. giraffe, gazelle, gerbil, hare), with a reduction in flooding levels when compared to the nearby Mesolithic site of Early Khartoum, indicates a decrease in rainfall and humidity in this area (Bate, 1953:17; Arkell, 1953:8-9). Changes in the makeup of the faunal assemblage at Shaqadud from the Mesolithic and Early Neolithic to the Late Neolithic show a shift from humid conditions to a dry savannah (Peters, 1991:234). However, the change in environment appears to have been slow at Shaqadud, allowing a hunter-gathering way of life to persist until at least around 4000 BC (Marks & Mohammed-Ali, 1991:238, 258). Other Early Neolithic sites in Central Sudan lack any faunal species typical of wetland environments and demonstrate an increase in the presence of drier savannah-adapted species when compared to Mesolithic sites (L. Krzyżaniak, 2011:33).

In Central Sudan, between 8000 and 4900 BC, L. Krzyżaniak (2011:28-29) describes three ecological niches: riverbanks with associated marshes and the presence of aquatic fauna and a vegetation cover of papyrus, reeds, and some tree and grass species; flat river plains with rich plant vegetation and a large concentration of fauna, with seasonal marshes; and the Butana plateau, which is an elevated plain located between the Nile, Blue Nile, and Atbara rivers, with acacia trees, bushes, and grasses and specifically dry savannah-adapted fauna during the dry-season, like gazelle and antelope. This was followed by a shift between 4900 and 3800 BC to the disappearance of permanent marshes around the river, a change in the flat river plain to savannah-adapted species and a vegetation of tall grasses and acacia trees, a lower rainfall in the Butana, and semi-arid zones in areas without permanent water (L. Krzyżaniak, 2011:34-35). A shift in site placement in favour of closer proximity to the river can also be seen in the location of Neolithic sites in Upper Nubian regions from 5500 BC onwards (Honegger, 2014:20-21, Fig. 2; Usai, 2016:8), suggesting water availability was becoming more limited (Honegger & Williams, 2015:146).

This has led to suggestions that adaptation to climate change was one of the driving forces for the adoption of agriculture during the Neolithic period (Jesse, 2004:39; Honegger, 2014:27). The sudden appearance of domestic livestock in Central Sudan has been partly attributed to the movement of Nubian people, and their cultural practice of pastoralism, south along the river as a result of worsening climatic conditions in Upper Nubia (Gautier & Van Neer, 2011:407; Usai, 2016:17). Additionally, it has been suggested that the adoption of pastoralism, over grazing of land, and the practice of burning grasses to promote new growth may have also impacted the southward shift of vegetation (L. Krzyżaniak, 2011:21)

However, the change to a more arid environment was gradual and conditions during the Neolithic were still wetter and more hospitable than in subsequent periods (Haaland, 1981:46-47; Lario et al., 1997:587; L. Krzyżaniak, 2011:20-21; Woodward et al., 2015:133). Sedimentological analysis shows that there was a large flow of water into the Nile from wadis in Upper Nubia during the Neolithic, as opposed to the succeeding Kerma period (Woodward et al., 2015:133). Neolithic occupation of areas that would later become too arid is evidenced by habitation of palaeovalleys far from sources of water present today (McHugh et al., 1989:333). The wetter conditions allowed for a greater availability of flora and fauna and the use of a wide range of subsistence strategies during the Neolithic.

4.2.2 Subsistence economy

The first evidence for the adoption of domestic cattle in Sudan comes from el-Barga in Upper Nubia, where a grave dating to around 5800 BC contained a bucranium (frontal portion and horns of a cattle skull) (Honegger, 2014:24; Usai, 2016:15). Sites in Central Sudan do not contain domestic animal assemblages until approximately 5000 BC onwards (Hassan, 1986:84), but the more detailed evidence of subsistence activities from Neolithic settlement sites mainly stems from this region. Haaland (1981, 1987) produced a model of Neolithic subsistence strategies in Central Sudan based on specific seasonal activities and division of labour by sex. Using the Neolithic sites of Zakiab, Kadero I, Kadero II, Um Direiwa I, and Um Direiwa II, all located on the east bank of the Nile between 14 and 18 km north of Khartoum, as examples, Haaland (1981) suggested that sites can be divided into permanent base camps, dry-season fishing and herding camps, and wet-season herding and hunting camps, based on the location of the site and the type and quantity of archaeological material recovered.

Base camps are posited to be located on the fringes of the high flood levels and are characterised by a large size and a high density of ceramics, stone grinders, and scrapers, as evidence by Kadero I and II and Um Direiwa I and II (Haaland, 1981:48-52). Dry season fishing and herding camps are located on the alluvial plain near to the river, are small in size, and have fishing equipment and a high density of waste related to lithic production, as evidenced by Zakiab. No site was given as evidence for a wet-season camp, although it was hypothesised that Neolithic groups would use the higher savannah plains of the Butana, east of the Nile, for cattle grazing and hunting purposes (Haaland, 1981:46, 58). Using ethnographic data as evidence, Haaland (1981:45) also suggested that women would have been responsible for food gathering, plant cultivation, and ceramic production at base camps, while the role of men would have lain mainly in the herding of livestock, fishing, and the production of lithics at the seasonal camps. The only Upper Nubian settlement to be related to this model is the Neolithic site found in the Eastern Cemetery at Kerma, which was suggested to possibly represent a dry-season camp occupied when floods were low (Honegger, 2001:19-20, 2014:28).

Although this model may be appropriate to a certain extent for the groups living along the river in Central Sudan, it is clear that subsistence strategies varied between sites (L. Krzyżaniak. 1984:314;

Marks & Mohammed-Ali, 1991:255). The Neolithic site of Shaqadud is located in the western region of the Butana plain, about 50 km southeast of the Nile. Haaland (1981:59) suggested that this site may support the hypothesis that the Butana was utilised for temporary wet-season herding. However, the absence of domestic animal bones but an abundance of wild animal remains from the Early Neolithic part of the site (Peters, 1991:229) suggests that the people living there were not involved in pastoral production, but instead relied on hunting and gathering within the vicinity of the site (Marks & Mohammed-Ali, 1991:257). In addition to this, the quantity of material from the site indicates a prolonged occupation of the area. Ceramics and tools were produced locally and there is little evidence for the movement of raw goods from the Nile Valley to Shaqadud or a reliance on the river as part of the subsistence economy (Marks & Mohammed-Ali, 1991:256-257). Marks and Mohammed-Ali (1991:257) instead suggest that Shaqadud could represent a steppe-oriented economy, permanently utilising the wild flora and fauna of the woodland savannah of the Butana for subsistence.

Other sites show variations in the extent to which pastoralism was relied upon. L. Krzyżaniak (1978) used differences between the archaeological material found at Esh Shaheinab and Kadero to suggest a difference in the prioritisation of certain subsistence activities at each site. Archaeological evidence at Esh Shaheinab suggests a reliance on hunting and fishing and some gathering of plants and molluscs, with only a minor focus on the herding of livestock (L. Krzyżaniak, 1978:162). At Kadero, however, large assemblages of domestic animal remains, in particular of cattle, suggest a far greater reliance on pastoral activities, with no evidence for harpoons or fish-hooks that might indicate fishing (L. Krzyżaniak, 1978:164-165). The percentage of domestic animal remains found at Esh Shaheinab was originally given as 2%, consisting of caprines with an absence of cattle (Bate, 1953:15, 18). However, a re-evaluation of the faunal material now indicates that cattle may have been present at the site and domestic animals could have made up to 40% of the mammalian assemblage (Peters, 1986:26).

Despite this, the difference between assemblage composition at Esh Shaheinab (40%) and at Kadero (88%) is still appreciably large. Kadero was located further from the river than Esh Shaheinab, and was surrounded by flat grassland, which would have provided good grazing for the livestock (L. Krzyżaniak, 1978:172). It has also been suggested that differences between the percentage of domestic livestock present in mammalian assemblages on the west Nile bank in central Sudan (40-50%, including Esh Shaheinab) and on the east bank (70-90%, including Kadero, Um Direiwa, and Zakiab) may be due to the smaller size of the floodplain on the left bank, limiting the herd size it could sustain (Peters, 1986:26; Gautier & Van Neer, 2011:405-406). The differences in economy at these roughly contemporaneous sites suggests that Neolithic populations may have been adapting their subsistence strategies to best suit the ecological niches they were exploiting (L. Krzyżaniak, 1978:171).

Evidence for plant cultivation and domestication is far scarcer than that for animal husbandry. Preserved physical plant remains from sites are rare and, instead, the presence of grain imprints in pottery (e.g. from Kadero, Um Direiwa, Zakiab) and the large numbers of grinding stones recovered from the majority of sites have been used to suggest the exploitation of vegetation as a valuable source of food (Usai, 2014:42; Out, et al., 2016:37). In particular, the number of grinding stone fragments recovered at a site has been used to suggest the intensity with which plants were exploited (e.g. L. Krzyżaniak, 1978:165, 1984:311; Haaland, 1981:48; Marks & Mohammed-Ali, 1991:254). However, this does not provide direct evidence for the specific use of domesticated species of plants (Haaland, 1987:204; Usai, 2014:42). Only from the site of Conical Hill in the Wadi Howar have plant materials been recovered from the surface of a Neolithic grindstone, providing evidence for wild grass processing (Radomski & Neumann, 2011:163). Grinding stones were also used to work materials such as ochre (Out et al., 2016:49), as evidenced by traces left on the stone's surface, for example at Esh Shaheinab and Al Khiday (Arkell, 1953:42; Usai, 2014:42).

Important evidence for the use of domesticated wheat and barley was found at the Neolithic sites of Ghaba and R12 in a microbotanical study of plant remains from dental calculus, as well as phytoliths sampled from pillow-like structures found under the skulls within burials (Madella et al., 2014). The study found domestic cereals (wheat/barley) present in the dental calculus of individuals from both sites and in the phytolith samples from R12, implying that domestic cereals were being utilised in the region from at least c. 5300 to 5100 BC onwards (Madella et al., 2014:5). This predates the previous earliest evidence of domesticated cereals, dating to around 4500 to 4000 BC, at Kadruka 1 in the same region as R12, in which pillows of bovine skin stuffed with barley were recovered (Reinold, 2001:3; Madella et al., 2014:5). It was also demonstrated that individuals at Ghaba consumed a variety of wild grasses, legumes, and other starchy plants, such as tubers (Madella et al., 2014:6). A further study on the same samples indicated that grasses at Ghaba were being processed, possibly by some form of threshing tool (Out et al., 2016:44). These studies provide valuable evidence of plant processing methods and the cultivation of domesticated cereal crops during the Neolithic that is otherwise absent in Sudan. However, large numbers of pits for grain storage in the region of Kerma and Saï Island have been found at sites following on from the Neolithic (Pre-Kerma period), which have never been found in Neolithic contexts, perhaps suggesting that the large-scale cultivation of grains was not a priority during the Neolithic period (Honegger & Williams, 2015:149).

Very little evidence exists for activities related to occupation during the Neolithic. However, a study of Mesolithic and Neolithic pottery from Al Khiday, in Central Sudan, has demonstrated that pottery production became more standardised in the Neolithic and, at least at this site, people may have taken on the role of full or part-time potters (Dal Sasso et al., 2014:139).

4.2.3 Habitation

Neolithic settlement sites are usually characterised as surface scatters of archaeological material, with very little evidence for habitation structures (Reinold, 2001:6; Welsby, 2001:569; Jesse, 2004:39; Usai & Salvatori, 2005:480; Usai, 2016:16). A rare example of a Middle Neolithic settlement dating to around 4500 BC was excavated at the Eastern Cemetery of Kerma, revealing circular hut-like structures around 4m in diameter, two other rectangular constructions, and palisades providing enclosures around the huts, possibly for livestock (Honegger, 2001:18). Numerous hearths were found outside the huts. Two groups of four to five hearths were located to the south of palisades that formed an arc and it is possible that these fences were constructed to protect the fires from the wind (Honegger, 2001:18-19).

Hearths appear to be one of the few extant pieces of evidence that indicate Neolithic occupation at a site (Honegger, 2001:17). At Esh Shaheinab 38 hearths were recorded, many lined with small pieces of sandstone, which have been interpreted as cooking slabs for meat (Arkell, 1953:79-80). Within the Fourth Cataract the Neolithic site of 3-J-26 contained fireplaces, pits, and some post-holes that suggested a semi-permanent settlement in which the production of lithics, and possibly of pottery, were taking place (Osypiński, 2010:LI, 2014:12). An investigation of the tertiary palaeovalleys Wadis Arid and Safsaf, just north of the Egypt-Sudan border, revealed numerous Neolithic sites with domed hearths, numbering up to a few dozen at the largest sites (McHugh et al., 1989:328). None of these examples of hearths have been found in association with habitation structures.

However, the earlier Mesolithic settlement at Al Khiday, along the White Nile, has produced circular semi-subterranean huts with fireplaces located inside mud walls (Salvatori et al., 2014:245), as well as numerous fireplaces outside these habitation structures (Salvatori et al., 2011:207; Usai, 2016:9). At el-Barga, in upper Nubia, a semi-subterranean hut dating to the Mesolithic (c. 7500 – 7000 BC) and just under 5m wide contained ashy deposits, charcoal, and burned objects on the floor, possibly suggesting that fires were lit inside the hut (Honegger, 2004a:27). Similar huts located at Nabta Playa, just north of the Egypt-Sudan border, are contemporary to el-Barga and also contained hearths (Królik & Schild, 2001:118-120). Instances of hearths being located inside habitation structures were known, therefore, prior to the Neolithic.

A study using dental calculus sampled from pre-Mesolithic, Neolithic, and Meroitic individuals from the cemetery at Al Khiday II identified evidence for smoke inhalation and the cooking of food over fires, including a higher percentage of 'char' markers (carbonised material) during the Neolithic than in the two other periods, perhaps suggesting prolonged cooking times and greater exposure to smoke over hearths (Buckley et al., 2014:7). Whether or not hearths were located within habitation structures, how ventilated these structures were, and whether Neolithic people were exposed to higher concentrations of smoke, remains unanswered, although the evidence for Neolithic housing at the Eastern Cemetery of Kerma does indicate hearths could have been located outside of dwellings. However, the effect that greater precipitation during the Neolithic period may have had on habitation structure and hearth placement should also be considered. Afterall, it may not have always been practical to locate hearths outside during the rainy seasons, nor for huts to have a great deal of ventilation in the roofs, where rain would be likely to enter.

The absence of any evidence for settlement structures at almost all Neolithic sites in Sudan has been explained by a number of factors, which could all have played a role, including poor preservation, aeolian (windblown) erosion, and disruption by later people (Honegger, 2001:17; Reinold, 2001:2; Welsby et al., 2002:30). It has also been suggested that the adoption of pastoralism during the Neolithic led to a more transient form of settlement, the temporary housing for which leaves little archaeological evidence (Usai & Salvatori, 2005:480). For the site of Esh Shaheinab, Arkell (1953:102) proposed that post-holes were absent as habitations were formed from grass mats. Although more substantial materials are likely to have also been used, it is possible that these structures were of a more temporary nature than previous Mesolithic dwellings or that their organic components have not survived well.

4.2.4 Social structure and ideology

The preservation of multiple Neolithic cemeteries has provided valuable information about social hierarchy and ideology that cannot be determined from the scattered remains of settlements (Reinold, 2001:2, 6). Adults and children were generally treated with the same funerary customs (Reinold, 2001:4). At two of the cemeteries at el-Kadada in Central Sudan, however, children below six years of age were not buried with the adults in the cemetery. Instead, they were placed inside large used vessels and the graves were located in the region of the nearby settlement in a sparse distribution that led Reinold (2001:3) to suggest that these children were buried inside or near dwellings. This differential treatment may suggest that full integration into society in this group may have occurred at a certain age, as burials of children above the age of six in the cemetery are very similar to those of the adults (Reinold, 2001:4). Pot burials of children have also been noted at the site of es-Sour, just north of el-Kadada (Sadig, 2014).

Social stratification of cemeteries has been noted at several Neolithic burial sites, for example at el-Barga where the majority of graves were of women and children. Although it is possible that the burials which could not be sexed were of males, it is likely that male graves were instead situated elsewhere in an unexcavated portion of the cemetery (Honegger, 2004a:29). At Kadero social differentiation was found in the form of clusters of burials with grave furnishings of a different quantity and quality (L. Krzyżaniak, 1991:525), with the richest burials located in the centre of the site and graves of poorer members of the group scattered across the cemetery and at the peripheries (A. Krzyżaniak, 2011:66). At el-Kadada the grouping of adult and adolescent graves into distinct clusters of ten to twelve individuals can be identified in the northern cemetery, with each burial in the group containing very similar grave good compositions and burial orientation, which may suggest the clustering of burials within family units (Reinold, 2001:4-5).

In the Kadruka region in Upper Nubia some cemeteries (e.g. KDK1, KDK18, and KDK21) appeared to be arranged around a central burial at the peak of a mound, sometimes containing a high number of grave goods of good quality (Reinold, 2001). In particular, at cemetery KDK1 a middle aged or older male was buried with a vast array of grave goods, including bovine skins, ivory bracelets, an anthropoid figurine, lithics, ivory combs, a cosmetics case and cosmetic palettes, ceramics, and two bucrania originally placed on top of the body (Reinold, 2001:8). The remainder of this cemetery displayed division of burials into two groups, with one group located on the summit of the mound surrounding the central burial and consisting mainly of men with the richest grave goods. The other mostly female group was located on the periphery of the mound at lower ground level (Reinold, 2001;7-8). This suggests some kind of hierarchical order within the cemetery and an important central individual (Reinold, 2001:9).

There is some evidence for the increasing importance of pastoralism and associated ideology, with the inclusion of bucrania as grave offerings (Jesse, 2004:40). The earliest evidence for the use of domesticated cattle is a bucranium in a grave at el-Barga, c. 5800 BC (Honegger, 2014:24; Usai, 2016:15). Bucrania have also been found in graves from Ghaba, Kadruka, el-Kadada, and R12 (Reinold, 2001:8; Pöllath, 2008: Table 6.1; Usai, 2016:17). However, they are not found in all Neolithic cemeteries and their symbolic character may hold other meaning that cannot be so easily interpreted (Usai, 2016:16).

Graves with a central individual and peripheral human burials have also been found in Neolithic cemeteries and have been suggested to represent human sacrifice (Reinold, 2001:4; Jesse, 2004:4).

Although there is no reported physical evidence for violence against the secondary individual, they are usually arranged in a way that suggests the use of the body as a funerary furnishing for the primary individual (Reinold, 2001:4). For example, at el-Kadada an adult burial also contained a child of eight to ten years located at the edge of the pit. A bucranium placed on top of the child was used as a headrest for the adult (Reinold, 2001:4). Although the sacrifice of humans cannot be confirmed, it may be that the hierarchical structure of groups within the Neolithic placed a greater importance on certain individuals and used others to furnish these burials.

Using evidence from Neolithic cemeteries, it is apparent that social stratification, possibly based on material wealth, sex, or age, is present during this period, at least in some of the larger sites. The introduction of cattle and pastoralism may have provided a medium for control and power over the collection and exchange of goods, including cattle (Haaland, 2012:331). Important individuals, likely to have had high status within the community, were furnished with rich grave goods and may have had central burials within the community's cemetery. This social stratification could have had implications for the roles and activities individuals undertook within the group and their likelihood of exposure to particulate pollution or infectious diseases.

4.3 The Kerma period

The Kerma period consists of three phases identified by distinctive developments in ceramic manufacture and funerary culture: Kerma Ancien (2500 – 2050 BC), Kerma Moyen (2050 – 1750 BC), and Kerma Classique (1750 – 1500 BC) (Bonnet, 2004a:72; Emberling, 2014) (Table 4.3). This is preceded by a transitional phase between the Neolithic and Kerma Ancien periods referred to as Pre-Kerma that may have stretched back to 4000 BC, but for which archaeological evidence is only available between 3100 to 2600 BC (Honegger, 2004b:62). Named after the central town and religious centre of Kerma, this culture can also be referred to as the first Kingdom of Kush, the ruling power of Upper Nubia mentioned in Egyptian texts (Emberling, 2014:127). At its greatest extent of influence, during the Kerma Classique, sites have been identified 1200km along the Nile from the First to the Fourth Cataract (Bonnet, 2004a:70) (Figure 4.3). The Kerma state eventually disappeared after invasion by the Egyptian pharaohs of the 18^{th} Dynasty at around 1500 BC (Bonnet, 2004b:78; Emberling, 2014:146).

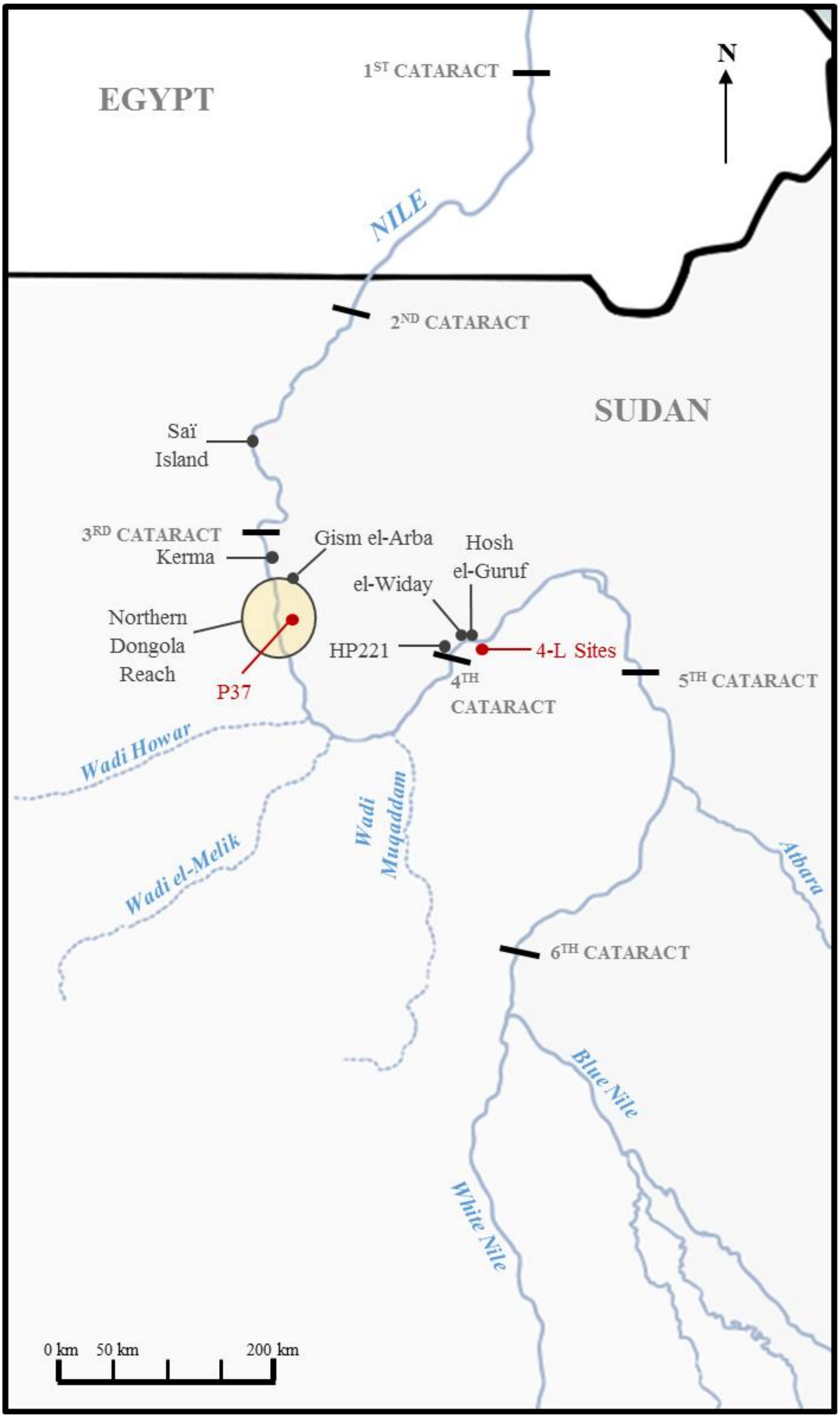


Figure 4.3 – Map of the Middle Nile Valley marking the location of all sites and geographical features mentioned in the Kerma section of this text. Sites marked in red are those included in the current study.

Table 4.3 - Time periods, with approximate dates, between 4000 and 1069 BC in the region of Upper Nubia (Bonnet, 2004a:72; Salvatori & Usai, 2007: Fig. 4; Emberling, 2014).

Approximate dates (BC)	Upper Nubia
4000 – 3100	?
3100 – 2600	Pre-Kerma
2600 – 2500	?
2500 – 2050	Kerma Ancien
2050 – 1750	Kerma Moyen
1750 – 1500	Kerma Classique
1500 – 1069	New Kingdom Egyptian control

4.3.1 Environment

Following on from the termination of the African Humid Period, the environment continued to become increasingly arid (Nicoll, 2004:569-572; Gatto & Zerboni, 2015:312; Woodward et al., 2015:138). Sedimentological analysis reveals that after 2500 BC the wadi systems of the Nile were drying up and people may have been increasingly exposed to aeolian sands (Nicoll, 2004:571; Woodward et al., 2015:138). In the Northern Dongola Reach Kerma sites were clustered along the then-active palaeochannels of the Hawawiya and Alfreda Niles and on the Dongola Nile (now the main river channel), demonstrating a clear dependence on a proximity to water (Welsby, 2001:589; Welsby et al., 2002:32). Results from isotopic analysis of human and cattle remains from the town of Kerma display elevated δ^{15}Nitrogen values, which is typical of populations exposed to hot arid environments (Iacumin et al., 2001:44; Thompson et al., 2008:383). The excellent preservation of organic materials within burials from the cemetery at Kerma, located four kilometres east of the town, has also been used to suggest prevailing arid conditions (Chaix & Grant, 1993:401).

However, the riparian region around Kerma and to the south in the Northern Dongola Reach, with its floodplains, many islands, and active palaeochannels, would have provided a more extensive area of cultivatable land than available today and supported a number of settlements throughout the Kerma period (Chaix & Grant, 1993:402; Welsby, 2004:90-91). Faunal assemblages at Kerma, including bones from hippopotamus, giraffe, and rhinoceros, and paintings or motifs of giraffes, rhinoceri, and antelope, indicate a grassy or wooded savannah in proximity to the town (Chaix & Grant, 1993:402; Emberling, 2014:Fig. 2). Additionally, a survey of the Northern Dongola Reach identified floral evidence at Kerma period sites that indicated the exploitation of riverine and nearby lightly wooded savannah environments (Cartwright, 2001:561; Welsby, 2001:589)

A shift away from the inclusion of cattle in favour of caprines (sheep/goat) in Kerma graves from between the Kerma Moyen and Kerma Classique periods has been linked to worsening environmental conditions towards the later part of the period, which, alongside population increase, was likely to have limited the availability of pasture for large grazing stock (Chaix, 2017:416). From the lack of Kerma Classique pottery on the banks of the Hawawiya Nile, this palaeochannel may have ceased to flow during the Kerma Moyen period (2050 – 1750 BC) (Welsby, 1995:27; Woodward et al., 2015: Fig. 12). Ultimately, by the end of the Kerma Classique period (c. 1500 BC), the Alfreda channel and local wadis in the Northern Dongola Reach had almost completely dried up (Woodward et al., 2015: 133, Fig. 12). Following this, water resources in Upper Nubia would have become significantly reduced (Welsby et al., 2002).

4.3.2 Subsistence economy and trade

During the Kerma period subsistence practices consisted of crop cultivation and pastoralism. The importance of cattle as part of the subsistence economy of the Kerma period is attested by their significant presence in funerary contexts and in iconography (Chaix, 2006:27, 2017:422). At the town of Kerma cattle bones made up 50% of the faunal assemblage within the food refuse (Chaix & Grant, 1993:402). They were not only relied upon for food, including meat and milk, but also for their skins for leather, bones for tools, and as an important part of funerary furnishings (Chaix, 2017:419, 422). Evidence for the consumption of caprines and a small amount of fish was also present at Kerma (Chaix, 2017:416).

Located 25km south of Kerma, the sites of Gism el-Arba I and II (just 3.5 km from one another) provide evidence of an extensive period of rural occupation throughout the Kerma period (Gratien, 1999; Gratien et al., 2003). The majority of the identifiable faunal assemblage from these settlements consisted of domestic animals (89.2%), with a dominance of caprines, and also some fish (~10%) (Chaix, 2006:26-27). The greater number of caprines at Gism el-Arba differs from Kerma, where cattle were predominant (Chaix, 2006:29, 35). It has been suggested that caprines may have been better suited to the environmental conditions of Gism el-Arba (Chaix, 2006:35), although Kerma is located fairly close and they are likely to have shared similar environments. Instead, cattle from Gism el-Arba may have been exported to Kerma for use as meat or as part of the funerary custom of depositing bucrania around the grave. Isotopic analysis of cattle skulls from Kerma graves suggest that animals were not raised in the same area, but may have been brought to the town from many different regions (Iacumin et al., 2001:45), possibly from as far as the Mediterranean (Bonnet, 2014a:88; Chaix, 2017:421). The presence of large numbers of clay cattle figurines at Gism el-Arba certainly demonstrates the importance of cattle to the people at this rural site (Chaix, 2006:27).

Evidence for the consumption of fish is also very rare at Kerma compared to Gism el-Arba, although this may be due to the poorer preservation conditions in the town (Chaix, 2006:35, 2017:416). Emberling (2014:140) does note, however, that a later Kushite inscription (c. 725 BC) denounces fish eating as unclean and suggests that the difference in fish and cattle bone assemblages between Kerma and Gism el-Arba could represent differences in the diet and status of people at the two sites. At both Kerma and Gism el-Arba wild mammals are poorly represented in the faunal assemblage, suggesting a lack of hunting and a concentration on the raising of domestic livestock during the Kerma period (Chaix, 2006:27-28, 2017:416).

Less is known about plant cultivation at this time and palaeobotanical evidence is limited. Analysis of plant remains from the Northern Dongola Reach survey, mainly recovered from funerary contexts, found evidence for the cultivation of wheat and barley, but also the exploitation of wild grasses, seeds, and fruits (Cartwright, 2001:560-561). Grains of barley and numerous grinding stones have been identified at Kerma (Chaix, 2001:364; Bonnet, 2004a:74) and the many ovens in the town testify to the abundant baking of bread (Chaix & Grant, 1993:399). Large buildings with raised floors for the storage of grain and other goods have also been identified at Gism el-Arba (Gratien et al., 2003:43) and at sites in the Northern Dongola Reach, for example at P4 (Welsby, 2001:577), while in Kerma large storehouses by the river port were likely used for the storage of shipped products, such as grain (Bonnet, 2004b:79-80; Emberling 2014:140). A field system at Kerma dating to the Kerma Classique has also been found with surviving furrows and associated hoof imprints, indicating the use of a wooden plough drawn by cattle (Bonnet, 2003:viii).

It has been suggested that the pastoral activities of Kerma period people were accompanied by a certain degree of mobility (Emberling, 2014:140). Isotopic analysis of human remains from Kerma has revealed a range of isotopic values in the population, which could indicate that people were migrating into the town (Thompson et al., 2008:385) (the movement of cattle has already been addressed above). Kerma was also likely a centre of trade networks that spread between Egypt, the Red Sea, and the southern Sahara (Bonnet, 2004a:71). Egyptian imports at Kerma sites have been found all the way to the Fourth Cataract (e.g. Kołosowska et al., 2003:22; Paner, 2003a:17, 2014:60;

Emberling & Williams, 2010:26; Emberling et al., 2014:334). Additionally, in the Fourth Cataract potential connections to eastern desert nomadic cultures can be identified from the inclusion of Pan-Grave ceramics in Kerma graves (Welsby, 2008:37), for example at the cemetery of el-Widay (Emberling et al., 2014:333-334).

4.3.3 Activities related to occupation

Areas of the town of Kerma demonstrate evidence for specialised activities related to the burning of fuels. Several pottery workshops and two types of pottery kiln have been identified: basic, small kilns with open fire pits and low mudbrick walls, possibly used for firing utilitarian pottery, and a more elaborate kiln, with a conical firing chamber constructed of brick, that could have been used for firing larger vessels (Bonnet, 1984:III, 2014a:89). Metalworking areas have also been identified in the town, including a bronze workshop containing several smelting furnaces dating to the Kerma Moyen (Bonnet, 1982:46, 2014a:90). The furnaces consisted of a rectangular fire chamber dug into the floor, with access to the hearth via eight shafts, oriented to funnel draughts from the wind into the chamber (Bonnet, 1982:47, 2014a:90). Evidence for the use of palm wood as a fuel was also found (Bonnet, 1982:47).

Additionally, industrial scale ovens for the production of bread have been identified at Kerma within the religious quarter (Bonnet, 2004b:79). In the north-east section of the town ten rectangular ovens were built in a row, presumably for simultaneous use (Bonnet, 1988:III). Their proximity to the large temple (the *defuffa*) suggests that the ovens provided the religious buildings with bread, which may have been used as offerings (Bonnet, 1988:III, 2004b:84). Circular bread ovens have also been identified at Gism el-Arba II, dating to the end of the Kerma Classique period and into the Egyptian conquest period. Gism el-Arba I and II also contained simple pottery kilns and possible copper-smelting furnaces (Gratien, 1999:11).

Within the Fourth Cataract, the site of Hosh el-Guruf has been interpreted as a Kerma gold mining site (Emberling & Williams, 2010; Meyer, 2010; Emberling, 2014:144; Paner, 2014:65). Surface finds included a high concentration of large grindstones, much larger than those used to grind grain during this period, and of a type that have been noted at gold mining sites in Egypt during the New Kingdom (Emberling & Williams, 2010:20-22). A large number of hand stones used for pounding, grinding, or hammering were also found (Meyer, 2010:42-43). It has been hypothesised that gold was extracted from the local quartz bedrock by crushing the stone into dust and panning or by crushing gravel and alluvial deposits that may have contained gold (Emberling & Williams, 2010:23). The number of grindstones, the size of the area, and evidence for structures built using stone suggests that the site may have been used as an area of industrial activity for quite some time and that people may have travelled to work at the site from nearby villages during agricultural off-peaks (Emberling & Williams, 2010:36-38; Meyer, 2010:52). Fine imports from Kerma found at the nearby cemetery of el-Widay, including scarabs and ceramics (Emberling & Williams, 2010:27) indicate that gold may have been exported to the capital in return for other items (Emberling, 2014:144). However, it should be noted that the interpretation of this site as a Kerma gold mining centre has been questioned, because identical types of grinding stones have been commonly found at Medieval sites in the Third and Fourth Cataracts (D. Welsby, pers. comm., 2018).

4.3.4 Habitation

During the early Kerma Ancien period at the city of Kerma circular hut-like structures with a diameter of between 4 and 5m were recorded across the town (Bonnet, 2014b:238). These structures resemble the clusters of circular dwellings made of wood or mud found at a pre-Kerma site located under the Kerma City cemetery (Bonnet, 2004b:84, 88, 2014b:238). The development of rectilinear brick buildings at Kerma, of one or more rooms with external courtyards and specialised areas for activities, occurred from 2000 BC onwards (Bonnet, 2004b:79, 2014b:238). However, as it developed, Kerma supported a diversity of habitation structures, the differences in size and complexity likely reflecting the stratification of society. The buildings ranged from huts and single-roomed brick dwellings to elite houses and royal apartments with large facilities for storage, cooking, and other activities (Bonnet, 2004b:79-80, 2014b:238-242). Kitchens or areas of burning are often described as being located within the courtyards of dwellings (Bonnet, 2004b:79, 2014b:239, Fig. 146), although indoor fireplaces have been noted within structures at Kerma (e.g. Bonnet, 2014b:241).

Evidence for rural settlement is more limited. At the rural site of Gism el-Arba I the progression in style and function of structures can be seen throughout the Kerma period. During the Kerma Ancien period dwellings are represented by circular huts, approximately 4m in diameter, and the presence of a rectangular structure that may represent an administrative building (Gratien, 1999:10). During the Kerma Moyen period a quadrangular structure with several hearths was constructed using layers of mud to form the walls (a technique known as *jalous*), with kilns and possible granaries located nearby (Gratien, 1999:10). By the end of the Kerma Moyen period this structure had been replaced by three others of more than 5m square in area and built of unfired mudbrick. These structures included a room containing a large fireplace (Gratien, 1999:10). During the Kerma Classique the site developed to contain large buildings of mudbrick, 15 to 20m in size, with central courtyards and adjoining quadrangular rooms, which have been interpreted as large farming compounds (Gratien, 1999:11; Chaix, 2006:25). The use of sizable indoor fireplaces continued and numerous kilns were located nearby (Gratien, 1999:11). At Gism el-Arba II similar buildings dating to the Kerma Classique period were present but also included mud and timber structures with raised floors, thought to be for the storage of grains or other materials, as noted above (Gratien et al., 2003:43).

Other rural settlement structures have been located in surveys of the regions north and south of Kerma, which were likely to have made up part of the town's hinterland and network of trade routes (Bonnet, 2004a:74). At least 70 Kerma settlements have been identified in the Third Cataract, just north of Kerma, usually as surface scatters of fragmentary material and Kerma ceramic sherds (Edwards et al., 2012:457, 459). Some rectilinear structures have been identified, constructed of mudbrick and stone (Edwards et al., 2012:459). Similarly, in the Northern Dongola Reach, of around 150 identified Kerma period settlement sites, several contained the remains of buildings. At the site of L12, for example, the remnants of mudbrick walls suggest a structure of similar size and form to the Kerma period houses at Gism el-Arba (Welsby, 2001:577). The remains of stones forming the base of structures were more commonly found in the Northern Dongola Reach, likely surviving better than mudbrick, and were arranged in a manner suggesting quadrangular buildings (Welsby, 2001:Fig. 14.3). At the site of M13 around 30 stone structures could be identified and at site P4 a raised floor may have been present within a large building, again suggesting a storage building (Welsby, 2001:577). Evidence for the possible use of daub as infilling material within the walls was found at several sites (Welsby, 2001:577).

Circular structures have been identified in the Fourth Cataract region at the site of HP221, in Wadi Umm Rahau, and have been associated with the Kerma Moyen period (Paner, 2014:60). Consisting of a wooden framework and reinforcements of stone at the base, these circular huts are thought to have been covered with some type of organic material, such as animal hides (Paner & Pudło, 2010:136; Paner, 2014:60). Their diameter ranged from 2.5 to 3.5m and occasionally from 5.5 to 7.5m (Paner, 2014:60). Single circular huts have been located in the Fourth Cataract at sites 4-L-41 and 4-L-232 and have been dated to the Kerma period based on the presence of Kerma pottery sherds (Welsby, 2005:3, 2006a:9). It has also been suggested that concentrations of stones at the gold mining site of Hosh el-Guruf may represent the remains of structures built of stone and mud (Emberling & Williams, 2010:20). However, more detailed evidence for the construction of dwellings in the Fourth Cataract is, as yet, unknown.

4.3.5 Social structure and ideology

Throughout the Kerma period society became increasingly hierarchical. At the Kerma City cemetery differences in status are reflected in the type of grave furnishings and monuments provided for the dead, including the number of sacrificed animals, the number and quality of grave goods, and the size of the grave pit and tumulus (Bonnet, 2004a:75). The inclusion of small numbers of cattle bucrania placed next to the grave began in the Kerma Ancien period and grew to include vast numbers among the elite burials of the Kerma Moyen period, with one grave associated with a vast 4,899 bucrania (Emberling, 2014:134; Chaix, 2017:420). By the Kerma Classique period elite or royal tumuli reached huge proportions. Whilst the deposition of large numbers of bucrania declined, this was replaced by the common inclusion of human sacrifices (Bonnet, 2004a:75-76). The last four royal tumuli of Kerma were between 70 and 90m in diameter and contained up to 400 human sacrificial victims, as well as subsidiary graves for affiliates of the occupant of the main burial (Bonnet, 2004a:76; Emberling, 2014:140-141).

The wide variety of housing at Kerma also points to status differences. Huts and one-room mudbrick houses were contemporaneous with large complex mudbrick buildings (Bonnet, 2014b:239). Due to the high number of large houses located by gates into the town and along the main thoroughfares and areas of commerce, it has been suggested that a kind of merchant elite, or high-ranking officials with control over the movement and organisation of goods, was present (Bonnet, 2004b:80, 2014a:84, 2014b:242). The elite, perhaps overseeing trade routes to and from Kerma, may have also been present in smaller towns such as at Saï Island, whose cemetery contained, alongside more modest graves, Kerma Classique tumuli of up to 40m in diameter (Gratien, 1986:337). Due to the presence of young males in subsidiary burials of royal tumuli at Kerma, who were associated with bronze daggers and trauma consistent with violence (Judd & Irish, 2009:714), it has also been suggested that a warrior elite serving the ruler may have existed (Hafsaas-Tsakos, 2013:89).

It is known that Kerma supported a large religious complex including a temple, the *defuffa,* throughout its occupation, but little of the religious practices can be reconstructed. It is likely that bread and domestic animals were used as offerings (Bonnet, 1988:III, 2004b:84; Chaix, 2001:364). Indeed, cattle had an important place in the ideology of the Kerma period, not just at Kerma but also within the rural settlements. Thousands of rock engravings of cattle, likely dating to the Kerma period, have been found between the Second and Fourth Cataracts (Kołosowska et al., 2003:22; Kleinitz, 2004:16; Edwards et al., 2012:459). Cattle are also represented in paintings on chapel walls, carved onto ostrich eggs at Kerma (Chaix, 2017:418, Fig. 26.2), and as figurines found at Kerma, Gism el-Arba, and in the Fourth Cataract region (HP221) (Gratien, 1999:12; Paner, 2003a:17). Finally, the inclusion of vast numbers of cattle bucrania placed around the graves of the Kerma elite suggests that the control of cattle may have been a powerful symbol of wealth and status during this period (Chaix & Grant, 1993:403; Chaix, 2017:422).

4.4 The Meroitic (Kushite) period

After the withdrawal of New Kingdom Egyptian control in Upper Nubia by 1069 BC, the remaining political powers gradually united into the Kingdom of Kush (Török, 2004:132). Only the royal cemetery site of el-Kurru has provided evidence for the development of the early Kushite state and the possible presence of burials of Kushite rulers before 800 BC (Welsby, 1996:13-14; Török, 1997a:88; Edwards, 2004:118-119). Following this, the Kushite period is generally divided into two phases. The Napatan period stretched from c. 800 to 300 BC and focussed on the presence of royal burials in the Napatan region at el-Kurru, Nuri, and Jebel Barkal (Edwards, 1996:1, 2004:112). Between c. 760 and 656 BC, the Kushite kings also temporarily expanded their control into Egypt, where they are known as the 25th Egyptian Dynasty (Török, 1997a, 2004:132). At the beginning of the third century BC rulers moved the royal burial ground from the Napatan region further south to Meroe, which had already been an important settlement and residence of Kushite kings during the Napatan period. The shift in royal focus to Meroe marks the beginning of what has been named the Meroitic period, dating from 300 BC to AD 350 (Török, 2004:135; Edwards, 1996:1, 2004:127, 141). From around the third century AD the power of the Kushite kings began to decline, eventually disintegrating in the middle of the fourth century AD (Welsby, 1996; Török, 1997a:485) (Table 4.4). At its most powerful, the Kushite kingdom stretched over 3000km from the Mediterranean to the Butana region in Central Sudan (Welsby, 2003a:65; Török, 2004:132) (Figure 4.4). It was a period characterised by the building of large temple towns, palaces, and pyramid tombs, and the maintenance of extensive trade and political networks (Török, 2004:132, 136).

Table 4.4 – Time periods, with approximate dates, between 1500 BC and AD 550 in the regions of Lower Nubia, Upper Nubia, and Central Sudan (Bass, 2015:Table 1; Török, 1997a; Welsby, 1996; Edwards, 2004).

Approximate dates	Lower Nubia	Upper Nubia	Central Sudan
1500 – 1069 BC	New Kingdom Egyptian control	New Kingdom Egyptian control	?
1069 – 800 BC	? (Early Kushite)	? (Early Kushite)	? (Early Kushite)
800 – 300 BC	Napatan (Kushite)	Napatan (Kushite)	Napatan (Kushite)
300 BC – AD 350	Meroitic (Kushite)	Meroitic (Kushite)	Meroitic (Kushite)
AD 350 – 550	X Group	Post-Meroitic	Post-Meroitic

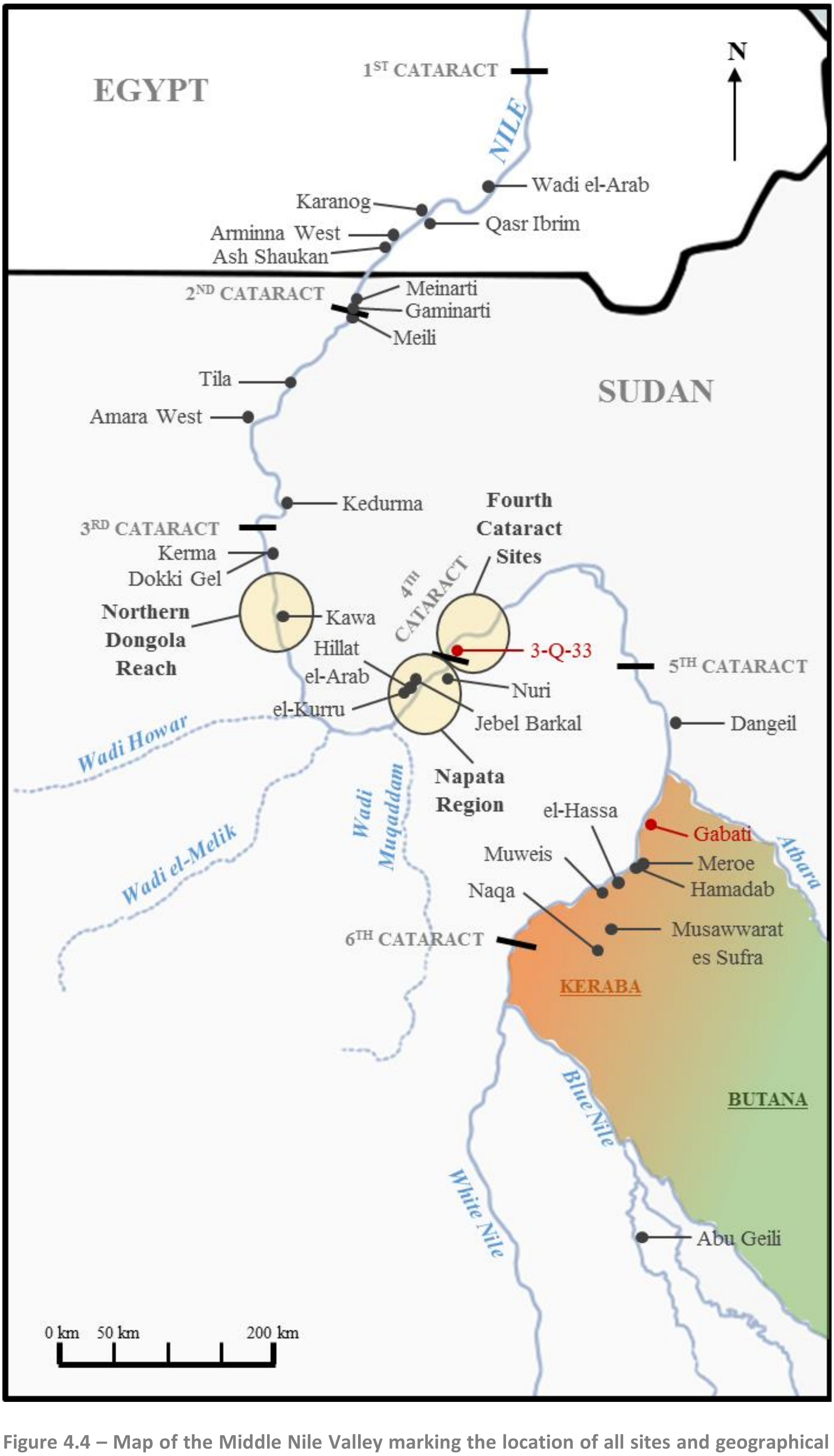


Figure 4.4 – Map of the Middle Nile Valley marking the location of all sites and geographical features mentioned in the Meroitic section of this text (except Kawa and Amara West, which are mentioned in Section 4.7). Sites marked in red are those included in the current study.

As the human remains from the Kushite period included in the current study only date to the Meroitic phase, a focus has been placed on the archaeological evidence dating from between 300 BC and AD 350. However, some reference has also been made to evidence from the Napatan or Kushite (both Napatan and Meroitic) periods.

4.4.1 Environment

The progression of aridification continued throughout the Kushite period, approaching the hyper-arid conditions in Sudan today, although there may have been brief fluctuations in the climate during this time (Nicoll, 2004:571-572; Gatto & Zerboni, 2015:312-313). By around 2000 BC most lake and wadi systems had completely dried up and by approximately the first century BC the Wadi Howar, once a tributary of the Nile, was defunct (Nicoll, 2004:572; Woodward et al., 2015:138).

The Kushite state stretched from north to south along a vast reach of the Nile river, encompassing a number of environments (Welsby, 1996:137). The north consisted of an arid semi-desert environment with acacia scrubland and small regions of habitable land along the banks of the river (Edwards, 1989:Fig. 5; Török, 1997a:30). In the Northern Dongola Reach, by around 1000 BC, the Alfreda palaeochannel had completely dried up, reducing the amount of cultivatable land and the number of people that could be supported in this region (Welsby et al., 2002:37). During the Meroitic period settlements in the Northern Dongola Reach were extremely sparse and confined to the banks of the main Nile (Welsby, 2001:591). Edwards et al. (2012:465) suggested the limited settlement data for the Meroitic in the Third Cataract region is also likely to have been due to the arid and inhospitable environment.

Further south precipitation was higher and Kushite sites have been located in the Keraba (a region consisting of Nubian sandstone in the western part of the Butana), some distance from the river (Edwards, 1996:22-23; Welsby, 2003a:71). Here, the environment will have consisted of savannah grasslands (Edwards, 1989:Fig. 5; Török, 1997a:30). Additionally, the floodplain region around Meroe was likely to have consisted of wooded savannah and alluvial forests particularly suited to agriculture, which may have favoured the city's development as a capital (Nowotnick et al., 2014:25; Wolf, 2015:130). At Musawwarat es Sufra, south of Meroe, there has been found evidence for a type of land snail that requires far higher precipitation levels for survival than is present today, suggesting greater rainfall during the Kushite period (Gabriel, 1997:28). However, statistical modelling of precipitation conditions in the south, at nearby Naqa, displayed a declining trend in rainfall throughout the Napatan and early Meroitic periods (Berking et al., 2012:166). Other evidence for a decrease in the availability of water in the south during the Kushite period can be seen in water retention techniques, such as the building of *hafirs* - human-made reservoirs to collect rainwater runoff - and wells. However, for the construction of *hafirs* to be worthwhile, there must have been a copious supply of rainfall for at least part of the year (Welsby, 2003a:73-76).

4.4.2 Subsistence economy and trade

The different environments along the river dictated the kind of agricultural activities present in certain regions (Welsby, 1996:153; Török, 2004:132-134). In the north the sedentary production of crops and animal husbandry were limited to the banks of the river, where land was still cultivatable. In the south there was enough rainfall for expansion into the Keraba for grazing livestock in a more nomadic manner and for some agricultural activities (Welsby, 1996:153; Török, 1997a:33, 2004:135; Edwards, 1998a:184; Fuller, 2014:166).

At Meroe, and the nearby town of Hamadab, barley, wheat, and sorghum have been identified (Shinnie & Anderson, 2004:366; Nowotnick et al., 2014:10) and at Qasr Ibrim, in Lower Nubia, the remains of crop plants such as sorghum, emmer wheat, barley, pearl millet, and cotton have been recovered (Clapham & Rowley-Conwy, 2006:25). In the Fourth Cataract, at Umm Muri, Meroitic charred plant remains of wheat, barley, sorghum, hyacinth bean, and cowpea were found (Edwards & Fuller, 2005:27-28). Sorghum has been argued to have been especially important during the Meroitic period and is represented in royal art of this period (Edwards, 1996:22; Welsby, 1996:160; Fuller, 2014:170).

The herding of cattle, sheep, and goats was also likely to have been an important part of Meroitic subsistence (Edwards, 1996:22, 1998a:185; Chaix, 2010:524). Animal remains have been analysed from the Kushite sites of Dokki Gel, Kerma, Hillat el-Arab, Dangeil, Meroe, and el-Hassa and at all sites cattle were predominant over caprines (Chaix, 2010:519, 521). Analysis of faunal remains at Meroe indicate a decline in caprines and an increase in cattle at the site over time, which has been attributed to possible over-grazing by, and subsequent decline of, caprines (Carter & Foley, 1980:304, Fig. B2). There was also a dominance of cattle reported at Hamadab, supplemented by sheep, goats, and some fish and oysters (Nowotnick et al., 2014:10). A small percentage of fish bones were identified at Meroe (Carter & Foley, 1980:305) and at the temple complex of Dangeil wild species of gazelle, fox, porcupine, hare, bird, and fish made up 36.8% of the faunal assemblage (Chaix, 2010:520). However, at the majority of sites there is very little evidence for a reliance on wild resources during the Meroitic period (Welsby, 1996:162; Chaix, 2010:Table 3). Instead, much of the land usually required for wild resources may have been adapted for agriculture (Kay & Kaplan, 2015:26).

Certain food stuffs, such as olive oil, wine, and honey, were also imported from Egypt and the Mediterranean (Welsby, 1996:174). It is likely that the Kushite state was part of an extensive trade network (Edwards, 1998a:183-184). Imported luxury objects, such as jewellery, bronzework, silverware, glassware, and ceramics originating from Greece, Egypt, the Red Sea coast, and Rome have been found in Meroitic contexts in Sudan (Edwards, 1996:31-32; Welsby, 1996:174; Grzymski, 2004:167). In return, gold, ivory, and slaves may have been exported to neighbouring states, such as Egypt (Haaland, 2014:650; Brass, 2015:282). This network may also have facilitated the widespread movement of tradesmen and specialised craftsmen (Haaland, 2014).

4.4.3 Activities related to occupation

Several Meroitic sites have provided evidence for craft specialisation and activities related to specific occupations that may have increased exposure to particulate pollution. At the city of Meroe ironworking is attested by the large mounds of iron slag found within the area of the town (Shinnie, 1967:161). Domed furnaces at Meroe were found in pairs facing each other inside a building with a sunken floor, thought to be constructed in such a manner as to prevent windblown sand from entering the work area (Shinnie & Anderson, 2004:75-76). An investigation into the technical ceramics used in the manufacture of iron at Meroe revealed a high level of standardisation in their production, which included a high degree of skill and technological knowledge on the part of the producer (Ting & Humphris, 2017:40-41). Iron slag from the site also indicates that the smelting technology of the time was potentially very efficient (Rehren, 2001:106; Humphris, 2014:122). This specialisation may indicate that people were specifically trained for the craft (Shinnie & Kense, 1982:27) and may have spent a large portion of their working time in the same industry. It has been suggested that iron production at Meroe was controlled by the rulers or elite (Haaland, 2014:658, Ting & Humphris, 2017:42). Control by royal elites may be reflected in the high level of standardisation of iron production but also in the decline in standardisation during the later Meroitic and Post-Meroitic periods at Meroe and the adoption of manufacture at the nearby town of Hamadab, at a time when royal control was waning (Ting & Humphris, 2017:42).

The production of pottery may not have faced such restrictions and it is likely that several production centres existed in different regions and that some ceramics had a wide distribution (Edwards, 1996:27, 1998a:187; Welsby, 1996:166). Sites may have had allocated industrial areas, such as at Muweis, where an area for pottery and metalworking was present at the north-eastern fringes of the settlement (Baud, 2008:53). Hamadab and Meroe also contained pottery workshops on the periphery of the main towns, containing multiple contemporary kilns at both sites (Török, 1997b:174; Wolf et al. 2014:728-730). Kilns at Muweis, Hamadab, and Meroe were likely to have had open tops which would have been temporarily covered over during firing (Török, 1997b:174; Baud, 2008:53; Wolf et al., 2014:729). At the settlement of Kedurma in Lower Nubia a circular kiln has also been identified in an area presumed to be some kind of industrial zone (Edwards, 1996:116).

At Musawwarat es Sufra a large deposit of fine and coarseware pottery and items associated with ceramic production indicate that a pottery production centre was present at this site (Edwards, 1999). The lack of pottery types in other regions matching those in this deposit and the unsuitability of the site as a large production area may indicate ceramic manufacture here was being undertaken to meet the local demand of the temple complex (Edwards, 1999:40). Therefore, pottery production may have been undertaken on a more local scale at certain sites. Other specialised manufacture likely to have been taking place in the Meroitic period includes textiles, faience, and other types of metallurgy, such as bronze working (Edwards, 1996:28, 1998a:187; Welsby, 1996:168-169). On a smaller scale, people were likely to have performed small crafts, such as the production of textiles and goods for personal use or trade, within their houses (Wolf et al., 2015:132). At Abu Geili, for example, a large assemblage of ceramic spindle whorls has been found that suggests that textile production was an important part of the everyday lives of the people at this site (Yvanez, 2016:174).

4.4.4 Habitation

An example of urban habitation structures can be seen at the Meroitic site of Hamadab, located just 3km south of Meroe. Buildings here consisted of dense multi-roomed units, some of which contained fireplaces and ovens, with narrow streets between the buildings (Wolf & Nowotnick, 2006a:258; Wolf et al., 2014:Fig. 1). An excavation of one house revealed that the building was perhaps divided into two separate living suites with individual entrances, kitchens, and other domestic rooms (Wolf et al., 2014:723-728). The long-term use of kitchens is indicated by the renewal of oven pots set over one another into the floor (Wolf et al., 2014:727). One large kitchen contained fireplaces, a large flat baking plate, and twelve oven pots, two or three of which might have been in use simultaneously, while other rooms contained fireplaces and concentrations of finds such as grinders, pestles, and palettes that may indicate areas dedicated to specialised crafts (Wolf et al., 2014:728). Other rooms, characterised by sandy floors, may have been open patios designed to provide light and allow air into the building (Wolf et al., 2014:727).

Agglomerations of rooms in large building complexes, that are likely to have made up several living units, have also been identified at Abu Geili and Gaminarti (Crawford & Addison, 1951:9, Plates VII-XII; Adams & Nordström, 1963). More than eighty small rooms were clustered together at Abu Geili

(W. Y. Adams, 1984a:272) and the lack of doorways to some rooms has been used to suggest that they were multi storey (Welsby, 1996:127, Fig. 53.1). At Gaminarti two large mudbrick buildings were found to contain a series of standardised two-roomed suites, with a hearth and cooking pots in the larger room and a storage area containing utility vessels in the smaller room (Adams & Nordström, 1963:26; Edwards, 1996:Fig. 16; Welsby, 1996:Fig. 53.4). The division into domestic suites with the same function may represent individual residences within one building (W. Y. Adams, 1984a:272). At these two sites pots set into the floor of rooms were also used as ovens or fireplaces for prolonged periods of time, with new pots placed on top of old (W. Y. Adams, 1984a:272). Similar two-roomed units, as standalone buildings, have been found at Meili Island and at Arminna West (Adams & Nordström, 1963:28; Trigger, 1967: 38-41; Welsby, 1996:Figs. 53.2 & 53.5).

In the Fourth Cataract a large later Meroitic settlement (3-J-5) at Umm Muri was excavated, revealing a mudbrick rectilinear building with clusters of small rooms and evidence in certain rooms for burning associated with food preparation and pottery vessels used as ovens (Payne, 2005:11-12), similar to that at Hamadab, Abu Geili, and Gaminarti. The size of this site has led to the suggestion that it may have been the centre of Kushite power in the region (Ahmed, 2014:112) and Meroitic pottery imports, including a large proportion of transport and storage vessels and Roman amphorae (Thomas, 2008:65-66), reveal the site may have had important trade connections. Site 3-R-112, in the Wadi Thannori, contained potsherds dating from the Meroitic to Medieval periods. This site consisted of concentrations of animal shelters, semi-circular structures, and round huts up to 8m in diameter that were likely constructed from organic materials. Fireplaces were also found in association with the settlement, but the report does not specify if these were located inside the huts (Wolf & Nowotnick, 2006b:27-28). Other Meroitic settlements in the Fourth Cataract are scarce (Ahmed, 2014:111), although earlier Napatan settlements consisting of stone dwellings have been found at Umm Gibeir and in Wadi Umm Rahau (Paner & Borcowski, 2005a:98; Ahmed, 2014:111).

Houses of square or rectangular plan, with vaulted ceilings, making up a minimum of two or four rooms and sometimes referred to as ‘de luxe’ houses, can be found in Lower Nubia at Wadi el-Arab, Arminna West, Meinarti, Karanog, and ash-Shaukan (Woolley, 1911:26-40; Emery & Kirwan, 1935:111-115; W. Y. Adams, 1965:153-155, 1984:272-273; Trigger, 1967:58; Jacquet, 1971) and perhaps in the south in the Royal City at Meroe (Hinkel & Sievertsen, 2002:74). The vaulted ceiling was constructed using mudbricks and mortar placed at an angle, known as the ‘Nubian vault’ (see Woolley & MacIver, 1910a:18-19 for construction method). 'De luxe’ houses are sometimes surrounded by clusters of flimsier structures, with walls one brick thick, which would only have been able to support a light roof of matting. As well as representing possible outbuildings and storehouses, these buildings may also have served as lower-class residences, as evidenced by the presence of fireplaces inside at Wadi el-Arab and Meinarti (W. Y. Adams, 1984a:273).

In addition to ash-Shaukan, Karanog, Gaminarti, Wadi el-Arab, and Arminna West, a number of other settlements have been identified in Lower Nubia, including substantial sites at Tila Island and Kedurma (Edwards, 1996:62-70). At Tila Island houses consisted of complex multi-roomed buildings containing areas with hearths and oven jars (Edwards, 1996:106-113). Also identified was a room containing ovens built externally to the main building that may have acted as a bakery and a building containing a small room filled with faeces that may have been the refuse area for a toilet (Edwards, 1996:106-108).

Apart from Hamadab and Abu Geili, evidence for habitation structures in the south is lacking. At the capital of Meroe domestic architecture has been poorly investigated (Grzymski, 2004:167). The earliest dwellings appear to have been circular wooden huts, which were replaced by rectangular mudbrick domestic buildings (Shinnie & Bradley, 1980:28-32). Other evidence for huts is lacking, but structures made of organic material may have been more common than the archaeological record reveals, particularly as they cannot be detected by survey and need to be identified through excavation (Bradley, 1984:285; Welsby, 1996:152). For example, in Meroitic art a round hut constructed from organic material was depicted in a rural agricultural scene on a bronze cup from a tomb at Karanog (Woolley & MacIver, 1910b: Plates 26 & 27). It is possible that the use of wooden huts or more ephemeral buildings is responsible for the lack of evidence for habitation structures in areas such as Central Sudan and the Fourth Cataract (Welsby, 1996:152; Paner & Borcowski, 2005a:98).

4.4.5 Social structure

It is likely that the major towns and temple complexes contained a social hierarchy consisting of royalty, elites, religious officials, and the lower classes. The 'de luxe' houses found at more rural Meroitic sites alongside insubstantial buildings may also indicate the presence of elite or higher social classes in less populated settlements (W. Y. Adams, 1984a:273), who may have played a role in the local control of resources (Edwards, 1996:22). In many towns there may have been artisan classes responsible for the production of specialised goods and exports (Welsby, 1996:173; Wolf et al., 2015:132). Certain fine imported luxury items have been found only in royal or elite graves and access to certain items was likely to have been dictated by, and used as a marker of, power and prestige (Edwards, 1996:21, 1998a:189-190; Brass, 2015:260).

There may have been royal or elite control, in the form of taxation or tributes, over the redistribution of food from rural agricultural areas to the towns, temples, and royal households (Edwards, 1998a:184). Many Kushite palaces have large magazines for the storage and control of goods (Edwards, 1996:26-27, 1998a:186). For example, in a storeroom of a Kushite palace at Jebel Barkal a large number of administrative clay sealings, originally applied to jars, bottles, sacks, and wooden boxes, provide clear evidence for the use of palaces for the storage, administration, and redistribution of goods (Vincentelli, 1993:139). Furthermore, the construction of *hafirs* in rural areas and at monumental sites in the Keraba, such as at Musawwarat es Sufra and Naqa, would have involved considerable man power (Edwards, 1998a:185). It has been suggested that rulers may have constructed and maintained *hafirs* as a way of extending control over the access to water by the local sedentary and nomadic populations, perhaps in return for tributes (Edwards, 1998a:185-186; Welsby, 2003a:75; Brass, 2015:261-262).

4.5 The Post-Meroitic period

The Post-Meroitic period marks the two-century long transition between the disintegration of the Kushite state at the end of the Meroitic period and the formation of the Medieval states in the Middle Nile Valley (Table 4.5). There is strong evidence for the continuity of aspects of Meroitic lifestyle during this period, but also for some political, religious, and economic changes (Welsby, 1996:202-203; Edwards, 2004:189-191). By this time the Kushite royalty appears to have lost power and the construction of pyramid tombs ceased, with a return to the use of tumuli in elite burials once more (Welsby, 1996:202; Edwards, 2004:182, 185). The observance of Meroitic religion is likely to have fallen into decline or was no longer respected, as is indicated by the presence of Post-Meroitic burials found within abandoned temples (Welsby, 1996:202).

Table 4.5 - Approximate time periods, with associated dates, between 300 BC and AD 1500 in the regions of Lower Nubia, Upper Nubia, and Central Sudan (Edwards, 2004).

Approximate dates	Lower Nubia	Upper Nubia	Central Sudan
300 BC – AD 350	Meroitic (Kushite)	Meroitic (Kushite)	Meroitic (Kushite)
AD 350 – 550	X- Group	Post-Meroitic	Post-Meroitic
AD 550 – 1500	Medieval	Medieval	Medieval

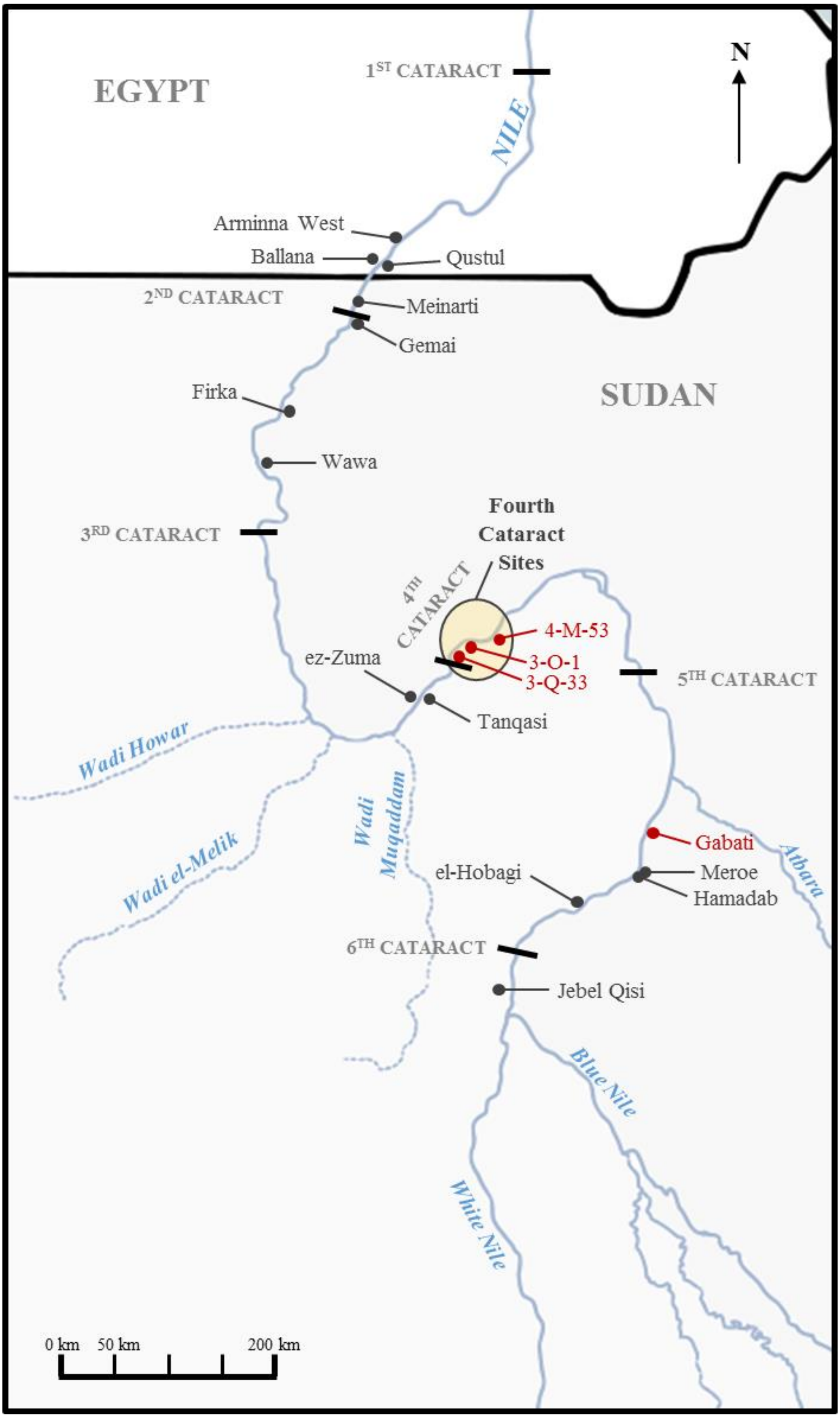


Figure 4.5 – Map of the Middle Nile Valley marking the location of all sites and geographical features mentioned in the Post-Meroitic section of this text. Sites marked in red are those included in the current study.

External trade also appears to have been much reduced (Welsby, 1996:204; Török, 1997a:485) and a more regional based political structure and culture may have come into effect (Török, 1997a:485; Edwards, 2004:182). This is evidenced by the high number of Post-Meroitic elite tumuli cemeteries located along the Nile, which include, but are not limited to, Qustul, Ballana, Gemai, Firka, Wawa, ez-Zuma, Tanqasi, el-Hobagi, and Jebel Qisi, which indicate the dispersal of power among regional elites (Welsby, 2002:20-23, 47) (Figure 4.5). However, despite changes in funerary customs and tomb superstructure, many of the excavated elite graves demonstrate the inclusion of grave goods, iconography, funerary ritual, and human and animal sacrifice that were typical of the Meroitic period, suggesting some continuation in Kushite ideology or the use of signifiers of status and power (Welsby, 2002:21, 41-43; Lenoble 1999:180).

In Lower Nubia this period saw the development of a distinctive regional culture with Romano-Egyptian influences, known as the X-group or Ballana culture (Edwards, 2004:195).

4.5.1 Subsistence economy and activities related to occupation

It is likely, particularly in rural communities, that subsistence- and occupation-related activities continued in a similar fashion to the Meroitic period. However, the disintegration of the state may have had an effect on the system of redistribution and trade and led to a greater focus on localised village communities rather than hierarchical towns, temples, and palaces (Török, 1997a:485). One of the major shifts in the Post-Meroitic period was the adoption of the *saqia*, a cattle-driven waterwheel used to raise water from the river and capable of irrigating greater areas of land (Fuller, 2014:165; Welsby, 2002:Fig. 75). Introduced to Lower Nubia during the late Meroitic period, the use of the *saqia* became widespread in the Post-Meroitic in this region. The irrigation system provided by the *saqia* enabled extended periods of cultivation, a greater proportion of land use, and greater production of summer crops requiring irrigated environments, such as sorghum and cotton (Fuller, 2014:172). Using isotopic analysis of tissue samples from human mummified remains from Lower Nubia, it has been demonstrated that the consumption of C_4 plants, such as sorghum, substantially increased between the Meroitic and Post-Meroitic periods (White & Schwarcz, 1994:184).

Fuller (2014:172-174) argues that the use of the *saqia* during this time allowed for the expansion and intensification of agriculture in the north, which in turn potentially increased the number of people who could be fed, increasing population density, disease load (because of a variety of risk factors associated with a sedentary existence), and violent conflict due to competition for resources. The inclusion of weaponry as part of male grave furnishings certainly becomes widespread in the Post-Meroitic period (Edwards, 2004:191). The greater proportion of time and labour that could be dedicated year-round to agricultural-related activities using the *saqia* may also have led to a decrease in part-time specialists, like potters and metallurgists, and increased sedentism in the more northern regions (Fuller, 2014:174). The use of the *saqia* towards the south, however, does not seem to be as widely adopted, where precipitation would have been more common, allowing for greater crop production without the use of irrigation systems.

Meroitic crafts such as wheelmade pottery and faience production seem to have disappeared during the Post-Meroitic period, but iron production continued (Edwards, 2004:189). The working of iron and the retention of specialist knowledge related to its production at Meroe and Hamadab between the late Meroitic and Post-Meroitic periods has been demonstrated at both sites (Ting & Humphris, 2014). The mass production of iron at Hamadab suggests that there was a system in place for supporting specialised craftsmen and redistributing their products (Humphris, 2014:127). Indeed, iron objects became more regularly deposited within graves during the late Meroitic and Post-Meroitic periods, suggesting they may have been more readily available (Edwards 1998a:187, 2004:189). Some pottery production was also likely to have continued to be undertaken by craftsmen. Handmade Post-Meroitic pottery of a standardised type, that suggests production by specialists in workshops, has been found widely distributed (Edwards, 2004:189-190; el-Tayeb, 2010:10-11).

4.5.2 Habitation

The presence of Post-Meroitic populations in most regions is attested only by the discovery of cemetery sites (Edwards, 2004:191-194). In the south many Meroitic sites appear to have been abandoned (Edwards, 1996:92; Török, 1997a:485) and evidence for Post-Meroitic settlement is lacking, in particular in the stretch of river between the Third and Fourth Cataracts (Edwards, 1996:93; Welsby, 2001:597). Some sites have evidence for continuity of habitation into the Post-Meroitic/X-Group period (Welsby, 1996:203), such as at the Lower Nubian sites of Meinarti and Arminna West (Weeks, 1967:5; W. Y. Adams 2000; Welsby, 2006b:25). At Meroe the temples, in particular temple M.720, show abundant evidence for squatters not long after the abandonment of the buildings, including the use of hearths and grindstones within the rooms (Shinnie & Anderson, 2004:32-34, 64). At Hamadab squatting is attested by the digging of refuse pits containing Post-Meroitic potsherds and the creation of hearths set into the remains of late Meroitic period walls (Wolf et al., 2014:736).

In the Fourth Cataract, however, the presence of Post-Meroitic settlements provides some indication of permanent habitation structures (Ahmed, 2014:112). At 3-Q-14 and 3-Q-102 evidence for Post-Meroitic clusters of circular huts with associated pits and fences have been found (Wolf & Nowotnick, 2005a:25). These huts may have been constructed from wooden posts, thatched roofs, and wicker-work walls perhaps layered with mud, and contained stones inside the huts marking the remains of fireplaces (Wolf & Nowotnick, 2005a:26). At 3-Q-102 fireplaces were also located south of the huts and were protected from the wind by low stone walls (Wolf & Nowotnick, 2005a:28). A stone enclosure at 3-Q-14 in association with the huts may have been used for the penning of livestock (Wolf & Nowotnick, 2005a:26). A Post-Meroitic hamlet at 3-R-103 consisted of a mix of rectangular and circular dwellings, probably constructed of organic materials, containing fireplaces (Wolf & Nowotnick, 2006b:26-27).

More substantial Post-Meroitic structures of stone have also been identified in the Fourth Cataract. At 3-J-64 a three-roomed stone building with a courtyard was discovered containing a possible hearth in one room and a large jar employed as an oven in another (Welsby, 2007:17-18). Rectangular stone-walled houses containing Post-Meroitic pottery sherds were recorded at site HP461 (Paner, 2003b:179-180) and stone rings between 3 and 4 metres in diameter, possibly representing circular dwellings, were found at site HP135 along with the remains of a hearth (Paner & Borcowski, 2005b:214). Site 3-R-69 consisted of the stone foundations of a cluster of Post-Meroitic circular huts, which may have numbered up to ten (Wolf & Nowotnick, 2006b:27). Near site 3-R-106 the circular stone foundation of a possible Post-Meroitic hut contained a fireplace lined with stone slabs located near the doorway (Wolf & Nowotnick, 2006b:29), perhaps for ventilation purposes.

4.6 The Medieval (Christian) period

At the end of the Post-Meroitic period three separate kingdoms had emerged along the Middle Nile Valley: Nobadia (First to Third Cataracts), Makuria (Third to approximately Fifth Cataracts), and Alwa (or Alodia) (south of the Fifth Cataract), with their capitals at Faras, Old Dongola, and Soba East, respectively (Welsby, 2002:24, 28; Anderson, 2004:202) (Figure 4.6). Christianity was introduced to Nubia during the sixth century AD and was quickly adopted by each kingdom (Anderson, 2004:202; Edwards, 2004:212), bringing about a considerable change in religious ideology, funerary practices, written text, and artistic motifs and leading to the prolific establishment of churches and religious complexes (Welsby, 2002:35; Anderson, 2004:204). The Medieval Christian period can be divided into three main phases: Early (AD 600 – 850), Classic (AD 850 – 1100), and Late (AD 1100 – 1400), with short transitional phases before and after (Table 4.6).

By the mid-seventh century the kingdom of Nobadia was absorbed by Makuria, becoming the province of Maris (Welsby, 2002:83-84; Anderson, 2004:203) and from the twelfth century onwards the remaining Christian kingdoms faced issues with government, including power struggles, the rise in influence of local authorities, external threats from Arab populations, and the loss of religious power (Anderson, 2004:207). According to literary sources Makuria disintegrated around AD 1365, after a short period of Muslim rule from AD 1323 onwards, and Alwa followed suit by AD 1504 (Welsby, 2002:251, 255; Anderson, 2004:207-208). In the sixteenth century the Middle Nile Valley saw the rise of Islamic states under the Ottoman empire in the north and the Funj sultanate in the south (el-Zein, 2004:240; Welsby, 2002:256-258).

Table 4.6 - Approximate time periods, with associated dates, between AD 350 and 1820 in the region of the Middle Nile Valley (W. Y. Adams, 2001:Fig. 2; Welsby, 2002: Table 1; Welsby & Anderson, 2004:315).

Approximate dates (AD)	Middle Nile Valley
350 – 550	X Group / Post-Meroitic
550 – 600	Transitional Christian
600 – 850	Early Christian
850 – 1100	Classic Christian
1100 – 1400	Late Christian
1400 – 1500	Terminal Christian
1500 – 1820	Islamic Period

4.6.1 Environment

The environment during the Medieval period was likely to have been similar to today, with minimal rainfall and arid desert conditions in the north and a higher level of precipitation and a greater density of vegetation, producing semi-desert and grassland, in the south (J. Adams, 2002; Welsby, 2002:8, 2006b:21). Some fluctuation in annual precipitation and Nile flooding will also have occurred during the Medieval period and may have had various impacts on agriculture (Welsby, 2002:8, 2006b:21; Edwards, 2004:212-213). The overgrazing of land and the exploitation of timber could also have increased desertification in some areas during this period (Welsby, 2002:9).

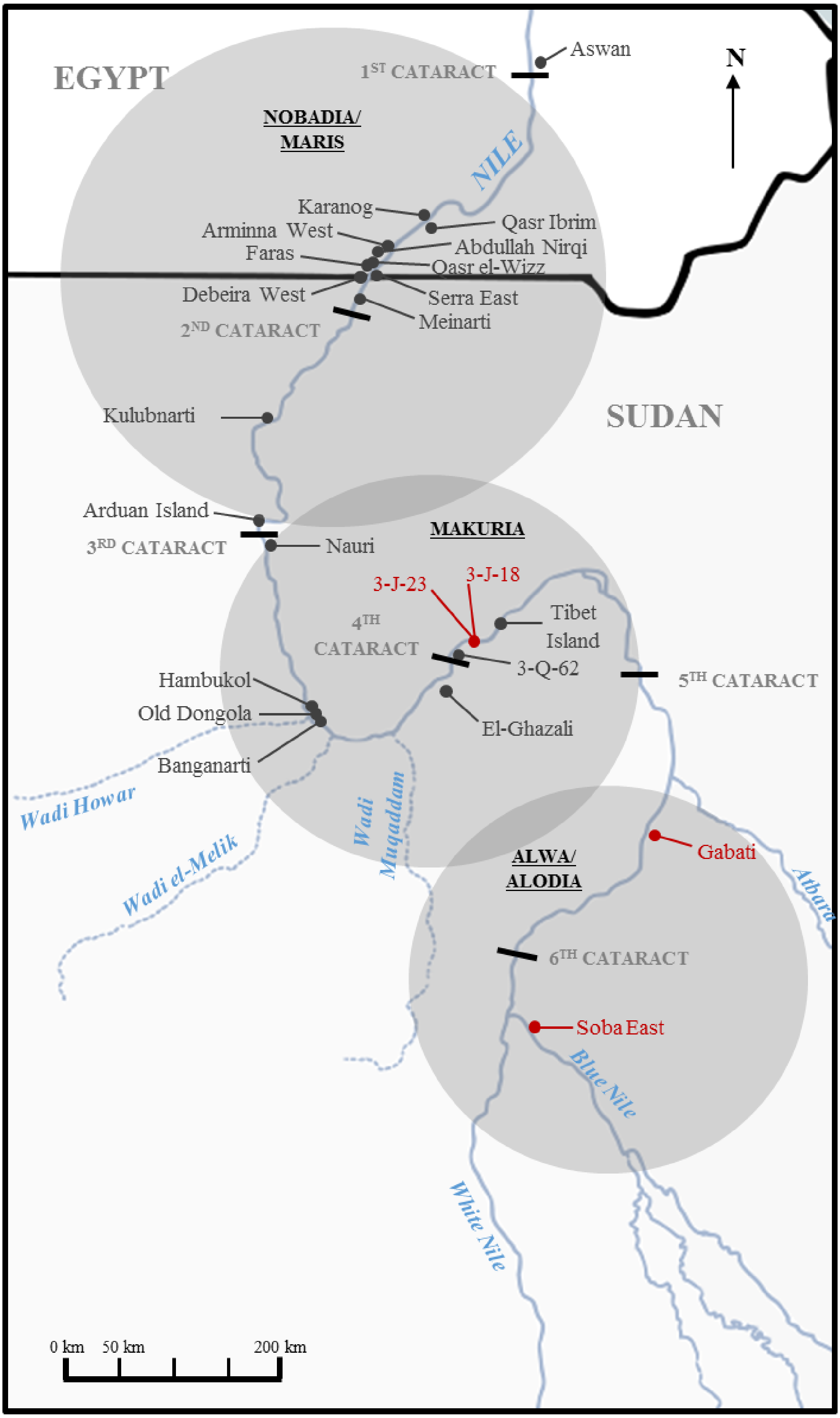


Figure 4.6 – Map of the Middle Nile Valley marking the location of all sites and geographical features mentioned in the Medieval section of this text. Sites marked in red are those included in the current study.

In the south at Soba East archaeobotanical evidence indicates that vegetation cover may have been more extensive than that found today (van der Veen, 1991:270-271), but overgrazing was beginning to be evident (Cartwright, 1999:256). Vegetation found at this site demonstrated four main environments: a narrow but dense strip of vegetation in the riverine zone, thorny scrubland and savannah, small thickets of woodland amongst the savannah, and agricultural land (Cartwright, 1999:254-255). Unfortunately, archaeobotanical and palaeoenvironmental data from other Medieval sites in Nubia is lacking. However, the aridity in the north is attested by the constant in-blown sand that threatened to bury settlements during their use, for example at Faras, Abdullah Nirqi, Meinarti and as far south as Old Dongola and Banganarti (W. Y. Adams, 1961:43; Hajnóczi, 1974:341-342; W. Y. Adams, 1984b:492; Welsby, 2002:117-118, 126; Drzewiecki, 2014:901).

4.6.2 Subsistence economy and trade

The production of grains as a staple of the diet was predominant in the Medieval period and the use of the *saqia* for agricultural production was of considerable importance (Welsby, 2002:185). Sorghum has been found at many sites and appears to have been commonly grown and consumed during this time (Welsby, 2002:185). At the Alwan capital of Soba East sorghum, bulrush millet, and barley have all been identified (van der Veen, 1991:265; Cartwright, 1998:260) and at Nauri, near the Third Cataract, evidence for sorghum, barley, wheat, pearl millet and foxtail millet were recovered (Fuller & Edwards, 2001:Table 1). At Qasr Ibrim the presence of farming and food processing equipment during the Early Medieval period, such as iron sickle blades, a possible winnowing tray, and rotary querns attest to the preparation of harvested grains during this time (W. Y. Adams, 2010:73-75). Sorghum and cowpea pulses have also been recovered from Medieval contexts at this site (Rowley-Conwy, 1989:135).

It is not known what proportion of the Medieval population relied on nomadic pastoralism, as evidence for nomadic groups during this period is rare (Welsby, 2002:188). However, animal husbandry was a major part of Medieval subsistence and in permanent settlements animals were commonly kept within towns and even within dwellings, such as at Qasr Ibrim, Old Dongola, Hambukol, and Debeira West (Shinnie & Shinnie, 1978:440; Grzymski, 1990:155; Godlewski, 1991:89; W. Y. Adams, 1996:101). In a study of Makurian faunal assemblages from Old Dongola and Banginarti cattle, caprines, pigs, and camel were all recorded (Osypińska, 2014). A rise in beef consumption was demonstrated over time and the elite at Old Dongola may have imported cattle from other areas (Osypińska, 2014:914). During the Late Medieval period at Qasr Ibrim caprine bones were most numerous, but cattle, pig, and camel are all present and there is some evidence for fishing (W. Y. Adams, 1996:101). Cattle and caprines made up the majority of the faunal assemblage at Soba East, with a dominance of cattle and the presence of possible domestic chickens (Chaix, 1998:234, 241). While no evidence for the consumption of pork was found at Soba East, at Debeira West pigs appeared to form a substantial part of the diet and a small amount of evidence exists for the consumption of fish (Shinnie and Shinnie 1978:107). There also appears to be some evidence, in Makuria at least, for the hunting of antelope, gazelle and crocodile (Osypińska, 2014:915).

The towns were likely to have been centres of production and redistribution, where surplus agricultural produce was traded for specialised goods and services (Welsby, 2002:128, 2006b:39). At Soba East a large number of mud bungs used to seal jars have been recovered (Welsby & Daniels, 1991:151), perhaps indicating the mass import and storage of certain products within the city (Welsby, 2002:210). Some types of ceramics were widely traded and pottery from Aswan and Faras has been found along the length of the Nile Valley (Welsby, 2002:208). Amphorae recovered from a number of sites, for example at Debeira West, hint at the large-scale importation of wine and other products from Egypt in the Early Medieval period (Shinnie & Shinnie, 1978:107; Welsby, 2002:210). In storerooms of the palace complex at Old Dongola numerous amphorae have been found originating not only from Egypt, but also Cyprus, Gaza, and Syria (Godlewski, 2010:76). Glass and textile imports are also found in Lower Nubia (Edwards, 2004:248). The volume of trade during the Medieval period appears to be considerable. Muslim traders from Egypt and the Arab world were the major medium for international exchange, with historically documented trading hubs, for example, at Philae (in Egypt, downstream of Aswan), Aswan, Qasr Ibrim, and as far south as Soba East (Welsby & Daniels, 1991:9; Welsby, 2002:205). However, the movement of goods not undertaken using routes through Egypt appears to be limited, although Qasr Ibrim may have acted as a major centre of trade between Nubia and the Red Sea coast (Welsby, 2002:205, 210).

4.6.3 Activities related to occupation

An extensive area dedicated to pottery manufacture was found at Faras, including a building complex containing small kilns and fireplaces, with four large kilns located outside (W. Y. Adams, 1961:31-32). The large kilns were cylindrical in shape, enclosed by a high wall, but had an open roof, as is common in Meroitic and Medieval kilns (W. Y. Adams, 1961:33, 37, Fig. 3). The scale of production and the distribution of pottery from Faras indicate that the city was a major producer of fine ware in Lower Nubia during the Classic Christian period (W. Y. Adams, 1986:22).

At Old Dongola pottery production appears to have also been on a massive scale (Pluskota, 2001:365). The use of magnetometery has led to the identification of twelve separate kiln sites in the area (Pluskota, 2001:357). At least seven kilns have been excavated at the site, the majority of which were large, over two metres in diameter, and associated pottery represented a range of types and functions (Pluskota, 2001:359, 361-363). A single kiln at Soba East has also been found containing *qawadis* - ceramic water jars used on a *saqia* (Welsby & Daniels, 1991:105, 245). Pottery manufacture was likely to have also taken place on a smaller scale in more rural communities and pottery kilns have been found at a number of sites in Lower Nubia (W. Y. Adams, 1961:43), for example at Meinarti and Serra East (Knustad, 1966:170; W. Y. Adams, 2001:59-60). Although fine wheelmade wares were likely to have been fired in a kiln, other handmade wares could have been fired on open bonfires using fuels such as timber, agricultural waste, and animal dung (Welsby, 2002:190).

Evidence for metalworking during the Medieval period is slim. At Soba East no definite furnaces were found but the site contained evidence for the metalworking of copper alloys and precious metals in the form of crucibles and moulds (Welsby, 1998:81-83). Additionally, near the monastery site of el-Ghazali two iron smelting centres have been identified, including several furnaces, which likely indicate that monks at this site were involved in iron production in some manner (Obłuski, 2018:160).

4.6.4 Habitation

Evidence for habitation structures in Makuria and Alwa is scarce, with only the major sites of Soba East (in Alwa) and Old Dongola and Hambukol (in Makuria) having been extensively excavated (Welsby, 2002:127-128). The earliest evidence for occupation at Soba East consisted of circular and rectangular timber huts and associated enclosures (Welsby, 1998:269). One hut contained a burnt area on its floor, perhaps related to domestic activities (Welsby, 1998:273). Other buildings of mudbrick were also present. Only one contained evidence for domestic habitation, being partitioned in the later phases of its use into smaller rooms containing hearths and storage bins (Welsby, 1998:273-275). Several mud-brick rectilinear houses have been identified at Old Dongola. There is evidence in these early Medieval houses for toilet rooms, a kitchen with a hearth, and upper floors (Godlewski, 1997:183-184, 1998:173-175). Another larger house with a flat wooden roof was constructed between the 7th and 9th Centuries AD at Old Dongola but was later divided into three separate living units with barrel-vaulted roofs (Godlewski, 1990:16, 1991), possibly suggesting a shift in the economic status of the occupants (Welsby, 2002:118). At Hambukol a mud-brick building with a barrel-vaulted ceiling contained several rooms, including a possible kitchen and an animal pen (Anderson, 1994:225, 2001:101).

Surveys within the Fourth Cataract have provided a greater range of evidence for habitation in Makuria, with houses having small rooms and courtyards, usually built of stone or a combination of mud-brick and stone (Wolf & Nowotnick, 2005b:191). Site 3-Q-62, an extensive Medieval settlement with more than 230 houses, had buildings of roughly rectilinear rooms, constructed of stone and possibly mud-brick (Wolf & Nowotnick, 2005b:191-193). Excavations of a typical dwelling at this site revealed hearths set into the floor and possible evidence for a second storey. The roof may have been made from a light wooden material (Wolf & Nowotnick, 2005b:193). A tight cluster of rooms to the north of the site, in the proximity of the church, has led to the suggestion that this building complex may have had a monastic function (Wolf & Nowotnick, 2005b:192). On Tibet Island several settlement sites consisted of the stone foundations of circular huts. One site also contained rectangular structures with up to four rooms (Näser, 2005:81). The island of Umm Melyekta (site 4-F-16) also had two rectangular structures, one of mudbrick and the other of wattle and daub, that may have dated to the Terminal Christian period (Fuller, 2004:8-9). Within the first building a fragment of Medieval ceramic was found that was likely produced in Raqqa or Damascus, in Syria (Fuller, 2004:9), providing evidence for long distance trade in the region during this period. A shift to a more sedentary settlement pattern during the Medieval period in the Fourth Cataract has been suggested by the greater visibility of occupational sites and permanent buildings (Żurawski, 2014:149). However, the more recent construction of these structures and the use of stone as a building material may have also increased the visibility of settlement sites compared to previous periods.

Far more is known about habitation in Nobadia. Here, numerous settlement sites retained their original house structures and demonstrated an increasing density in the population (W. Y. Adams, 1984b:488). The majority of Medieval dwellings were constructed from mudbrick or stone in a rectilinear fashion (Welsby, 2002:166). The architecture of these houses varied, but one type of structure recognised at several sites is the unit house. Freestanding and square in shape, the number and layout of rooms could vary but often up to half of the building consisted of one long transverse room and the other half of smaller rooms (W. Y. Adams, 1984b:491; 1994:37; Welsby, 2002:167-169, Fig. 67c). This type of building has been found, for example, at Abdullah Nirqi, Meinarti, Kulubnarti, and Serra East (Knustad, 1966:169; Hajnóczi, 1974:353-354; W. Y. Adams, 1994a:37, 2002:21).

Brick vaulted roofs were common, but houses with less substantial walls were likely to have had lighter roofs of organic material (e.g. Hajnóczi, 1974:349; W. Y. Adams, 1994a:50, 1996:39, 2001:9). Within the dense settlements of Meinarti, Arminna West, and Debeira West (Weeks, 1967:12-14; Shinnie & Shinnie, 1978:106; W. Y. Adams, 2001:53) and in the rough stone houses at Kulubnarti (W. Y. Adams, 1994a:31) it was common to find rooms, presumably kitchens, containing ovens. It has been suggested that the slits high up on the walls in houses at Debeira West may have allowed the escape of smoke (Shinnie & Shinnie, 1978:105). These types of slit windows, arranged in two or threes at the end of vaulted rooms, were common in domestic and religious building at many Medieval sites, as far south as Soba East (Welsby, 2002:179), but their small size may have provided only limited ventilation. The provision of toilets was common in the Medieval period (W. Y. Adams, 1984b:491) and have been described, for example, at Debeira West, Kulubnarti, Serra East, and Meinarti (Shinnie & Shinnie, 1978:106; Knustad, 1966:169; W. Y. Adams, 1994a, 2001:53-54) and towards the south at the monastery of el-Ghazali (Obłuski, 2018:162).

At Qasr Ibrim Late Christian houses were constructed of stone or mudbrick, with irregular sizes and layouts, and thinly plastered interior walls (W. Y. Adams, 1996:35-36). Toilets were found in two houses and roofs were either constructed of mudbrick barrel vaulting or from palm logs overlaid with palm leaf ribs, the majority of the stone house roofs likely built from the latter (W. Y. Adams, 1996:39). Very little evidence for hearths or cooking was found within the Late Christian houses at Qasr Ibrim, with food preparation perhaps being conducted outside (W. Y. Adams, 1996:103). However, an annex of a church containing a small room filled with a ceramic oven has been suggested to represent a bakery (W. Y. Adams, 2010:29). As noted above, animals also seemed to have been penned in close vicinity to, or even inside, habitations, as evidenced by the presence of animal dung throughout the site (W. Y. Adams, 1996:101).

A unique type of housing was developed in the Late Medieval period between the First and Third Cataracts, named the 'castle house' (Welsby, 2002:169; W. Y. Adams, 1994b). These square dwellings were two storeys high, with the ground floor only accessible from the upper storey, and are believed to have been built this way for defensive purposes (W. Y. Adams, 1994b:11). Both vaulted ceilings and flat wooden roofs have both been noted in relation to 'castle houses' (W. Y. Adams, 1994b:18; Edwards et al., 2012:471). These houses have been found at numerous sites from Qasr Ibrim to as far south as the region of Arduan Island in the Third Cataract (W. Y. Adams, 1994b:13-14; Edwards et al., 2012:470-471) and may have been used by elite families (W. Y. Adams, 1994b:35).

As with other time periods, there is also the likelihood that buildings and huts constructed of organic materials were commonly present but cannot be easily identified in the archaeological record (Welsby, 2002:166). For example, a form of 'flimsy house' noted at Kulubnarti may have been partially constructed of organic material, with a foundation of brick or stone (W. Y. Adams, 1994a:26).

4.6.5 Socioeconomic status and religion

The introduction of Christianity changed the way that burials were conducted during the Medieval period, usually removing all but the most basic of grave goods (Welsby, 2002:44; Anderson, 2004:205). This hinders interpretations of the socio-economic status of burials, although the type of superstructure over a grave could be an indication of status (Edwards, 2004:219). Additionally, in settlements the presence of stoutly built houses, such as 'castle houses', have been suggested as the residences of wealthier families and may have been constructed by professional builders (W. Y. Adams, 1994b:35, 1994a:37). However, at other settlements, such as Qasr Ibrim, it is difficult to identify any differences in social status between households (W. Y. Adams, 1996:212).

The major towns of Faras, Old Dongola, and Soba East were the seats of the rulers of each territory and they likely enjoyed considerable status. A palatial or official building associated with three churches has been uncovered at Soba East (Welsby & Daniels, 1991:318, Fig. 2), another has been found at Old Dongola (Godlewski, 2002:206-208), and at the same site a large structure, which was later converted into a mosque, may have originally functioned as a throne room (Godlewski, 1989:28). As well as royalty, these towns were likely to have been the homes to elite families, religious officials, artisans, and craftsmen (Welsby, 2006b:39). In wall paintings the elite have been depicted as wearing fine clothes (Welsby, 2002:200). Similarly, at Old Dongola, Qasr Ibrim, and Soba East wealthy individuals have been identified from burials containing clothing woven with gold thread (Crowfoot,1977:48; Vogelsang-Eastwood, 1991:307; Żurawski, 1999:233-234) and a bishop from Qasr Ibrim was also found with a fine cloak decorated with dyed silk (Crowfoot, 1977:48).

Another class of society made up of monks was also present during the Medieval period (Welsby, 2002:203). Monastic complexes have been noted throughout Nubia during this period, including at Qasr el-Wizz, two at Old Dongola on Kom H and on Kom D, at el-Ghazali, Hambukol, and possibly at 3-Q-62 (Shinnie & Chittick, 1961; Scanlon, 1972; Jakobielski, 1991:67-69, 2008; Anderson, 1999; Wolf & Nowotnick, 2005b:192; Obłuski, 2018). Some monasteries linked to the urban centres may have been places of great wealth and importance (Edwards, 2004:245). The individuals at these religious centres may have undertaken specialised crafts, such as pottery, wall painting, the production of parchment and written materials, and other skilled services (Edwards, 2004:247; Obłuski, 2018:160). At el-Ghazali large numbers of fine pottery sherds have been found (Shinnie & Chittick, 1961:24, 28), which may hint at pottery production processes taking place at the monastery (W. Y. Adams, 1986:23). The proximity of religious buildings to the pottery at Faras, to the kiln at Soba East, and to the large number of pottery sherds at el-Ghazali, has led to the suggestion of some potential form of religious control or involvement over production (W. Y.

Adams, 1986:42; Welsby, 2002:212). Additionally, evidence for iron working, oil pressing, and grain milling have also been found at el-Ghazali and it is evident that the monastery was an important centre of production (Obłuski, 2018:160-161).

4.7 Summary

Table 4.7 summarises the archaeological evidence for factors that may have affected the prevalence of respiratory disease during different time periods in the Middle Nile Valley. There is a clear trend towards increasing aridity from the Neolithic onwards, culminating in desert or semi-desert environments during the Medieval period. The resultant loss of vegetation increases the likelihood of erosion of the soil surface during periods of aridity, producing aeolian dust and sand and introducing higher levels of particulate matter into the air (Field et al., 2010; Ravi et al., 2011:7). It is likely, therefore, that exposure to environmental particulate matter increased over time, particularly in the northern regions where desertification had a major impact on settlement distribution from the Kerma period onwards (e.g. Welsby, 2001:Figs. 14.1-14.9). At Medieval sites in the north windblown sand was an evident problem (Welsby, 2002:117-118; Munro et al., 2012), but can be traced back even earlier to sites like Amara West near Saï Island, which dates from around 1280 to 800 BC. During the later phases at this site large deposits of aeolian sand have been observed in occupation levels (Spencer et al., 2012:41-42).

Similarly, at Kawa in the Northern Dongola Reach, during the early Kushite period many deposits of windblown sand were noted and on one building excavations revealed the rising level of sand accumulating against the exterior walls by the successive layers of replastering during its use, which progressively covered less of the bottom half of the building as the sand encroached (Welsby, 2000a:6, Plate II; 2011). Inscriptions at the temples of Kawa also provide evidence of the attempts by Kushite kings to keep the encroaching sands at bay. In an inscription of Taharqo (who ruled from 690 – 664 BC), the king noted the poor state of the Temple of Amun, which had sand up to the roof, and ordered the building to be restored (Macadam, 1949:15-16). Later, the king Irike-Amanote (who ruled from 431 – 405 BC) also observed that the sacred roadway leading to the temples at Kawa had become inundated with sand and ordered it to be cleared (Macadam, 1949:62, 1955:53). It is also worth noting that in addition to producing environmental particulate matter, inhalation of extremely arid air can also dry out the mucosa of the respiratory tract, leaving it vulnerable to infection (e.g. Sterling et al., 1985; Arundel et al., 1986; Singh et al., 2016).

Table 4.7 – Summary of the archaeological evidence for factors that may have had an effect on the prevalence of respiratory disease during each time period.

	Neolithic	Kerma	Meroitic	Post- Meroitic	Medieval
Environment	Humid conditions. Savannah and riparian/river plain environment.	Savannah and riparian/river plain environment, becoming increasingly arid.	Arid semi-desert and scrubland in the north, savannah in the south.	Desert in the north, semi-desert and grassland in the south.	Desert in the north, semi-desert and grassland in the south.
Subsistence	Pastoralism/ hunter-gatherer-fisher.	Pastoralism/ agrarian.	Agrarian, some pastoralism in the south.	Mainly agrarian (introduction of the saqia in the north). Some pastoralism likely took place, but there is little evidence.	Mainly agrarian. Some pastoralism likely took place, but there is little evidence.
Trade	Local scale.	Trade with Egypt, Red Sea, and southern Sahara regions. Long-distance movement of cattle.	Large scale trade via Egypt, with objects from the Red Sea Coast, Greece, and Rome. Potential widespread movement of tradesmen and specialised craftsmen.	Possibly only at the local scale.	Extensive trade taking place via Egypt. Movement of Muslim traders along the Nile all the way to Soba East.
Occupation related activities	Pottery (but little evidence of production process).	Pottery and metalworking (urban and rural), industrial bread making (urban), potential gold mining (rural).	Iron working (urban), pottery (urban and rural), textile production (at the household level?).	Iron working. Pottery (local, handmade). Perhaps some loss of part-time specialists in pottery and metalworking due to greater time spent in agricultural production.	Large scale potteries in urban centres, smaller scale pottery production at rural sites. Some evidence for iron working (associated with religious centre).
Habitation	Unknown. Possibly temporary organic structures. Some evidence in Upper Nubia for huts.	Wooden huts, mudbrick buildings with external courtyards. Roofs likely constructed from organic materials. Possible daub used on the walls.	Mudbrick rectilinear buildings. Some sites show dense agglomerations of housing units. Brick vaulted roofs are introduced. Huts constructed from organic material may also have been present.	Likely continuation with Meroitic housing styles. Huts constructed from organic material present in Fourth Cataract region.	Stone or mudbrick rectilinear buildings with multiple storeys. Toilets found inside buildings. Roofs could be brick vaulted or constructed from organic materials. Animal pens beside or inside habitations. Increasing size and density of settlements.
	Hearths may have been situated outside, although evidence is limited.	Fireplaces and kitchens located both inside (rural) and outside (urban) buildings.	Kitchens and fireplaces located within buildings	Hearths located inside.	Kitchens and hearths located indoors (exception at some sites).
Social structure and ideology	Some stratification at the local level. Possible importance of cattle, bucrania deposited in graves.	Social stratification, with possible merchant elite and artisan classes in urban centres. Importance of cattle for status demonstrated through iconography and bucrania deposited beside graves.	Social stratification. Artisan classes in urban areas. Potentially some elite control over iron production.	Loss of centralised royal control. Likely the presence of small regionalised elite groups. Some ideological continuation with the Meroitic.	Presence of elite classes at urban sites. Religious institutions may have had some responsibility for specialised crafts.

The change in climate also had an effect on the subsistence strategies employed by the inhabitants of the Middle Nile Valley. The adoption and reliance on grains from at least the Kerma period onwards, if not earlier, required the processing and grinding of plant material. Grindstones are commonly present at occupation sites in all time periods discussed here and the grinding of not only grains, but other materials, such as ochre, can produce particulates in the air (e.g. Grobbelaar & Bateman, 1991). In particular, the grain dust from sorghum, which made up a major staple of the diet by the Medieval period, is known to be especially allergenic when inhaled (Kirkhorn & Garry, 2000:706). Additionally, the ploughing, tilling and harvesting of fields, particularly in arid dusty conditions, and the burning of land for agricultural use can expose individuals to particulate matter (e.g. Kirkhorn & Garry, 2000:706; Schenker, 2000:664; Goto et al., 2011). A lesser reliance over time on hunting and fishing and the introduction of cattle and other domestic animals may have increased exposure to zoonotic infection and animal allergens (Kirkhorn & Garry, 2000:707). The penning of animals inside settlements or even houses, particularly noted in the Medieval period, will have led to greater exposure and lower levels of sanitation within the vicinity of the occupation, introducing pests and diseases.

Nomadic or semi-nomadic pastoralism was likely to have taken place at various scales during all time periods. For example, small pastoralist groups living in the Fourth Cataract region were still present in recent times prior to the flooding of the area (Wolf & Nowotnick, 2005a:28; Reshetnikova, 2012:94-96). Unfortunately, the transient lifestyle of pastoralists often makes identifying evidence for their presence difficult (e.g. Chang & Koster, 1986:114-115; Brass, 2015:259). However, the ideology surrounding cattle during the Neolithic and Kerma periods does provide an indication of the significance of pastoralism during these time periods. The importance of cattle may have contributed to close contact and greater exposure to zoonotic diseases. Recent pastoralist societies in Africa use a wide range of products from their animals, including milk, meat, blood, and urine, for various functions, which can all cause the transmission of zoonotic diseases, such as tuberculosis (Daborn et al., 1996:30S-31S). Additionally, the driving of cattle over long distances in dry dusty environments can produce large quantities of particulate matter in the air (e.g. Baddock et al., 2011) that may have increased the susceptibility of certain individuals to respiratory diseases. For example, in the Kerma period there is isotopic evidence that cattle were transported from great distances to the city of Kerma (Iacumin et al., 2001:45).

While pastoralist activities in the Neolithic and Kerma periods may have increased exposure to animal allergens, particulates, and diseases, it is worth noting that the nomadic lifestyle could have been advantageous for controlling levels of sanitation within settlements. Pastoralist groups could have moved on before land, habitation, and water sources became too polluted, while the more sedentary and increasingly populated settlements of the Meroitic and Medieval periods may have led to poorer levels of sanitation (e.g. Kent & Dunn, 1996:467-468). There is evidence in the Medieval period (and one possible instance in the Meroitic) for the use of toilets within some habitations, possibly as a way to control sanitation and pollution within settlements. However, this strategy may also have encouraged vermin and pests within the household and facilitated the spread of diseases, particularly in smaller houses where the kitchen or food stores were located close to the toilet (e.g. Scobie, 1986:410; Taylor, 2005:59, 62).

Habitation structures show a great deal of variability. Huts, usually circular and constructed from organic materials, are present in almost all time periods and are still used today in Sudan (e.g. Wolf and Nowotnick, 2005a:29-30). In interviews with local people of the Fourth Cataract region Wolf and Nowotnick (2005a:29) recorded that an agglomeration of huts with different functions may all be used by one family. These recent huts are formed of *jalous* (layered mud walls) or branches and wickerwork, with thatched roofs of twigs, straw, and wickerwork palm fronds. It is likely that these structures were far more common in the past than is indicated by archaeological evidence (Paner & Borcowski, 2005a:98; Welsby, 1996:152, 2002:166;). The use of mudbrick to form rectilinear style houses was also common by the Kerma Moyen period and the brick vaulted ceiling became popular by the Kushite period. However, vaulted roofs in domestic contexts are most commonly found in Lower Nubia and northern Upper Nubia and may have been an adaptation in later periods to the scarcity in organic roofing materials in the arid environment in this region (D. Welsby, pers. comm., 2018).

The type of material used for construction may have had a major effect on the ventilation of a house, and thus the level of exposure individuals may have had to particulate matter (e.g. Nazaroff, 2013:3; Kim et al., 2015:137). While houses with walls and ceilings of organic materials may have allowed smoke from cooking or heating fires to escape more easily, constructions of mud and brick may have retained particulates for longer, introducing individuals to prolonged and more concentrated levels of particulate matter. The presence of slit windows in Medieval dwellings may indicate issues with the circulation of air within the thick walls of houses, particularly those with brick vaulted roofs. In the modern day Fourth Cataract *jalous* buildings were recorded as having ceilings of wooden poles and palm reeds, layered with palm leaves, mud, and animal dung to make them waterproof (Welsh, 2005:21, 2013:x; Reshetnikova, 2014:XVIII-XIX). These roofs have been noted to be particularly insulating (Reshetnikova, 2014:XIX) and may have provided poor ventilation for smoke. The kitchens, however, supported lighter and more ventilated roofs of palm fronds to allow smoke to escape (Welsh, 2005:19, 2013:xi). It is possible that in the archaeological examples of houses that had organic roofing a similar technique may have been used to ventilate the kitchen.

The study of dental calculus by Buckley et al. (2014) provides firm evidence that at least in the Neolithic and Meroitic periods individuals were cooking using fires and breathing in smoke. The intensity of exposure whilst cooking relies not only on the length of time spent over the fire but also where the cooking is taking place. In the Neolithic period the only evidence for hearths in relation to dwellings suggests that fires may have been located outside where the smoke could easily dissipate. Similarly, in the city of Kerma the majority of kitchens appeared to have been located outside in courtyards, perhaps protected from the elements by a simple cover of organic roofing (Bonnet, 2014b:Figs. 146 & 148), but at the rural Kerma site of Gism el-Arba I hearths were located within the buildings. During the Meroitic and Medieval periods the location of the kitchen is also most commonly found within the building, suggesting that smoke would have been retained within the household. It is worth noting, however, that while more sturdy constructions of brick may have kept smoke and other particulates in, they would have also been more likely to protect individuals from external sources of particulate pollution (Riley et al., 2002).

Individuals may also have been exposed to particulate matter from a number of activities related to occupation. The production of pottery was evident during all periods and was carried out on an industrial scale in Kerma, Meroitic, and Medieval urban centres. Metal-working in urban contexts is also evident on a large scale during the Meroitic and Post-Meroitic periods, and, during the Kerma period, bread-making appeared to have been a major activity within Kerma City. All of these activities required the use of fires burning at some intensity. It is likely that in urban areas specialised craftsmen and labour forces were responsible for production and may have spent long periods of time exposed to smoke. From the Kerma period onwards evidence for small-scale kilns, metalworking furnaces, and bakeries at rural sites have also been identified and other activities that may have exposed people to particulate matter, such as textile production, were also likely to have taken place. Practical and necessary objects, such as hand-made pottery wares or agricultural tools, were likely to have been produced on a local scale at rural sites. Pots, for example, may have been fired in open bonfires or small kilns. However, these activities were likely to have been part-time, perhaps taking place during agricultural off-peak seasons (e.g. Fuller, 2014:174) and individuals may not have experienced prolonged exposure to particulates.

Unfortunately, little can be gleaned from the archaeological record about differing activities between men and women. It has been suggested that men were likely to have been responsible for the production of fine-ware wheel-made pottery, while women may have produced rough hand-made ceramics (W. Y. Adams, 1986:38-39; Welsby, 2002:190). However, in certain periods, such as the early Kerma and Post-Meroitic periods, only handmade wares, including standardised and high-quality products, were produced (e.g. el Tayeb, 2010:10-11; D’Ercole et al., 2017:28). A model for the division of labour during the Neolithic has also been proposed, in which men were responsible for herding livestock, fishing, and producing lithics, while women produced ceramics and gathered and cultivated plants (Haaland, 1981:45). However, in both cases the assumptions are based on ethnographic examples and no actual archaeological evidence exists to support the statements. In the Medieval period there is some suggestion that male monks may have controlled or been responsible for the production of certain objects (Edwards, 2004: 247), but, again, firm evidence is lacking. In urban contexts there was likely to have been social stratification and division of labour based on socio-economic status. From the Kerma period onwards royalty and elite classes were present within the cities and there were also likely to have been artisan classes with specialist skills. In rural areas, however, differences in socio-economic status may have been less disparate. In the Kushite period, in particular, the acquisition of 'exotic' items was used as a signifier of prestige. As a result, the maintenance of trade networks and systematic long-distance travel may also have been instrumental in introducing new infectious diseases to the Middle Nile Valley (e.g. Tatem et al., 2006; Yue et al., 2017).

It should also be noted that the Middle Nile Valley has a number of indigenous flies that can bite or cause a nuisance to both humans and livestock, such as the *nimitti* or the biting fly known variously as the *kunteb, kunteib, or gunteib* (e.g. D. J. Lewis, 1954). Smoke, provided by the burning of materials such as animal dung or green wood, is used as a repellent to provide relief for humans and cattle during the season when the flies are most common (D. J. Lewis, 1954:85; Glanville, 1993:59). It would not be surprising if past populations also used similar techniques during seasons of peak fly activity, and this would have exposed people to the inhalation of particulate matter. Additionally, the green *nimitti* are known to cause a hypersensitivity to airborne allergens, including increased asthma and rhinitis symptoms, during the winter months when the flies are found in large numbers (Gad El Rab et al., 1980; Kay et al., 1983). Asthma and allergic rhinitis have been closely linked to the development of sinusitis (Wald, 1995:343; Nacleiro & Gungor, 2001:51; Slavin et al., 2005:S30, S35; Steinke, 2006:498; Frieri, 2014:e44).

4.7.1 Fourth Cataract

It is possible that for large periods of time the inhabitants of the Fourth Cataract may have relied on pastoral activities within temporary settlement sites. The minimal evidence for settlement sites when compared to cemeteries until the Medieval period may indicate that inhabitants were less sedentary (Paner, 2014:62; Żurawski, 2014:149). However, while the rocky landscape of this region may have made agrarian activities on the Nile banks difficult, the islands were likely to have been easier to cultivate (Welsby, 2008:44; Ahmed, 2014:114; Paner, 2014:77). In particular, during the low Nile season when the river level dropped and the channels between islands dried out, this would have provided fertile agricultural land (known as *seluka* land) for part of the year, which is likely to have provided the region with significant advantages for human settlement (Welsby, 2008:44). At Umm Muri Meroitic deposits contained evidence for the possible cultivation of wheat, barley, sorghum, hyacinth bean, and cowpea (Edwards & Fuller, 2005:27-28), suggesting some agricultural activities were taking place in the region at least as early as the Meroitic period (Ahmed, 2014:115). Recent occupants of the Fourth Cataract relied mainly on agriculture, but some families did still practice a form of pastoralism in the rainy season, during which time men would herd livestock far away from the river and women and children would stay in permanent camps near the Nile (Wolf & Nowotnick, 2005a:28). The temporary circular houses of recent nomads in the Fourth Cataract were constructed from branches, mats, palm fronds, or straw bundles, or consisted of a low freestanding wall and raised roof, providing plenty of ventilation but also protection from wind and sand (Reshetnikova, 2012:94-96; 2014:VI, XIX). Food was often prepared outside in designated places protected from the wind by small walls (Reshetnikova, 2014:VI).

Permanent archaeological settlements in the Fourth Cataract are likely to have been small rural villages (e.g. Ahmed, 2014:115). Although larger settlements in this region are seen during the Meroitic and Medieval periods, such as at Umm Muri (Payne, 2005:11-12) and 3-Q-62 (Wolf & Nowotnick, 2005b:191-193), they do not reach the scale of contemporary urban towns and cities in other areas. Habitation structures in the Fourth Cataract during most periods are predominantly circular huts of wood or stone. Meroitic and Medieval rectilinear mudbrick buildings containing hearths or ovens inside have been noted in the larger settlements, but there is scarce evidence for brick vaulting and it is likely that the majority of houses were roofed with organic materials, as has been recorded in recent Fourth Cataract towns (e.g. Welsh, 2005:21; 2013:x; Reshetnikova, 2014:XVIII). However, the lack of evidence does not necessarily indicate absence and major habitation sites during all periods, including those of mudbrick and vaulted roofs, may have existed in the Fourth Cataract but could have been eroded or robbed for materials over time, as has been suggested for other regions where evidence is lacking (e.g. Welsby, 2014a:192)

There is also very little to indicate the production of ceramics or metal objects in this region during any time period. The evidence for goldmining at Hosh el-Guruf in the Fourth Cataract during the Kerma period may provide an additional possible occupation taking place at this time (Emberling & Williams, 2010; Meyer, 2010; Emberling, 2014:144; Paner, 2014:65). The methods for extracting gold from the alluvial gravel or quartz rock require grinding and were likely to have produced considerable amounts of inorganic dust (Emberling & Williams, 2010:23), which can lead to pneumoconiosis and silicosis (Rom et al., 1987:1429; Sirajuddin & Kanne, 2009:310). It is unknown if individuals undertook these activities over a long period of time, thus prolonging exposure and the likelihood of developing respiratory diseases, or not. Meyer (2010:52) suggests that goldmining may have been performed during agricultural off-seasons for only part of the year. The production of gold and the presence of imported items at the cemetery near Hosh el-Guruf also suggest that the Fourth Cataract region had a developed trade network with more urban areas (Emberling & Williams, 2010:27; Emberling, 2014:11). Other evidence for trade in the Fourth Cataract during the Kerma, Meroitic, and Medieval periods is also evident from imported ceramics, for example, from Old Dongola, Kerma City, Egypt, and even as far as Syria (e.g. Kołosowska et al., 2003; Fuller, 2004:9; Thomas, 2008:65-66).

Following on from a general understanding of the archaeological evidence for risk factors related to respiratory disease during different time periods in the Middle Nile Valley, the archaeological context of the specific sites included in the current study will be discussed in the next chapter.

Chapter 5: Materials

5.1 Introduction

The British Museum curates a number of human skeletal collections from cemetery sites excavated in the Middle Nile Valley. In particular, the museum stores human remains from many sites in the Fourth Cataract region, dating to various time periods. The geographical proximity of these sites provided an excellent opportunity to investigate potential variation in respiratory disease in this region due to environmental, socioeconomic, or cultural conditions and changes over time. Additionally, the human remains from four comparative sites from other regions of the Middle Nile Valley to the north and south of the Fourth Cataract, also curated at the British Museum, were analysed. These sites provided the opportunity to investigate the potential variability in respiratory disease during different time periods according to geographic region (Figure 5.1). Information for each individual site is discussed below, including the date, the number of individuals from the site included in the current study, and any relevant archaeological data from the site itself or nearby contemporaneous settlements.

5.2 Fourth Cataract

Between 1995 and 2007 archaeological salvage projects took place in the region of the Fourth Cataract of Sudan to rescue archaeological material that was predicted to be lost by flooding caused by the construction of the Merowe Dam. As part of this the Sudan Archaeological Research Society (SARS) surveyed and excavated within a 40km concession along the left bank of the Nile, including all adjacent islands (Welsby, 2000b, 2003b:26). This work involved the investigation of numerous sites dating to various time periods, including the excavation of human remains from multiple cemeteries (e.g. Welsby, 2003b; Wolf & Nowotnik, 2005a, 2006b; Ginns, 2007). The human remains excavated from many of these sites are now curated at the British Museum, after being generously donated by the National Corporation for Antiquities and Museums in Sudan (NCAM), and were accessible for the current study. Eight of the Fourth Cataract sites (4-L-2, 4-L-88, 4-L-100, 3-Q-33, 3-O-1, 4-M-53, 3-J-23, and 3-J-18) were analysed for evidence of respiratory disease and were chosen specifically to investigate time periods ranging from the Kerma Classique to the Medieval period. Unfortunately, the results of the excavations within the Fourth Cataract are still in the process of

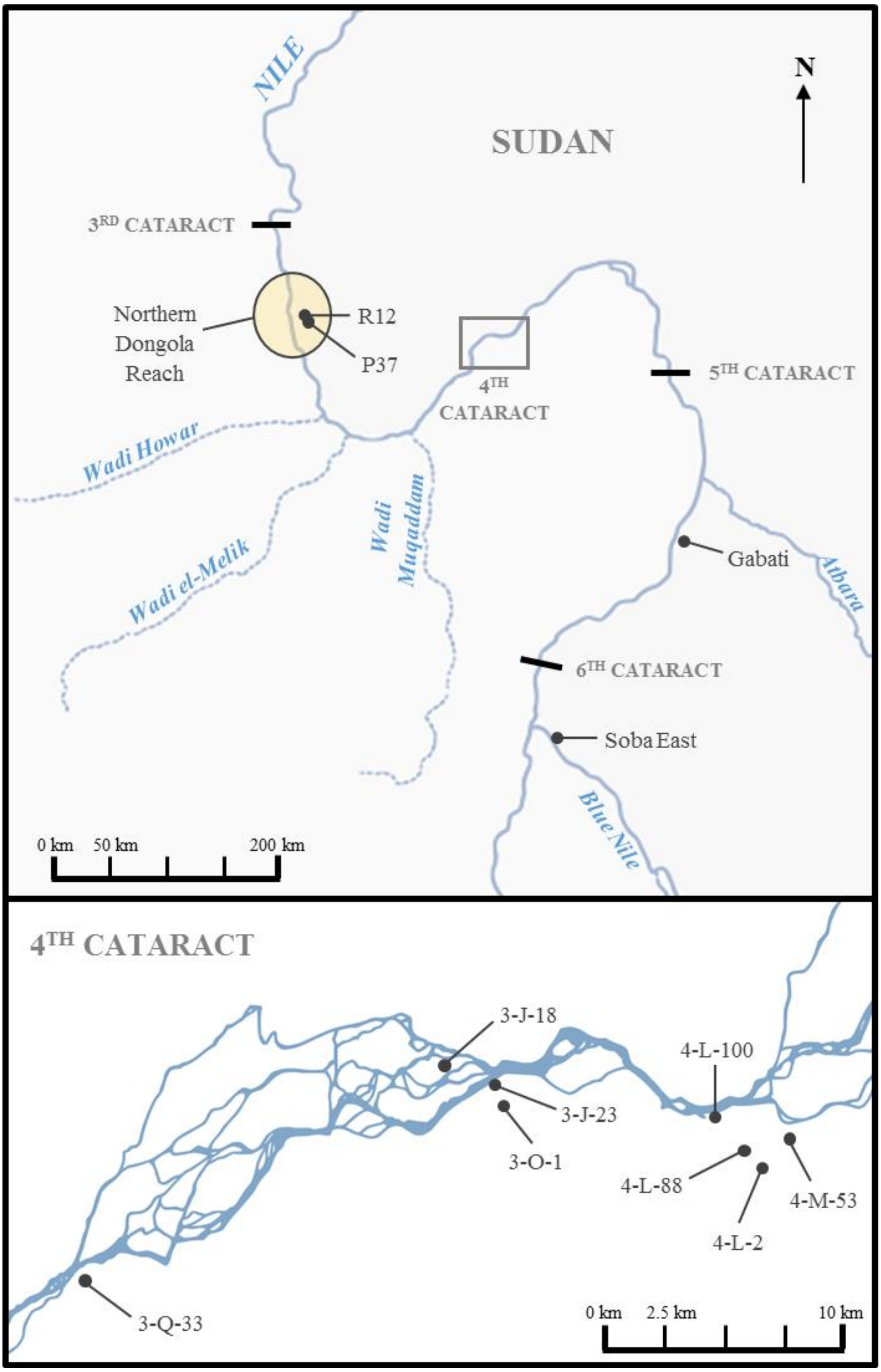


Figure 5.1 - Map of the Middle Nile Valley (top), displaying the locations of comparative cemetery sites included in the current study, and a detailed map of the Fourth Cataract region (bottom) with the exact locations of the Fourth Cataract sites.

being published and much of the information on the context, dating, and finds of these sites has been obtained from preliminary reports, draft reports, and personal communications, and thus remains fairly limited and subject to revision.

5.2.1 4-L grid sites

The sites of 4-L-2, 4-L-88, and 4-L-100 were located close together on the south bank of the river Nile, approximately 15km east of Mis Island. Site 4-L-2 was identified as a dense cluster of approximately fifty stone tumuli, dating to the Kerma Classique period (Welsby, 2005:3, 2010:I). A total of 31 adult individuals from this site were included in the current study. Excavations at the site of 4-L-88 revealed circular stone grave monuments covering crouched inhumations, accompanied by pottery vessels, animal hides, and ochre (Welsby, 2006a:11). Some of the pottery within the graves was considered typical of the Kerma Classique period (Welsby, 2006a:11). 4-L-100, consisting of a cemetery of approximately seventy scattered tumuli (Welsby, 2005:3, 2010:XXXVIII-XLI), is likely to be close to the Kerma Classique period in date, but may have been in use slightly later (D. Welsby, pers. comm., 2017). Preservation at 4-L-88 and 4-L-100 was particularly poor and only eight individuals from 4-L-88 and five individuals from 4-L-100 could be included in the current study. Grave robbing of Kerma period tumuli in the Fourth Cataract was severe (Welsby, 2005:3), 4-L-88 was looted in between excavation seasons (Welsby, 2007:16), and this is likely to have affected the complete recovery of the individuals within. Nearby evidence for settlements is limited but the remains of circular huts that may date to the Kerma period have been noted at sites 4-L-41 and 4-L-232 (Welsby, 2005:3; 2006a:9). Circular stone monuments have also been recorded at 4-L-69, potentially forming the bases of mud storage bins and likely indicating there had once been a settlement in the vicinity (Welsby, 2006a:9-10).

5.2.2 3-Q-33

Located on the south bank of the river Nile, the site of 3-Q-33 consisted of 40 graves, identified by poorly preserved Meroitic superstructures and Post-Meroitic tumuli (Wolf & Nowotnik, 2006b:21). Division of the cemetery into east and west portions seemed to correspond to different time periods, although there may have been some continuity between burial practices (Wolf & Nowotnik, 2006b:24). The eastern portion of the cemetery contained 32 graves in a fairly clustered arrangement, with various types of substructures sealed by granite slabs (Wolf & Nowotnik, 2006b:21). The limited grave goods consisted of beads, one example of a copper-alloy bowl, and pottery, the majority of which could be dated to the Meroitic period (Wolf & Nowotnik, 2006b:22). The western part of the cemetery consisted of eight Post-Meroitic tumuli, which had all been robbed (Wolf and Nowotnik, 2006b:23). Two graves still contained furnishings typical of the Post-

Meroitic period, including a leather quiver and iron arrow-heads, bracelets, necklaces, copper-alloy rings, and pottery (Wolf & Nowotnik, 2006b:23-24). Dating of this portion of the cemetery to the Post-Meroitic is uncertain but graves do in general correspond to other Post-Meroitic cemeteries in Sudan and show a clear transition from the typically Meroitic graves of the eastern part of the cemetery (Wolf & Nowotnik, 2006b:24). A total of 20 individuals from 3-Q-33 could be included in the current study, 14 of them dating to the Meroitic and 6 dating to the Post-Meroitic.

Although evidence for an associated Meroitic settlement at 3-Q-33 was absent (Wolf & Nowotnik, 2006b:24), several nearby possible Post-Meroitic occupation sites have been recorded and may provide evidence for the habitation practices of individuals buried at 3-Q-33. At 3-Q-14 and 3-Q-102 clusters of Post-Meroitic huts, possibly constructed from wooden posts, wickerwork walls plastered with mud, and thatched roofs, have been recorded (Wolf & Nowotnick, 2005a:25-26). 3-Q-14 contained evidence for possible fireplaces inside the huts and a structure next to the houses that may have penned livestock (Wolf & Nowotnick, 2005a:26-27). At 3-Q-102 fireplaces were located outside the structures, in regions protected from the wind by boulders or walls (Wolf & Nowotnik, 2005a:28).

The settlement site of 3-R-103 consisted of three dwelling complexes of circular huts, ranging from approximately 2 to 3.5m in diameter and one rectangular dwelling of 2.5 by 3.5m. All three complexes contained some evidence for fireplaces within the dwellings and it was hypothesised that the circular huts may have been constructed of wooden posts, bound by wickerwork forming the walls, and may then have been plastered with mud (wattle and daub) (Wolf & Nowotnik, 2006b:26-27). Similar circular structures of approximately 2m in diameter, delimited by stone settings, were observed at 3-R-69 and it has been estimated that five to ten round huts may have been constructed at this site (Wolf & Nowotnik, 2006b:27).

The complex settlement site of 3-R-112 may date from between the Meroitic and Medieval periods, with evidence for extended use of the site and multi-period settlement. Post holes possibly belonging to round huts and animal shelters, rectangular post trenches for larger dwellings, and evidence for fire pits and cooking places were found. Some circular structures were unusually large at 8m in diameter. More permanent fireplaces, lined by potsherds or stone settings, were recorded. However, it was not specified in the report whether cooking areas were located within the vicinity of dwellings or outside (Wolf & Nowotnik, 200b6:28). Fireplaces certainly could be located within the dwellings themselves, as is attested by 3-Q-14, 3-R-103 and by a Post-Meroitic circular dwelling near 3-R-106, which contained a fireplace lined with stone slabs near the doorway (Wolf & Nowotnik, 2006b:29).

5.2.3 3-O-1

A total of 27 Post-Meroitic tumuli were excavated at 3-O-1, which is located approximately 1.2km south of the river Nile and to the southeast of Mis Island (Welsby, 2003b:28-29, 2013). Overall, 17 individuals from this site were included in the current study. Although many had suffered from looting, the tumuli were rich in grave goods, including beads of faience, carnelian, ostrich-shell, and glass, numerous pottery jars and bowls, basketry, and various pieces of metalwork and leather (Welsby, 2013). Three areas of the site were excavated but, due to time constraints, the tumuli and surrounding region of the largest area (Area P) were not investigated in as much detail (Welsby, 2013:I) and no Post-Meroitic settlements have been recorded in the immediate vicinity (see Section 5.2.2 for Post-Meroitic settlement sites in the general region).

5.2.4 4-M-53

The Post-Meroitic tumuli cemetery site of 4-M-53, located on the south bank of the river Nile, was only partially excavated before activities were called to a halt (Welsby, 2015:I), yielding only seven individuals that could be included in the current study. The majority of the burials consisted of roughly circular shafts sealed by stone slabs, under which were dug sub-circular or sub-rectangular grave pits. Although the burials had been previously disturbed, grave goods included beads of glass and ostrich eggshell, pottery bowls and a jar, finger and toe rings, and an archer's loose (used to protect the thumb in archery) (Welsby, 2015). No Post-Meroitic settlement sites have been recorded in the immediate vicinity (see Section 5.2.2 for Post-Meroitic settlement sites in the general region).

5.2.5 3-J-23

The Medieval cemetery at 3-J-23 lies on the south bank of the Nile, southeast of Mis Island. Burials consisted of characteristic examples of Christian funerary tradition in this area. Seventy-one of the graves were still marked by existing box-grave monuments aligned east-west, although other monuments had been disturbed (Welsby, 2003b:26-27, Carpio & Guillen, 2005:14). Three areas of the cemetery were excavated between 2002 and 2005, the majority of the inhumations recovered in the final excavation between 2004 and 2005. During that season 134 Medieval and 11 Post-Meroitic burials were unearthed (Carpio & Guillen, 2005:14). In total, 67 Medieval adult individuals from this site were included in the current study. Preservation was particularly good, with natural mummification of many of the individuals recovered (Welsby, 2003b:26-27). Grave goods were rare but included rings and metal or stone crosses (Carpio & Guillen, 2005:14). While radiocarbon dating of one naturally mummified individual does reveal that 3-J-23 was in use during the earlier part of the Medieval period, from c. AD 550 – 1000 (Taylor & Antoine, 2014:178), no further carbon dating has provided the terminal date of the cemetery. Therefore, individuals from this cemetery have been broadly dated to the whole Medieval period (AD 550 – 1500).

No nearby Medieval settlement sites were recorded. However, the large site of 3-Q-62, which contained over 230 houses, attests to the type of Medieval village in the region that individuals buried at 3-J-23 may have inhabited. A typical building at this site was constructed of stone and mudbrick with two rooms measuring 2.5 by 5m, a courtyard on the ground floor, and possibly a second storey. Rooms contained hearths for cooking and the buildings may have been roofed with light organic materials (Wolf & Nowotnick, 2005b:191-193). Within the fireplaces the remains of grains, fish, and sheep bones provide evidence for some components of the Medieval diet in this region (Wolf & Nowotnick, 2005b:193).

5.2.6 3-J-18

The site of 3-J-18 consisted of a church and associated cemetery, located slightly east of the centre of Mis Island (Ginns, 2010a:I). Four burials predate the construction of the church, lying beneath the original foundations, and may date to the Post-Meroitic or Early Christian periods (Ginns, 2010a:XXVI). The remaining burials correspond to intensive use of the cemetery during the life of the church and even after its disuse, with two graves cut into deposits produced by the church's collapse (Ginns, 2010a:XXVI). In total, 217 individual inhumations were excavated at this site (Ginns, 2010b:I), 116 of which were available for research and corresponded to the inclusion criteria for the current study. As with 3-J-23, the preservation of human remains at 3-J-18 was, in the majority of cases, excellent. The natural mummification of soft tissue was also common (Ginns, 2007:23). The architecture of the church associated with the cemetery suggests that it was constructed in the latter part of the Medieval period, from c. AD 1000 – 1500 (Ginns, 201a:III), and the majority of burials are likely to correspond to this date.

A settlement (3-J-19), approximately 130m^2 in size, was located on Mis Island, 50m east from 3-J-18 (Ginns, 2010c:I). Medieval potsherds were recovered from this site, suggesting that occupation may have been contemporary with the use of the church and cemetery (Ginns, 2006:18). Excavation of 3-J-19 uncovered a number of structures, including a cluster of three sub-circular buildings located at the northern end. These structures were built from stones, with an internal diameter ranging from approximately 2 to 3m (Ginns, 2010c:I). At the southern end of the excavation area, several rectangular structures had been built of stone against a 'boundary' wall. The internal dimensions of two of these structures were approximately 1.75 by 2.5m. No deposits in any of these structures were found to suggest a function. Other regions of the site contained discrete stone spreads, which may have been evidence for the disturbed foundations of other structures but were too poorly defined to be identified as specific buildings (Ginns, 2010c:III). It has been suggested that the rectangular structures may have been used as animal pens, while the irregular circular structures clustered together have been interpreted as the foundations of huts (Ginns, 2010c:II, III) (see Section 5.2.5 for other Medieval settlements in the region).

Determining the status of the individuals buried at this site is problematic. Burials within the Christian period were simplistic, with minimal to no grave goods that could have given an indication of status (Welsby, 2002:44; Anderson, 2004:205). Various monuments of brick or stone were constructed over many of the graves and spatial groupings of monuments into those constructed of fired mudbrick and those of unfired mudbrick can be seen within the cemetery (Ginns, 2010b:III). The longer-lasting fired brick monuments, which were often additionally rendered with lime mortar and located closer to the church, may represent higher status burials. However, variation in the type of monument present may also reflect changes in funerary traditions rather than differing levels of status (Welsby, 2002:57-60), with a distinct shift from the use of mud and fired brick monuments in one phase of the site, to the use of stone in the later phase (Ginns, 2010b:III, VII). In addition to this, many of the graves were found without monuments, having been lost to erosion or human activities (Ginns, 2010b:III). Nevertheless, two graves were deliberately placed underneath the western church wall and this unusual position must indicate individuals with some form of social status that points to close ties to the church itself (Ginns, 2010a:XI-XII). One burial was interred with silk clothing that is directly comparable to material recovered from archbishops' tombs at Old Dongola, suggesting that this person may have had significant status within the church (Ginns, 2010a:XII; D. Welsby, pers. comm., 2018)

5.3 Comparative Middle Nile Valley sites

The sites of P37, Gabati, and Soba East were chosen to provide a comparison for respiratory disease during similar time periods to those investigated in the Fourth Cataract. P37 is located downstream of the Fourth Cataract in the Northern Dongola Reach, while Gabati and Soba East are located to the south. Their inclusion presents the opportunity to explore how regional differences, such as environment or socio-economic variations, may have affected susceptibility to respiratory disease. The site of R12, in the Northern Dongola Reach, was also analysed to investigate changes between the humid Neolithic and later more arid periods.

5.3.1 R12

The Neolithic cemetery site of R12 was originally identified during the SARS Northern Dongola Reach survey, which took place between 1993 and 1997 (Welsby, 2001:146). The survey area stretched 80km along the east bank of the Nile, south of the Third Cataract (Welsby, 2001:1). R12 was located approximately 5km east of the Nile on a raised mound. The cemetery was excavated between 2000 and 2003, revealing 166 graves (Salvatori & Usai, 2008a:3-4). While 168 inhumations were excavated, preservation was poor (Judd, 2008:83), and only 43 individuals could be included in the current study. Radiocarbon dates indicate use of the site during the Middle Neolithic, between approximately 4900 and 4300 BC (Salvatori, 2008:143).

Within the burials orientation of the body differed, most frequently lying on the left side in a flexed or tightly contracted position, with the head lying at various compass orientations (Salvatori & Usai, 2008a:4). Later graves cut into earlier ones, in some cases disturbing the skeleton beneath (Salvatori & Usai. 2008a:5). Grave goods, including pottery, tools, jewellery, and other ornaments, were common (Salvatori & Usai, 2008a:4). Beads and beaded jewellery were a frequent find in graves, formed of amazonite, carnelian, quartz, white stone, soap-stone, ostrich eggshell, sea shells, and ochre (Salvatori & Usai, 2008b:21). Tools included stone axes, palettes, mace-heads, and grinders (Usai, 2008:53), and spatulae, perforators, and polishers carved from bone (Cenci, 2008:80).

The funerary data indicates that herding and hunting of animals were prized activities for the population buried at R12. Bucrania were recovered from a number of graves and the remains of wild animals such as gazelle, elephant, and hippopotamus were also found (Pöllath, 2008). The faunal remains suggest that individuals at R12 were exploiting the riverine region and the forest zones near the river for food, in conjunction with the raising of livestock (Pöllath, 2008:73). Cultivated plants, including cereal grains, were also consumed, as evidenced by isotopic analysis of the diet and the presence of barley and wheat phytoliths and grinding tools within graves (Salvatori et al., 2008:157; Madella et al., 2014:5).

Neolithic activity in the area of the Northern Dongola Reach during the latter part of the period (c. 4500 – 3500 BC) was recorded during the SARS survey (Welsby, 2001). Occupation of the region was evidenced by the surface scatter of Neolithic pottery, lithics, and bone (Welsby, 2001:569). Some hearth-like features were recorded, which may have been formed during Neolithic occupation, but very little other evidence for settlement was noted (Welsby, 2001:569). Forty Neolithic cemeteries were identified during the survey, occupying mounds similar to R12, and they also contained burial goods such as pottery, tools, and beads (Welsby, 2001:571-572), suggesting that the region was relatively densely occupied during the Neolithic. At Kerma, located just to the north of the Northern Dongola Reach survey area, a Neolithic settlement roughly contemporaneous with R12 contained circular huts constructed of organic materials, enclosures for livestock, and hearths located outside in sheltered areas (Honegger, 2001:18-19).

5.3.2 P37

The cemetery site of P37 was excavated as part of the SARS Northern Dongola Reach survey, located approximately 14km east of the Nile. The site consisted of two prominent mounds and some preserved tumuli rings. The northern mound produced large quantities of Kerma Ancien (2500 – 2050 BC) pottery and consisted of small circular or oval grave pits (Welsby, 2001:206). The southern mound consisted of flat bottomed graves with vertical sides (Welsby, 2001:215), which produced classic examples of pottery from the Kerma Moyen period (2050 – 1750 BC) (Welsby Sjöström, 2001). A total of 46 individuals were excavated from the burials at P37 (Judd, 2001), of which 34 individuals fit the criteria for the current study, 24 from the Kerma Ancien period and 10 from the Kerma Moyen period.

Many of the graves had suffered from extensive looting (Welsby, 2001:206, 215). While small finds from the northern Kerma Ancien graves remained few, consisting of faience beads and some other small objects, some Kerma Moyen graves in the southern mound still retained pottery, 'meat cuts' and sacrificed animals, faience beads, and the remains of leather and hide. The outline of a wooden bier was preserved in one grave, two sandstone palettes - one retaining remains of yellow and red ochre - in a second, and beads of gold and chalcedony from an anklet were found in a third (Welsby, 2001:206-224). Whole animals and meat cuts from sheep, goat, and dog were found in twelve of the thirteen Kerma Moyen graves and around twenty cattle bucrania were discovered as deposits around one Kerma Moyen burial (Grant, 2001:545).

The inclusion of bucrania mirrors the practice seen at the cemetery belonging to the city of Kerma and indicates strong cultural ties to the urban centre. The inclusion of high numbers of animals within certain graves and bucrania deposits around the outside may indicate the presence of individuals of high status and a hierarchical structure that may have operated both on a regional and local level (Grant, 2001:550). Kerma is located just to the north of the Northern Dongola Reach survey area and it is likely that the Northern Dongola Reach, in which P37 is located, served as a region of agricultural production for Kerma (Welsby et al., 2002:30, 37; Bonnet, 2004a:74; Emberling, 2014:146; Welsby, 2014b:7). Buildings within Kerma and at the more rural site of Gism el-Arba I during the Kerma Ancien were constructed of circular huts between 4 and 5m in diameter. During the Kerma Moyen and onwards houses at both sites were developed into rectilinear mudbrick structures, likely with roofing of organic materials (Gratien, 1999:10; Bonnet, 2014b:238). While kitchen areas and ovens were for the most part located outside at Kerma (Bonnet, 2004b:79-80, 2014b:238-242), at Gism el-Arba I hearths were located indoors and numerous kilns were found nearby (Gratien, 1999:10-11).

The floral and faunal analysis from the SARS survey indicates that the environment in the Northern Dongola Reach during this period consisted of lightly wooded savannah, with the exploitation of riverine zones and the raising of livestock (Cartwright, 2001:561; Welsby, 2001:589). The cultivation of wheat and barley, as well as the use of wild grasses, seeds, and fruit, is also demonstrated (Cartwright, 2001:560-561). If individuals from P37 lived in a rural agricultural settlement like Gism el-Arba, they may have inhabited similar buildings. Around one hundred and fifty Kerma settlement sites were recorded in the vicinity of the cemetery site of P37 during the SARS Northern Dongola Reach survey and mostly consisted of prominent settlement mounds and a surface scatter of fragmentary material and potsherds. However, these mounds were not excavated and so little of the functions and activities taking place at these sites are known (Welsby, 2001:572). A few sites contained the remains of buildings, for example at L12, which had mudbrick walls similar in size and structure to the Kerma period houses at Gism el-Arba (Welsby, 2001:577). Despite the large number of settlements for the Kerma period, cemeteries were rare and it has been noted that, although some sites could have been missed, cemeteries such as P37 may have served more than one settlement, perhaps located near local seats of authority (Welsby, 2001:582-583).

5.3.3 Gabati

The cemetery site of Gabati lies on the east bank of the Nile, upstream (south) of the Atbara-Nile confluence (Edwards, 1998b:1). The site was excavated in the winter between 1994 and 1995 and radiocarbon dates have indicated three main phases of use: Meroitic (c. 200 BC – AD 200), Post-Meroitic (c. AD 400 – 700), and Medieval (c. AD 800 – 1200) (Edwards, 1998b:245-251; Judd, 2012:2). A total of 108 skeletons from this site were included in the current study, 76 dating to the Meroitic period, 20 to the Post-Meroitic, and 12 to the Medieval.

Meroitic graves were identified by the presence of characteristic pottery and by the tomb structure, which consisted of a shaft leading to a chamber sealed by blockings of stone slabs or mudbrick, with no discernible superstructures (Edwards, 1998b:195). Grave goods were limited but included rings, numerous beads usually of faience and glass, and vessels of bronze, glass, faience, and ivory (Edwards, 1998b:61-67). Post-Meroitic graves were identified by the presence of tumuli and Medieval graves by substructures typically associated with 'Christian' burials and others covered with stone cairns, although whether or not the individuals buried in the graves beneath the latter monuments were Christian cannot be determined (Edwards, 1998b:202, 208). In Post-Merotic and later burials grave goods included the remains of wooden beds, basketry and leatherwork, iron arrowheads, anklets, rings, and beads of glass, ostrich eggshell, and faience (Edwards, 1998b:124-130).

No settlement sites have been associated with Gabati. However, the cemetery is situated approximately 50km north of the Meroitic capital of Meroe and the nearby town of Hamadab. At Hamadab Meroitic rectilinear mudbrick buildings consisted of dense multi-roomed units, containing separate living suites, kitchens, and rooms for domestic activities (Wolf et al, 2014:723-728). Hearths and ovens within the buildings were common and rooms generally measured between 3 and 8 square meters (Wolf & Nowotnick, 2006a:258). Hamadab also contained a pottery workshop at the periphery of the site, containing multiple kilns (Wolf et al., 2014:728-730). In the town cattle was predominantly consumed, supplemented with sheep, goat and some fish (Nowotnick et al., 2014:10). Whether the individuals at Gabati inhabited a town like Hamadab or a more rural settlement is unknown, particularly as there is some distance between the cemetery and these other sites and living conditions may have been considerably different. For example, burial practices at Gabati indicate a departure in custom from the typically elite graves excavated at Meroe (Edwards, 1998b:201). Analysis of the Meroitic floral remains indicates barley and sorghum were cultivated near to the cemetery during this period (Clapham & Edwards, 1998:241-242).

Unfortunately, little is known about settlement in the south during the Post-Meroitic and Medieval periods. Soba East is the only major Medieval settlement to have been excavated in this region and has provided only limited evidence for habitation and activities related to occupation (see Section 5.3.4).

5.3.4 Soba East

Located on the east bank of the Blue Nile, 22km upstream of Khartoum (Welsby & Daniels, 1991:1), Soba was referred to in historical texts as the Medieval capital of the kingdom of Alwa and may have become the centre of power in this region by c. AD 580 (Welsby & Daniels, 1991:7). The kingdom of Alwa was described in texts as prosperous and more powerful than neighbouring Makuria (Welsby and Daniels, 1991:7). Historical texts also suggest that there were strong trading links between Soba and the Arab world and archaeological evidence indicates that trade of high-value goods, such as glassware, took place (Welsby & Daniels, 1991:9). The presence of wealthy individuals within the city has been identified by high status burials, including some individuals interred wearing fine clothing woven with gold thread (Vogelsang-Eastwood, 1991:307). In AD 1523

Soba was described by the traveller David Reubeni as in ruins, but archaeological evidence indicates the city’s decline, including the destruction of churches and the robbing of high-status tombs, may have already been well advanced by the early thirteenth century (Welsby & Daniels, 1991:34; Welsby, 2002:255).

The first modern excavations of Soba East, undertaken between 1950 to 1952, uncovered several mudbrick buildings, possibly for habitation, and a church (Shinnie, 1961:18-27). Later, two campaigns of excavation by the British Institute in Eastern Africa took place between 1981 to 1986 and 1989 to 1992 (Welsby, 1998:1-2). The first campaign focussed on three red brick churches and a large palatial or official building, which may have been used for domestic activities or storage related to the churches (Welsby & Daniels, 1991:310-318). During the second campaign, some evidence for habitation and occupation was uncovered. In area MN8 two circular huts were identified, one of which contained evidence for burning or a hearth. This area also contained a large amount of artefactual evidence for domestic activity, likely food preparation, and the metalworking of copper alloys (Welsby, 1998:273). Excavations in area MN3 revealed some evidence for rectilinear timber structures and mudbrick buildings. Building F, a large mudbrick structure originally with some ‘official’ function, was partitioned into smaller units in a later phase and more small rooms were added on to the exterior of the original building. These small units contained hearths and storage bins that suggested the building was converted into domestic occupation (Welsby, 1998:275). Indications of metalworking of copper alloy, gold and/or silver, and iron also existed in this area (Welsby, 1998:273). Archaeobotanical evidence indicated an environment of farmland, scrubland, savannah, small thickets of woodland, and dense vegetation by the river (Cartwright, 1999:254-255).

The human remains uncovered during the second campaign were donated to the British Museum and, of the 74 inhumations discovered, 35 skeletons fit the requirements of the current study. Individuals were recovered from three separate burial grounds (Welsby, 1998:45-59). Burials were in the Christian tradition, in either simple grave cuts or in brick vaulted chambers (Filer, 1998:213). Heads were oriented to the west, with the feet to the east, the majority lying in an extended supine position (Filer, 1998:216). One tomb contained a multiple inhumation of seventeen individuals all interred at the same time (Welsby, 1998:278), from which fourteen individuals were included in the current study. Grave goods were absent in the burials, although remains of textiles were found and wooden coffins were present within many of the vaulted graves (Filer, 1998:213-214).

5.4 Summary

Table 5.1 displays a summary of each site analysed, including the approximate location, subsistence strategy, time period, dates, and the number of individuals from each site included in the current study. The sites included were specifically chosen to represent a range of time periods. Attempts were made to include as many skeletons as possible from each period by looking at several contemporaneous sites, although this was hindered in some cases by the number of skeletons available to analyse and the level of preservation of the human remains at certain sites. Of approximately 750 skeletons assessed for eligibility according to the inclusion criteria of this research, it was possible to analyse a total of 493 for bony changes associated with respiratory disease.

The majority of cemetery sites analysed in the current study were not associated with settlements. Therefore, it remains difficult to interpret the type of subsistence economy people from these sites were undertaking. While R12 and Soba East give some indication of the subsistence economies of the people buried at these sites, the nature of the rural agricultural sites was inferred from similar contemporaneous sites, as well as the geographical location, the environment, and, therefore, the types of subsistence that could be feasibly undertaken. However, these inferences do not preclude these sites from having had a different subsistence strategy that cannot be identified with the available evidence. Unfortunately, due to the flooding within the Fourth Cataract region after the construction of the Merowe Dam, the subsistence practices in this region cannot be further investigated beyond the data that has already been recorded.

The following chapter will outline the inclusion criteria for skeletons within the current study and the methods used to analyse the preservation, age, sex, and the presence or absence of respiratory disease for each individual.

Table 5.1 – Summary of sites included in the current study, including approximate location, subsistence economy, time period, dates, and the number of individuals analysed.

Site	Approximate location	Subsistence economy	Time period	Approximate dates	No. of individuals analysed	
					Period	Total
4-L-2	4th Cataract	Rural Agriculture	Kerma Classique	1750 – 1500 BC		31
4-L-88	4th Cataract	Rural Agriculture	Kerma Classique	1750 – 1500 BC		8
4-L-100	4th Cataract	Rural Agriculture	Kerma Classique	1750 – 1500 BC		5
3-Q-33	4th Cataract	Rural Agriculture	Meroitic	300 BC – AD 350	14	20
			Post-Meroitic	AD 350 – 550	6	
3-O-1	4th Cataract	Rural Agriculture	Post-Meroitic	AD 350 – 550		17
4-M-53	4th Cataract	Rural Agriculture	Post-Meroitic	AD 350 – 550		7
3-J-23	4th Cataract	Rural Agriculture	Medieval	AD 550 – 1500		67
3-J-18	4th Cataract	Rural Agriculture	Late Medieval	AD 1000 – 1500		118
R12	Northern Dongola Reach	Hunter-gatherer/early agriculture	Middle Neolithic	4900 – 4300 BC		43
P37	Northern Dongola Reach	Rural Agriculture	Kerma Ancien	2500 – 2050 BC	24	34
			Kerma Moyen	2050 – 1750 BC	10	
Gabati	Atbara-Nile Confluence	Rural Agriculture	Meroitic	200 BC – AD 200	76	108
			Post-Meroitic	AD 400 – 700	20	
			Medieval	AD 800 – 1200	12	
Soba East	Khartoum	Urban	Medieval	AD 550 – 1500		35
					Total	493

Chapter 6: Methods

6.1 Introduction

The aim of this study was to investigate the prevalence of respiratory disease at different sites during different time periods and also to determine variations in prevalence according to sex or age. Therefore, the methods used in this research were chosen to produce data that would best answer the research questions. In bioarchaeology bony changes assumed to be related to upper and lower respiratory tract disease can be detected in the maxillary sinuses and on the visceral surfaces of the ribs, respectively. The current study focused on recording the completeness, preservation, and, thus, the observability of the ribs and maxillary sinuses and any bony changes that may have been observed on their surfaces. In order to identify potential differences in the prevalence of respiratory disease between demographic groups, age-at-death and biological sex were estimated, where possible, for each individual. Additionally, any bony changes present in the skeleton that may have been related to specific diseases known to directly or indirectly affect the sinuses and pleura and to produce bony changes in those regions, such as leprosy or tuberculosis, were also recorded. An example of the full inventory and recording form produced for this research can be found in Appendix B.

6.2 Preservation

In order to provide a general overview of skeletal completeness and preservation from different sites and to assess the possible obstacles in the observation and analysis of pathological changes related to respiratory disease, the completeness, level of fragmentation, and cortical preservation of the sinuses and the ribs were recorded.

6.2.1 Maxillary sinus preservation

Preservation has been found to significantly affect the frequency with which maxillary sinusitis can be identified (Sundman & Kjellström, 2013:454). Therefore, it was considered important to investigate the impact of preservation on the observation and recording of maxillary sinusitis in the current research. Maxillary sinus completeness was scored for both left and right sinuses independently, in five categories: *'<5%'*, *'5-24%'*, *'25-49%'*, *'50-74%'*, and *'75-100%'*. These categories consist of a slight modification of the criteria used by Sundman and Kjellström (2013:451) in their investigation of preservation and its effect on the recording of maxillary sinusitis. As the shape and size of the maxillary sinus varies considerably, 25% was considered to roughly equate to the surface area of one medial or lateral wall, or one floor or roof. No attempt to analyse a sinus for bony changes related to maxillary sinusitis was made if the remaining preserved surface area was in the completeness category of <5%.

Early on in the current study it was noted that a variety of factors affected surface observability and the recording of bony changes to the sinuses and ribs to varying degrees, including soft tissue preservation, taphonomic erosion and discolouration, and adherent soil that could not be removed with gentle cleaning. For this reason, a basic surface observability grading system was produced to investigate the potential effect of surface observability on the recording of prevalence rates. This system consists of four grades (Table 6.1). Surface observation grades were given to both the right and left sinuses separately. No attempt to analyse a sinus for bony changes related to maxillary sinusitis was made if the surface observation score was 4 (indicating completely unobservable sinus surfaces). It was also noted whether or not a sinus was observable due to a non-damaged medial wall or the presence of soft tissue preservation, preventing access of the endoscope, and whether endoscopy was utilised to observe the sinus (see Section 6.5.4).

Table 6.1 – Grading system for surface observability.

Grade	Description
1	Surface is completely observable. Only slight taphonomic discolouration may be present.
2	Minor, thin patches of soft tissue or adherent soil, or some discolouration, which may obscure subtle periosteal reaction or bone changes. <50% of surface affected.
3	Large areas of soft tissue preservation or thick adherent soil, which prevents observation of moderate periosteal lesions or bone changes. Thickening of the bone and/or extreme periosteal reactions may still be observable. >50% of surface affected.
4	Surfaces are completely unobservable for bony changes.

Although rib fragmentation and cortical surface preservation scores were recorded for the ribs (see below), these scores were not recorded for the maxillary sinuses. The walls and roof of the maxillary sinuses are very delicate, which means that poor preservation often leads to disintegration and lack of recovery of sinus fragments, making it difficult to accurately assess the extent of fragmentation and cortical surface preservation. Additionally, in sinuses that were preserved, poor cortical preservation of the entire skeleton was not observed in this study to affect the sinuses in the same manner. This may be because for some time after burial the sinuses remain enclosed, offering protection from weathering processes, or because the regions of the sinus that do have poor cortical surface preservation are made too fragile to survive excavation.

6.2.2 Rib preservation

In order to investigate the impact of the preservation of the ribs on the recorded IPR prevalence rates in this study, overall ribcage completeness, rib fragmentation, cortical preservation, and rib surface observability were all graded. Rib cage completeness was scored, for both the left and right sides of the rib cage independently, into five categories: '<5%', '*5-24%*', '*25-49%*', '*50-74%*', and '*75-100%*'. No attempts to analyse the rib cage for IPR were made if both the left and right sides of the rib cage in a skeleton were in the completeness category of <5%.

Taphonomic changes to the visceral surface of the ribs have been identified as a possible hindrance in the identification of pathological processes (Naples & Rothschild, 2011:369). Therefore, cortical surface preservation of the entire rib cage in relation to taphonomic damage was recorded using the established grading system and diagrammatic aides of McKinley (2004:Fig. 6) (Table 6.2). Surface observability of the ribs was also recorded (Table 6.1). As the observation of the visceral surface for periosteal reaction was the main priority, because new bone on this surface is thought to relate to inflammation of the lungs and pleura (e.g. Roberts, Boylston et al., 1998:56), only the observability of the visceral surface was scored. It was found that surface observation between rib sides could vary considerably. Therefore, both the right and left ribs were scored independently for surface observation. No attempt to analyse the rib cage for IPR was made if both the left and right sides of the rib cage in a skeleton had a surface observation score of 4 (indicating completely unobservable rib surfaces).

Table 6.2 - Cortical surface preservation grades for the abrasion and erosion of bone (McKinley, 2004:Fig. 6).

Grade	Description
0	Surface morphology clearly visible with fresh appearance to bone and no modifications.
1	Slight and patchy surface erosion.
2	More extensive surface erosion than grade 1 with deeper surface penetration.
3	Most of the bone surface affected by some degree of erosion; general morphology maintained but detail of parts of surface masked by erosive action.
4	All of bone surface affected by erosive action; general profile maintained and depth of modification not uniform across whole surface.
5	Heavy erosion across whole surface, completely masking normal surface morphology, with some modification of profile.
5+	As grade 5 but with extensive penetrating erosion resulting in modification of profile.

Table 6.3 - Grades for assessing the fragmentation of the rib cage.

Grade	Description
None (0)	No fragmentation except very minor 'chipping' at peripheral and vulnerable areas.
Minor (1)	Fragmentation consists of large fragments, easily pieced back together; less than 25% of each rib is affected.
Moderate (2)	Between 25 and 75% of each rib is fragmented; pieces may range in size; the morphology of the ribs may still be recognised when pieces are aligned together.
Severe (3)	Fragmentation is extreme, with small, often unidentifiable fragments consisting of more than 75% of each rib.

The fragmentation of ribs in archaeological populations has also been suggested as a factor affecting the recorded prevalence of periosteal reaction on the ribs (Santos & Roberts, 2006:47). Thus, a grading system was produced for the purposes of the current study, with scores based on the overall percentage of the surviving rib cage that was fragmented and the size and number of fragments. Rib fragmentation of the entire rib cage was categorised into one of the four score categories (Table 6.3).

6.3 Biological sex

The biological sex of each individual was assessed using the morphological characteristics of the pelvis and skull, as detailed below. Each morphological trait was attributed a nominal score of '*F*' (probable female), '*F?*' (possible female), '*?*' (indeterminate), '*M?*' (possible male), '*M*' (probable male), and '*/*' (unobservable due to poor preservation). The score observed in morphological traits with the greatest frequency was generally used to establish an assessment of sex. However, those traits that are considered more reliable were given greater importance in establishing sex. If the pelvis and skull conflicted in their sex assessment, only the pelvis was used as an indicator of sex (see Section 6.3.3).

6.3.1 Pelvic morphology

The pelvis is considered to be the most reliable indicator of biological sex (Bass, 2005: 207; Garvin et al., 2014:259). The morphology of the pelvis reflects the different functional roles that males and females carry out, producing certain dimorphic characteristics related to childbirth and bipedalism (Mays & Cox, 2000:118; White et al., 2012:415). The main morphological features used to establish biological sex of the pelvis are presented in Table 6.4**,** although other features such as overall morphology of the os coxa (Bass, 2005:207), acetabular height and depth (Bass, 2005:213; White et al., 2012:416), and width of the sacral alae in relation to the width of the body of the 1st sacral vertebra (Flander, 1978:109) were also taken into consideration. The features presented in Table 6.4 have been extensively described by Phenice (1969), Acsádi and Nemeskéri (1970), Ferembach et al. (1980), Krogman and İşcan (1986), Buikstra and Ubelaker (1994), Bruzek (2002), and Bass (2005), among others.

Establishing sex from macroscopic observation of the morphological characteristics of the pelvis has generally proved to be reliable. For example, assessments of major dimorphic traits of the pelvis have produced an accurate sex determination in 95-96% of cases (Meindl et al., 1985:80; Rogers &

Table 6.4 – Morphological characteristics of the pelvis, used to determine biological sex, and their descriptions (Phenice, 1969; Acsádi and Nemeskéri, 1970; Ferembach et al., 1980; Krogman & İşcan, 1986, Buikstra & Ubelaker, 1994; Bruzek, 2002).

Morphological Trait	Description
Greater sciatic notch	Width of the sciatic notch, being narrow and V-shaped in males and wide and U-shaped in females.
Composite Arch	The rotation of the auricular surface in relation to the greater sciatic notch. In females, the arch of the anterior margin of the auricular surface falls within the arch of the inferior margin of the greater sciatic notch, producing a composite arch. In males, the two arches align, to produce a single arch.
Preauricular sulcus	A depression between the inferior margin of the auricular surface and the superior margin of the greater sciatic notch. It is found more commonly and of greater size and depth in females.
Subpubic angle	Consisting of the angle formed between the ischio-pubic rami when the pubic symphyses are articulated. Wide and U-shaped in females, narrow and V-shaped in males.
Subpubic concavity	The curvature of the ischio-pubic ramus below the pubic symphysis, being present or more pronounced in females and absent in males.
Ventral arc	Ridge of bone on the ventral surface, at the inferior corner of the pubic symphysis. Present in females, absent in males.
Medial ischio-pubic ridge	The medial aspect of the ischio-pubic ramus, inferior to the pubic symphysis. Sharp and raised in females, flat and broad in males.
Ischiopubic morphology	The superior pubic ramus is longer in proportion to the ischium in females, while the ischio-pubic ramus is more robust and rugged in males.

Saunders, 1994:1053; Bruzek, 2002:166). Sex estimation from single traits provides varying degrees of reliability. For example, Sutherland and Suchey (1991:503), found a 96% accuracy in sex estimation using the ventral arc, but only a 70% accuracy using the medial ischio-pubic ridge. Furthermore, an accuracy of 84.7% and 79.3% was found in English and Dutch populations, respectively, using the greater sciatic notch (MacLaughlin & Bruce, 1986:1385), and an accuracy of 75.8% was found in individuals from the Hamann-Todd collection, using the presence or absence of a preauricular sulcus to estimate sex (Karsten, 2018:606). Factors, such as age or muscle development, may also affect the development of certain morphological traits. For example, the ventral arc does not begin to develop until the mid-twenties (Sutherland & Suchey, 1991:504), making it an unreliable indicator of sex in very young adults. For these reasons, a range of morphological traits were examined when estimating sex.

6.3.2 Skull morphology

The skull is considered the second best indicator of biological sex (Bass, 2005:81). Features of the male skull are generally more robust and rugged, representing increased muscle mass during development (Bass, 2005:81; Mays & Cox, 2000:119). The main morphological features used to establish biological sex of the skull are presented in Table 6.5, although other features such as overall cranial morphology (White et al., 2012:412) and mandibular robusticity and morphology (Loth and Henneberg, 1996; White et al., 2012:412) were also taken into consideration. As with the pelvis, these features have been extensively described by Acsádi and Nemeskéri (1970), Ferembach et al., (1980), Krogman and İşcan (1986), Buikstra and Ubelaker (1994), and Bass (2005), among others.

The reliability of sex estimation using only the cranium is less than that of the pelvis, with some studies producing accurate sex determination in 85-92% of cases (Meindl et al., 1985:80; Williams & Rogers, 2006:733; Walker, 2008:46; Spradley & Jantz, 2011:291; Garvin et al., 2014:Table 5). Cranial morphology may be affected by intrinsic and extrinsic factors, such as environment, diet, disease and population genetics (Mays & Cox, 2000:119; Walker, 2008:49; Garvin et al., 2014:268). Age may also have an effect on cranial morphology development, with adolescent male skulls tending to appear more gracile and feminine, and both males and females developing more robust, masculine morphological traits with increasing age (Walker, 1995). However, a study on the reliability of cranial trait scoring found no significant effect of age and body size on cranial trait expression (Garvin et al., 2014:268).

Table 6.5 – Morphological characteristics of the skull, used to determine biological sex, and their descriptions (Acsádi & Nemeskéri, 1970; Ferembach et al., 1980; Krogman & İşcan, 1986; Buikstra & Ubelaker, 1994; Bass, 2005).

Morphological Trait	Description
Glabellar profile	The glabella projects prominently from the frontal bone in males and remains flat with little or no projection in females.
Supraorbital ridges	The supraorbital ridges project prominently from the frontal bone in males and remain flat with little or no projection in females.
Supraorbital margin	Border of supraorbital margin is thick and rounded in males and sharp and thin in females.
Suprameatal crest extension	The suprameatal crest running posteriorly from the zygomatic process of the temporal extends further, past the external auditory meatus, in males.
Mastoid process	The mastoid processes are larger and thicker in males.
Nuchal area and crest	Muscle markers in the region of the nuchal area and crest are more pronounced in males.
Mental Eminence	The mental eminence is pointed and small in females, projecting from the midline. In males the eminence is squarer and larger.

6.3.3 Population specificity

The original sex estimation criteria produced by Walker and presented in Buikstra and Ubelaker, (1994:16-21) were developed on British and American human identified skeletal collections of European and African ancestry (Walker, 2008:40). In the original sex-related criteria it was noted that morphological traits of both the pelvis and skull are likely to be population-specific, varying between groups separated by time and/or space (Buikstra & Ubelaker, 1994:16). Garvin et al. (2014) investigated the reliability of the five major cranial morphological traits (nuchal crest, mastoid process, orbital margin, glabella, and mental eminence) presented in Buikstra and Ubelaker (1994) in four diverse population samples, including a sample of individuals buried at

Kulubnarti, a Medieval Middle Nile Valley site. An overall correct sex classification of 84.8% using cranial morphological traits (when relying on the pelvis as the correct indicator of sex) was produced from the Kulubnarti sample (Garvin et al., 2014: Table 5). The average difference between trait score distribution between males and females for Kulubnarti was low, with the majority of cranial traits for both males and females averaging as either 1 (female) or 2 (possible female) (Garvin et al., 2014: Table 2).

In the process of this research, it was found that the majority of skulls from the Middle Nile Valley groups lacked pronounced sexual dimorphism, particularly of the glabella, supraorbital ridges, orbital margins, and nuchal crest. The majority of skulls appeared as female or indeterminate in morphology according to standard osteological sexing grades, and in concordance with the findings of Garvin et al. (2014). The pelvis, however, displayed a far greater degree of sexual dimorphism. Therefore, if morphological traits of the pelvis were present and observable, they were used preferentially in attributing biological sex. If only the morphological traits of the skull were present, only the skulls which displayed pronounced male morphological characteristics were assigned a biological sex. Skulls displaying female morphological traits could not be relied upon to accurately and purely represent females, and they were, therefore, assigned to the indeterminate sex group. This is likely to have introduced an inherent sexing bias, with a larger number of individuals attributed a biological sex of male or indeterminate when compared to the category of female. However, the pelves were well preserved in the majority of the assemblages studied and the number of individuals assessed solely from the skull was small.

6.4 Age-at-death estimation

In young non-adults it has been noted that the maxillary sinuses often display porosity and large pits, believed to represent normal growth and development of the sinuses, while the eruption of the permanent molars can also produce changes to the inferior bone surface of the sinus (Lewis et al., 1995:501; Sundman & Kjellström, 2013:449). Additionally, normal growth of sub-adult bone, particularly around the growth plates, can mimic the disorganised appearance of woven bone caused by pathological stimuli and can lead to confusion when differentiating from "pathological" periosteal reaction (M. E. Lewis, 2007:135, 2017:132; Ortner, 2012:252). In the current study it was noted that this appearance persists into adolescence at the sternal ends of the ribs and at the neck of unfused rib heads and can confound accurate recording of periosteal reaction. For this reason, the initiation of the fusion of the rib heads in at least one rib or more (usually occurring between 17 and 22 years of age) and the complete eruption of the third maxillary molars (if present) were considered requisites for the inclusion of an individual in this study. Therefore, this study consists of late adolescent and adult individuals only.

Standard osteological methods employed for estimation of age consist of stages of epiphyseal fusion (Schaefer et al., 2009) and age-related morphological changes to the auricular surface (Lovejoy et al., 1985), pubic symphysis (Brooks and Suchey, 1990), and the fourth sternal rib end (İşcan et al., 1984a, 1984b, 1985). Using these methods, individuals in this study were categorised into five different groups, following the criteria of Buikstra and Ubelaker (1994:36) (Table 6.6). Age estimation methods often provide scores with age ranges that can overlap. Therefore, providing a general age category with a broad age range into which mean scores from different methods can fit, as was employed in the current study, reduces the effect of inaccuracies within and between methods (Falys & Lewis, 2011:705). The category of '*unknown adult*' was used in examples where insufficient presence or preservation of certain bones and teeth prevented analysis of age beyond that of definite adult.

Table 6.6 – Age categories applied to individuals in this study (after Buikstra and Ubelaker, 1994:36).

Age category	Age-at-death (years)
Adolescent	16 – 19
Young adult	20 – 34
Middle adult	35 – 49
Old adult	50+
Unknown adult	20+

In any cases where abrasion to the pubic symphysis, auricular surface, or sternal rib end, or unusual development of the morphology of these surfaces were present, which did not conform to the descriptions provided for each method (such as pathological changes), the joint surface was not considered in the estimation of age-at-death.

Other age estimation methods, such as dental attrition models (e.g. Miles, 1963; Brothwell, 1972; Lovejoy, 1985) and cranial suture fusion (Meindl & Lovejoy, 1985), have been developed, but are considered less reliable (Cox, 2000:68). In particular, dental attrition models were developed using specific populations and the rate of wear is impacted by the type of diet of a population and any abrasive inclusions in the food (Brothwell, 1972:67; Whittaker, 2000:87). Therefore, it has been suggested that attrition models should not be applied to populations that are geographically or temporally distant to the original sample (Brothwell, 1972:67). In particular, excessive tooth wear in Nile Valley populations has been noted and is thought to be a result of the unintentional incorporation of grit or sand into food during preparation (Beckett & Lovell, 1994:233), making the application of established attrition models to Middle Nile Valley populations unsuitable. For this reason, tooth attrition models were not considered a reliable method for age estimation in this study.

6.4.1 Late stages of epiphyseal fusion

Although the majority of epiphyses fuse during childhood, several stages of epiphyseal fusion occur during adolescence and early adulthood, making it possible to identify and differentiate adolescents and young adults based on progression of epiphyseal fusion (Cox, 2000:65). Some of the latest fusing epiphyses include the medial clavicle, the rib heads, the iliac crest, the inferior angle of the scapula, the sacral bodies two to five, and the ischial tuberosity. These epiphyses were visually assessed for stage of fusion, and graded as '*open*', '*partially fused'*, or '*completely fused*' (after Schaefer et al., 2009). The union times for these bone elements were taken from the adolescent and postadolescent ageing forms for males and females from Shaefer et al. (2009:354-355) and are presented in Table 6.7. However, it should be noted that these forms were designed to provide only general age parameters for epiphyseal fusion (Schaefer et al., 2009:350) and fusion timings may vary between populations, both modern and archaeological, and in relation to nutrition, height, and weight (Crowder & Austin, 2005:1).

6.4.2 Pubic symphyseal morphology

Assessing age-related changes to the pubic symphysis is often considered the most reliable method of estimating adult age-at-death (Buikstra & Ubelaker, 1994:21; Bass, 2005:198). This method was first published by Todd (1920), and a revised version, often referred to as the Suchey-Brooks method (Brooks & Suchey, 1990), is most commonly used today in osteological analysis (White et al., 2012:394). The Suchey-Brooks method categorises the phases of pubic symphyseal change into six stages, based on the morphology of the symphyseal face, marginal changes, integrity of the surface of the bone, and the development of new bone formation related to ligamentous strain (Buikstra & Ubelaker, 1994:23-24).

Table 6.7 – Union times for late stages of epiphyseal fusion (Schaefer et al., 2009:354-355).

Epiphysis	Sex	Open (years)	Partial Fusion (years)	Complete Fusion (years)
Medial clavicle	Male and Female	≤23	17-30	≥21
Rib heads	Male and Female	≤21	17-22	≥19
Iliac crest	Male	≤20	17-22	≥18
	Female	≤16	14-21	≥18
Inferior angle of scapula	Male and Female	≤21	17-22	≥17
S2-S5 bodies	Male	≤20	19-30+	≥20
	Female	≤20	12-26	≥19
Ischial tuberosity	Male	≤18	16-20	≥17
	Female	≤15	14-19	≥16

Detailed descriptions of the morphological changes, photographs, and casts of symphyses displaying typical changes for each Suchey-Brooks phase were employed to help accurately allocate stages. Table 6.8 displays the mean age, standard deviation, and 95% confidence interval range of each phase originally produced by Brooks and Suchey (1990:Table 1). The mean age of each phase was used to estimate into which age group the individual should fall. Phase 1 corresponded to an age group of either adolescent or young adult, depending on the accompanying epiphyseal fusion data. Phases 2 and 3 corresponded to an age group of young adult, phases 4 and 5 to middle adult, and phase 6 to older adult. Both the right and left symphyses were scored separately, if preserved.

The use of the Suchey-Brooks method does have its limitations. The pubic symphysis is susceptible to damage and poor preservation in the burial environment and at certain archaeological sites it may not survive well (Cox, 2000:69). In addition, the age ranges for each stage are very wide and only represent a 95% confidence interval range, and there is a considerable overlap in age ranges between different stages (Cox, 2000:69; White et al., 2012:396). Factors, such as trauma, may impact on normal activity and movement and confound the expected standard age-related changes to the pubic symphysis (Klepinger et al., 1992:768).

When producing the original Suchey-Brooks method, differences between white, black, and Mexican males were investigated and it was found that the black and Mexican samples were significantly overaged (Katz & Suchey, 1989: Table 2). The paper suggested that variability across different populations should be considered when applying the Suchey-Brooks method (Katz & Suchey, 1989:171). More recent studies of the accuracy of the Suchey-Brooks method on different known-age populations have produced variable results. For example, Sarajlić and Gradaščević (2012:54) found an overall accuracy of 94.7% in allocating individuals in their Bosnian sample to the relevant stage, but there was a significant error in age classification in individuals allocated to stage 5 and a general underestimation of age. Using a sample from the American Bass collection, Miranker (2016:Table 5) found an accuracy of only 64.76% using the Suchey-Brooks method. However, Sakaue (2006:Table 3) found that the mean age of their known-age Japanese sample in each allocated phase did not vary by more than three years from the original mean ages of each phase produced by Brooks and Suchey (1990). In general, increasing inaccuracy in stage allocation with increasing age has been found (e.g. Klepinger et al., 1992:767; Hoppa, 2000:186; Sakaue, 2006:60; Miranker, 2016:1176).

Table 6.8 – Statistical data (in years) for each phase of the Suchey-Brooks pubic symphysis age estimation method in males and females (Brooks & Suchey, 1990:Table 1).

Phase	Female			Male		
	Mean age	Standard deviation	95% confidence interval	Mean age	Standard deviation	95% confidence interval
1	19.4	2.6	15 – 24	18.5	2.1	15 – 23
2	25.0	4.9	19 – 40	23.4	3.6	19 – 34
3	30.7	8.1	21 – 53	28.7	6.5	21 – 46
4	38.2	10.9	26 – 70	35.2	9.4	23 – 57
5	48.1	14.6	25 – 83	45.6	10.4	27 – 66
6	60.0	12.4	42 – 87	61.2	12.2	34 – 86

6.4.3 Auricular surface

Although changes to the auricular surface morphology are considered more complex and problematic to score than the pubic symphysis, the auricular surface survives intact more frequently in the burial environment, and, therefore, offers a useful indicator of age in less well preserved individuals (Lovejoy et al., 1985:15; Buikstra & Ubelaker, 1994:24, White et al., 2012:400). An eight stage method for estimating age from the auricular surface was produced by Lovejoy et al. (1985), based on changes to the morphology, porosity, and granularity of the auricular surface, changes to the apex and joint margins, and activity in the retroauricular region (Buikstra & Ubelaker, 1994:25).

Detailed descriptions of each phase and photographs were used to allocate stage. The modal age range of each phase (Table 6.9), determined by Lovejoy et al. (1985), was used to estimate into which age group the individual should be allocated. Phase 1 corresponded to an age group of either adolescent or young adult, depending on the accompanying stages of epiphyseal fusion. Phases 2 and 3 corresponded to an age group of young adult, phases 4, 5 and 6 to middle adult, and phases 7 and 8 to older adult. Both the right and left auricular surfaces were scored separately, if available.

When testing the accuracy of this method on known-age individuals from the Terry collection, Murray and Murray (1991:1168) found a tendency for over-ageing in younger individuals and under-ageing in older individuals. A test of the auricular surface ageing method on a known-age Thai sample found that the method massively underaged the majority of individuals over 40 years, with an increasing inaccuracy with age, and suggested caution in applying this method to populations geographically distant to those used for producing the original method (Schmitt, 2004:4). Using the Portuguese Coimbra identified skeletal collection, with known biographical information, Santos (1996:31) also found that the age of individuals older than 45 years was underestimated. This may suggest that individuals aged using only the auricular surface in this study, when the pubic symphysis was not present or was unobservable, may have produced an inherent bias towards the inclusion of older individuals into the young and middle adult categories. Additionally, in the development of the auricular surface aging method by Lovejoy et al. (1985), males and females were pooled into one group. This may have overlooked sex-specific variability in changes to the auricular surface that could have affected the accurate estimation of age. However, another study of age-related changes to the auricular surface found no significant differences in changes between males and females (Buckberry & Chamberlain, 2002:236).

Table 6.9 – The modal age ranges for each phase of the auricular surface age estimation method produced by Lovejoy et al. (1985).

Phase	Modal age range (years)
1	20 – 24
2	25 – 29
3	30 – 34
4	35 – 39
5	40 – 44
6	45 – 49
7	50 – 59
8	60+

6.4.4 Sternal rib end

A method for ageing an individual based on changes to the morphology of the fourth sternal rib end was produced by İşcan et al. (1984a, 1984b, 1985). A rib end can be allocated to one of nine age phases (0 – 8) based on changes to the depth and shape of the pit, modification to the walls and rim, and decreasing integrity of the bone itself (İşcan et al., 1994a:1096; 1995:855). As this research required the accurate seriation of the ribs, it was possible in many cases to identify the fourth rib. Additionally, the application of this method to ribs 3 to 9 has demonstrated that phase scores do not significantly vary between ribs and this method can be applied, with some caution, to sternal ends other than those belonging to the fourth rib (Yoder et al., 2001:227). However, even in well preserved skeletons, the sternal ends of the ribs are the most delicate region and are often damaged or abraded. Therefore, this method was applied infrequently to the most well-preserved individuals as a secondary estimation of age, after the pubic symphysis and auricular surface.

Detailed descriptions of each phase and accompanying images were used to allocate a phase. Table 6.10 displays the mean age, standard deviation, 95% confidence interval, and age range for phases

1 – 8 originally produced by İşcan et al. (1984a:Table2, 1985:Table 2) for white males and females. The mean age of each stage was used to determine into which age group the individual should fall. In males, phases 0 and 1 corresponded to an age group of adolescent or younger, phases 2 to 4 corresponded to an age group of young adult, phases 5 and 6 to an age group of middle adult, and phases 7 and 8 to a category of old adult. In females, phases 0 and 1 corresponded to age groups too young to be included in this research, phase 2 corresponded to an age group of adolescent, phases 3 and 4 to young adult, phase 5 to middle adult, and phases 6 to 8 to old adult (White et al., 2012:Fig. 18.17). If the sex of an individual could not be assessed, this ageing method was not applied. Although İşcan et al. (1987:Table 2) also produced statistical data, including mean age ranges, for the allocation of the method to black males and females, the mean ages from the publication were not used in the current research as they were produced from a small sample group that did not represent all phases.

The applicability of this method has been criticised by several authors (e.g. Cox, 2000:69-70). The ribs do not survive well within the burial context and are often fragmented and difficult to accurately seriate, making identification of the fourth rib problematic (Cox, 2000:69; White et al., 2012:404). In addition to this, the method was originally focussed only on white males and white females. As mentioned above, the original authors tested their method on a skeletal collection of black individuals with known age-at-death and found, in later phases, that black individuals were over-aged, and they subsequently suggested population specific modifications to the original method (İşcan et al., 1987:455, 464). On the other hand, a slight tendency to under-age black individuals was found when applying the method to black and white male individuals from the Haman-Todd collection, but this difference was not found to be statistically significant (Russell et al., 1993:61). Furthermore, Oettlé and Steyn (2000:1073) applied the white standard to a South African black collection and found that the method was not sufficiently accurate when applied to their population. They, instead, adapted the method to produce new age ranges more applicable to their population (Oettlé and Steyn, 2000:1073-1078). The reliability of this method for individuals of non-white and non-black ancestry is as yet unknown (White et al., 2012:405).

Table 6.10 – Statistical data (in years) for phases 1 to 8 of the fourth sternal rib end age estimation method in white males and females (İşcan et al., 1984a:Table 2, 1985:Table 2).

Phase	Female				Males			
	Mean age	Standard deviation	95% confidence interval	Age range	Mean age	Standard deviation	95% confidence interval	Age range
1	14.0	-	-	-	17.3	0.5	16.5 – 18.0	17 – 18
2	17.4	1.52	15.5 – 19.3	16 – 20	21.9	2.13	20.8 – 23.1	18 – 25
3	22.6	1.67	20.5 – 24.7	20 – 24	25.9	3.50	24.1 – 27.7	19 – 33
4	27.7	4.62	24.4 – 31.0	24 – 40	28.2	3.83	25.7 – 30.6	22 – 35
5	40.0	12.22	33.7 – 46.3	29 – 77	38.8	7.00	34.4 – 42.3	28 – 52
6	50.7	14.93	43.3 – 58.1	32 – 79	50.0	11.17	44.3 – 55.7	32 – 71
7	65.2	11.24	59.2 – 71.2	48 – 83	59.2	9.52	54.3 – 64.1	44 – 85
8	76.4	8.83	70.4 – 82.3	62 – 90	71.5	10.27	65.0 – 78.0	44 – 85

6.5 Maxillary sinusitis

The methods that were used to identify and record bony changes to the maxillary sinuses related to sinusitis are presented below. This includes the criteria used in the current study for identifying odontogenic sinusitis and the methods employed for calculating and presenting prevalence data. Additionally, the specifications of the endoscopic equipment used to observe enclosed sinuses are also presented.

6.5.1 Identifying pathological changes

If approximately 5% or more of one of the maxillary sinuses was present, then all internal surfaces of the sinus were observed for bony changes. Using a combination of macroscopic and/or endoscopic recording, a diagnosis of sinusitis was attributed according to the presence of at least one of the diagnostic criteria produced by Boocock et al. (1995), the established method used in studies of maxillary sinusitis in bioarchaeology. These criteria consist of pitting, spicules of new bone, remodelled spicules, and white pitted bone (Figure 6.1) (see Table 3.1 for morphological descriptions of each criterion). During the course of this research it was noted that the changes

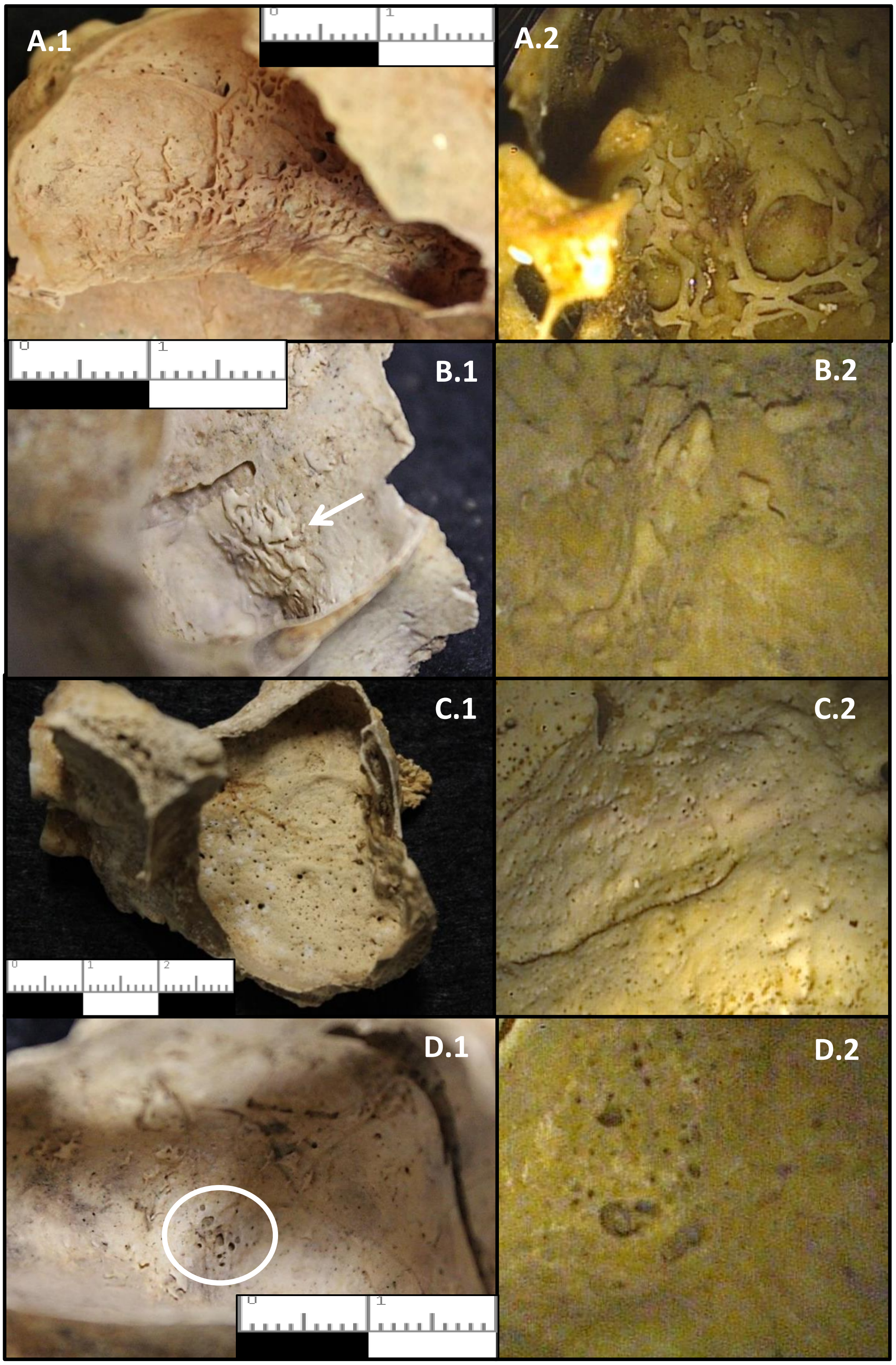


Figure 6.1 – Examples of the four diagnostic criteria produced by Boocock et al. (1995), viewed macroscopically and via an endoscope.

- **A.** **Spicules** (A.1. Macroscopic*:* site 3-J-18, Sk4375, left maxillary sinus; A.2. Endoscopic: site 3-J-23, Sk22, right maxillary sinus).
- **B.** **Remodelled spicules (arrow on left)** (B.1. Macroscopic*:* site 3-J-18, Sk4154, left maxillary sinus; B.2. Endoscopic: site 3-J-18, Sk2136, left maxillary sinus).
- **C.** **Porous new bone (previously referred to as "white pitted bone" by Boocock et al., 1995)** (C.1. Macroscopic: site 3-J-18, Sk4010, right maxillary sinus; C.2. Endoscopic: site 3-J-23, Sk20, left maxillary sinus).
- **D.** **Pitting (circled on left)** (D.1. Macroscopic: site 3-J-18, Sk4154, left maxillary sinus; D.2. Endoscopic: site 3-J-18, Sk4348, left maxillary sinus).

Images courtesy of the Trustees of the British Museum conventionally referred to as “white pitted bone” could often appear in a range of colours caused by taphonomic discolouration and a “white” appearance was not a necessary criterion for the identification of this type of bony change. Therefore, in order to avoid confusion when presenting images of taphonomically discoloured sinuses, and to distinguish this diagnostic criterion from pitting, ‘white pitted bone’ is henceforth referred to as ‘porous new bone’. Additionally, two other criteria not described by Boocock et al. (1995) were also considered as an indication of maxillary sinusitis, after Sundman and Kjellström (2013:450): unusual lobules of bone and very obvious thickening and irregular surface morphology caused by the formation of dense lamellar bone (Figure 6.2) (see Table 3.2 for descriptions).

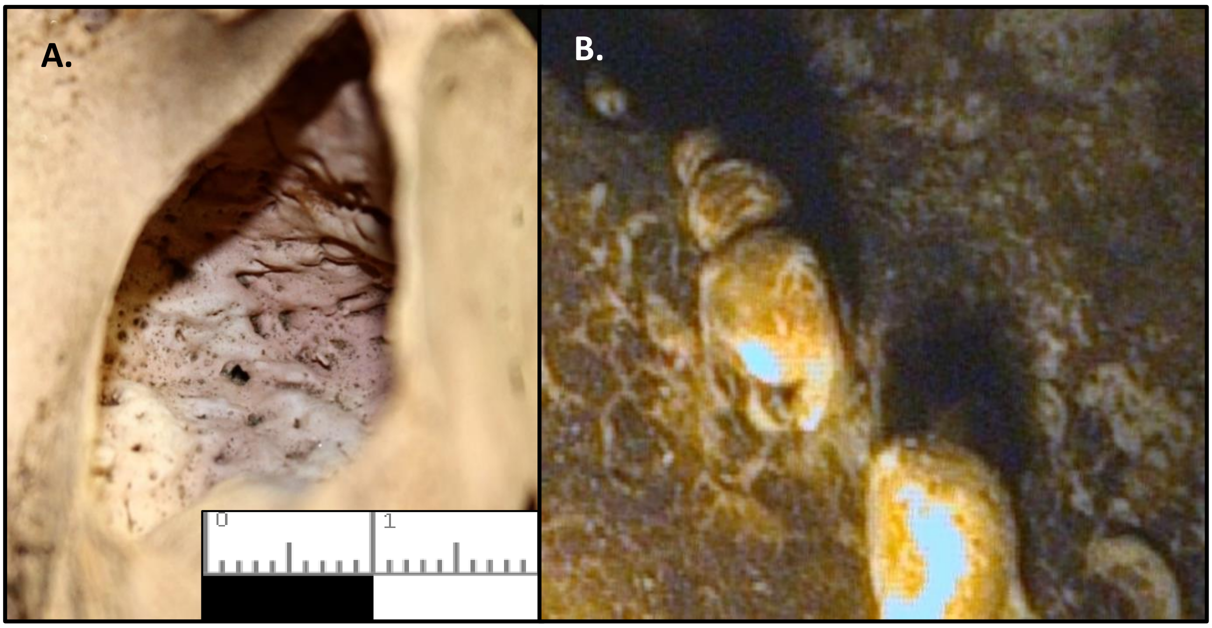


Figure 6.2 – Two other diagnostic criteria considered in the current research: thickening and irregular surface morphology (A.) and unusual lobules (B.).

A. **Thickening of the walls and irregular surface, also accompanied in this case by porous new bone** (site 3-Q-33, Sk63, right maxillary sinus).
B. **Endoscopic image of small rounded lobules** (site 3-J-23, Sk109, left maxillary sinus).

Images courtesy of the Trustees of the British Museum

It has been speculated that the presence of certain types of bony changes related to sinusitis may be indicative of specific disease processes (Boocock et al., 1995:487; Merrett & Pfeiffer, 2000:313), but they lack any diagnostic value until different types of bone change within the sinuses can be investigated clinically (Boocock et al., 1995:493). Although the main priority of this research was to record maxillary sinusitis within each sinus as either present or absent, the types of bone change apparent were also recorded for each sinus, should future research into bone typologies related to maxillary sinusitis provide diagnostic value.

6.5.2 Oroantral fistulae and periapical lesions

To assess the possible origin of sinus infection, periapical lesions associated with all present maxillary alveolar bone were recorded. A potential cause of odontogenic sinusitis was only attributed when a direct link between oral infection and the maxillary sinus was present in the form of an oroantral fistula, after studies such as Roberts (2007:797), Liebe-Harkort (2012:389), and Sundman and Kjellström (2013:450-451). An oroantral fistula was considered present if a hole in the maxillary sinus above the dentition presented an obviously remodelled and rounded margin, which was sometimes accompanied by a 'chimney-like' margin of new bone (Figure 6.3). All available sinuses for each individual were recorded separately for oroantral fistulae and graded as either '*absent*', '*present*', or '*unobservable*'. Although the maxillary sinus can extend over the roots of the premolars, it is usually situated above the three maxillary molars. Therefore, if the alveolar bone and the floor of the sinus above these three molars were absent or damaged beyond accurate observation, the grade for an oroantral fistula for that sinus was recorded as '*unobservable'*.

The roots of the molars can naturally protrude into the floor of the maxillary sinus. This can either cause small perforations in the floor of the sinus, with smooth margins where the bone has remodelled around the tooth root, or push the floor upwards producing small 'bumps' of thinned bone that project into the sinus and are highly susceptible to post-mortem damage from abrasion, producing small holes in the floor with sharp edges that have not remodelled (Lewis et al., 1995:502). Either type of hole can often be mistaken for an oroantral fistula (Figure 6.4). Therefore, the presence of a thickened and rounded rim with clear signs of new bone formation around the margins is vital in positively identifying an oroantral fistula (Lewis et al., 1995:502; Sundman & Kjellström, 2013:450-451) and was required in the current study for a grade of '*present*'.

Other studies (e.g. Panhuysen, 1997:612-613; Merrett & Pfeiffer, 2000:309-310) have suggested that evidence for dental disease without an oroantral fistula may also be suggestive of odontogenic sinusitis. It was decided that all maxillary periapical lesions and their position within the maxilla should be recorded in the event that future clinical research should discover a causative relationship between periapical lesions and odontogenic sinusitis, without an oroantral fistula being present. Lesions of the maxilla were recorded according to descriptions of periapical lesions by Hillson (2005:307-310) and Ogden (2008) as either '*absent*', *'present as granuloma or cyst*', *'present as abscess*', *'present as oroantral fistula', 'unobservable/alveolar bone absent',* or '*resorption of alveolar bone due to antemortem tooth loss'.*

However, the recording of all dental disease, its extent, and severity is complex and time consuming. For this reason, non-periapical diseases of the maxilla, such as carious lesions and periodontal disease, and all dental disease of the mandible, including periapical lesions, were not recorded.

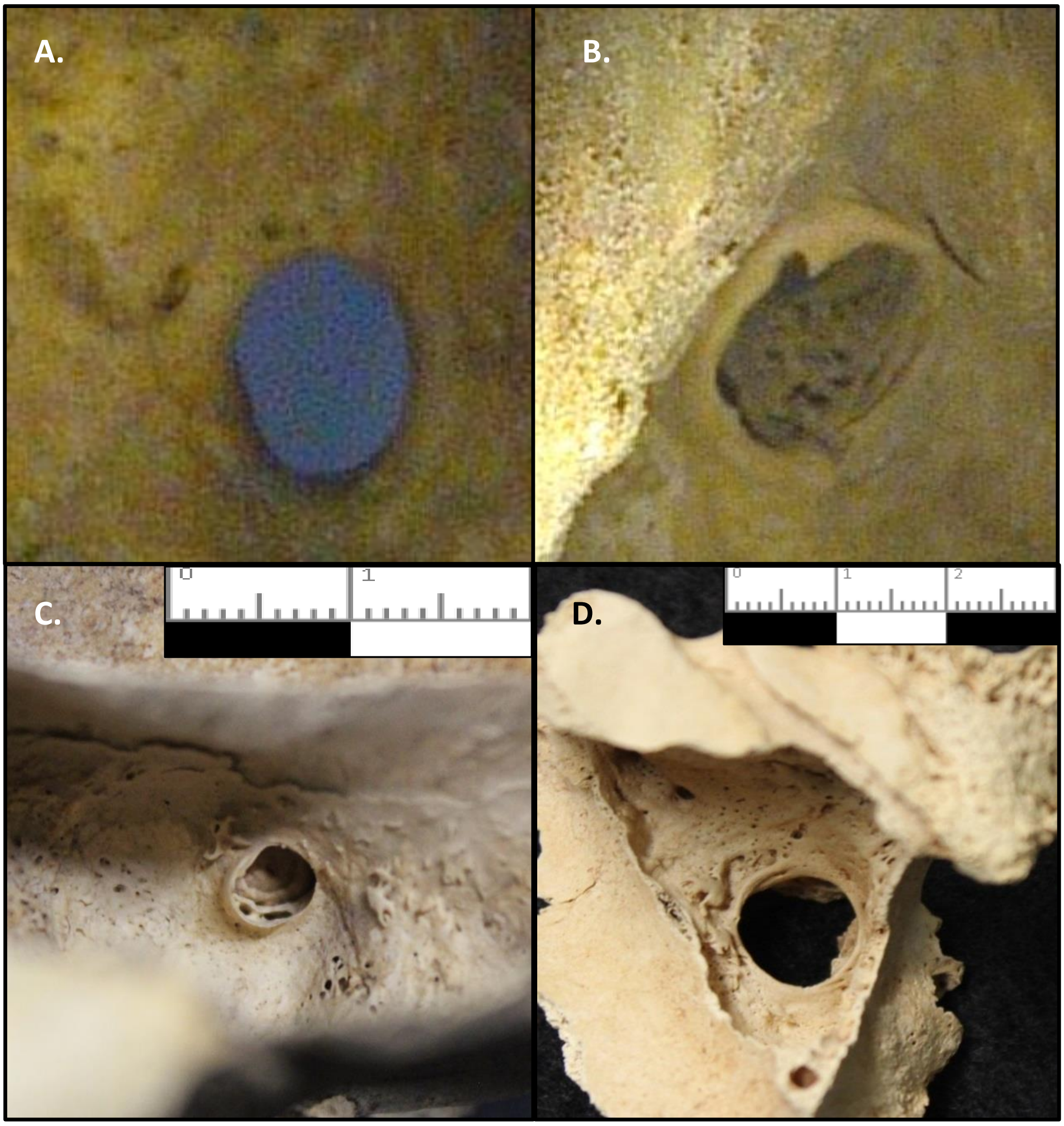


Figure 6.3 – Examples of oroantral fistulae.

A. **Endoscopic image of an oroantral fistula. Although chimney-like bone is not present, a thickened and remodelled rim of bone is evident around the fistula** (site 3-J-18, Sk2067, left maxillary sinus).
B. **An endoscopic image of a classic chimney-like rim of new bone formation** (site 3-J-18, Sk4361, left maxillary sinus).
C. **Chimney-like fistula, possibly causing the spicule formation and pitting present** (site 3-J-18, Sk4154, left maxillary sinus).
D. **Very large oroantral fistula, likely to have caused the associated remodelled spicules, porous new bone, and thickening of the walls and floor seen within the sinus** (site 4-L-2, Sk1003, left maxillary sinus).

Images courtesy of the trustees of the British Museum

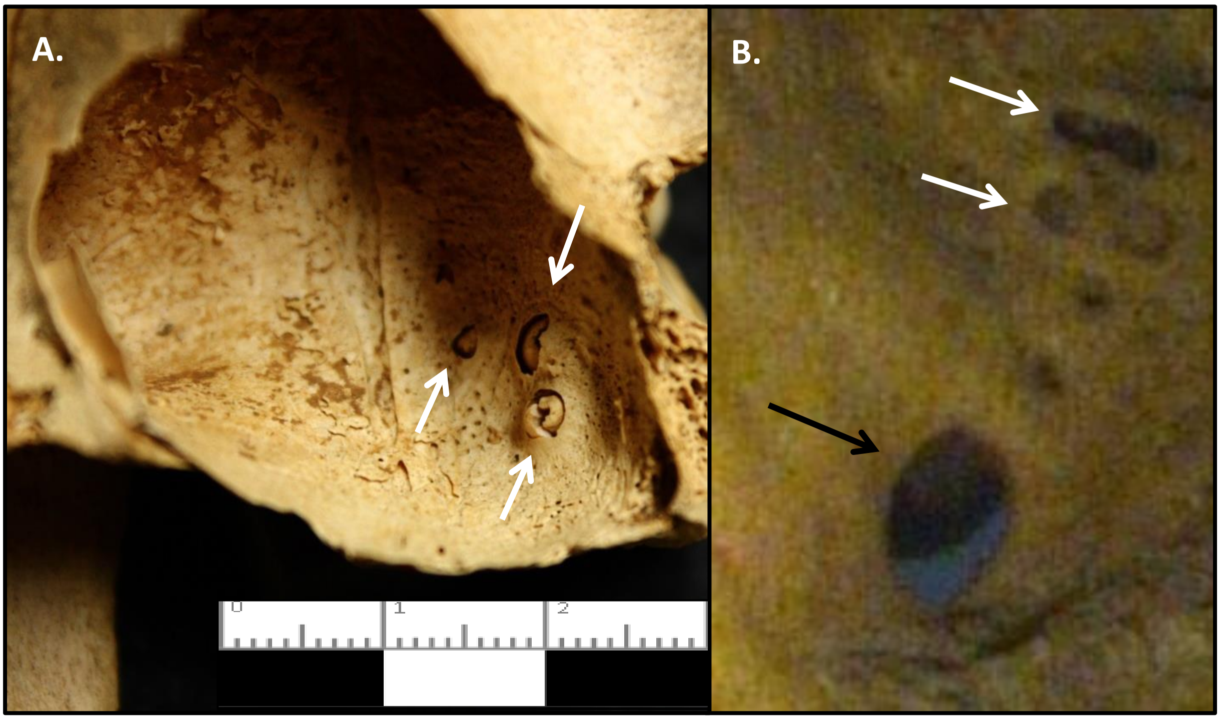


Figure 6.4 – Examples of the natural perforation of the roots of the molars into the maxillary sinus.

A. **Post-mortem damage of root protrusion (arrows), causing holes that can be confused with oroantral fistulae** (site 3-J-23, Sk21, left maxillary sinus).

B. **Endoscopic image of possible remodelling of the margins around tooth-root perforations (white arrows). An oroantral fistula may also be present (black arrow). However, the quality of the endoscopic image prevents the identification of a distinctive thickened margin of new bone formation and this hole may also represent a remodelled tooth-root perforation** (site 3-J-18, Sk2048, right maxillary sinus).

Images courtesy of the Trustees of the British Museum

6.5.3 Presenting prevalence

The prevalence of maxillary sinusitis has been presented in different bioarchaeological studies in various ways. The majority of studies of maxillary sinusitis present the prevalence rate as a percentage of the number of individuals within that sample to display bony changes to either one or both sinuses (e.g. Boocock et al., 1995; Panhuysen et al., 1997; Roberts, 2007; Liebe-Harkort, 2012;). For comparative purposes, the prevalence rates in the current study are presented in the same manner. However, this method does not take into account the error introduced from the inclusion of individuals with only one sinus present. The presence of only a single unaffected sinus is not a definitive indication that an individual did not have sinusitis, as there is no way to tell if the absent sinus displayed bone changes or not. This can reduce the total prevalence rate calculated for a sample. Therefore, prevalence rates were also calculated separately for a group containing only individuals that had both sinuses preserved and observable. Despite this, poor preservation of the sinus will also affect the total prevalence calculated for a sample, as incomplete sinuses may present bony changes on unobservable or missing regions. Therefore, despite attempts to minimise error, the prevalence of sinusitis presented in the current study represents only the very minimum observable.

The true prevalence of maxillary sinusitis, as the percentage of sinuses within the total sample group demonstrating bony changes, has also been calculated in some studies (e.g. Bernofsky, 2010). While this type of data was not useful for answering the research questions posed in the current study (i.e. determining the number of individuals within a population who had sinusitis), for comparative purposes with previous and future studies of maxillary sinusitis, true prevalence rates for maxillary sinusitis are also presented in Appendix E.

6.5.4 Endoscopy

In the well-preserved sites the crania were often complete, preventing the direct observation of the enclosed sinuses. However, the medial wall of the maxillary sinus, located within the nasal cavity of the cranium, is often naturally perforated or thinned and is easily damaged post-mortem during the excavation and processing of the cranium. In many cases, the perforation or damage to the medial wall was great enough to provide access into the maxillary sinus for a small endoscopic camera on a flexible wire.

The Department of Scientific Research within the British Museum kindly provided the loan of an Olympus Series 6 industrial videoscope (Olympus, 1997). This equipment consisted of an IV6C6-13 tapered flex insertion tube, IV-6A camera control unit, MAJ-522 power unit, and ILH-1 light source (Figure 6.5A). The distal end of the insertion tube had a diameter of 6mm and could be bent remotely up to 150° in up/down and right/left directions with a minimum bending radius of 30mm. The insertion tube was equipped with an LED light on the distal end. The flexible wire length was 13.4cm (Figure 6.5B). Two different optical adaptors were provided (Figure 6.5C-D). These could be attached to the end of the insertion tube to change the direction of the camera angle, the depth of field (the distance from the object that the camera can view whilst still in focus), and field of view (the extent of the camera's view). The AT80D/NF-IV6C6 optical adaptor faced forward from the insertion tube, providing a field of view of 80° and a depth of field from 10mm upwards. The AT120S/NF-IV6C6 faced out of the side of the insertion tube at a 90° angle, providing a field of view of 120°, and a depth of field of 1-9 mm (Olympus, n.d.:7). Both optical adaptors were used to view each sinus to provide the greatest observation of all surfaces.

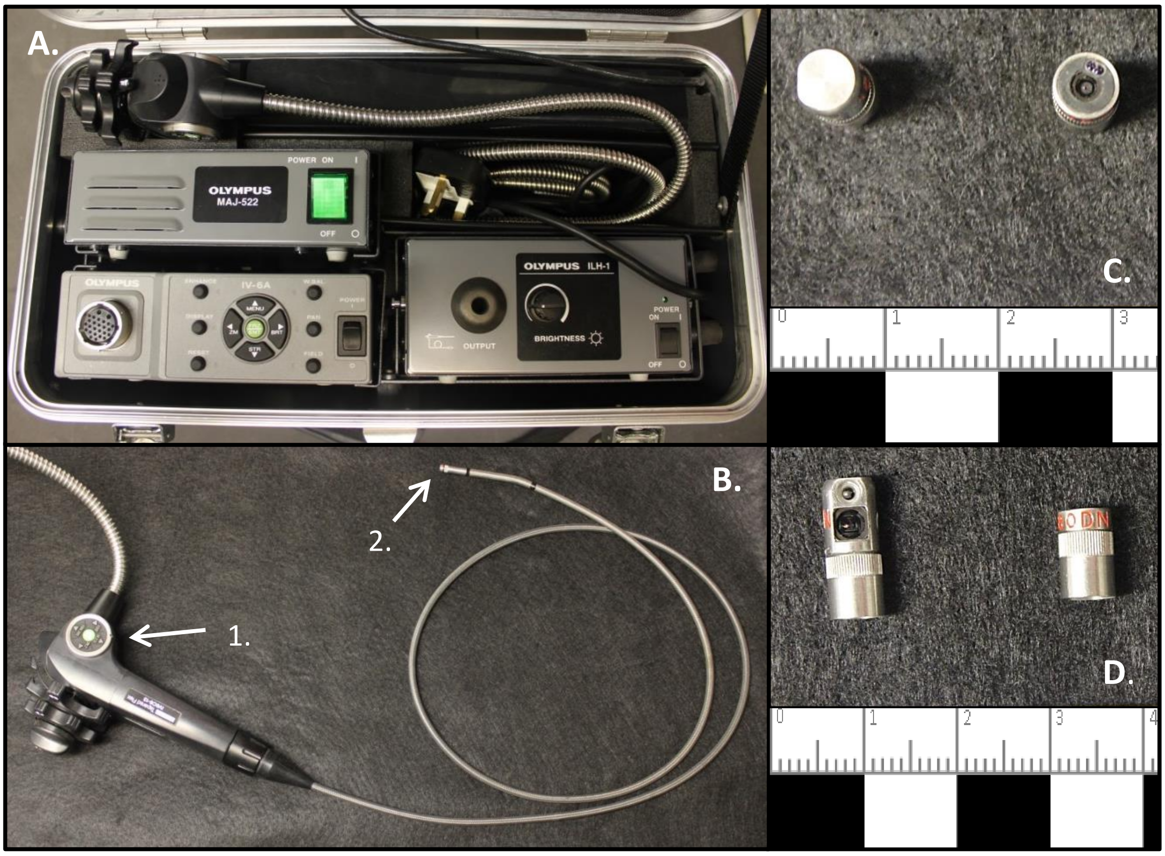


Figure 6.5 – Components of the Olympus Series 6 industrial videoscope. A. The camera control unit, power unit, and light source, all of which are self-contained within a protective case. B. The remote control unit (1) and flexible insertion tube with wire (2). C. The end view of the AT120S (left) and AT80D (right) optical adaptors. D. The side view of the AT120S (left) and AT80D (right) optical adaptors.

The IV-6A control unit provided a variety of settings that allowed for image adjustments and better visualisation of the sinus depending on light levels and distance. To maintain consistency, the same settings were used in all observations of the maxillary sinuses. This consisted of a brightness setting of '*three*' or '*four',* depending on light levels, and a focus setting of '*enhanced*'. The image transmitted from the endoscope was displayed on a computer screen using the image software EZgrabber. An image capture device, named ImageClimax, connected the endoscope to the computer and, by pressing a button on this device, the EZgrabber software captured an image. This enabled the capture and storage of a range of endoscopic images of maxillary sinuses both with and without sinusitis for comparative purposes (Figure 6.6).

Figure 6.6 - An example of an image captured by the endoscope, in this case an oroantral fistula with associated new bone formation. Settings, including brightness level, exposure, time, and date, are displayed on the bottom quarter of the screen (site 3-J-23, Gr126, right maxillary sinus).

Image courtesy of the Trustees of the British Museum

Due to the changing perspective and depth of field of the endoscope, it was not possible to provide a scale with endoscopic images. It should also be noted that the quality of the image of the endoscope varied with angle and distance of the lens, which of the two optical adaptors was being used, and thickness and taphonomic discolouration of the walls, which affected the brightness of the image. This did, to some extent, impact the ability to accurately observe the presence of pathological changes within some sinuses (Figure 6.7). It was also speculated during the current research that certain bone changes, such as porous new bone or thickening, were not as easy to observe using the endoscope as other types of bone formation, for example spicules, which stood out from the walls and, therefore, cast a shadow, making these types of changes easier to identify.

It should be noted that the utmost priority when using the endoscope was to observe as much of the sinus as possible without causing further damage. In some cases, where damage to the medial wall was extensive, this was fairly easy as the angle of the endoscope could be adjusted without causing further damage. However, where damage of the medial wall was minimal, it was often not possible to access the sinus at different angles. The restriction on visualisation of the sinus could

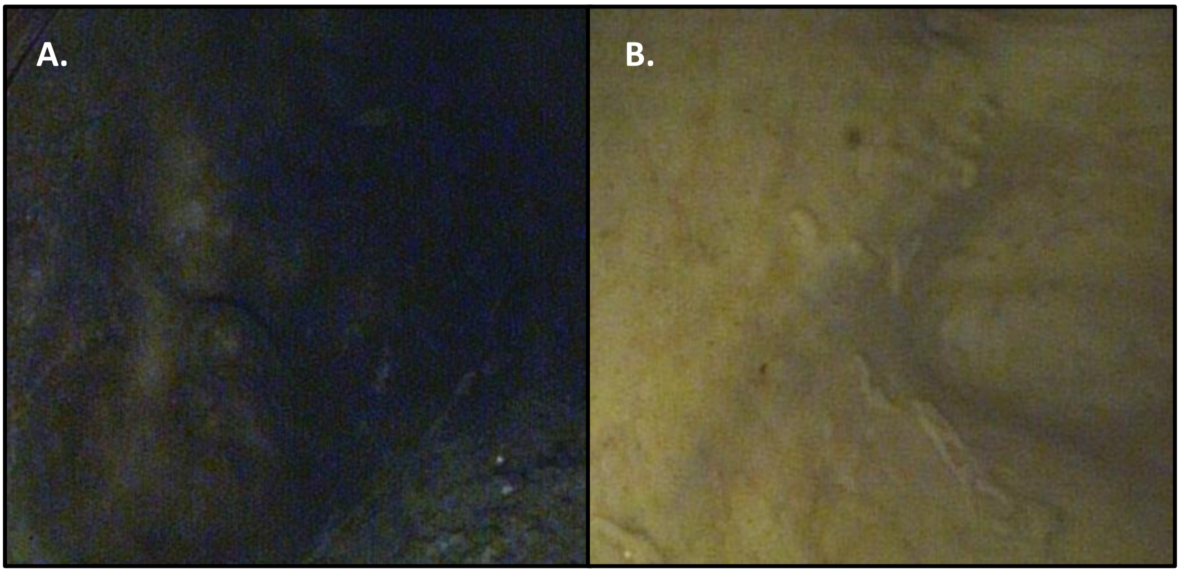


Figure 6.7 – Examples of the reduced quality of some endoscopic images.

A. **Darkening of the image due to taphonomic discolouration and soft tissue preservation, preventing any identification of bony changes to the sinus** (site 3-J-18, Sk2124, right maxillary sinus).
B. **Blurring of the image due to angle and distance of the lens. In this case, faint spicules can still be identified** (site 3-J-23, Gr22A, left maxillary sinus).

Images courtesy of the trustees of the British Museum

range from being unable to view the medial wall and far corners of the sinus, to only being able to observe the lateral wall. It should be reiterated, therefore, that the results in the current study provide only the minimum prevalence rates of sinusitis in these populations. As with the fragmentation and incompleteness of the sinuses, the inability to observe the entire sinus with the endoscope means that the prevalence of maxillary sinusitis in these populations may be higher.

6.6 Inflammatory periosteal reaction on the ribs

The methods that were used to identify and record inflammatory periosteal reaction on the visceral surfaces of the ribs are presented below. This includes the techniques used for seriating the ribs, for identifying different types of IPR and differentiating it from other bony changes on the visceral surfaces of the ribs, and for calculating and presenting prevalence data.

6.6.1 Rib seriation

It has been suggested that the region of the rib cage affected by periosteal reaction may provide some insight to the type of respiratory disease affecting the individual (Santos & Roberts, 2006:47; Waldron, 2009:117). For this reason, the ribs were carefully sided as either left or right and placed into sequential order, wherever possible. Seriation of the ribs was aided by descriptions of morphological variation provided by Dudar (1993), Mann (1993), Scheuer and Black (2000:232-235), and Cirillo and Henneberg (2012). If a rib could not be accurately seriated due to poor preservation, then the approximate region of the rib cage that it corresponded to was recorded. These rib cage regions constituted five categories: '*upper*' (ribs 1-3), '*upper-middle*' (ribs 4-6), '*lower-middle*' (ribs 7-9), '*lower*' (ribs 10-12), and an additional category of '*middle*' (ribs 4-9) for ribs that were particularly problematic to identify, for example because of extreme fragmentation. In this way, the approximate region of the affected rib cage could be recorded.

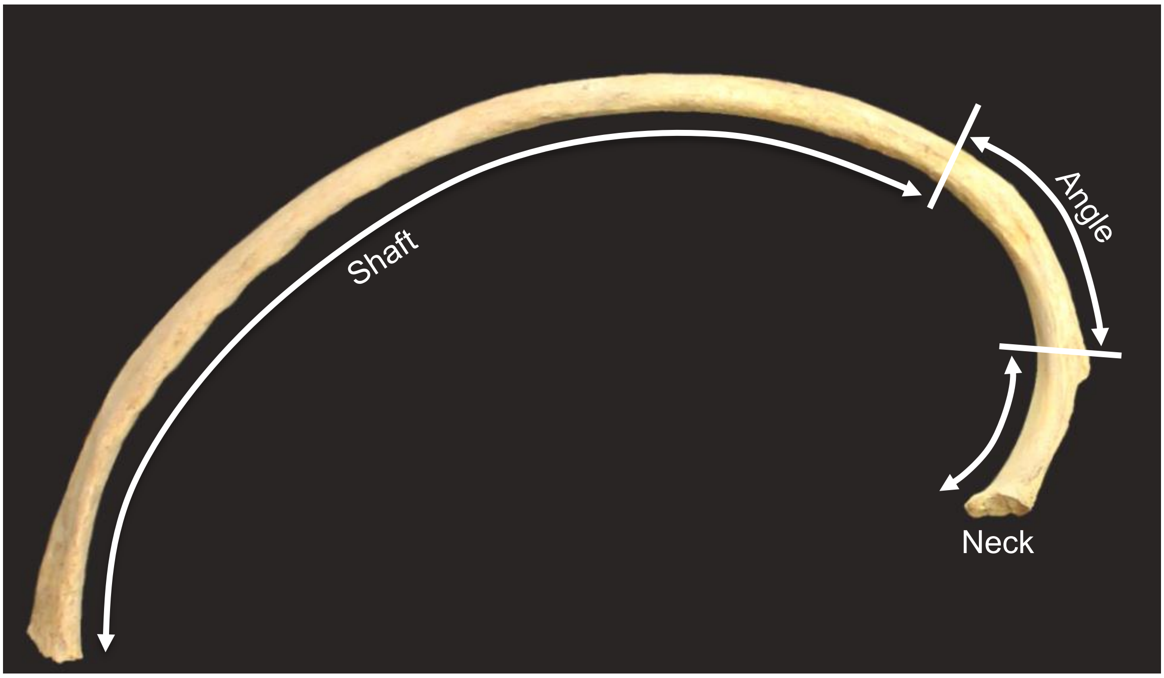


Figure 6.8 – The three sections of the rib recorded separately in the current study.
Image courtesy of the Trustees of the British Museum

To further investigate the distribution of IPR on the rib itself, the presence or absence of three separate sections of each rib were recorded: the neck, angle, and shaft (Figure 6.8). These sections were chosen because they could be demarcated by specific morphological features, and because they corresponded to the "zones" recommended for recording ribs in fragmented skeletal remains, according to the "zonation method" (Knüsel & Outram, 2004). The 'neck' consisted of the region of the rib from the costovertebral facet to the tubercle, the 'angle' from the tubercle to the furthest extent of the angle, usually delimited by a roughened line running supero-inferiorly (sometimes referred to as the oblique line), and the 'shaft' consisted of the remaining rib body to the sternal end. The presence of the visceral surface of each section of the rib was recorded separately within the same completeness categories used to record the sinuses and the rib cage as a whole (<5%, 5-24%, 50-74%, 75-100%).

6.6.2 Identifying pathological changes

Each fragment of rib larger than approximately $1cm^2$ was examined for evidence of periosteal reaction using a hand lens (x12 magnification) as an aide. If bony changes were identified, the rib number or rib cage region, the side, surface (external or visceral), and section of the rib affected (neck, angle, shaft) were all recorded, were it possible to identify these. The type of bone change (destructive, proliferative, or mixed) and the stage of IPR remodelling (woven, lamellar, or mixed/remodelling) were also noted. If bony changes were extensive, the distribution of IPR was drawn on a simple diagrammatic outline of the rib cage.

There are a lack of clear definitions and criteria related to the identification of different types of bone changes occurring on the visceral surfaces of the ribs (Naples & Rothschild, 2011:369) and this may have affected the consistency with which rib IPR has been recorded. During the process of the current research several types of bony changes to the visceral surfaces of the ribs were noted that lacked any current clinical evidence for a relationship to pleural or respiratory disease. These changes included irregular rib surface morphology and dense transverse bone formation at the tubercle. Additionally, destructive and mixed-reaction lesions on the ribs can have a variety of causes other than respiratory-related diseases. Therefore, the current research sought to establish criteria for identifying inflammatory periosteal reaction on the visceral surfaces of the ribs, and to differentiate it from other bony changes. To aid in identification and differentiation of bony changes on the ribs during this research a diagnostic flow chart was produced (Figure 6.9).

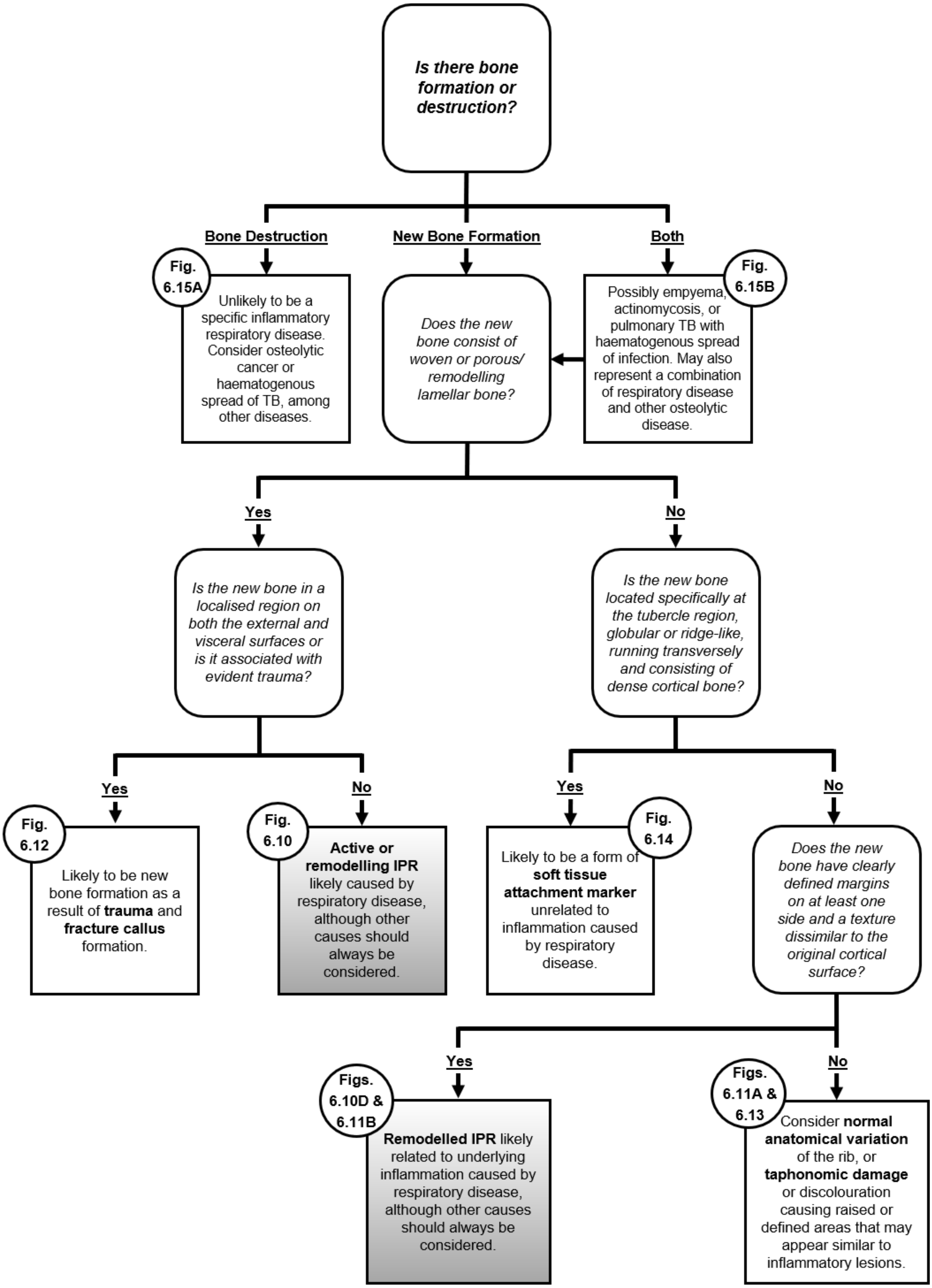


Figure 6.9 – A flowchart of the diagnostic criteria for identifying IPR likely related to respiratory disease (grey boxes) and differentiating it from other bony changes to the ribs.

6.6.2.i Inflammatory periosteal reaction

Only diffuse new bone formation (affecting the surface of the bone in a widespread or continuous distribution) on the visceral surface of the rib was considered to be evidence for inflammation of the underlying soft tissues (Figure 6.10). Considering the location of the pleurae and lungs in relation to the ribs, diffuse IPR was considered to most likely be caused by respiratory-related inflammatory processes. It should be noted, however, that other conditions, such as trauma or a chest wall tumour or abscess, could also be responsible (e.g. Waldron, 2009:117).

The descriptions for differentiating woven and lamellar bone provided by Matos and Santos (2006:Table 2), in their study of rib IPR in skeletons from the Luís Lopes Collection from Lisbon, were used to determine the type of new bone present, either '*woven*', '*mixed/remodelled*', or '*lamellar*' (Table 6.11). New bone formation was recorded as 'remodelled/mixed' if it demonstrated characteristics belonging to both the woven and lamellar bone categories. Completely remodelled lamellar bone is often difficult to distinguish from the original cortical surface. To reduce false-positive recording, lamellar IPR was only recorded as present if the new bone formed a distinct layer on top of the original surface, with a texture dissimilar to the original cortical bone and/or clearly defined margins. The processes of taphonomic delamination can also appear similar to some forms of lamellar IPR formation (Figure 6.11). Care was taken to distinguish new bone formation from taphonomic delamination by identifying a surface texture dissimilar to the original cortical bone or evidence for a distinct raised new layer of bone on top of the original surface.

Table 6.11 – Descriptions of the distinctive characteristics of lamellar and woven bone, used for macroscopic differentiation (after Matos & Santos, 2006:Table 2).

	Woven bone	**Lamellar bone**
Surface	Heterogenous unstructured appearance. Thin, scalloped, and irregular.	Homogenous structured appearance. Thick, compact, and dense.
Porosity	Intense porosity, with pores usually small in diameter. Many sinuous vascular grooves and channels.	Sparse or non-existent porosity. Pores usually large in diameter and scattered.
Limits and cortical integration	Limits well-defined. Irregular margins. Cortical integration non-existent. Detachable appearance.	Regular limits but difficult to differentiate from original cortex of rib. High cortical integration.

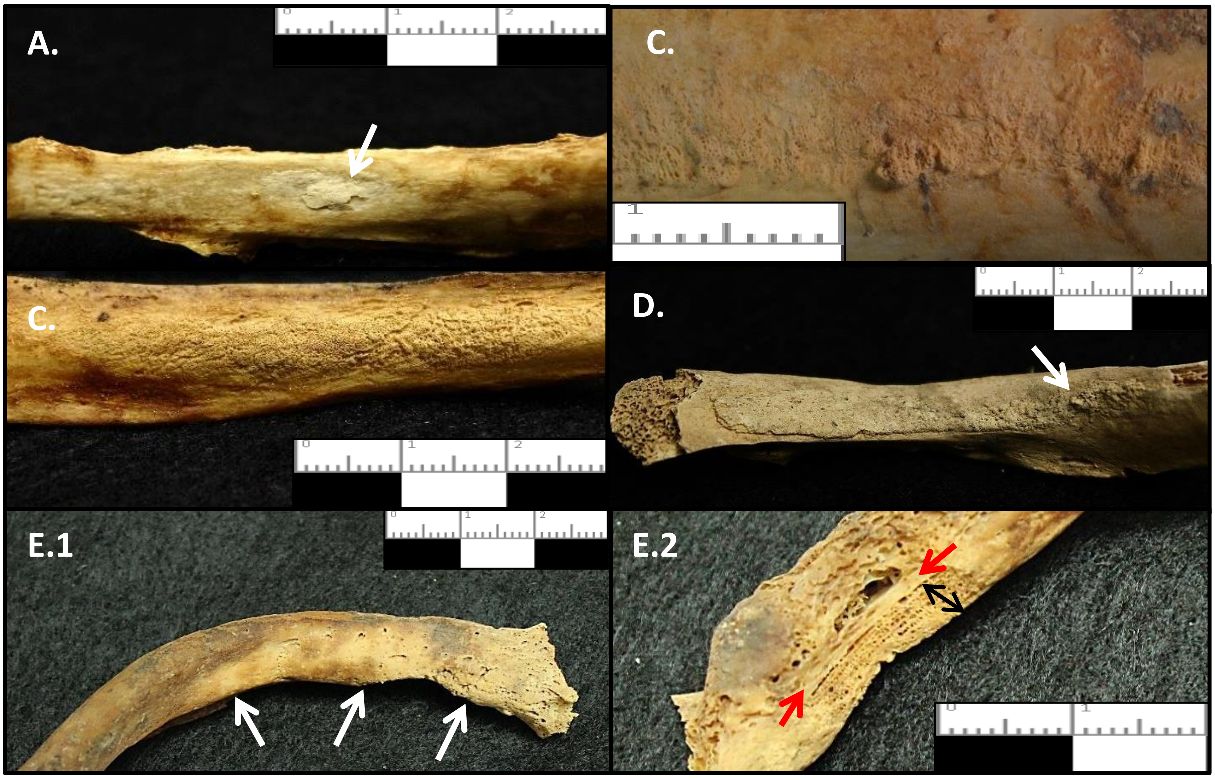


Figure 6.10 – Examples of the range of periosteal new bone formation that can be observed on the visceral surfaces of the ribs, from a small subtle deposit to extensive thickening.

A. **A very fine plaque of remodelling woven bone (arrow) on the angle section, becoming detached from the cortical surface. This can be mistaken for taphonomic delamination of the outer surface of the cortical bone (see Figure 6.11)** (site 3-J-23, Sk39, right 3rd rib).

B. **Subtle and irregular patches of woven bone along the shaft, just above the costal groove** (site 3-J-23, Sk55, right 7th rib).

C. **A large diffuse region of woven bone along the shaft** (site 3-J-23, Sk38, left 5th rib).

D. **A plaque-like layer of woven and lamellar bone on the neck, with a region of irregular remodelling woven bone (arrow) at the angle** (site 3-J-23, Sk132, left 7th rib).

E.1. **The superior view of extremely thickened neck and angle regions (arrows) as a result of prolific periosteal bone formation. E.2. Inferior view, revealing layers of new bone deposits (black arrow), approximately half a centimetre in width, on top of the original cortical surface (red arrows)** (site 3-J-18, Sk2248, right middle rib).

Images courtesy of the Trustees of the British Museum

Rib fractures in various stages of healing can also mimic the appearance of respiratory-related IPR on the visceral surface of the rib (Figure 6.12). Therefore, care was taken to identify and record new bone formation related to rib fractures separately from IPR, usually with the identification of the remodelled margins of the fracture or localised callus formation on both the visceral and external rib surfaces, particularly at the superior and inferior borders.

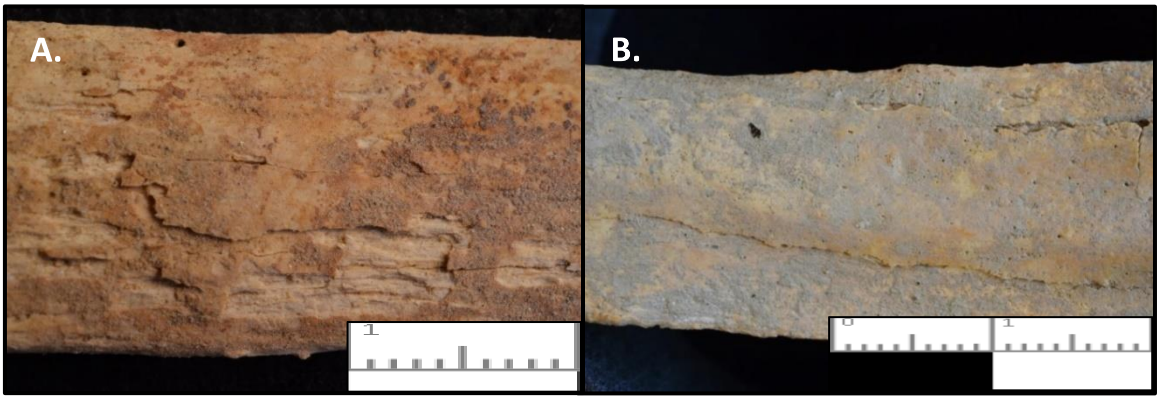


Figure 6.11 – An example of the similarity between taphonomic delamination (A.) and plaque-like periosteal bone formation (B.) on the visceral surfaces of the ribs. (See also Figure 6.10A).

A. **Taphonomic delamination of the cortical surface of the shaft, which can be mistaken for remodelled lamellar bone formation** (site 3-J-18, Sk4188, left upper-middle rib).
B. **Remodelled lamellar bone formation on the shaft, with clearly defined margins** (site 3-J-23, Sk132, left 10th rib).

Images Courtesy of the Trustees of the British Museum

Figure 6.12 – Woven bone on the visceral surface of the rib (arrows) as a result of antemortem fractures, which can be mistaken for periosteal reaction related to respiratory disease (site 3-J-23, Sk126, left 9th rib).

Image Courtesy of the Trustees of the British Museum

6.6.2.ii Irregular surface morphology and transverse bone formation

The visceral surfaces of the ribs can often be irregular and it has been suggested that striated or nodular surface morphology may represent initial or healed subtle IPR (Nicklisch et al., 2012:393) (Figure 6.13). However, Naples and Rothschild (2011:371) have noted that the attachment sites of the intercostal muscles, which can be found on the superior and inferior margins of the ribs, can often extend onto the visceral surfaces. Additionally, any region of the rib not serving as an attachment site for muscle is covered by aponeuroses, thin fibrous tissue that acts like a tendon for sheet-like muscles (Naples & Rothschild, 2011:371). It is not known to what extent the attachment of the intercostal muscles or the aponeuroses can affect variability in visceral surface morphology.

Strain on these soft tissues could stimulate mild irregular new bone formation. Therefore, irregular surface morphology was not considered as evidence of IPR related to respiratory disease.

Figure 6.13 – An example of irregular and slightly nodular visceral surface morphology on the rib shaft (site 3-J-23, Sk39, Right lower-middle rib).
Image courtesy of the Trustees of the British Museum

Additionally, raised globular or ridge-like new bone can form in the regions of the neck and tubercle, running transversely along the visceral surface (Figure 6.14). This type of bony change was commonly observed in skeletons from the sites analysed in the current study. Variable in size, this unusual bone formation consisted of dense cortical bone, usually confluent with the original surface, and is reminiscent of osteoblastic bone changes related to entheseal changes (bone forming at a tendon or ligament attachment site) or exostosis (a benign bony growth on the surface of the bone) (e.g. Resnick, 2002:Chapter 76; Ponce, 2010; Henderson et al., 2016). Due to the specific location, composition of the bone, and transverse organisation of these lesions, they were not considered to be consistent with diffuse inflammation and were, therefore, not recorded in the current study as IPR. Instead the invariable position of these lesions at the neck and tubercle region suggests they may be related to specific soft tissue attachments in this area.

These unusual ridges may be evidence for the origin or insertion points of subcostal muscles, which can be found on the dorsal aspect of the thoracic cavity, around the angle. These small muscles originate on the superior visceral surface of the rib, bridge one or two ribs, and insert into the visceral surface of a rib two or three places higher (Rickenbacher et al., 1982:76). However, the presence and position of these muscles is highly variable between individuals and their insertion point has not been well documented. Extreme strain around the costo-transverse ligament and subsequent trauma or micro-tearing of the endothoracic fascia or local soft tissue may also be a cause, considering the specific location of these lesions at the region of the tubercle. Strain of subcostal muscles or the costo-transverse ligaments could be related to respiratory symptoms such as chronic and violent cough. However, further research into these unusual lesions is required before a concrete cause can be suggested.

Figure 6.14 – Transverse bone formation in the region of the neck and tubercle, consisting of dense cortical bone confluent with the original rib surface

A. **Small globular raised areas of bone at the tubercle region, running in a transverse line (arrow)** (site Gabati, Sk41-929, right 6th rib).
B. **A thin transverse ridge protruding considerably from the visceral surface at the neck and tubercle region (arrow)** (site 3-J-23, Gr67B, right 4th rib).
C. **An example of the contrast between transverse bone formation (white arrow) and diffuse periosteal reaction (red arrow). The small dense globule at the tubercle region is far more similar in appearance and density to the original cortical surface than the remodelling periosteal reaction on the neck** (site 3-J-23, Sk31, left 4th rib).

Image courtesy of the Trustees of the British Museum

It is unclear how many researchers have recorded transverse bone formation at the tubercle region as inflammatory periosteal reaction. Only Lambert (2002:286) has noted similar changes in skeletons from southwestern Colorado, USA, suggesting that the bony ridges observed may have been caused by a mechanical stressor. However, while this study also provided an image of a rib with bone changes in the neck and tubercle region, which appeared very similar to the globular transverse bone formation observed in the current research, it was described as an example of IPR (Lambert, 2002:Fig. 1F). This demonstrates the lack of consistency in diagnostic criteria for the identification of respiratory-related IPR, which can present a challenge for comparing prevalence rates between studies. In light of this, and to maintain consistency during this research and during the process of inter-observer error testing, the production of the flowchart (Figure 6.9) was considered essential.

6.6.2.iii Destructive and mixed bone reaction

Destructive lesions on the visceral surfaces of the ribs, with minimal to no new bone formation (Figure 6.15A), can be caused by a range of diseases, including cancer, haematogenous spread of extrapulmonary TB, and other conditions that can cause bone destruction (Guttentag & Salwen, 1999; Jeung et al., 1999). In skeletal tuberculosis, destructive lesions on the spine have been observed to extend onto the heads and necks of the ribs (e.g. Capasso & Di Tota, 1999; Mays et al., 2002:28; Ortner, 2003:246). However, this form of rib lesion is likely to be caused by the indirect impact of spinal tuberculosis rather than by inflammation caused by specific infection of the lower respiratory tract. As skeletal tuberculosis is more commonly caused by a non-pulmonary route of infection, for example by the consumption of infected animal products (Resnick, 2002:2524; Talbot et al., 2007:405), extension of destructive lesions from the spine to the ribs cannot be considered as direct evidence for lower respiratory tract infection. Pulmonary tuberculosis may also cause isolated destructive lesions on the ribs, for example through formation of chest wall abscesses or soft tissue masses, but this is rare (Ip et al., 1989:242; Asnis & Niegowska, 1997:1019) and is difficult to distinguish from other destructive disease processes, such as cancer. Therefore, destructive lesions on the ribs were not included as evidence for respiratory disease in the current study.

Mixed reaction lesions on the visceral surfaces of the ribs, consisting of destruction and new bone formation (Figure 6.15B), have been linked to respiratory diseases such as tuberculosis, pneumonia, and actinomycosis, which can cause pleural empyema and subsequent osteomyelitis of the ribs (e.g. Guttentag & Salwen, 1999:1138; Jeung et al., 1999:621; Madeo et al., 2013). Mixed-bone reaction can also be the result of the co-occurance of IPR, due to a lower respiratory tract disease, and rib destruction caused by another form of disease. In the current study, on the rare occasion that diffuse IPR was present alongside destructive lesions, it was considered to be evidence for bony reaction related to respiratory disease. However, there are a number of other conditions that can cause a mixed reaction on the ribs, including neoplastic disease or osteomyelitis resulting from chest wall trauma (e.g. Guttentag & Salwen, 1999:1130-1133). Thus, the entire skeleton was examined for any further evidence that a mixed bone reaction may have been caused by another type of disease, such as evidence for related metastases on other bones.

Figure 6.15 – Destructive lesions of the ribs, possibly the result of tuberculosis, empyema, or metastases.

A. **A destructive lesion on the superior margin of the rib, at the angle** (site 3-J-23, Sk59, right 9th rib).
B. **A mixed destructive and prolific lesion on the visceral surface of the shaft. Destruction of the cortical surface is accompanied by diffuse woven bone formation around the margins** (site 3-J-18, Sk4361, left 9th rib).

Image courtesy of the Trustees of the British Museum

6.6.3 Presenting prevalence

Studies of rib IPR have usually presented prevalence rates based on a calculation of the percentage of individuals within the total sample displaying periosteal reaction (referred to as crude prevalence). This form of prevalence was also calculated in the current study. However, the poor preservation of the ribs can often affect the proper identification and recording of IPR (Roberts, Boylston et al., 1998:58; Santos & Roberts, 2006:47). The preservation of the ribs in individual skeletons, or between different sites, can be highly variable and the survivability of different sections of the rib itself differs. For example, the shaft often does not survive as well as the neck and angle, and can become very fragmented during burial and excavation. This affects the observation of the complete rib cage and the accurate assessment of the presence or absence of rib IPR. Therefore, in poorly preserved skeletal remains, presenting prevalence rates by the number of individuals affected does not take into consideration that only a small portion of the rib cage may be observable and can skew frequencies towards lower prevalence rates when compared to well-preserved sites. This affects the direct comparability of crude prevalence rates between sites with differing levels of preservation.

In order to provide a form of data more comparable between sites with different levels of preservation, a new method of recording and presenting the true prevalence of rib IPR was also produced. This method takes into consideration the variable preservation and fragmentation of different parts of the rib, presenting true prevalence rates for the three separate sections of the rib that were recorded: the neck, angle, and shaft. Prevalence rates were calculated according to rib number (e.g. the percentage of 5th ribs affected), when specific ribs could be identified, and according to rib cage region (e.g. the percentage of ribs in the upper-middle rib cage region affected). Simple conversion of prevalence by rib number into prevalence by rib cage region allowed for the direct comparison between poorly-preserved sites, where exact rib number could not always be easily identified, and well-preserved sites.

While this method does not provide information about the number of people within a population who had respiratory disease, it does allow for a comparison between differentially preserved sites. It also provides the means to accurately reconstruct the distribution of IPR within the rib cage in different populations. As it has been suggested that the region of the rib cage affected by IPR may provide some insight to the type of disease present (Santos & Roberts, 2006:47; Waldron, 2009:117), this method will allow for a greater investigation into the potential differential diagnoses of rib IPR in different populations.

6.7 Other disease processes

In order to investigate evidence for specific diseases that may have caused maxillary sinusitis or rib IPR in Middle Nile Valley populations every available bone from each individual was analysed. In instances of pathological lesions, the element affected, its side, the region on the bone, the type of bone activity, and the distribution of the lesion were all recorded and described. As tuberculosis and leprosy are thought to increase susceptibility to maxillary sinusitis (e.g. Hauhnar et al., 1992; Sharma et al., 1998; Kiris et al., 2007; Kant et al., 2013; Kim et al., 2014), and tuberculosis has been closely linked to the presence of rib IPR (e.g. Roberts, 1994; Santos & Roberts, 2001, 2006; Matos & Santos, 2006), lesions fitting the changes associated with these diseases were investigating according to established diagnostic criteria.

While the skeletal response to disease is limited, meaning that many conditions can produce similar pathological reactions within the skeleton, different pathological processes may manifest in different ways and can affect different groups of bones. An analysis of the form and distribution of lesions can allow for possible differentiation (e.g. Ortner, 2008:62). Therefore, in the current research, a careful consideration of the type and distribution of pathological changes across the bones of the skeleton was employed when suggesting the presence of any potential specific diseases.

6.7.1 Tuberculosis

Skeletal tuberculosis targets areas with a high proportion of trabecular bone (Resnick, 2002:2535). It frequently affects the spine, forming expansive abscesses in and between the vertebrae, which produce erosive lesions. The anterior aspect of the vertebral body is most commonly affected, with a predilection for involvement of the thoracolumbar region of the spine, most frequently of the first lumbar vertebra (Turgut, 2001:11; Resnick, 2002:2527-2529; Garg & Somvanshi, 2011:442). Expansion of abscesses and erosion of the vertebrae may eventually result in collapse of one or more vertebral bodies and ankylosis of the posterior elements, producing an angulated kyphosis of the spine, known as Pott's spine (Resnick, 2002:2532; Garg & Somvanshi, 2011:442; Pigrau-Serrallach & Rodríguez-Pardo, 2013:S559). The posterior elements of the vertebra, including the neural arch, spinous process, and superior and inferior articular facets, are only rarely affected (Resnick, 2002:2527; Garg & Somvanshi, 2011:442). New bone formation in association with these lesions is generally absent (Harisinghani et al., 2000:456). The tuberculous mycobacteria can also spread haematogenously to the joints and metaphyses of other bones (Al-Sayyad & Abumunaser, 2011:398). This form of arthritis leads to erosion of the cartilage, and destruction of the bone surfaces of the joints and metaphyses, and can result in ankylosis (Resnick, 2002:2540-2541; Talbot, 2007:408). Usually only one joint is involved, most frequently the hip or knee (Watts & Lifeso, 1996:292; Resnick, 2002:2539; Talbot et al., 2007:408; Pigrau-Serrallach & Rodríguez-Pardo; 2013:S561). While involvement of the joints is more common in adults, in children the hands, feet, skull vault, and diaphyses can be frequently involved, producing osteomyelitis and uni- or multi-focal cystic lesions (Tao & Peh, 2004:858-859).

In the current study, potential instances of tuberculosis were identified according to the classic skeletal changes described in palaeopathology textbooks, such as Aufderheide and Rodríguez-Martín (1998), Ortner (2003), Roberts and Manchester (2010) and Waldron (2009), among others. This includes, in general, almost exclusively lytic lesions, with very little new bone formation, localised to areas of bone with high proportions of trabecular bone (e.g. Kelley & El-Najjar, 1980; Aufderheide & Rodríguez-Martín, 1998:134; Ortner, 2003:230). Significant lytic lesions of the vertebral bodies, with possible vertebral collapse and kyphosis of the spine, and/or unifocal joint destruction, with minimal new bone formation and possible ankylosis, were considered as essential criteria for distinguishing tuberculosis (Figure 6.16).

Figure 6.16 – Typical changes related to tuberculosis (site 3-J-23, Sk75, right aspect of spine and superior aspect of left and right 8th and 9th ribs).

A. **A reconstruction of a spine with Pott's disease, displaying collapse of the vertebral bodies and angular ankylosis of the vertebral column (arrow), which resulted in considerable kyphosis of the upper part of the spine.**
B. **The spread of destruction from the vertebrae was also likely to have caused the large cystic-like destructive lesions present on the heads of the ribs. These ribs also displayed thickened regions on the visceral surfaces at the neck and angle, as a result of lamellar periosteal bone formation.**

Images courtesy of the Trustees of the British Museum

Other possible skeletal indicators of tuberculosis have also been investigated by bioarchaeologists (e.g. Roberts & Buikstra, 2003:99-109), including IPR on the ribs (e.g. Kelley & Micozzi, 1984; Roberts, 1994; Santos & Roberts, 2001, 2006; Matos & Santos, 2006). Hypertrophic osteoarthropathy (HOA), which among other clinical manifestations causes digital clubbing and extensive bilateral new bone formation on the long and short bones (Meyer et al., 2017:1; Yap et al., 2017:163), has been significantly associated with individuals who died from tuberculosis in the Coimbra Collection, when compared to those with a non-pulmonary cause of death (Assis et al., 2011:160). A high number of instances of HOA are also caused by altered lung function, related to interstitial lung disease, lung tumour, or reduced circulation to the lungs, and other pulmonary and pleural disease can also be involved (Yap et al., 2017:160). However, HOA can be produced by a wide range of diseases, including various cancers, infections, inflammatory diseases such as sarcoidosis, cardiac disease, and numerous other conditions (Meyer et al., 2017:3; Yap et al., 2017:Table 2). Thus, the presence of the disease cannot specifically be related to tuberculosis or another respiratory condition without evidence for further specific pathological changes in the skeleton.

The identification of tuberculosis is complicated by several differential diagnoses. Other destructive diseases, such as malignant bone tumours, osteomyelitis, actinomycosis, sarcoidosis, and brucellosis, can mimic lytic lesions produced by TB (Aufderheide & Rodríguez-Martín, 1998:140-141; Ortner, 2003:263; Roberts & Buikstra, 2003:Table 3.3). Additionally, non-tuberculous septic arthritis of the joints, caused by other types of infection, can be confused with that caused by TB. While both are accompanied by marginal erosions, ankylosis and bony proliferations occur more frequently in septic arthritis, and osteoporosis and slow progression of the diseases arise more commonly with tuberculosis, providing a possible differentiation (Resnick, 2002:Table 61-2).

Brucellosis, a bacterial disease passed from animals to humans, was also likely to have been common in the past and can produce lytic lesions of the vertebral plates (Young, 1995:283; Alp & Doganay, 2008:574). The disease can also cause osteomyelitis and septic arthritis, particularly of the weight bearing joints (Al-Shahed et al., 1994:334; Young, 1995:285; Ebrahimpour et al., 2017:46), which occurs in tuberculosis, making it difficult to differentiate the two diseases. However, brucellosis can involve new bone formation, including prolific periosteal reaction and dense sclerosis of the margins of lytic lesions, providing a possible differentiation (Al-Shahed et al., 1994; Aufderheide & Rodríguez-Martín, 1998:140, Waldron, 2009:96). The disease can have a distinctive focal form that only affects the anterior region of the superior end plate of the vertebra, producing erosive lesions, sclerosis of the margins, and anterior osteophyte formation in this area (Al-Shahed et al., 1994:336). For example, Capasso et al. (1999:278) used the presence of anteriorly-located erosive lesions on the superior endplate, accompanied by periosteal reaction and sclerosis, to identify brucellosis in archaeological skeletons from Herculaneum, Italy. If the disease persists, diffuse erosion of the entire vertebral end plate can occur (Al-Shahed et al., 1994: 339). The lumbar spine, particularly L4, has been found to be the most common site of brucellar infection (Al-Shahed et al., 1994:335). Collapse and kyphosis of the spine and the production of paraspinal abscesses are rare compared to tuberculosis, also allowing for possible differentiation (Al-Shahed et al., 1994:340; Young, 1995:285).

6.7.2 Leprosy

Leprosy is a chronic infection caused by the pathogens *Mycobacterium leprae* and *M. lepramatosis* (Lastória & de Abreu, 2014:205; White & Franco-Paredes, 2015:80). It primarily affects the skin and nerves, but can also involve the eyes, mucous membranes, bones, and multiple organ systems (Lastória & De Abreu, 2014:213; White & Franco-Paredes, 2015:80). The clinical manifestations and severity of the disease are dependent on the immune response of the sufferer (Lastória & De Abreu, 2014:209; White & Franco-Paredes, 2015:82). Thus, expression of the disease has been categorised into several stages, the mildest known as tuberculoid leprosy and the most severe known as lepromatous leprosy (Bhat & Prakash, 2012:2; White & Franco-Paredes, 2015:82). During the course of the disease the bacilli infect the peripheral nerves, leading to sensory and motor loss (White & Franco-Paredes, 2015:80). Additionally, acute episodes of inflammation can occur, increasing nerve damage and sensory loss, and affecting the skin and other organs (Bhat & Prakash, 2012:2; Lastória & De Abreu, 2014:209; White & Franco-Paredes, 2015:82).

Leprosy can affect the skeleton via three different mechanisms: primary lepromatous osteomyelitis and periosteal reaction, resorption of bone due to neurological degeneration, and non-specific osteomyelitis and septic arthritis as a result of secondary infection (Enna et al., 1971; Resnick, 2002:2546). Direct invasion of the bone by lepromatous bacteria is rare, affecting the small bones of the hands and feet and causing diffuse periosteal reaction or small destructive lesions (Resnick, 2002:2547). Infection of the peripheral nerves, the loss of sensation, and the lack of muscle innervation can result in atrophy, causing the concentric loss of the diaphyseal bone of the phalanges, metatarsals and metacarpals. The loss of sensation can also lead to injury and secondary infection, particularly to the hands and feet (Enna et al., 1971:299-301; Resnick, 2002:2548-2550; Lastória & De Abreu, 2014:212). This is apparent as septic arthritis, osteomyelitis, and diffuse periosteal reaction in the hands and feet, and periosteal reaction on the distal ends of the lower leg bones (Enna et al., 1971:298; Skinsnes et al., 1972:378; Resnick, 2002:2547, 2551). As leprosy is transmitted by inhaled infectious droplets, the nasal region is directly affected, leading to chronic rhinitis and damage to the bones of the nasal cavity, such as the anterior nasal spine, vomer, and nasal conchae. Resorption and remodelling of the margins of the nasal aperture and anterior maxillary alveolar process also occur, and result in inflammatory pitting of the palate. These changes in the facial region are known as facies leprosa or, preferably, as rhino-maxillary syndrome (Enna et al., 1971:296; Marks & Grossetete, 1988:21; Kasai et al., 2018:8).

As with tuberculosis, leprosy was diagnosed according to the classic skeletal changes extensively described in palaeopathology textbooks (e.g. Aufderheide & Rodríguez-Martín, 1998:150-154; Ortner, 2003:265-271; Waldron, 2009:100-101), which generally place importance on the presence of rhino-maxillary syndrome and atrophic loss of the bone of the metatarsals/metacarpals and phalanges (Figure 6.17). Although rhino-maxillary syndrome is often considered pathognomonic of leprosy (e.g. Aufderheide & Rodríguez-Martín, 1998:150; Roberts & Manchester, 2010:198; Waldron, 2009:101), other disease processes such as syphilis, leishmaniasis, tuberculosis, osteomyelitis, and other infections of the nasal, sinus, or oral cavities can cause similar resorption (Ortner, 2003:264; Roberts & Buikstra, 2003:100; Roberts & Manchester, 2010:198; Robbins et al., 2009:e5669; Antunes-Ferreira et al., 2013:156). Resorption of the phalanges, known as acroosteolysis, and concentric bone loss can occur due to a number of conditions, including psoriatic arthritis, thermal injuries such as frostbite, hereditary conditions, neural conditions, rheumatoid arthritis, tuberculous arthritis, and systemic sclerosis (Destouet & Murphy, 1983; Antunes-Ferreira et al., 2013:156). Thus, recording the distribution pattern of characteristic lesions of different pathological conditions is essential to differentiate potential causes.

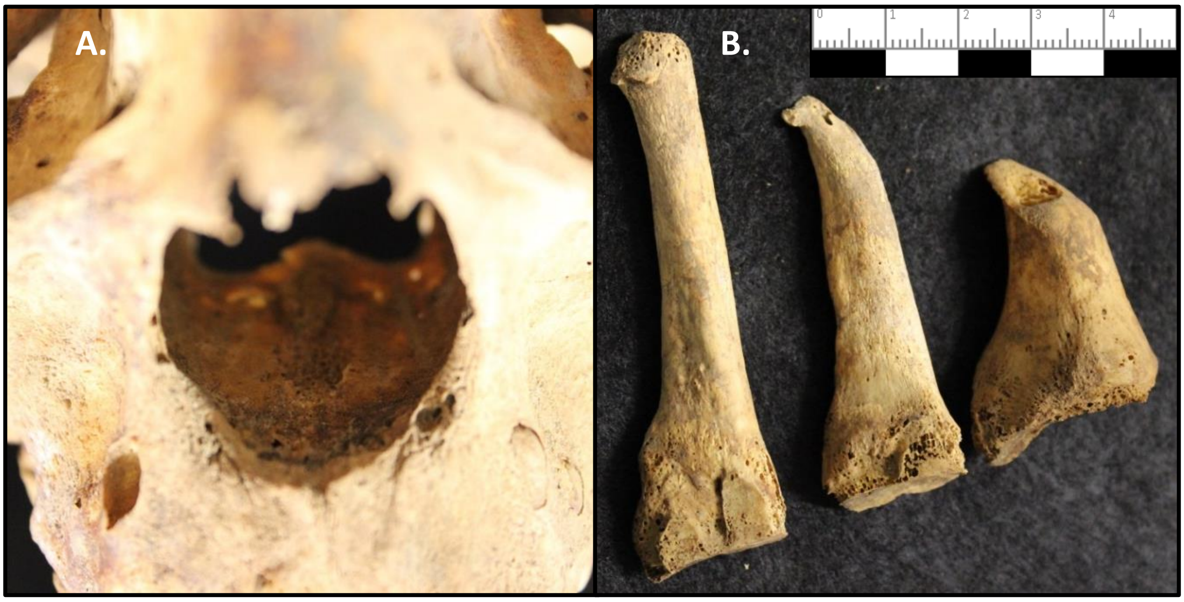


Figure 6.17 – Typical changes of the nasal region (A.) and metatarsals (B.), related to leprosy.

A. **Anterior aspect of the nasal cavity, displaying resorption and widening of the nasal aperture, porosity of the margins, and complete resorption of the anterior nasal spine, vomer, and inferior nasal conchae** (site 3-J-18, Sk2097, cranium).
B. **Medial aspect of the right metatarsals, displaying pronounced concentric resorption of the heads and diaphyses** (site 3-J-18, Sk2139, right 3rd, 2nd, and 1st metatarsals).

Images courtesy of the Trustees of the British Museum

6.8 Intra- and inter-observer error testing

To test for inconsistencies in using the developed methods, intra- and inter-observer error testing was undertaken. This testing can highlight issues with the consistency of recording by an observer, or between observers, and can give an indication of the reproducibility of results.

6.8.1 Intra-observer error testing

Eight skeletons were randomly selected to be reanalysed by the author six months after the original analysis. The left and right maxillary sinuses were recorded separately for completeness, the presence or absence of bony changes related to maxillary sinusitis, and the type of bony change observed according to the diagnostic criteria of Boocock et al. (1995). The left and right rib cages were also recorded separately for completeness, the presence or absence of new bone formation on the visceral surfaces, the type of bone formed (woven, lamellar, or mixed/remodelling), and the specific ribs affected, as per the original methodology. The data obtained from the intra-observer error testing are presented in Appendix C and are summarised below.

The intra-observer error results indicate that data recorded by the author in the first and second instances corresponded fairly well. In particular, the recording of the presence or absence of sinusitis and rib IPR matched in most instances. Only in one sinus were bony changes not noted in the second recording. As the first recording observed a wide range of bony changes to the sinus surface, this discrepancy is unusual but may have resulted from subsequent handling and damage in between analyses, which prevented further observation of bony changes. The right side of one rib cage was not analysed for rib IPR in the second recording because it was allocated a completeness category of <5%, whereas in the first recording it was allocated a completeness category of 5-24%. This may be due to damage occurring in between recordings or to slight changes in the criteria of the author for determining the percentage of rib cage completeness. There were some discrepancies between the completeness category allocated for both ribs and sinuses, with one in four instances of completeness category allocation not matching with the original recording. Again, this may be due to slight changes in the criteria used by the author to allocate percentage completeness.

There was only one minor discrepancy in the type of bone changes recorded in the maxillary sinuses, suggesting that the type of bone changes present at each site were recorded with consistency throughout the research. However, when the results for the type of bone formed on the ribs were compared, in two out of three instances the results of the first and second recordings did not correspond. It appears that differentiation between woven and remodelling bone proved problematic and the criteria of the author for distinguishing the two types of bone may have changed over time and with experience. Nevertheless, in general the results indicate that the recording of prevalence (i.e. presence or absence) of maxillary sinusitis and rib IPR across all sites was likely to have been relatively consistent throughout the data collection period undertaken for the current study.

6.8.2 Inter-observer error testing

Eight skeletons were selected to be recorded by two other bioarchaeologists (RW and TVM), to compare with the data recorded by the original researcher (ADB). Specific skeletons were chosen by the author to represent a range of pathological changes and degrees of preservation and fragmentation. The two participants had no prior experience of recording either bony changes related to maxillary sinusitis or IPR on the ribs. Participants of the inter-observer error testing were provided with a detailed printout of the methods employed in the current study, as described in this chapter, and were also given the diagnostic criteria for maxillary sinusitis produced by Boocock et al. (1995) and the flowchart (Figure 6.9) for identifying rib IPR and differentiating it from other bony changes on the ribs. To counteract inexperience, labelled images of a range of bony changes to the ribs and in the sinuses were also provided. To save time, the ribs were sided and seriated by the original researcher (ADB). Participants were then asked to analyse the ribs and sinuses of the eight skeletons according to the methods provided. These results were recorded using the same recording form employed in the current study and were compared to the original results produced by the author. The data obtained from the inter-observer error testing are presented in Appendix D and are summarised below

The results for the recorded presence or absence of maxillary sinusitis corresponded between observers in the majority of instances. In one skeleton, subtle bony changes of the sinuses were recorded by only two observers. Additionally, one sinus was allocated by two observers to the completeness category of <5% and was not recorded for bony changes, but was observed for maxillary sinusitis by one observer who recorded a completeness category of 4-24% for this sinus. While the recording of the presence and absence of bony changes within the sinus for the most part corresponded between observers, the type of bony changes identified did not match in any instances. Although images were provided to aid in the identification of the type of bony change, this discrepancy may be the result of the inexperience of the two participants in identifying and differentiating the range of bone changes that can occur in the sinus, including more subtle bone changes.

Similarly, correspondence between results for the recorded presence or absence of rib IPR was poor in the early stages of the test, but increased over time. This may be due the increasing experience of the participants in identifying rib IPR with each skeleton analysed. Indeed, after the inter-observer error testing had been completed, it was noted by both participants that the identification of rib IPR became easier over the course of the test after skeletons with more obvious examples of rib IPR had been examined. There was also very little correspondence between the type of bone formation observed or the number of ribs affected. Again, this may be due to inexperience, for example in identifying the more subtle bone changes occurring on ribs.

These results indicate that the level of experience of a researcher may have a significant impact on the data recorded. To counteract the effect of inexperience on the accurate identification of pathological changes related to respiratory disease, prior to undertaking data collection for the current study, the author observed a range of skeletons with different types of bony changes to both the ribs and sinuses that had been previously identified by other experienced bioarchaeologists.

Overall, the results of the inter-observer error testing indicate that, while the recording of maxillary sinusitis prevalence corresponds between observers and, therefore, prevalence rates between studies may be comparable, the accurate identification of rib IPR is likely to be dependent on the level of experience of the observer. Additionally, the type of bony changes recorded for the sinuses and the ribs, and the distribution of rib IPR in the rib cage, may be highly variable between researchers. Caution should be applied when comparing this form of data between studies.

6.9 Statistical analysis

All data collected and analysed was input into the statistical analysis software SPSS 24. This software was used to calculate frequencies and percentages of disease prevalence and to statistically analyse the data. The majority of the data collected was categorical, in that it had one or more categories with no intrinsic ordering. To test for statistically significant differences in disease prevalence between groups using categorical data, Pearson's Chi-Square and Fisher's Exact tests were employed and the two-tailed p-value was used (testing for the possibility of a relationship in two directions, as either significantly greater or significantly less than the expected distribution). In the results, the p-value obtained from a Pearson's Chi-Square test is denoted by the symbol χ^2 and the p-value obtained from a Fisher's Exact test is denoted by the symbol [FET]. Differences between groups were considered statistically significant if the p-value was equal to or below 0.05. This value indicated there was only a 5% chance that the results were different due to random sampling error.

Fisher's exact test is considered more accurate for smaller sample sizes and was applied to all tests between groups that contained a sample size less than 100. A Pearson's Chi-Square test was employed when all categories within the test had a sample size over 100, or in instances when more than three groups of data were being compared (i.e. a contingency table larger than 2x2), as this cannot be facilitated by a Fisher's exact text. Yate's correction is often applied to the results of Chi-

Square tests, to account for a bias towards a lower p-number in small sample sizes. However, this correction is not applicable to two-sided tests as it can cause an overcorrection of the p-value, producing overly conservative results (Stefanescu et al., 2004:4) and was, therefore, not employed in the current study.

Chapter 7: Results

7.1 Introduction

The results from each site are presented below in three separate sections: demography and preservation, prevalence and statistical testing of maxillary sinusitis, and prevalence and statistical testing of inflammatory periosteal reaction of the ribs. In the maxillary sinusitis section, the different potential routes of sinus infection (i.e. rhinogenic or odontogenic), the side of the sinus affected (i.e. left, right, or bilateral), and the percentage of the different types of bony changes observed are all presented by site and by time period. In the rib IPR section, the stages of remodelling of IPR and the side of the rib cage affected (i.e. left, right, or bilateral) are also provided by site and by time period. The results are presented first by the Fourth Cataract sites/time periods in chronological order and then according to comparative sites/time periods in chronological order.

7.2 Demography and preservation

The results relating to sex and age estimation and maxillary sinus and rib cage preservation in skeletons from each site are presented below. Table 7.1 displays the number and percentage of skeletons within each sex category recorded for each site. For the further analysis of data by sex, these categories were pooled into '*female*' (consisting of female and female? groups), '*male*' (consisting of male and male? groups) and '*unknown*' (consisting of unknown and indeterminate groups). Figure 7.1 displays the proportion of each pooled sex category observed at each site. A slightly higher proportion of males than females were observed at the majority of sites.

Table 7.1 – The percentage of individuals in each sex category from each site. Frequencies are presented in brackets below.

Site	Female	Female?	Indeterminate	Male?	Male	Unobservable
4-L-2	6.5% (2/31)	16.1% (5/31)	3.2% (1/31)	19.4% (6/31)	25.8% (8/31)	29.0% (9/31)
4-L-88	12.5% (1/8)	0.0% (0/8)	0.0% (0/8)	0.0% (0/8)	50.0% (4/8)	37.5% (3/8)
4-L-100	0.0% (0/5)	0.0% (0/5)	0.0% (0/5)	0.0% (0/5)	20.0% (1/5)	80.0% (4/5)
3-Q-33	20.0% (4/20)	20.0% (4/20)	0.0% (0/20)	5.0% (1/20)	50.0% (10/20)	5.0% (1/20)
3-O-1	5.9% (1/17)	5.9% (1/17)	11.8% (2/17)	5.9% (1/17)	52.9% (9/17)	17.6% (3/17)
4-M-53	28.6% (2/7)	0.0% (0/7)	0.0% (0/7)	0.0% (0/7)	57.1% (4/7)	14.3% (1/7)
3-J-23	34.3% (23/67)	14.9% (10/67)	4.5% (3/67)	9.0% (6/67)	37.3% (25/67)	0.0% (0/67)
3-J-18	38.1% (45/118)	7.6% (9/118)	4.3% (5/118)	11.9% (14/118)	37.3% (44/118)	0.8% (1/118)
R12	0.0% (0/43)	9.3% (4/43)	0.0% (0/43)	30.2% (13/43)	2.3% (1/43)	58.2% (25/43)
P37	5.9% (2/34)	20.6% (7/34)	5.9% (2/34)	8.8% (3/34)	44.1% (15/34)	14.7% (5/34)
Gabati	24.1% (26/108)	13.9% (15/108)	0.9% (1/108)	10.2% (11/108)	29.6% (32/108)	21.3% (23/108)
Soba East	8.6% (3/35)	8.6% (3/35)	5.7% (2/35)	25.7% (9/35)	22.9% (8/35)	28.5% (10/35)
Total	22.1% (109/493)	11.8% (58/493)	3.2% (16/493)	13.0% (64/493)	32.7% (161/493)	17.2% (85/493)

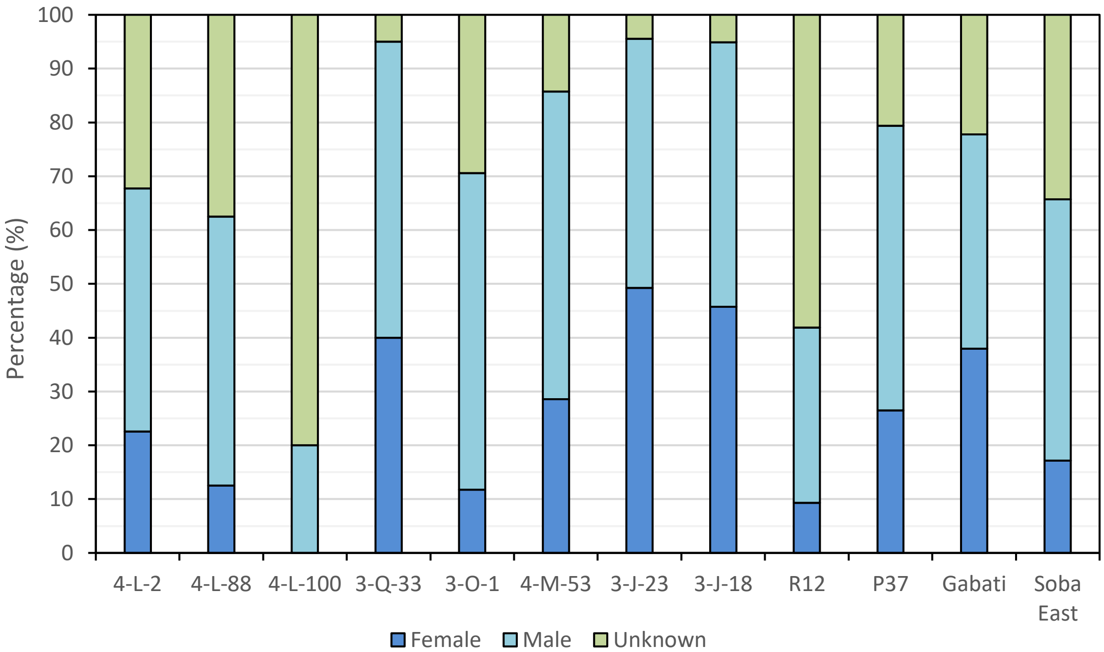


Figure 7.1 – The proportion of individuals from each site who were attributed to the pooled sex category of female, male, or unknown.

7.2.1 Age

Table 7.2 displays the number and percentage of skeletons within each age category recorded for each site. Very few individuals were attributed an age estimation of adolescent or old adult. For the further analysis of data by age, the categories were pooled into '*young adult'* (consisting of adolescent and young adult groups), '*middle adult'* (consisting of middle adult and old adult groups), and '*unknown adult'* (see Table 6.6 for corresponding age ranges). Figure 7.2 displays the proportion of each pooled age category observed at each site. Most sites had a relatively equal distribution of young and middle adult individuals. However, 3-O-1 demonstrated a higher number of young adult burials, while 3-J-18 had a higher proportion of middle adults. The majority of the skeletons buried at 4-L-100 and R12 could not be attributed an age beyond that of adult.

Table 7.2 – The percentage of individuals in each age category from each site. Frequencies are presented in brackets below.

Site	Adolescent	Young adult	Middle adult	Old adult	Unknown adult
4-L-2	0.0% (0/31)	32.3% (10/31)	41.9% (13/31)	3.2% (1/31)	22.6% (7/31)
4-L-88	0.0% (0/8)	25.0% (2/8)	37.5% (3/8)	0.0% (0/8)	37.5% (3/8)
4-L-100	0.0% (0/5)	20.0% (1/5)	0.0% (0/5)	0.0% (0/5)	80.0% (4/5)
3-Q-33	5.0% (1/20)	40.0% (8/20)	50.0% (10/20)	0.0% (0/20)	5.0% (1/20)
3-O-1	0.0% (0/17)	64.7% (11/17)	35.3% (6/17)	0.0% (0/17)	0.0% (0/17)
4-M-53	14.3% (1/7)	42.8% (3/7)	28.6% (2/7)	0.0% (0/7)	14.3% (1/7)
3-J-23	6.0% (4/67)	45.2% (31/67)	41.8% (28/67)	0.0% (0/67)	5.0% (4/67)
3-J-18	7.6% (9/118)	32.2% (38/118)	51.7% (61/118)	3.4% (4/118)	5.1% (6/118)
R12	0.0% (0/43)	18.6% (8/43)	14.0% (6/43)	0.0% (0/43)	67.4% (29/43)
P37	5.9% (2/34)	32.4% (11/34)	35.3% (12/34)	0.0% (0/34)	26.4% (9/34)
Gabati	0.9% (1/108)	39.8% (43/108)	38.0% (41/108)	0.0% (0/108)	21.3% (23/108)
Soba East	2.8% (1/35)	34.3% (12/35)	34.3% (12/35)	0.0% (0/35)	28.6% (10/35)
Total	3.9% (19/493)	36.1% (178/493)	39.3% (194/493)	1.0% (5/493)	19.7% (97/493)

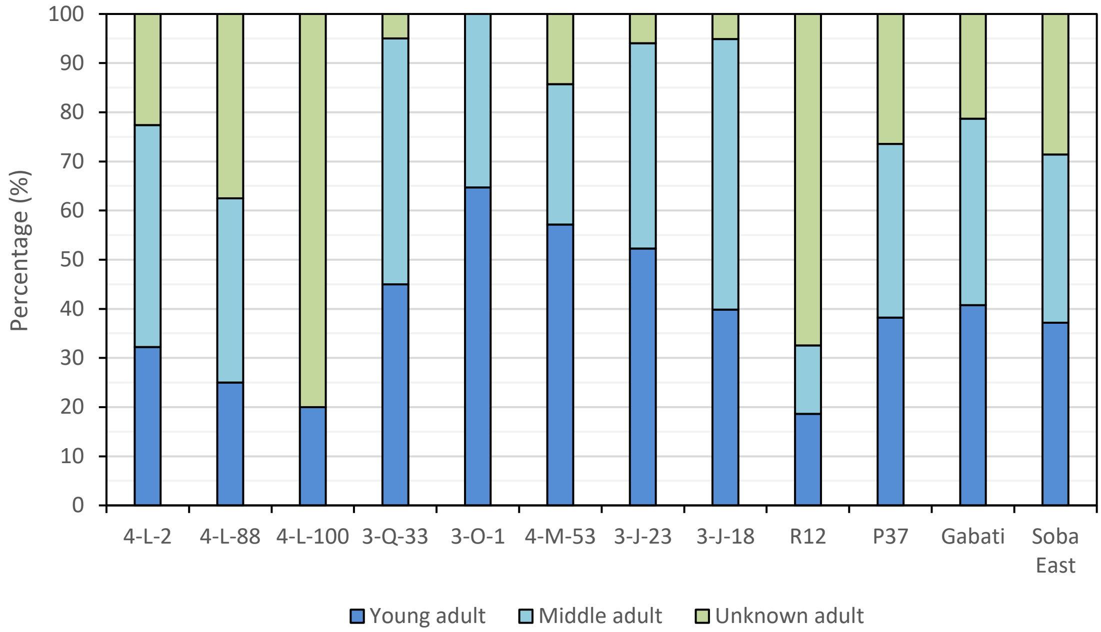


Figure 7.2 – The proportion of individuals from each site who were attributed to the pooled age category of young adult, middle adult, or unknown adult.

7.2.2 Maxillary sinus preservation

Frequency data for maxillary sinus preservation at each site, consisting of individual scores for sinus completeness and sinus observability, are presented below. The mean score for sinus observability at each site was also calculated. Both the left and right maxillary sinuses were originally scored individually for completeness and observability. The scores for left and right have been combined here.

7.2.2.i Maxillary sinus completeness score

Table 7.3 presents the percentage of maxillary sinuses within each completeness score category at each site. Figure 7.3 compares these data between sites. 3-J-18 and 3-J-23 displayed the highest proportion of maxillary sinuses that were 75+% complete, while 4-L-88 displayed a high number of maxillary sinuses that were less than 5% complete. Those sinuses within the category of 0-4% complete were not included in the further analysis of sinusitis.

Table 7.3 – The percentage of combined left and right maxillary sinuses in each completeness score category from each site. Frequencies are presented in brackets below.

Site	0-4%	5-24%	25-49%	50-74%	75-100%
4-L-2	14.5% (9/62)	58.1% (36/62)	22.6% (14/62)	3.2% (2/62)	1.6% (1/62)
4-L-88	43.8% (7/16)	25.0% (4/16)	31.2% (5/16)	0.0% (0/16)	0.0% (0/16)
4-L-100	20.0% (2/10)	70.0% (7/10)	10.0% (1/10)	0.0% (0/10)	0.0% (0/10)
3-Q-33	5.0% (2/40)	7.5% (3/40)	7.5% (3/40)	27.5% (11/40)	52.5% (21/40)
3-O-1	11.8% (4/34)	14.7% (5/34)	14.7% (5/34)	29.4% (10/34)	29.4% (10/34)
4-M-53	7.1% (1/14)	14.3% (2/14)	21.4% (3/14)	28.6% (4/14)	28.6% (4/14)
3-J-23	4.5% (6/134)	1.5% (2/134)	7.5% (10/134)	10.4% (14/134)	76.1% (102/134)
3-J-18	3.0% (7/236)	2.5% (6/236)	3.0% (7/236)	7.2% (17/236)	84.3% (199/236)
R12	23.6% (20/85)	54.1% (46/85)	17.6% (15/85)	3.5% (3/85)	1.2% (1/85)
P37	17.6% (12/68)	32.4% (22/68)	29.4% (20/68)	13.2% (9/68)	7.4% (5/68)
Gabati	11.1% (24/216)	19.0% (41/216)	16.2% (35/216)	19.9% (43/216)	33.8% (73/216)
Soba East	5.7% (4/70)	60.0% (42/70)	15.7% (11/70)	8.6% (6/70)	10.0% (7/70)
Total	10.0% (98/985)	21.9% (216/985)	13.1% (129/985)	12.1% (119/985)	42.9% (423/985)

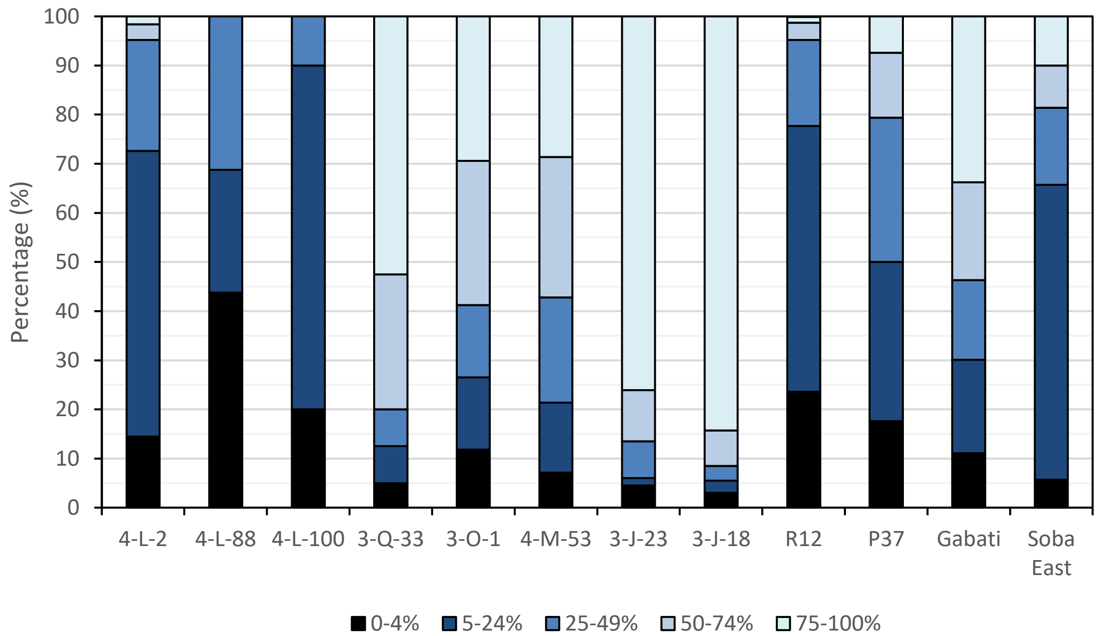


Figure 7.3 – The proportion of combined right and left maxillary sinuses at each site that were attributed to each completeness score category.

7.2.2.ii Maxillary sinus observability score

Table 7.4 presents the percentage of maxillary sinuses within each sinus observability score category and the mean score for sinuses from each site. The site of 3-J-18 showed the highest mean observability score (2.29), and Soba East the lowest (1.21). Figure 7.4 compares the proportion of sinuses within each observability score category between sites. Those sinuses with an observability score of 4 (i.e. sinus surfaces were completely unobservable) were not included in the further analysis of sinusitis.

Table 7.4 – The percentage of combined right and left maxillary sinuses in each observability score category and the mean score from each site. Frequencies are presented in brackets below.

Site	1	2	3	4	Mean score
4-L-2	64.1% (34/53)	34.0% (18/53)	1.9% (1/53)	0.0% (0/53)	1.38
4-L-88	77.8% (7/9)	11.1% (1/9)	11.1% (1/9)	0.0% (0/9)	1.33
4-L-100	62.5% (5/8)	12.5% (1/8)	25.0% (2/8)	0.0% (0/8)	1.62
3-Q-33	62.5% (20/32)	25.0% (8/32)	12.5% (4/32)	0.0% (0/32)	1.50
3-O-1	41.4% (12/29)	27.6% (8/29)	24.1% (7/29)	6.9% (2/29)	1.97
4-M-53	46.2% (6/13)	53.8% (7/13)	0.0% (0/13)	0.0% (0/13)	1.54
3-J-23	60.0% (63/105)	27.6% (29/105)	11.4% (12/105)	1.0% (1/105)	1.53
3-J-18	23.6% (33/140)	42.1% (59/140)	15.7% (22/140)	18.6% (26/140)	2.29
R12	54.5% (36/66)	39.4% (26/66)	4.6% (3/66)	1.5% (1/66)	1.53
P37	82.1% (46/56)	12.5% (7/56)	3.6% (2/56)	1.8% (1/56)	1.25
Gabati	53.0% (96/181)	38.7% (70/181)	6.1% (11/181)	2.2% (4/181)	1.57
Soba East	78.8% (52/66)	21.2% (14/66)	0.0% (0/66)	0.0% (0/66)	1.21
Total	54.1% (410/758)	32.7% (248/758)	8.6% (65/758)	4.6% (35/758)	1.64

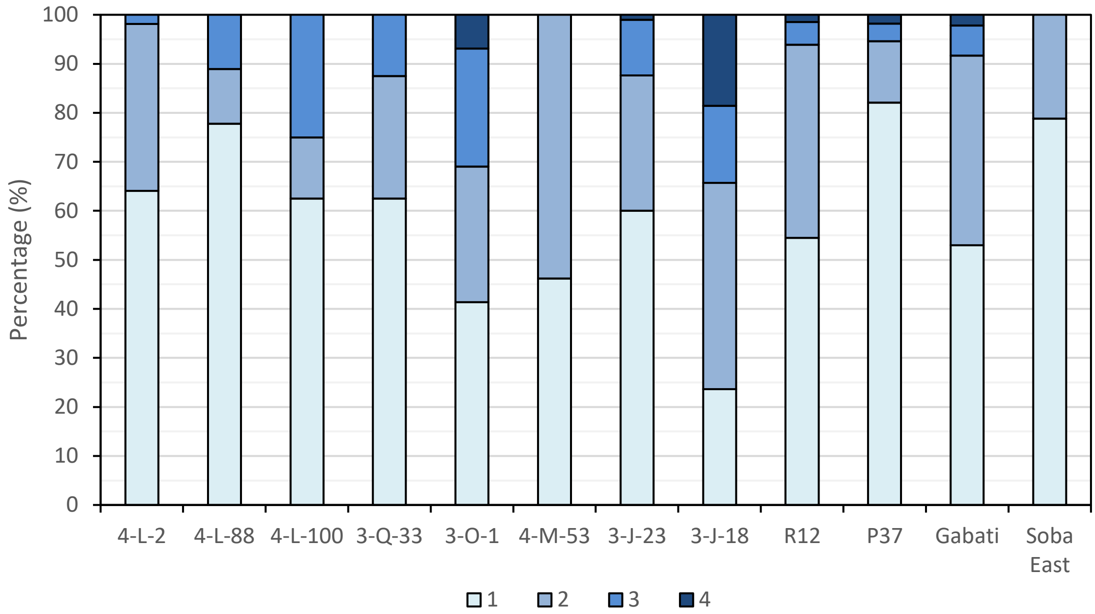


Figure 7.4 – The proportion of combined right and left maxillary sinuses at each site that were attributed to each observability score category.

7.2.3 Rib cage preservation

Data reflecting rib cage preservation at each site, consisting of individual scores for rib cage fragmentation, cortical preservation, completeness, and observability, are presented below. Where possible, the mean scores for each site were calculated. Both the left and right sides of the rib cages were originally scored individually for completeness and observability. The scores for left and right have been combined here. Rib cage preservation scores were recorded for all available adult rib cages at each site, regardless of completeness. Therefore, not all of the rib cages that were scored for preservation were included in the final analysis of rib IPR.

7.2.3.i Rib cage fragmentation score

Table 7.5 presents the percentage of rib cages within each fragmentation score category and the mean score for rib cages at each site. The site of R12 presented the highest mean fragmentation score (2.57), and 3-J-23 the lowest (0.89). Figure 7.5 compares the proportion of rib cages within each fragmentation score category between sites.

Table 7.5 – The percentage of rib cages in each fragmentation score category and the mean score from each site. Frequencies are presented in brackets below.

Site	None (0)	Minor (1)	Moderate (2)	Severe (3)	Mean score
4-L-2	0.0% (0/27)	3.7% (1/27)	59.3% (16/27)	37.0% (10/27)	2.33
4-L-88	0.0% (0/7)	0.0% (0/7)	85.7% (6/7)	14.3% (1/7)	2.14
4-L-100	0.0% (0/2)	0.0% (0/2)	50.0% (1/2)	50.0% (1/2)	2.50
3-Q-33	5.0% (1/20)	45.0% (9/20)	45.0% (9/20)	5.0% (1/20)	1.50
3-O-1	5.9% (1/17)	29.4% (5/17)	23.5% (4/17)	41.2% (7/17)	2.00
4-M-53	0.0% (0/7)	42.9% (3/7)	42.9% (3/7)	14.2% (1/7)	1.71
3-J-23	28.8% (19/66)	56.1% (37/66)	12.1% (8/66)	3.0% (2/66)	0.89
3-J-18	31.0% (36/116)	38.8% (45/116)	19.8% (23/116)	10.4% (12/116)	1.09
R12	0.0% (0/14)	7.1% (1/14)	28.6% (4/14)	64.3% (9/14)	2.57
P37	0.0% (0/32)	25.0% (8/32)	59.4% (19/32)	15.6% (5/32)	1.91
Gabati	7.8% (6/77)	32.4% (25/77)	46.8% (36/77)	13.0% (10/77)	1.65
Soba East	0.0% (0/28)	25.0% (7/28)	50.0% (14/28)	25.0% (7/28)	2.00
Total	15.3% (63/413)	34.1% (141/413)	34.6% (143/413)	16.0% (66/413)	1.51

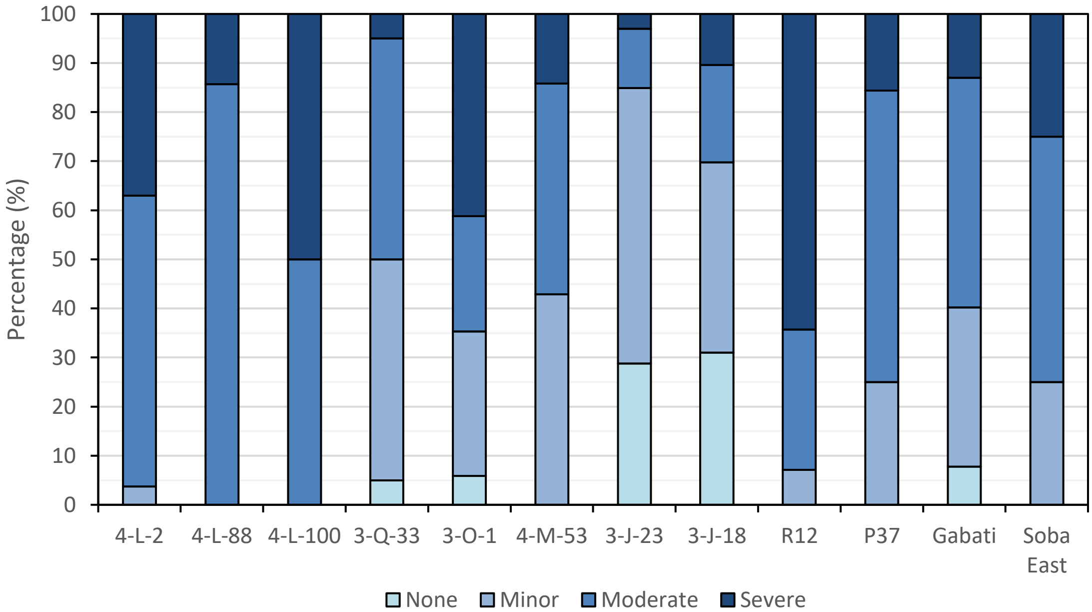


Figure 7.5 – The proportion of rib cages at each site that were attributed to each fragmentation score category.

7.2.3.ii Rib cage cortical preservation score

Table 7.6 presents the percentage of rib cages within each cortical preservation score category and the mean score for rib cages at each site. The site of R12 showed the highest mean cortical preservation score (2.79), and 3-J-23 the lowest (0.92). Figure 7.6 compares the proportion of rib cages within each cortical preservation score category between sites.

Table 7.6 - Percentage of rib cages in each cortical preservation score category and the mean score from each site. Frequencies are presented in brackets below.

Site	0	1	2	3	4	Mean score
4-L-2	0.0% (0/26)	19.2% (5/26)	34.6% (9/26)	34.6% (9/26)	11.6% (3/26)	2.38
4-L-88	0.0% (0/7)	42.9% (3/7)	14.2% (1/7)	42.9% (3/7)	0.0% (0/7)	2.00
4-L-100	0.0% (0/2)	0.0% (0/2)	50.0% (1/2)	50.0% (1/2)	0.0% (0/2)	2.50
3-Q-33	0.0% (0/20)	55.0% (11/20)	40.0% (8/20)	5.0% (1/20)	0.0% (0/20)	1.50
3-O-1	0.0% (0/17)	41.2% (7/17)	52.9% (9/17)	5.9% (1/17)	0.0% (0/17)	1.65
4-M-53	0.0% (0/7)	71.4% (5/7)	14.3% (1/7)	14.3% (1/7)	0.0% (0/7)	1.43
3-J-23	31.8% (21/66)	45.5% (30/66)	21.2% (14/66)	1.5% (1/66)	0.0% (0/66)	0.92
3-J-18	23.3% (27/116)	49.1% (57/116)	23.3% (27/116)	2.6% (3/116)	1.7% (2/116)	1.10
R12	0.0% (0/14)	7.1% (1/14)	28.6% (4/14)	42.9% (6/14)	21.4% (3/14)	2.79
P37	0.0% (0/31)	35.5% (11/31)	32.2% (10/31)	19.4% (6/31)	12.9% (4/31)	2.10
Gabati	9.1% (7/77)	63.6% (49/77)	19.5% (15/77)	7.8% (6/77)	0.0% (0/77)	1.26
Soba East	0.0% (0/28)	28.6% (8/28)	42.8% (12/28)	14.3% (4/28)	14.3% (4/28)	2.14
Total	13.4% (55/411)	45.5% (187/411)	27.0% (111/411)	10.2% (42/411)	3.9% (16/411)	1.46

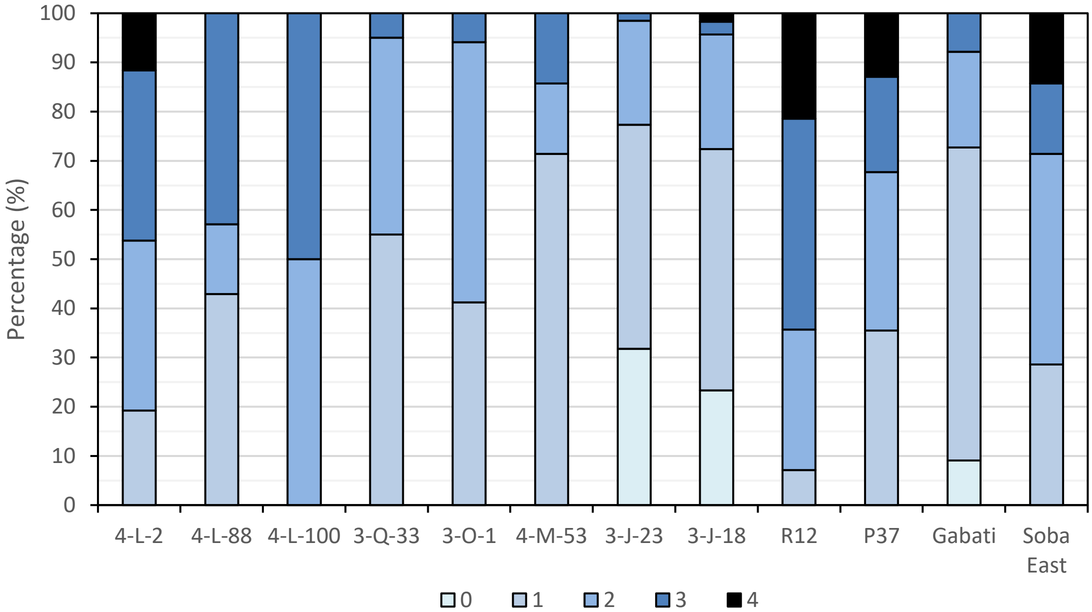


Figure 7.6 – The proportion of rib cages at each site that were attributed to each cortical preservation score category.

7.2.3.iii Rib cage completeness score

Table 7.7 presents the percentage of both left and right rib cages within each completeness score category at each site. Figure 7.7 compares these data between sites. The sites of 4-M-53, 3-J-23, and 3-J-18 displayed a high proportion of ribcages that were 75+% complete, while R12 displayed a high number of ribcages that were less than 5% complete. Individuals with both left and right ribcages within the category of 0-4% complete were not included in the further analysis of rib IPR.

Table 7.7 – The percentage of combined right and left rib cages in each completeness score category from each site. Frequencies are presented in brackets below.

Site	0-4%	5-24%	25-49%	50-74%	75-100%
4-L-2	21.0% (13/62)	50.0% (31/62)	17.7% (11/62)	6.5% (4/62)	4.8% (3/62)
4-L-88	18.8% (3/16)	25.0% (4/16)	6.3% (1/16)	31.2% (5/16)	18.7% (3/16)
4-L-100	33.3% (2/6)	66.7% (4/6)	0.0% (0/6)	0.0% (0/6)	0.0% (0/6)
3-Q-33	0.0% (0/40)	0.0% (0/40)	12.5% (5/40)	17.5% (7/40)	70.0% (28/40)
3-O-1	0.0% (0/34)	32.4% (11/34)	14.7% (5/34)	5.9% (2/34)	47.0% (16/34)
4-M-53	0.0% (0/14)	14.3% (2/14)	0.0% (0/14)	0.0% (0/14)	85.7% (12/14)
3-J-23	1.5% (2/134)	3.0% (4/134)	1.5% (2/134)	3.0% (4/134)	91.0% (122/134)
3-J-18	2.1% (5/236)	3.8% (9/236)	6.8% (16/236)	3.8% (9/236)	83.5% (197/236)
R12	73.8% (62/84)	16.6% (14/84)	6.0% (5/84)	2.4% (2/84)	1.2% (1/84)
P37	8.8% (6/68)	14.7% (10/68)	13.3% (9/68)	14.7% (10/68)	48.5% (33/68)
Gabati	30.4% (65/214)	20.1% (43/214)	12.6% (27/214)	8.4% (18/214)	28.5% (61/214)
Soba East	24.3% (17/70)	27.1% (19/70)	11.4% (8/70)	12.9% (9/70)	24.3% (17/70)
Total	17.9% (175/978)	15.4% (151/978)	9.1% (89/978)	7.2% (70/978)	50.4% (493/978)

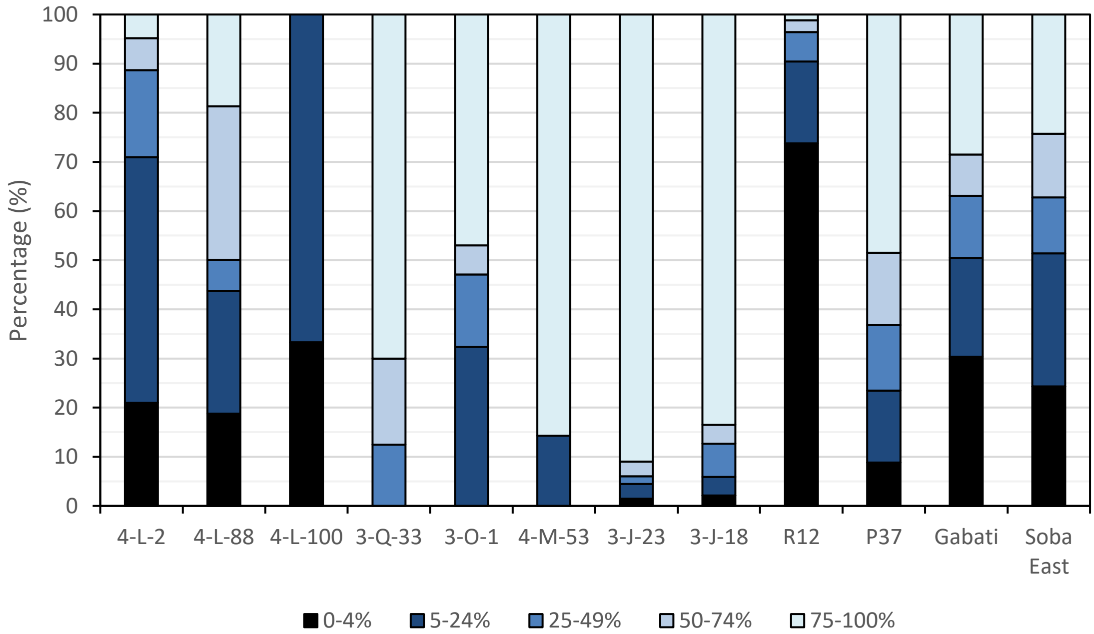


Figure 7.7 – The proportion of combined right and left rib cages at each site that were attributed to each completeness score category.

7.2.3.iv Rib cage observability score

Table 7.8 presents the percentage of both left and right rib cages within each observability score category and the mean score for rib cages at each site. The site of 3-J-18 showed the highest mean observability score (1.97), and 4-L-2 the lowest (1.00). Figure 7.8 compares the proportion of rib cages within each observability score category between sites. Those individuals with an observability score of 4 (i.e. visceral rib surfaces were completely unobservable) on both the left and right side of the rib cage were not included in the further analysis of rib IPR.

Table 7.8 - Percentage of combined left and right ribcages in each observability score category and mean score from each site. Frequencies are presented in brackets below.

Site	1	2	3	4	Mean Score
4-L-2	30.6% (15/49)	63.3% (31/49)	6.1% (3/49)	0.0% (0/49)	1.76
4-L-88	53.8% (7/13)	46.2% (6/13)	0.0% (0/13)	0.0% (0/13)	1.46
4-L-100	100% (2/2)	0.0% (0/2)	0.0% (0/2)	0.0% (0/2)	1.00
3-Q-33	77.5% (31/40)	22.5% (9/40)	0.0% (0/40)	0.0% (0/40)	1.23
3-O-1	67.6% (23/34)	26.5% (9/34)	5.9% (2/34)	0.0% (0/34)	1.38
4-M-53	85.7% (12/14)	14.3% (2/14)	0.0% (0/14)	0.0% (0/14)	1.14
3-J-23	39.4% (52/132)	47.7% (63/132)	12.1% (16/132)	0.8% (1/132)	1.74
3-J-18	33.2% (58/175)	40.0% (70/175)	23.4% (41/175)	3.4% (6/175)	1.97
R12	51.9% (14/27)	48.1% (13/27)	0.0% (0/27)	0.0% (0/27)	1.48
P37	75.8% (47/62)	17.7% (11/62)	6.5% (4/62)	0.0% (0/62)	1.31
Gabati	64.0% (98/153)	35.3% (54/153)	0.7% (1/153)	0.0% (0/153)	1.37
Soba East	61.8% (34/55)	34.6% (19/55)	3.6% (2/55)	0.0% (0/55)	1.42
Total	52.0% (393/756)	38.0% (287/756)	9.1% (69/756)	0.9% (7/756)	1.60

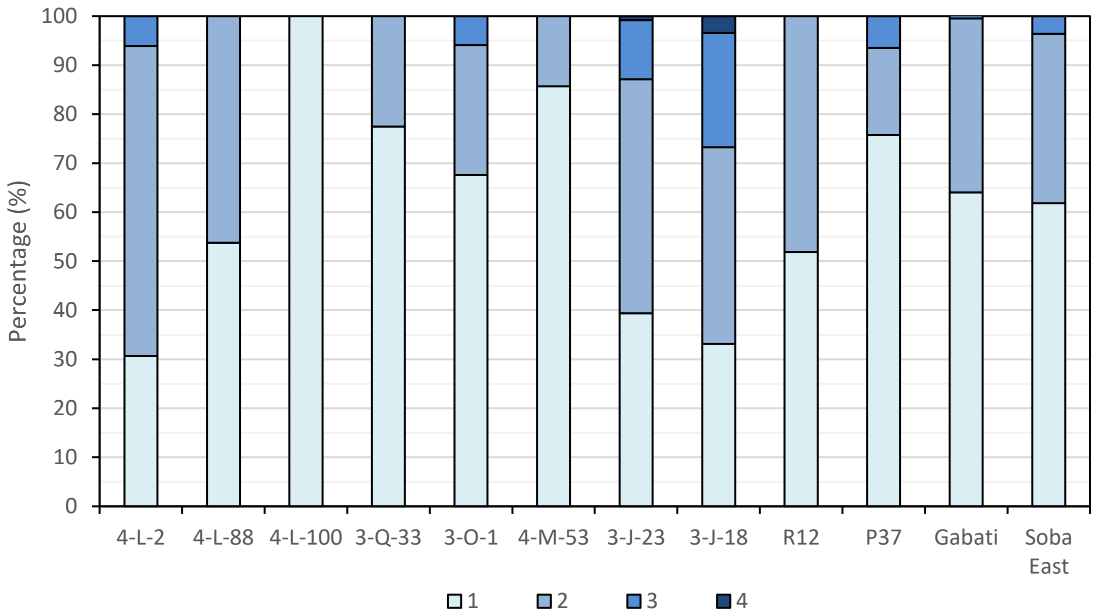


Figure 7.8 – The proportion of combined right and left rib cages at each site that were attributed to each observability score.

7.2.4 Summary of demography and preservation

A general trend in preservation was observed for the skeletal remains from each site studied using the different methods of scoring, whereby certain sites generally displayed preservation scores indicating good preservation (e.g. at 3-J-18, 3-J-23, 3-Q-33) or poor preservation (e.g. at R12, 4-L-100, 4-L-2) using all the methods. This is also reflected in the ability to estimate sex and age at the sites with scores indicating poorer preservation, where higher proportions of individuals in the unknown sex and age categories were present (e.g. at R12 and 4-L-100). However, surface observability scores for both ribs and maxillary sinuses did not fit this trend, displaying a higher score (indicating a lower observability) in skeletons from the sites which displayed generally better preservation scores (e.g. at 3-J-23, 3-J-18). This was due to instances of good preservation and adherence of soft tissue to the ribs and skull or to the complete preservation of the maxillary sinuses, which prevented the observation of the surfaces of the ribs and sinuses.

7.3 Prevalence of maxillary sinusitis

The prevalence of people with maxillary sinusitis at each site and for each time period is presented below in two ways: by the percentage of maxillary sinusitis in individuals with both sinuses preserved and observable (summarised as: 2SP) and by the percentage of maxillary sinusitis in individuals with either one or both sinuses preserved and observable (summarised as: 1+SP). While presenting prevalence rates using only individuals with both sinuses preserved increases the accuracy of the data, the poor preservation of skeletons can greatly reduce the sample size available for statistical analysis. Therefore, prevalence by 1+SP, representing a larger sample size but potentially less accurate data, was included separately. Due to the small sample sizes presented here, the majority of the statistical analyses applied to the data consisted of Fisher's Exact tests (denoted as [FET]), using the two-sided P-value, which were employed to determine any statistically significant differences between groups (see Section 6.9). All statistical analyses with significant outcomes (p-value = $\leq$0.05) have been highlighted in grey within the tables below.

The prevalence rate for the number of sinuses observed with sinusitis (rather than according to the number of individuals affected) was not utilised in this analysis. While this type of data constitutes a true prevalence, it does not provide information about the number of people who had sinusitis and is, therefore, not useful for answering the research questions in the current study. However, due to the multiple ways in which prevalence rates of maxillary sinusitis are calculated and presented by various authors, this form of prevalence data is presented in Appendix E for each site and time period, including prevalence by right and left sinus and within age, sex, and time period categories. Thus, these data are made available for future potential comparison with other studies of maxillary sinusitis.

7.3.1 Maxillary sinusitis by site

Maxillary sinusitis prevalence and frequency are presented below for each site. Where sample sizes were large enough, statistical tests were calculated. When the samples sizes were smaller, further statistical analysis was undertaken once data were pooled into time period groups (Section 7.3.2).

7.3.1.i 4-L-2 (Fourth Cataract)

The prevalence of maxillary sinusitis for people buried at 4-L-2 is presented in Table 7.9. No statistically significant differences were found between sex or age groups when calculated using the frequency for both sinuses preserved or for one or both sinuses preserved.

Table 7.9 – 4-L-2 (Fourth Cataract) maxillary sinusitis prevalence rates, according to sex, age, and within the total group, and results of tests of significant difference between categories. Prevalence rates are presented separately for individuals with evidence for sinusitis who have two sinuses preserved (2SP) or have one or both sinuses preserved (1+SP). Frequencies are presented in brackets below.

Category		2SP	Statistical significance	1+SP	Statistical significance
Sex	Male	61.5% (8/13)	P = 1.000 [FET]	61.5% (8/13)	P = 1.000 [FET]
	Female	66.7% (4/6)		66.7% (4/6)	
Age	Young adult	40.0% (2/5)	P = 0.326 [FET]	28.6% (2/7)	P = 0.159 [FET]
	Middle adult	69.2% (9/13)		71.4% (10/14)	
Total		64.0% (16/25)		60.7% (17/28)	

7.3.1.ii 4-L-88 (Fourth Cataract)

The prevalence of maxillary sinusitis for people buried at 4-L-88 is presented in Table 7.10. Due to the small number of individuals available for study from this site, no statistical tests were undertaken on prevalence rates. However, further analysis of these data is presented (Section 7.3.2.i) within the pooled dataset for the Fourth Cataract Kerma Classique time period.

Table 7.10 – 4-L-88 (Fourth Cataract) maxillary sinusitis prevalence rates, according to sex, age, and within the total group. Prevalence rates are presented separately for individuals with evidence for sinusitis who have two sinuses preserved (2SP) or have one or both sinuses preserved (1+SP). Frequencies are presented in brackets below.

Category		2SP	1+SP
Sex	Male	100% (1/1)	100% (2/2)
	Female	0.0% (0/1)	0.0% (0/1)
Age	Young Adult	- (0/0)	- (0/0)
	Middle Adult	50.0% (1/2)	66.7% (2/3)
Total		66.7% (2/3)	66.7% (4/6)

7.3.1.iii 4-L-100 (Fourth Cataract)

The prevalence of maxillary sinusitis for people buried at 4-L-100 is presented in Table 7.11. Due to the small number of individuals available for study from this site, no statistical tests were undertaken on prevalence rates. However, further analysis of these data is presented (Section 7.3.2.i) within the pooled dataset for the Fourth Cataract Kerma Classique time period.

Table 7.11 – 4-L-100 (Fourth Cataract) maxillary sinusitis prevalence rates, according to sex, age, and within the total group. Prevalence rates are presented separately for individuals with evidence for sinusitis who have two sinuses preserved (2SP) or have one or both sinuses preserved (1+SP). Frequencies are presented in brackets below.

Category		2SP	1+SP
Sex	**Male**	- (0/0)	0.0% (0/1)
	Female	- (0/0)	- (0/0)
Age	**Young Adult**	- (0/0)	0.0% (0/1)
	Middle Adult	- (0/0)	- (0/0)
	Total	33.3% (1/3)	20.0% (1/5)

7.3.1.iv 3-Q-33 (Fourth Cataract)

The prevalence of maxillary sinusitis for people buried at 3-Q-33 is presented in Table 7.12. No statistically significant differences were found between sex, age, or time period groups when calculated using the frequency for both sinuses preserved or by one or both sinuses preserved.

Table 7.12 – 3-Q-33 (Fourth Cataract) maxillary sinusitis prevalence rates, according to sex, age, time period, and within the total group, and results of tests of significant difference between categories. Prevalence rates are presented separately for individuals with evidence for sinusitis who have two sinuses preserved (2SP) or have one or both sinuses preserved (1+SP). Frequencies are presented in brackets below.

Category		2SP	Statistical significance	1+SP	Statistical significance
Sex	Male	55.6% (5/9)	P = 0.228 [FET]	54.5% (6/11)	P = 0.333 [FET]
	Female	100% (4/4)		83.3% (5/6)	
Age	Young Adult	60.0% (3/5)	P = 1.000 [FET]	62.5% (5/8)	P = 1.000 [FET]
	Middle Adult	62.5% (5/8)		55.6% (5/9)	
Time Period	Meroitic	55.6% (5/9)	P = 0.580 [FET]	53.8% (7/13)	P = 0.596 [FET]
	Post-Meroitic	80.0% (4/5)		80.0% (4/5)	
	Total	64.3% (9/14)		61.1% (11/18)	

7.3.1.v 3-O-1 (Fourth Cataract)

The prevalence of maxillary sinusitis for people buried at 3-O-1 is presented in Table 7.13. No statistically significant differences were found between sex or age groups when calculated using the frequency for both sinuses preserved or by one or both sinuses preserved.

Table 7.13 – 3-O-1 (Fourth Cataract) maxillary sinusitis prevalence rates, according to sex, age, and within the total group, and results of tests of significant difference between categories. Prevalence rates are presented separately for individuals with evidence for sinusitis who have two sinuses preserved (2SP) or have one or both sinuses preserved (1+SP). Frequencies are presented in brackets below.

Category		2SP	Statistical significance	1+SP	Statistical significance
Sex	Male	62.5% (5/8)	P = 1.000 [FET]	44.4% (5/9)	P = 1.000 [FET]
	Female	50.0% (1/2)		50.0% (1/2)	
Age	Young Adult	62.5% (5/8)	P = 1.000 [FET]	55.6% (5/9)	P = 1.000 [FET]
	Middle Adult	60.0% (3/5)		60.0% (3/5)	
	Total	61.5% (8/13)		57.1% (8/14)	

7.3.1.vi 4-M-53 (Fourth Cataract)

The prevalence of maxillary sinusitis for people buried at 4-M-53 is presented in Table 7.14. Due to the small number of individuals available for study from this site, no statistical tests were undertaken. However, further analysis of these data is presented (Section 7.3.2.ii) within the pooled dataset for the Fourth Cataract Post-Meroitic and Meroitic time period.

Table 7.14 – 4-M-53 (Fourth Cataract) maxillary sinusitis prevalence rates, according to sex, age, and within the total group. Prevalence rates are presented separately for individuals with evidence for sinusitis who have two sinuses preserved (2SP) or have one or both sinuses preserved (1+SP). Frequencies are presented in brackets below.

Category		2SP	1+SP
Sex	Male	0.0% (0/4)	0.0% (0/4)
	Female	50.0% (1/2)	50.0% (1/2)
Age	Young Adult	0.0% (0/4)	0.0% (0/4)
	Middle Adult	50.0% (1/2)	50.0% (1/2)
	Total	16.7% (1/6)	28.6% (2/7)

7.3.1.vii 3-J-23 (Fourth Cataract)

The prevalence of maxillary sinusitis for people buried at 3-J-23 is presented in Table 7.15. A statistically significant difference was present between males and females when calculated using the frequency for one or both sinuses preserved, but not when calculated using the frequency for both sinuses preserved. All other results were not statistically significant.

Table 7.15 – 3-J-23 (Fourth Cataract) maxillary sinusitis prevalence rates, according to sex, age, and within the total group, and results of tests of significant difference between categories. Prevalence rates are presented separately for individuals with evidence for sinusitis who have two sinuses preserved (2SP) or have one or both sinuses preserved (1+SP). Frequencies are presented in brackets below. Statistically significant values are highlighted in grey.

Category		2SP	Statistical significance	1+SP	Statistical significance
Sex	**Male**	70.8% (17/24)	P = 0.071 [FET]	74.1% (20/27)	P = 0.003 [FET]
	Female	42.1% (8/19)		32.1% (9/28)	
Age	**Young Adult**	52.2% (12/23)	P = 0.760 [FET]	46.7% (14/30)	P = 0.785 [FET]
	Middle Adult	60.0% (12/20)		54.2% (13/24)	
Total		55.6% (25/45)		50.0% (29/58)	

7.3.1.viii 3-J-18 (Fourth Cataract)

The prevalence of maxillary sinusitis for people buried at 3-J-18 is presented in Table 7.16. No statistically significant differences were found between sex or age groups when calculated using the frequency for both sinuses preserved or by one or both sinuses preserved.

Table 7.16 – 3-J-18 (Fourth Cataract) maxillary sinusitis prevalence rates, according to sex, age, and within the total group, and results of tests of significant difference between categories. Prevalence rates are presented separately for individuals with evidence for sinusitis who have two sinuses preserved (2SP) or have one or both sinuses preserved (1+SP). Frequencies are presented in brackets below.

Category		2SP	Statistical significance	1+SP	Statistical significance
Sex	**Male**	61.3% (19/31)	P = 0.539 [FET]	54.5% (24/44)	P = 0.508 [FET]
	Female	73.7% (14/19)		62.2% (23/37)	
Age	**Young Adult**	64.7% (11/17)	P = 1.000 [FET]	59.4% (19/32)	P = 0.821 [FET]
	Middle Adult	67.7% (21/31)		56.3% (27/48)	
Total		66.7% (34/51)		56.5% (48/85)	

7.3.1.ix R12 (comparative site)

The prevalence of maxillary sinusitis for people buried at R12 is presented in Table 7.17. Due to the small number of individuals available for study from this site when presenting the frequency of individuals affected by sinusitis with both sinuses preserved, no tests of statistical significance were undertaken for this group. No statistically significant differences were found between sex or age groups when calculated using the frequency for one or both sinuses preserved.

Table 7.17 – R12 (comparative) maxillary sinusitis prevalence rates, according to sex, age, and within the total group, and results of tests of significant difference between categories. Prevalence rates are presented separately for individuals with evidence for sinusitis who have two sinuses preserved (2SP) or have one or both sinuses preserved (1+SP). Frequencies are presented in brackets below.

Category		2SP	1+SP	Statistical significance
Sex	Male	40.0% (2/5)	18.2% (2/11)	P = 1.000 [FET]
	Female	- (0/0)	25.0% (1/4)	
Age	Young Adult	50.0% (1/2)	16.7% (1/6)	P = 1.000 [FET]
	Middle Adult	0.0% (0/1)	16.7% (1/6)	
	Total	35.7% (5/14)	32.5% (13/40)	

7.3.1.x P37 (comparative site)

The prevalence of maxillary sinusitis for people buried at P37 is presented in Table 7.18. No statistically significant differences were found between sex, age or time period groups when calculated using the frequency for both sinuses preserved or by one or both sinuses preserved.

Table 7.18 – P37 (comparative) maxillary sinusitis prevalence rates, according to sex, age, time period, and within the total group, and results of tests of significant difference between categories. Prevalence rates are presented separately for individuals with evidence for sinusitis who have two sinuses preserved (2SP) or have one or both sinuses preserved (1+SP). Frequencies are presented in brackets below.

Category		2SP	Statistical significance	1+SP	Statistical significance
Sex	Male	78.6% (11/14)	P = 0.521 [FET]	75.0% (12/16)	P = 0.273 [FET]
	Female	100% (6/6)		100% (7/7)	
Age	Young Adult	77.8% (7/9)	P = 1.000 [FET]	66.7% (8/12)	P = 0.646 [FET]
	Middle Adult	77.8% (7/9)		80.0% (8/10)	
Time Period	Kerma Ancien	78.9% (15/19)	P = 1.000 [FET]	76.2% (16/21)	P = 1.000 [FET]
	Kerma Moyen	83.3% (5/6)		77.8% (7/9)	
Total		80.0% (20/25)		76.7% (23/30)	

7.3.1.xi Gabati (comparative site)

The prevalence of maxillary sinusitis for people buried at Gabati is presented in Table 7.19. A Fisher's Exact test can only be used to compare significant differences between two groups. As the time period variable consisted of three separate groups, a Pearson's Chi-Square test (with two degrees of freedom) was used to test for statistically significant differences between time periods in the 1+SP group. Due to the small number of individuals available for study in the time period groups when presented by 2SP, a Pearson's Chi-Square test could not be legitimately applied to this category. No statistically significant differences were found between age or time period groups when calculated using the frequency for both sinuses preserved or by one or both sinuses preserved. However, a significant difference between males and females was found when calculated using the frequency for both sinuses preserved and by one or both sinuses preserved, with females displaying a significantly higher prevalence.

Table 7.19 – Gabati (comparative) maxillary sinusitis prevalence rates, according to sex, age, time period, and within the total group, and results of tests of significant difference between categories. Prevalence rates are presented separately for individuals with evidence for sinusitis who have two sinuses preserved (2SP) or have one or both sinuses preserved (1+SP). Frequencies are presented in brackets below.

Category		2SP	Statistical significance	1+SP	Statistical significance
Sex	**Male**	41.9% (13/31)	P = 0.035 [FET]	39.0% (16/40)	P = 0.026 [FET]
	Female	71.4% (20/28)		65.8% (25/38)	
Age	**Young Adult**	54.5% (18/33)	P = 0.197 [FET]	50.0% (21/42)	P = 0.257 [FET]
	Middle Adult	71.4% (20/28)		63.9% (23/36)	
Time Period	**Meroitic**	58.3% (35/60)	-	56.3% (40/71)	χ^2 (2) = 0.342, P = 0.843
	Post-Meroitic	60.0% (6/10)		50.0% (9/18)	
	Medieval	62.5% (5/8)		50.0% (6/12)	
Total		59.0% (46/78)		54.5% (55/101)	

7.3.1.xii Soba East (comparative site)

The prevalence of maxillary sinusitis for people buried at Soba East is presented in Table 7.20. No statistically significant differences were found between sex or age groups when calculated using the frequency for both sinuses preserved or by one or both sinuses preserved.

Table 7.20 – Soba East (comparative) maxillary sinusitis prevalence rates, according to sex, age, and within the total group, and results of tests of significant difference between categories. Prevalence rates are presented separately for individuals with evidence for sinusitis who have two sinuses preserved (2SP) or have one or both sinuses preserved (1+SP). Frequencies are presented in brackets below.

Category		2SP	Statistical significance	1+SP	Statistical significance
Sex	Male	81.3% (13/16)	P = 0.585 [FET]	81.3% (13/16)	P = 0.585 [FET]
	Female	66.7% (4/6)		66.7% (4/6)	
Age	Young Adult	84.6% (11/13)	P = 1.000 [FET]	84.6% (11/13)	P = 0.630 [FET]
	Middle Adult	80.0% (8/10)		72.7% (8/11)	
	Total	84.4% (27/32)		82.4% (28/34)	

7.3.1.xiii Summary

Table 7.21 displays the outcomes of Fisher's Exact tests between sites to explore significant differences. To provide a larger sample size, the statistical tests were calculated using the frequency data from the group with one or both sinuses preserved (1+SP). Data from individuals buried at 4-L-88, 4-L-100, and 4-M-53 were omitted due to small sample sizes. Several sites produced significant differences. People who were buried at R12 had a significantly lower prevalence of maxillary sinusitis when compared to all sites except 3-O-1 and 3-J-23. Conversely, rates at P37 and Soba East were significantly higher than 3-J-23, R12, and Gabati, while Soba East also had a significantly higher prevalence when compared to 3-J-18. No significant differences were found between any Fourth Cataract sites.

Figure 7.9 compares the prevalence of maxillary sinusitis at the majority of sites, presented by both sinuses preserved and by one or both sinuses preserved. The sample groups from 4-L-88, 4-L-100, and 4-M-53 contained too few individuals for data from these sites to be considered reliable measures of the frequency of maxillary sinusitis in these populations. Therefore, prevalence rates from these sites are not presented in Figure 7.9, but are further analysed when they are pooled into different time period groups (Section 7.3.2). People from Soba East and P37 displayed the highest prevalence rates of maxillary sinusitis, at 82.4% (1+SP) and 76.7% (1+SP), respectively. R12 had the lowest prevalence rate at 32.5% (1+SP). Sites within the Fourth Cataract showed little variation in prevalence, ranging from 50.0 – 61.1% (1+SP).

Table 7.21 – P-values calculated using Fisher's Exact tests between sites to measure for significant differences in maxillary sinusitis. Statistically significant values are highlighted in grey.

Site	4-L-2	3-Q-33	3-O-1	3-J-23	3-J-18	R12	P37	Gabati	Soba East
4-L-2	-								
3-Q-33	1.000	-							
3-O-1	1.000	1.000	-						
3-J-23	0.368	0.434	0.768	-					
3-J-18	0.826	0.797	1.000	0.496	-				
R12	0.027	0.050	0.123	0.100	0.021	-			
P37	0.258	0.330	0.288	0.022	0.079	<0.001	-		
Gabati	0.668	0.620	1.000	0.623	0.882	0.025	0.035	-	
Soba East	0.086	0.177	0.139	0.003	0.011	<0.001	0.757	0.004	-

Figure 7.10 compares the prevalence of maxillary sinusitis in males and females at the majority of sites, presented by both sinuses preserved and by one or both sinuses preserved. 4-L-88, 4-L-100, and 4-M-53 were omitted due to small numbers. Males buried at 3-J-23 had a significantly higher prevalence of sinusitis, while at Gabati there was a significantly higher prevalence of sinusitis in females. No other sites displayed significant differences between the sexes. A large disparity existed between the sexes at 3-Q-33, with a higher prevalence in females. However, the number of individuals whose sex could be estimated at this site was too small to yield significant results.

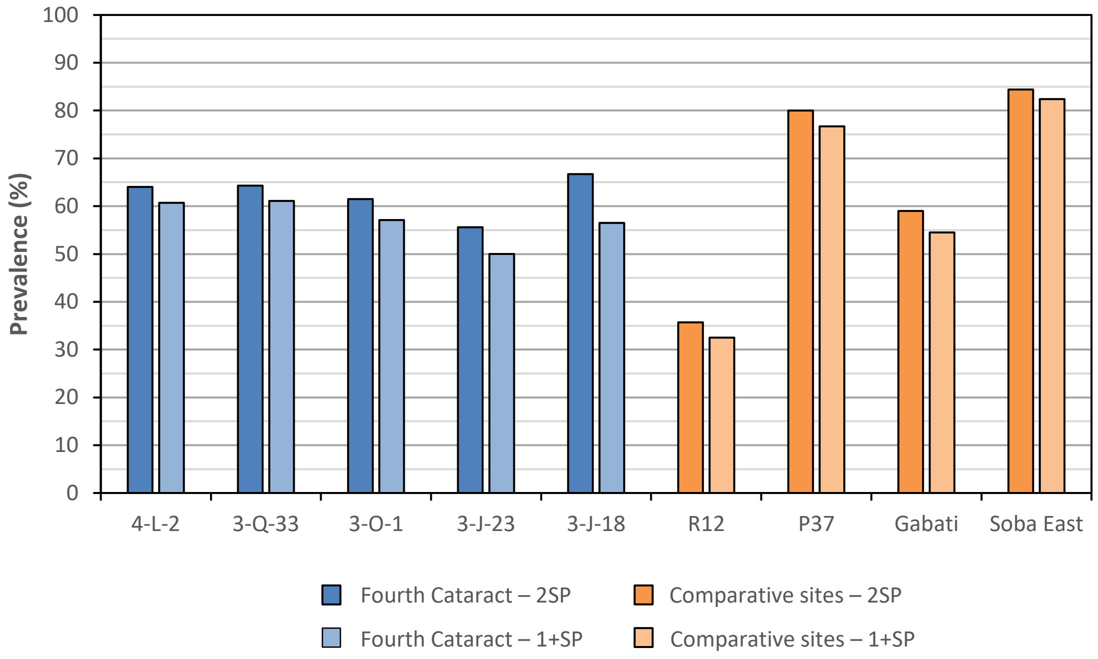


Figure 7.9 – A comparison of the prevalence of maxillary sinusitis from different sites.

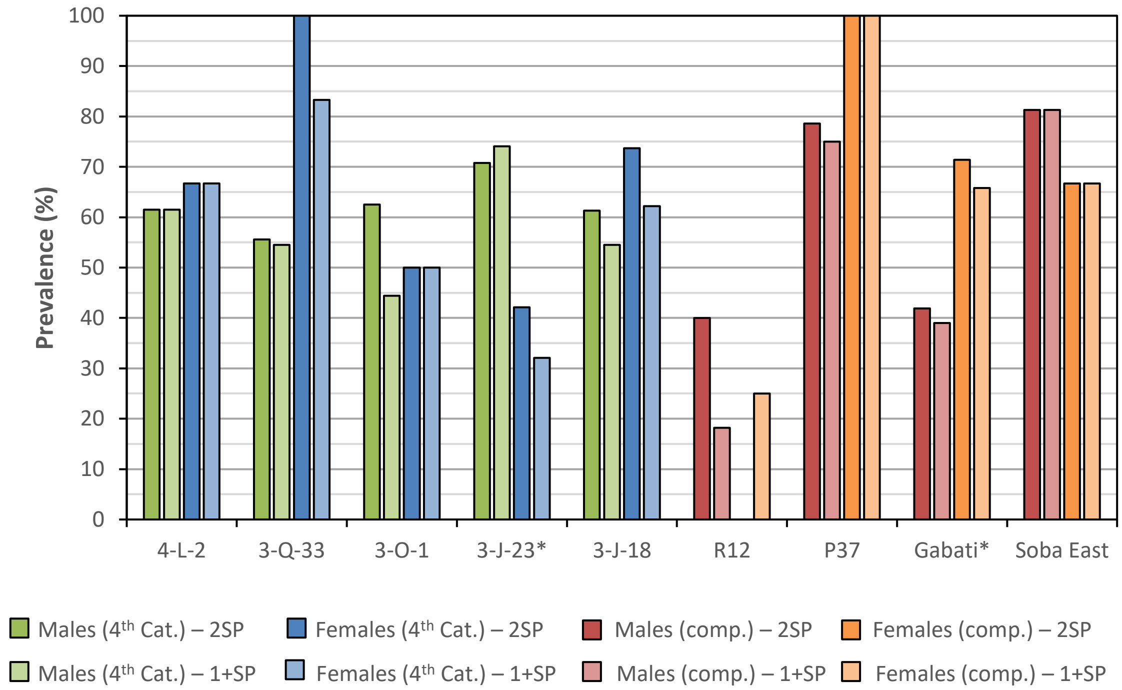


Figure 7.10 – A comparison of the prevalence of maxillary sinusitis between males and females from different sites (* = statistically significant differences between males and females).

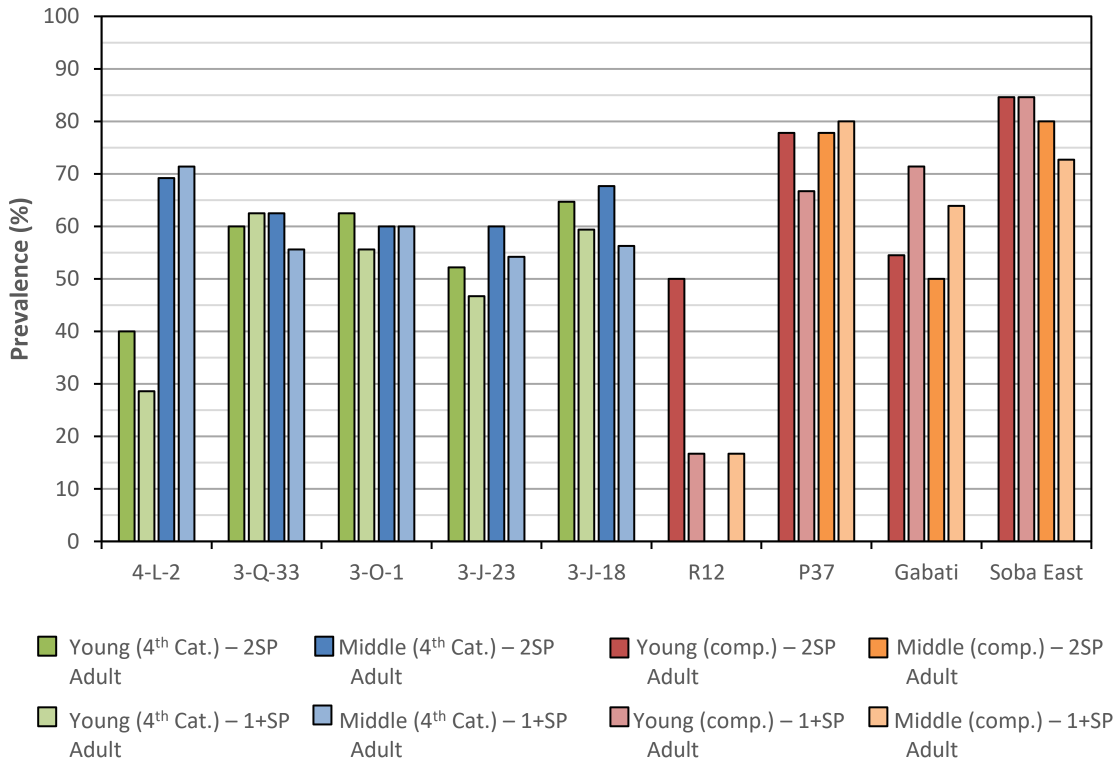


Figure 7.11 – A comparison of the prevalence of maxillary sinusitis between young adults and middle adults from different sites.

Figure 7.11 compares the prevalence rates of maxillary sinusitis in young and middle adults at the majority of sites, presented by both sinuses preserved and by one or both sinuses preserved. Sites 4-L-88, 4-L-100, and 4-M-53 were omitted due to small numbers. No sites presented a significant difference in frequency between young and middle adults. A higher prevalence in middle adults can be seen at 4-L-2, but this was not significantly different, due to the small number of individuals for whom age could be estimated at this site.

7.3.1.xiv The potential cause of maxillary sinusitis (by site)

Table 7.22 displays the percentage of all sinuses with sinusitis at each site that demonstrated evidence for potential odontogenic sinusitis (oroantral fistula present), potential rhinogenic sinusitis (oroantral fistula absent), or an unobservable origin (alveolar bone or sinus floor damaged/absent). For comparative purposes with other studies, the percentage of individuals with potential odontogenic or rhinogenic sinusitis is also presented, regardless of the state of preservation of the sinuses. However, as this method does not take into account whether or not an oroantral fistula was present in a damaged or absent sinus, this form of data is less accurate. Figure 7.12 compares the data between sites by the number of sinuses affected. In general, odontogenic sinusitis was low. The highest prevalence of odontogenic sinusitis was at R12, affecting 18.8% of all sinuses with sinusitis. People buried at the sites of 4-L-88, 4-L-100, 3-O-1, 4-M-53, P37, and Soba East displayed no evidence for odontogenic sinusitis. Certain sites with poor preservation, however, did contain a large proportion of sinuses with sinusitis that could not be observed for an oroantral fistula due to damage to the sinus floor. This was highest at 4-L-2, where 70.8% of all affected sinuses could not be reliably observed for an oroantral fistula.

Table 7.22 – The percentage of sinuses at each site with potential odontogenic sinusitis, rhinogenic sinusitis, or an unobservable origin, and the percentage of individuals at each site with potential odontogenic or rhinogenic sinusitis, regardless of preservation. Frequencies of sinuses/individuals with an oroantral fistula present/absent/unobservable are presented in brackets below.

Site	% of observed sinuses with sinusitis	Percentage of sinuses affected by:			Percentage of individuals affected by:	
		Odontogenic sinusitis (oroantral fistula present)	Rhinogenic sinusitis (oroantral fistula absent)	Unobservable (alveolar bone damaged or absent)	Odontogenic sinusitis (oroantral fistula present)	Rhinogenic sinusitis (oroantral fistula absent)
4-L-2	45.3% (24/53)	4.2% (1/24)	25.0% (6/24)	70.8% (17/24)	5.9% (1/17)	94.1% (16/17)
4-L-88	44.4% (4/9)	0.0% (0/4)	50.0% (2/4)	50.0% (2/4)	0.0% (0/4)	100% (4/4)
4-L-100	12.5% (1/8)	0.0% (0/1)	100% (1/1)	0.0% (0/1)	0.0% (0/1)	100% (1/1)
3-Q-33	53.1% (17/32)	5.9% (1/17)	76.5% (13/17)	17.6% (3/17)	9.1% (1/11)	90.9% (10/11)
3-O-1	48.1% (13/27)	0.0% (0/13)	84.6% (11/13)	15.4% (2/13)	0.0% (0/8)	100% (8/8)
4-M-53	23.1% (3/13)	0.0% (0/3)	100% (3/3)	0.0% (0/3)	0.0% (0/2)	100% (2/2)
3-J-23	42.3% (44/104)	11.4% (5/44)	84.1% (37/44)	4.5% (2/44)	17.2% (5/29)	82.8% (24/29)
3-J-18	50.0% (68/136)	10.3% (7/68)	85.3% (58/68)	4.4% (3/68)	14.6% (7/48)	85.4% (41/48)
R12	24.6% (16/65)	18.8% (3/16)	31.2% (5/16)	50.0% (8/16)	30.8% (4/13)	69.2% (9/13)
P37	63.6% (35/55)	0.0% (0/35)	54.3% (19/35)	45.7% (16/35)	0.0% (0/23)	100% (23/23)
Gabati	42.5% (76/179)	2.6% (2/76)	73.7% (56/76)	23.7% (18/76)	3.6% (2/55)	96.4% (53/55)
Soba East	72.7% (48/66)	0.0% (0/48)	68.8% (33/48)	31.2% (15/48)	0.0% (0/28)	100% (28/28)
Total	46.7% (349/747)	5.4% (19/349)	69.9% (244/349)	24.6% (86/349)	8.4% (20/239)	91.6% (219/239)

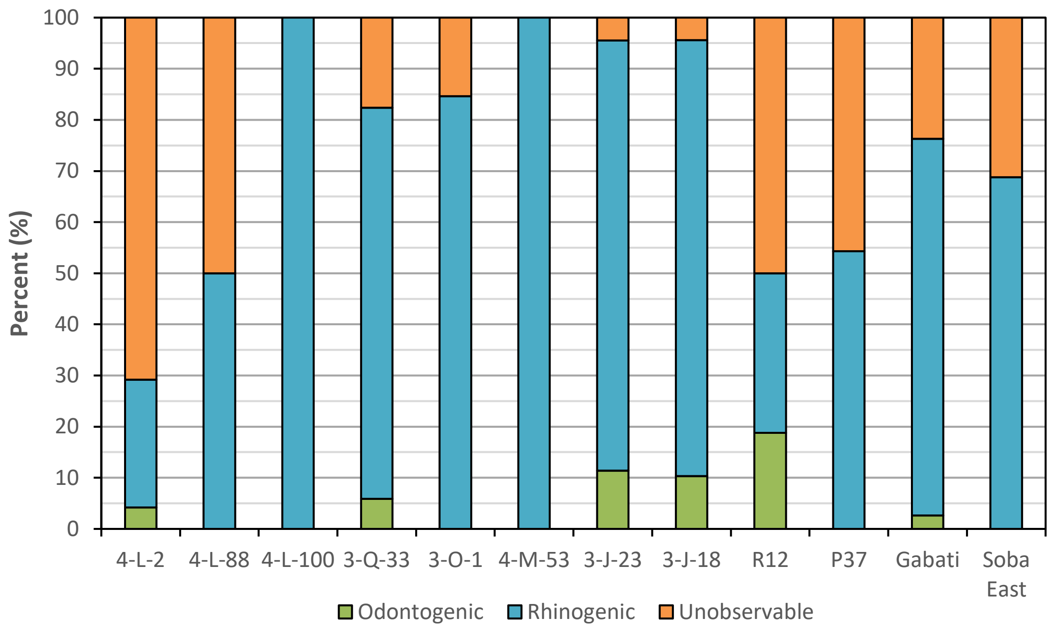


Figure 7.12 – A comparison between the proportion of different potential origins of maxillary sinusitis from different sites.

7.3.1.xv Unilateral or bilateral sinusitis (by site)

Table 7.23 displays the percentage of all individuals with sinusitis at each site that displayed unilateral sinusitis (one sinus affected), bilateral sinusitis (both sinuses affected), or was unknown (only one sinus present). Figure 7.13 compares these data between sites. In general, the proportion of bilateral and unilateral sinusitis was similar at most sites with a larger sample size. However, 3-O-1 and Soba East had higher prevalence rates of bilateral sinusitis and R12 displayed a higher prevalence of unilateral sinusitis in proportion to bilateral sinusitis.

Table 7.23 – The percent of individuals with sinusitis at each site with left, right, or bilateral sinusitis, or unknown due to the absence or unobservability of one of the skeleton's sinuses.

Site	Unilateral Sinusitis			Bilateral Sinusitis	Unknown (one sinus unobservable)
	Left	Right	Total		
4-L-2	23.5% (4/17)	17.6% (3/17)	41.1% (7/17)	47.1% (8/17)	11.8% (2/17)
4-L-88	25.0% (1/4)	25.0% (1/4)	50.0% (2/4)	0.0% (0/4)	50.0% (2/4)
4-L-100	0.0% (0/1)	100% (1/1)	100% (1/1)	0.0% (0/1)	0.0% (0/1)
3-Q-33	18.2% (2/11)	9.1% (1/11)	27.3% (3/11)	54.5% (6/11)	18.2% (2/11)
3-O-1	12.5% (1/8)	25.0% (2/8)	37.5% (3/8)	62.5% (5/8)	0.0% (0/8)
4-M-53	0.0% (0/2)	0.0% (0/2)	0.0% (0/2)	50.0% (1/2)	50.0% (1/2)
3-J-23	13.8% (4/29)	20.7% (6/29)	34.5% (10/29)	51.7% (15/29)	13.8% (4/29)
3-J-18	14.6% (7/48)	14.6% (7/48)	29.2% (14/48)	41.6% (20/48)	29.2% (14/48)
R12	15.4% (2/13)	30.8% (4/13)	46.2% (6/13)	23.0% (3/13)	30.8% (4/13)
P37	17.4% (4/23)	17.4% (4/23)	34.8% (8/23)	52.2% (12/23)	13.0% (3/23)
Gabati	25.5% (14/55)	20.0% (11/55)	45.5% (25/55)	38.2% (21/55)	16.3% (9/55)
Soba East	7.1% (2/28)	17.9% (5/28)	25.0% (7/28)	71.4% (20/28)	3.6% (1/28)
Total	17.2% (41/239)	18.8% (45/239)	36.0% (86/239)	46.4% (111/239)	17.6% (42/239)

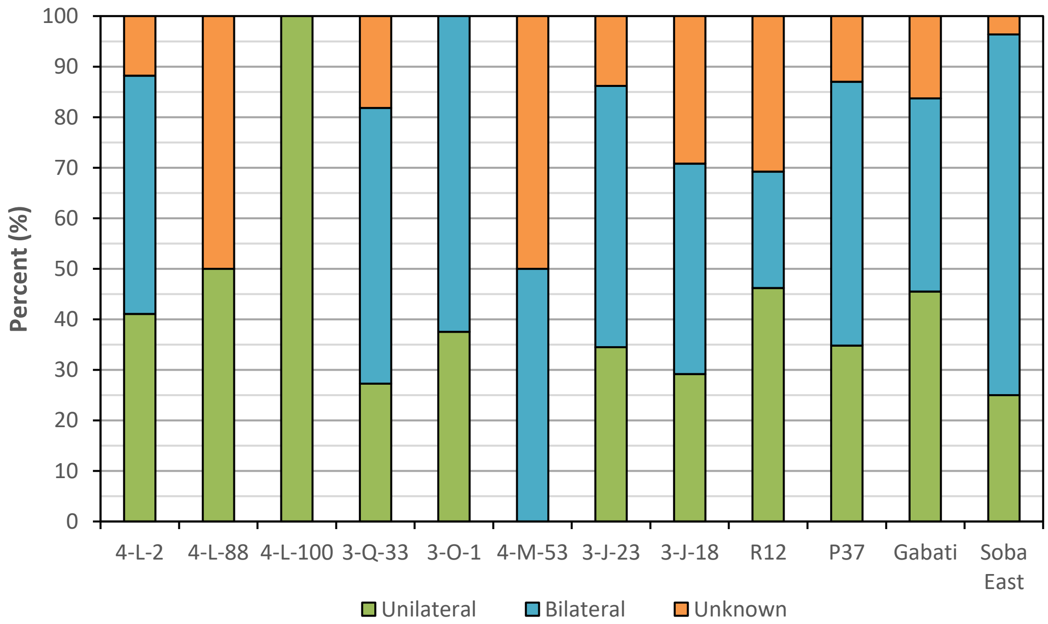


Figure 7.13 – A comparison between the proportion of individuals with unilateral, bilateral, or unknown sinusitis from different sites.

7.3.1.xvi Type of bony change (by site)

Table 7.24 displays the percentage of individuals with maxillary sinusitis at each site observed with the different types of bony change. Figure 7.14 compares these data between sites. Porous new bone was the most common form of bony change related to maxillary sinusitis, followed by spicules. However, percentages of each type of bony change varied by individual site. While a higher percentage of people buried at most sites had porous new bone formation, spicules were more common in individuals buried at 3-J-18, 3-J-23, and 4-M-53, although at 4-M-53 the sample size was too small (only two individuals with sinusitis) for this information to be of any value.

Table 7.24 – The percentage of individuals with maxillary sinusitis at each site observed with the different types of bony change.

Site	Spicules	Remodelled spicules	Pitting	Porous new bone	Other
4-L-2	11.8% (2/17)	35.3% (6/17)	29.4% (5/17)	64.7% (11/17)	17.6% (3/17)
4-L-88	0.0% (0/4)	25.0% (1/4)	50.0% (2/4)	100% (4/4)	0.0% (0/4)
4-L-100	0.0% (0/1)	0.0% (0/1)	0.0% (0/1)	100% (1/1)	0.0% (0/1)
3-Q-33	63.6% (7/11)	36.4% (4/11)	27.3% (3/11)	63.6% (7/11)	27.3% (3/11)
3-O-1	37.5% (3/8)	37.5% (3/8)	37.5% (3/8)	62.5% (5/8)	0.0% (0/8)
4-M-53	100% (2/2)	50.0% (1/2)	50.0% (1/2)	50.0% (1/2)	0.0% (0/2)
3-J-23	51.7% (15/29)	34.5% (10/29)	10.3% (3/29)	48.3% (14/29)	10.3% (3/29)
3-J-18	54.2% (26/48)	47.9% (23/48)	16.7% (8/48)	43.8% (21/48)	10.4% (5/48)
R12	15.4% (2/13)	0.0% (0/13)	23.1% (3/13)	92.3% (12/13)	15.4% (2/13)
P37	43.5% (10/23)	8.7% (2/23)	30.4% (7/23)	82.6% (19/23)	8.7% (2/23)
Gabati	41.8% (23/55)	32.7% (18/55)	14.5% (8/55)	63.6% (35/55)	23.6% (13/55)
Soba East	42.9% (12/28)	35.7% (10/28)	21.4% (6/28)	78.6% (22/28)	7.1% (2/28)
Total	42.7% (102/239)	33.1% (79/239)	20.5% (49/239)	64.0% (153/239)	13.8% (33/239)

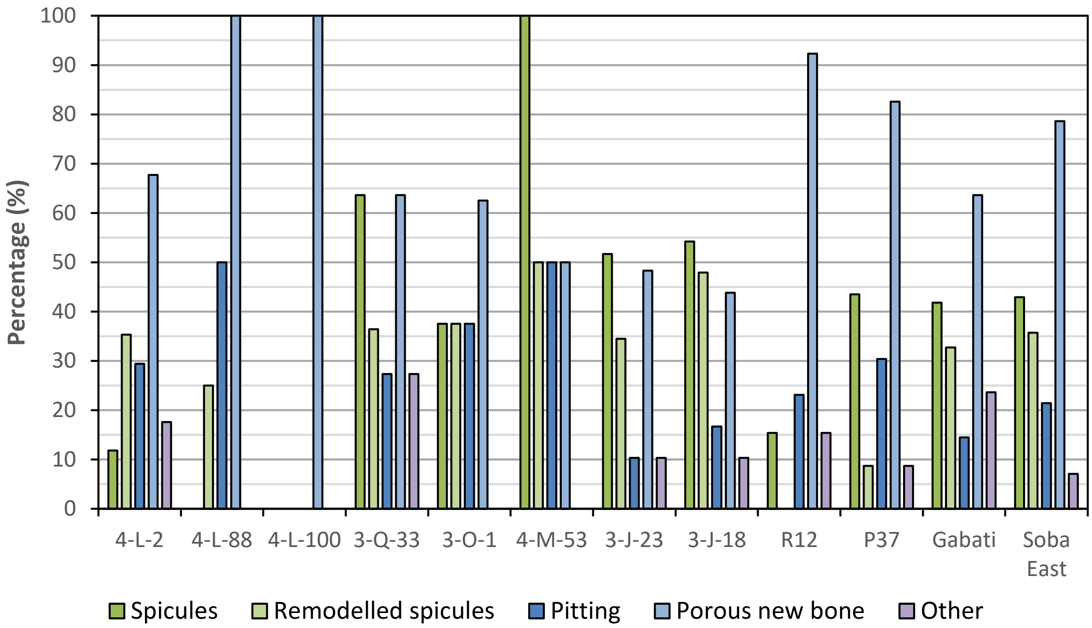


Figure 7.14 – A comparison of the percentage individuals with maxillary sinusitis at each site observed with the different types of bony change.

7.3.2 Maxillary sinusitis by time period

In order to determine the prevalence of maxillary sinusitis by time period, data from certain sites were pooled together. In addition, certain time periods were grouped to increase the number of individuals within the sample, to enable statistical testing.

The prevalence data for the Neolithic period derived only from R12 and for the comparative Kerma period consisted of pooled data from Kerma Ancien and Kerma Moyen individuals from P37 only. Therefore, comparative Neolithic prevalence data, including by sex and age groups, can be found in Section 7.3.1.ix and comparative Kerma prevalence data can be found in Section 7.3.1.x.

7.3.2.i Kerma Classique (Fourth Cataract)

The Kerma Classique group consisted of pooled data from sites 4-L-2, 4-L-88, and 4-L-100. The prevalence of maxillary sinusitis for people living during the Kerma Classique period is presented in Table 7.25. No statistically significant differences were found between sex or age groups when calculated using the frequency for both sinuses preserved or by one or both sinuses preserved.

Table 7.25 – Kerma Classique (Fourth Cataract) maxillary sinusitis prevalence rates, according to sex, age, and within the total group, and results of tests of significant difference between categories. Prevalence rates are presented separately for individuals with evidence for sinusitis who have two sinuses preserved (2SP) or have one or both sinuses preserved (1+SP). Frequencies are presented in brackets below.

Category		2SP	Statistical significance	1+SP	Statistical significance
Sex	**Male**	64.3% (9/14)	P = 1.000 [FET]	62.5% (10/16)	P = 1.000 [FET]
	Female	57.1% (4/7)		57.1% (4/7)	
Age	**Young Adult**	40.0% (2/5)	P = 0.603 [FET]	25.0% (2/8)	P = 0.081 [FET]
	Middle Adult	66.7% (10/15)		70.6% (12/17)	
Total		61.3% (19/31)		56.4% (22/39)	

7.3.2.ii Meroitic and Post-Meroitic (Fourth Cataract)

To increase the sample size to facilitate statistical testing, individuals from both the Meroitic and Post-Meroitic time periods from the Fourth Cataract were pooled (Post-/Meroitic group), consisting of data from sites 3-Q-33, 4-M-53, and 3-O-1. However, prevalence rates for both time periods, including by sex and age groups, are presented separately in Tables G.1 & H.1 within the Appendices. The prevalence of maxillary sinusitis for people living during the Post-/Meroitic period is presented in Table 7.26. No statistically significant differences were found between sex or age groups when calculated using the frequency for both sinuses preserved or by one or both sinuses preserved.

Table 7.26 – Post-/Meroitic (Fourth Cataract) maxillary sinusitis prevalence rates, according to sex, age, and within the total group, and results of tests of significant difference between categories. Prevalence rates are presented separately for individuals with evidence for sinusitis who have two sinuses preserved (2SP) or have one or both sinuses preserved (1+SP). Frequencies are presented in brackets below.

Category		2SP	Statistical significance	1+SP	Statistical significance
Sex	Male	47.6% (10/21)	P = 0.238 [FET]	45.8% (11/24)	P = 0.270 [FET]
	Female	75.0% (6/8)		70.0% (7/10)	
Age	Young Adult	47.1% (8/17)	P = 0.502 [FET]	47.6% (10/21)	P = 0.743 [FET]
	Middle Adult	60.0% (9/15)		56.3% (9/16)	
	Total	54.5% (18/33)		53.8% (21/39)	

7.3.2.iii Medieval (Fourth Cataract)

The Medieval group from the Fourth Cataract consisted of pooled data from sites 3-J-23 and 3-J-18. The prevalence of maxillary sinusitis for people living during the Medieval period is presented in Table 7.27. No statistically significant differences were found between sex or age groups when calculated using the frequency for both sinuses preserved or by one or both sinuses preserved.

Table 7.27 – Medieval (Fourth Cataract) maxillary sinusitis prevalence rates, according to sex, age, and within the total group, and results of tests of significant difference between categories. Prevalence rates are presented separately for individuals with evidence for sinusitis who have two sinuses preserved (2SP) or have one or both sinuses preserved (1+SP). Frequencies are presented in brackets below.

Category		2SP	Statistical significance	1+SP	Statistical significance
Sex	Male	65.5% (36/55)	P = 0.517 [FET]	62.0% (44/71)	P = 0.167 [FET]
	Female	57.9% (22/38)		49.2% (32/65)	
Age	Young Adult	57.5% (23/40)	P = 0.521 [FET]	53.2% (33/62)	P = 0.862 [FET]
	Middle Adult	64.7% (33/51)		55.6% (40/72)	
	Total	61.5% (59/96)		53.8% (77/143)	

7.3.2.iv Meroitic and Post-Meroitic (comparative)

To increase the sample size to facilitate statistical testing, individuals from both Meroitic and Post-Meroitic time periods from the comparative site of Gabati were pooled. However, the prevalence rates for each time period, including by sex and age groups, have been presented separately in Tables G.3 and H.3 within the Appendices. The prevalence of maxillary sinusitis in people living during the Post-/Meroitic period is presented in Table 7.28. A significant difference was found between the sexes when calculated using frequencies for both sinuses preserved and by one or both sinuses preserved, with females having a significantly higher prevalence of maxillary sinusitis. No statistically significant differences were found between age groups when calculated using the frequencies for both sinuses preserved or by one or both sinuses preserved.

Table 7.28 – Post-/Meroitic (comparative) maxillary sinusitis prevalence rates, according to sex, age, and within the total group, and results of tests of significant difference between categories. Prevalence rates are presented separately for individuals with evidence for sinusitis who have two sinuses preserved (2SP) or have one or both sinuses preserved (1+SP). Frequencies are presented in brackets below. Statistically significant values are highlighted in grey.

Category		2SP	Statistical significance	1+SP	Statistical significance
Sex	Male	41.4% (12/29)	P = 0.026 [FET]	40.0% (14/35)	P = 0.032 [FET]
	Female	73.9% (17/23)		66.7% (22/33)	
Age	Young Adult	51.9% (14/27)	P = 0.158 [FET]	48.6% (17/35)	P = 0.140 [FET]
	Middle Adult	73.1% (19/26)		67.7% (21/31)	
Total		58.6% (41/70)		55.1% (49/89)	

7.3.2.v Medieval (comparative)

The comparative Medieval group consisted of pooled data from the sites of Gabati and Soba East. The prevalence of maxillary sinusitis for people living during the Medieval period is presented in Table 7.29. No statistically significant differences were found between sex or age groups when calculated using the frequency for both sinuses preserved or by one or both sinuses preserved.

Table 7.29 – Medieval (comparative) maxillary sinusitis prevalence rates, according to sex, age, and within the total group, and results of tests of significant difference between categories. Prevalence rates are presented separately for individuals with evidence for sinusitis who have two sinuses preserved (2SP) or have one or both sinuses preserved (1+SP). Frequencies are presented in brackets below.

Category		2SP	Statistical significance	1+SP	Statistical significance
Sex	**Male**	77.8% (14/18)	P = 0.671 [FET]	68.2% (15/22)	P = 1.000 [FET]
	Female	63.6% (7/11)		63.6% (7/11)	
Age	**Young Adult**	78.9% (15/19)	P = 1.000 [FET]	75.0% (15/20)	P = 0.483 [FET]
	Middle Adult	75.0% (9/12)		62.5% (10/16)	
Total		80.0% (32/40)		73.9% (34/46)	

7.3.2.vi Summary

Table 7.30 displays the outcomes of Fisher's Exact tests between time periods to explore significant differences. To provide a larger sample size, the statistical tests were calculated using the frequency data from the group with one or both sinuses preserved (1+SP). Several time periods produced significant differences. People living during the Neolithic period had a significantly lower prevalence rate of maxillary sinusitis when compared to all other time periods, except the Fourth Cataract Post-/Meroitic period. The comparative Medieval period had a significantly higher prevalence when compared to the Fourth Cataract Medieval and the comparative Post-/Meroitic and Neolithic periods. People buried at the comparative Kerma period site had a significantly higher prevalence rate than during the Neolithic and the Fourth Cataract Medieval periods. No significant differences were found between time periods within the Fourth Cataract.

Table 7.30 – P-values for Fisher's Exact tests between time periods to measure for significant differences in maxillary sinusitis. Statistically significant values are highlighted in grey.

Time Period	Kerma Classique (4th Cat.)	Post-/Meroitic (4th Cat.)	Medieval (4th Cat.)	Neolithic (Comp.)	Kerma (Comp.)	Post-/Meroitic (Comp)	Medieval (Comp.)
Kerma Classique (4th Cat.)	-						
Post-/Meroitic (4th Cat.)	1.000	-					
Medieval (4th Cat.)	0.857	1.000	-				
Neolithic (Comp.)	0.042	0.071	<0.001	-			
Kerma (Comp.)	0.125	0.089	0.025	<0.001	-		
Post-/Meroitic (Comp.)	1.000	1.000	0.893	0.022	0.051	-	
Medieval (Comp.)	0.111	0.070	0.026	<0.001	1.000	0.040	-

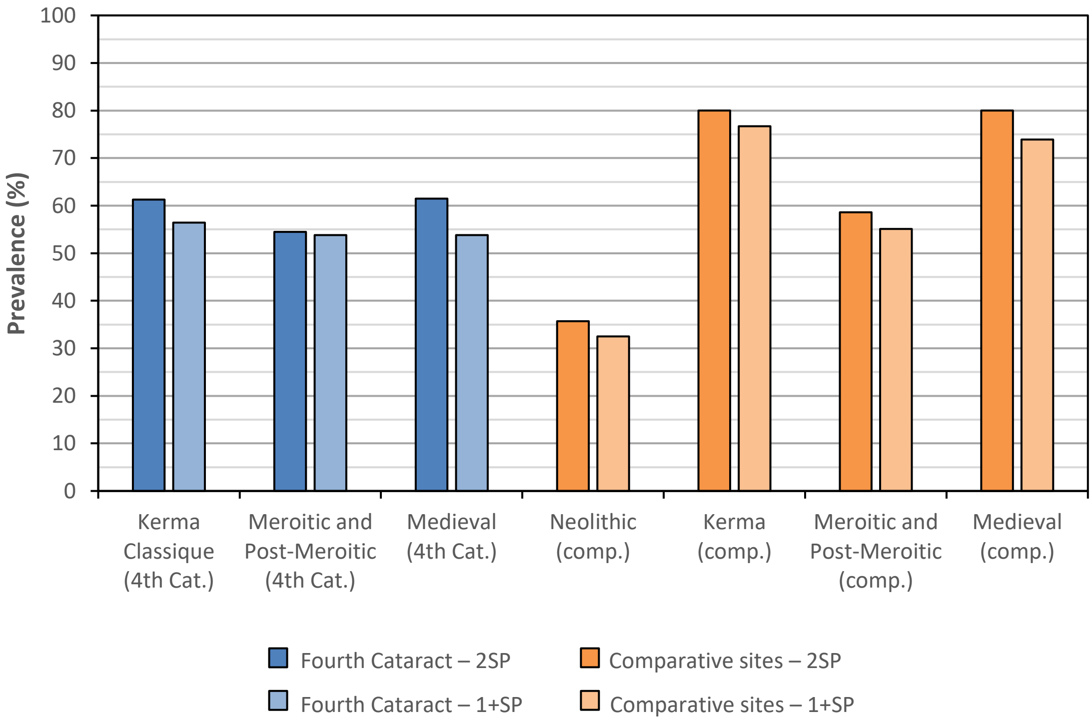


Figure 7.15 – A comparison of the prevalence of maxillary sinusitis between different time periods.

Figure 7.16 compares the prevalence of maxillary sinusitis in males and females within each time period, presented by both sinuses preserved and by one or both sinuses preserved. The comparative Post-/Meroitic time period was the only group to display a statistically significant difference between the sexes, with the prevalence of maxillary sinusitis in females being significantly higher. The Fourth Cataract Meroitic and Post-Meroitic group showed a similar pattern, with females having a higher prevalence, but this was not statistically significant. The comparative Kerma group also displayed a 100% prevalence in females, but this was not significantly different to males, due to the small numbers of individuals for whom sex could be estimated in this group.

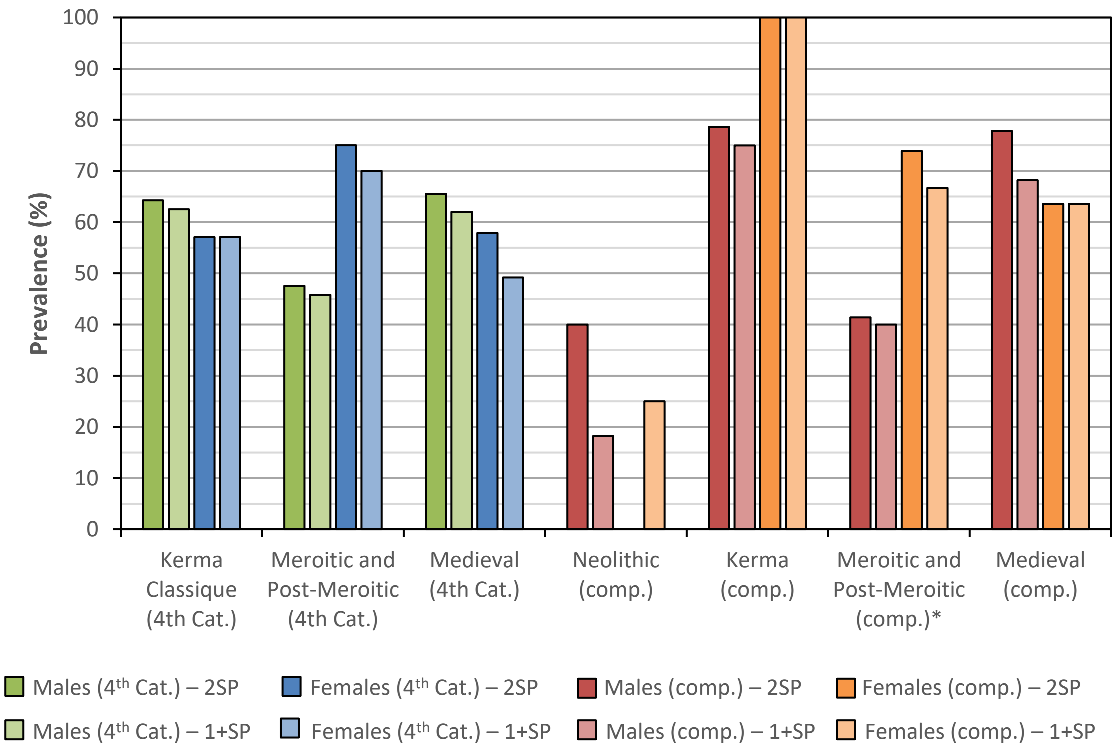


Figure 7.16 – A comparison of the prevalence of maxillary sinusitis between males and females during different time periods (* = statistically significant differences between males and females).

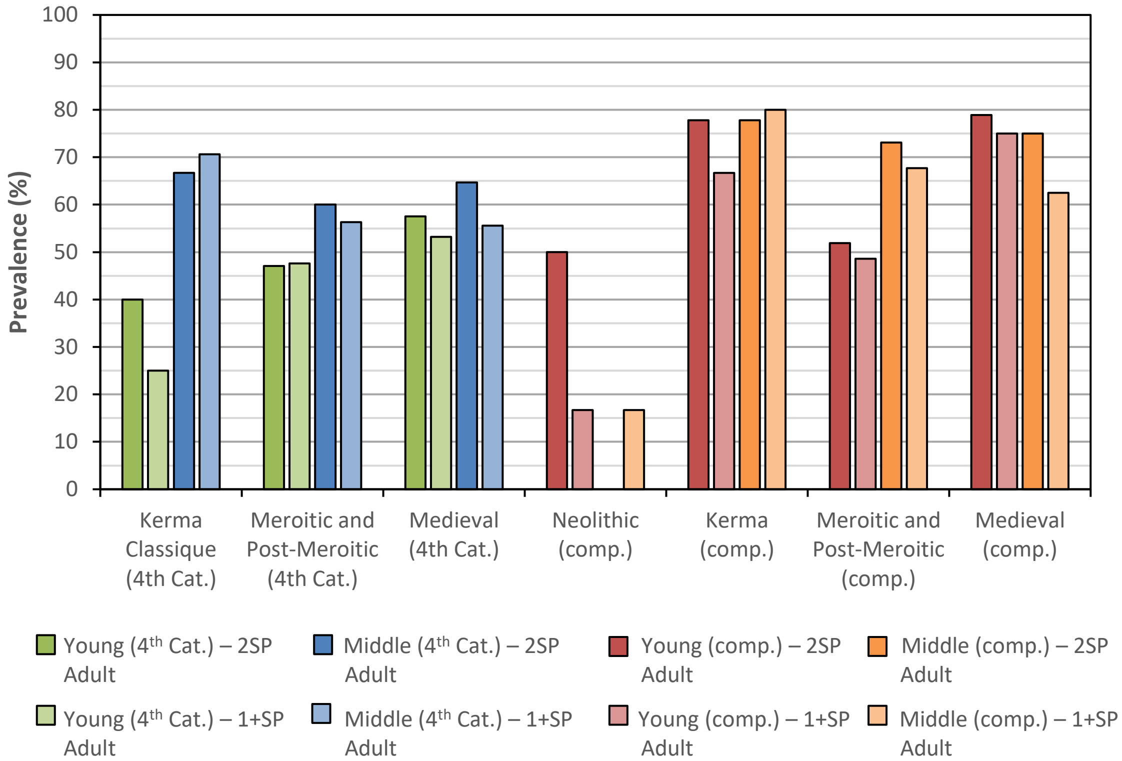


Figure 7.17 – A comparison of the prevalence of maxillary sinusitis between young adults and middle adults during different time periods.

Figure 7.17 compares the prevalence of maxillary sinusitis in young adults and middle adults between different time periods, presented by both sinuses preserved and by one or both sinuses preserved. No time period presented a significant difference between young and middle adults. A higher prevalence in middle adults can be seen during the Kerma Classique period in the Fourth Cataract, but was not significantly different, due to the small number of individuals for whom age could be estimated within this group.

7.3.2.vii The potential cause of maxillary sinusitis (by time period)

Table 7.31 displays the percentage of all sinuses with sinusitis during each time period that demonstrated evidence for potential odontogenic sinusitis (oroantral fistula present), potential rhinogenic sinusitis (oroantral fistula absent), or an unobservable origin (alveolar bone or sinus floor damaged/absent). For comparative purposes with other studies, the percentage of individuals with potential odontogenic or rhinogenic sinusitis is also presented, regardless of the state of preservation of the sinuses. Figure 7.18 compares the data during different time periods by the number of sinuses affected. In general, odontogenic sinusitis was low. The highest prevalence was during the Neolithic, in 18.8% of all sinuses with sinusitis, followed by the Fourth Cataract Medieval period (10.7%). People living during the comparative Kerma and Medieval periods displayed no evidence for odontogenic sinusitis, despite having the highest prevalence rates of sinusitis. Certain sites with poor preservation, however, did contain a large proportion of sinuses with sinusitis that could not be observed for an oroantral fistula. This was highest in the Fourth Cataract Kerma Classique, where 65.5% of affected sinuses could not be reliably observed for an oroantral fistula.

Table 7.31 – The percentage of sinuses during each time period with potential odontogenic sinusitis, rhinogenic sinusitis, or an unobservable origin, and the percentage of individuals during each time period with odontogenic or rhinogenic sinusitis, regardless of preservation. Frequencies of sinuses/individuals with an oroantral fistula present/absent/unobservable are presented in brackets below.

Site	% of observed sinuses with sinusitis	Percentage of sinuses affected by:			Percentage of individuals affected by:	
		Odontogenic sinusitis (oroantral fistula present)	Rhinogenic sinusitis (oroantral fistula absent)	Unobservable (alveolar bone damaged or absent)	Odontogenic sinusitis (oroantral fistula present)	Rhinogenic sinusitis (oroantral fistula absent)
Kerma Classique (4th Cat.)	41.4% (29/70)	3.5% (1/29)	31.0% (9/29)	65.5% (19/29)	4.5% (1/22)	95.5% (21/22)
Post-/Meroitic (4th Cat.)	45.8% (33/72)	3.0% (1/33)	81.8% (27/33)	15.2% (5/33)	4.8% (1/21)	95.2% (20/21)
Medieval (4th Cat.)	46.7% (112/240)	10.7% (12/112)	84.8% (95/112)	4.5% (5/112)	15.6% (12/77)	84.4% (65/77)
Neolithic (comp.)	24.6% (16/65)	18.8% (3/16)	31.2% (5/16)	50.0% (8/16)	30.8% (4/13)	69.2% (9/13)
Kerma (comp.)	63.6% (35/55)	0.0% (0/35)	54.3% (19/35)	45.7% (16/35)	0.0% (0/23)	100% (23/23)
Post-/Meroitic (comp.)	43.4% (69/159)	2.9% (2/69)	72.5% (50/69)	24.6% (17/69)	4.1% (2/49)	95.9% (47/49)
Medieval (comp.)	64.0% (55/86)	0.0% (0/55)	70.9% (39/55)	29.1% (16/55)	0.0% (0/34)	100% (34/34)
Total	46.7% (349/747)	5.4% (19/349)	69.9% (244/349)	24.6% (86/349)	8.4% (20/239)	91.6% (219/239)

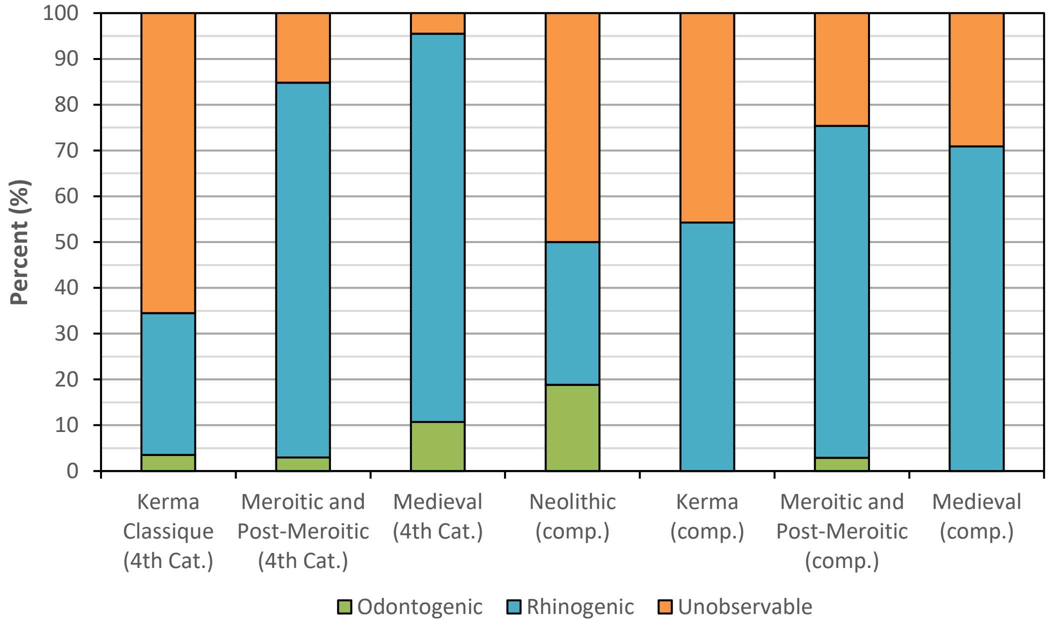


Figure 7.18 – A comparison between the proportion of different potential origins of maxillary sinusitis during different time periods.

7.3.2.viii Unilateral or bilateral sinusitis (by time period)

Table 7.32 displays the proportion of all individuals with sinusitis during each time period that displayed unilateral sinusitis (one sinus affected), bilateral sinusitis (both sinuses affected), or was unknown (only one sinus present). Figure 7.19 compares these data between time periods. The Fourth Cataract Post-/Meroitic and Medieval and the comparative Kerma and Medieval periods displayed a higher proportion of bilateral sinusitis compared to unilateral sinusitis, while the Fourth Cataract Kerma Classique and the comparative Neolithic time periods displayed a higher proportion of unilateral sinusitis. The comparative Post-Meroitic period displayed relatively equal proportions of unilateral and bilateral sinusitis.

Table 7.32 – The percent of individuals with sinusitis during each time period with left, right, or bilateral sinusitis, or unknown due to the absence or unobservability of one of the skeleton's sinuses.

Time Period	Unilateral Sinusitis			Bilateral Sinusitis	Unknown (one sinus unobservable)
	Left	Right	Total		
Kerma Classique (4th Cat.)	22.7% (5/22)	22.7% (5/22)	45.4% (10/22)	36.4% (8/22)	18.2% (4/22)
Post-/Meroitic (4th Cat.)	14.3% (3/21)	14.3% (3/21)	28.6% (6/21)	57.1% (12/21)	14.3% (3/21)
Medieval (4th Cat.)	14.2% (11/77)	16.9% (13/77)	31.1% (24/77)	45.5% (35/77)	23.4% (18/77)
Neolithic (comp.)	15.4% (2/13)	30.8% (4/13)	46.2% (6/13)	23.0% (3/13)	30.8% (4/13)
Kerma (comp.)	17.4% (4/23)	17.4% (4/23)	34.8% (8/23)	52.2% (12/23)	13.0% (3/23)
Post-/Meroitic (comp.)	28.6% (14/49)	14.3% (7/49)	42.9% (21/49)	40.8% (20/49)	16.3% (8/49)
Medieval (comp.)	5.9% (2/34)	26.5% (9/34)	32.4% (11/34)	61.7% (21/34)	5.9% (2/34)
Total	17.2% (41/239)	18.8% (45/239)	36.0% (86/239)	46.4% (111/239)	17.6% (42/239)

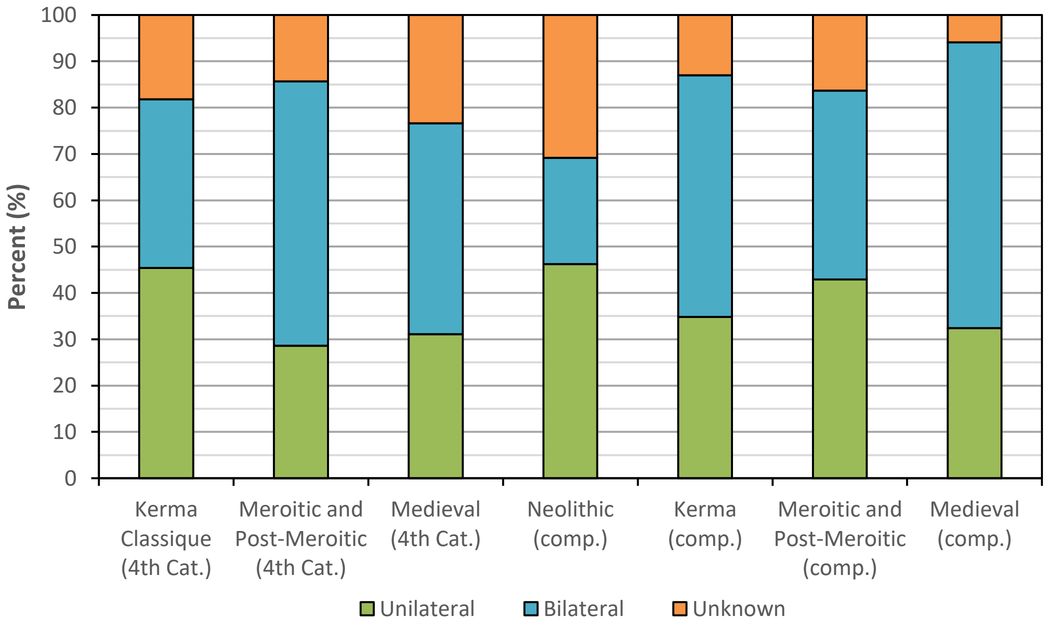


Figure 7.19 – A comparison between the proportion of individuals with unilateral, bilateral, or unknown sinusitis from different time periods.

7.3.2.ix Type of bony change (by time period)

Table 7.33 displays the percentage of individuals with maxillary sinusitis during each time period with the different types of bony change. Figure 7.20 compares these data between sites. Porous new bone was the most common form of bony change related to maxillary sinusitis during all time periods, except in the Medieval period in the Fourth Cataract, where spicules were more common.

Table 7.33 – The percentage of individuals with maxillary sinusitis during each time period with the different types of bony change.

Site	Spicules	Remodelled spicules	Pitting	Porous new bone	Other
Kerma Classique (4th Cat.)	9.1% (2/22)	31.8% (7/22)	31.8% (7/22)	72.7% (16/22)	13.6% (3/22)
Post-/Meroitic (4th Cat.)	57.1% (12/21)	38.1% (8/21)	33.3% (7/21)	61.9% (13/21)	14.3% (3/21)
Medieval (4th Cat.)	53.2% (41/77)	42.9% (33/77)	14.3% (11/77)	45.5% (35/77)	10.4% (8/77)
Neolithic (comp.)	15.4% (2/13)	0.0% (0/13)	23.1% (3/13)	92.3% (12/13)	15.4% (2/13)
Kerma (comp.)	43.5% (10/23)	8.7% (2/23)	30.4% (7/23)	82.6% (19/23)	8.7% (2/23)
Post-/Meroitic (comp.)	40.8% (20/49)	32.7% (16/49)	16.3% (8/49)	65.3% (32/49)	24.5% (12/49)
Medieval (comp.)	44.1% (15/34)	35.3% (12/34)	17.6% (6/34)	73.5% (25/34)	8.8% (3/34)
Total	42.7% (102/239)	33.1% (79/239)	20.5% (49/239)	64.0% (153/239)	13.8% (33/239)

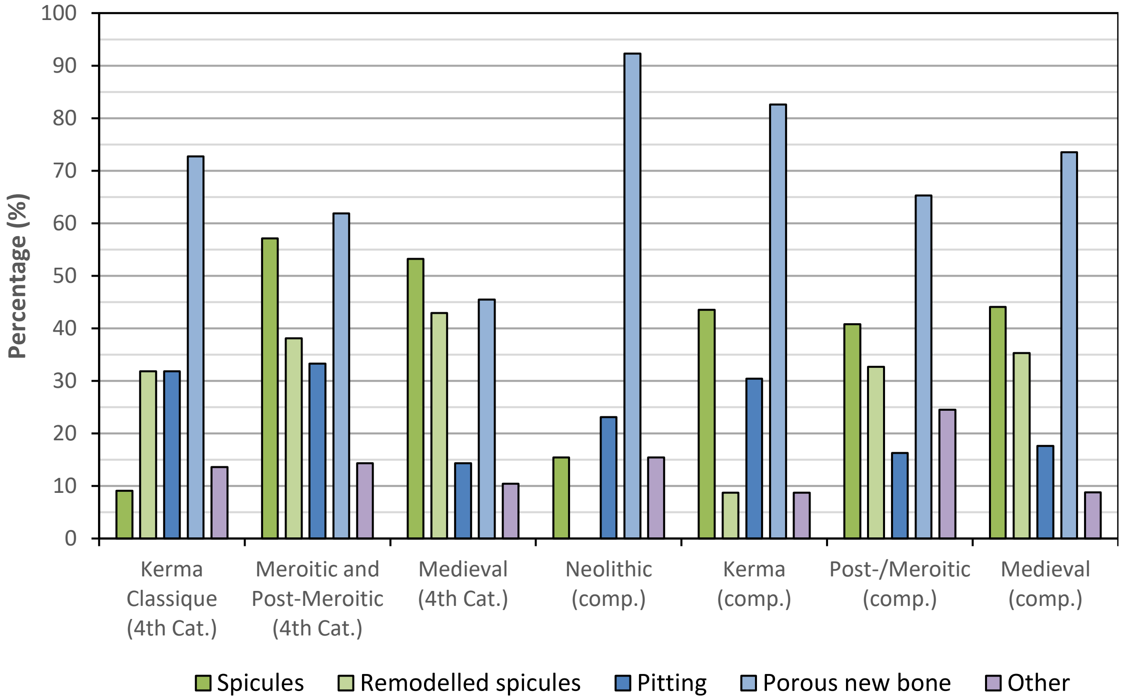


Figure 7.20 – A comparison of the percentage individuals with maxillary sinusitis during different time periods observed with the different types of bony change.

7.4 Prevalence of inflammatory periosteal reaction (IPR) on the ribs

The prevalence rates of IPR on the visceral surfaces of the ribs by site and by time period are given below. Prevalence is presented both by the percentage of individuals within the whole sample group displaying evidence for rib IPR (crude prevalence) and by the percentage of rib sections displaying evidence for rib IPR (true prevalence). Although true prevalence is not useful for answering the research questions of the current study, as this type of data does not provide information about the number of people who had rib IPR, it does allow for the analysis of the distribution of rib IPR within the rib cage in different populations. This could potentially aide in narrowing the scope of the differential diagnoses of rib IPR within different groups. Crude prevalence rates are also presented according to the categories of sex, age, and time period. For the purposes of comparison between differentially preserved sites, true prevalence is presented in rib cage region categories (i.e. upper, middle, lower). True prevalence rates presented by rib number for each site and for each time period can be found in Appendix F. This comparative data is made available for future studies that employ the analytical methods presented in the current research (See section 6.6.3).

Due to the small sample sizes presented here, the majority of statistical analyses relating to crude prevalence rates employed Fisher's Exact tests (denoted as [FET]), using the two-sided P-value, to determine statistically significant differences between groups. Rib section frequencies within true prevalence rate calculations were far larger and tests of significant difference between the different rib sections and rib cage regions consisted of more than two groups. Therefore, Pearson's Chi-Square test (denoted as χ^2) was employed for the majority of tests of statistical significance between the true prevalence groups. All statistical analyses with significant outcomes (p-value = $\leq$0.05) have been highlighted in grey within the tables below.

7.4.1 Rib IPR by site

Crude and true prevalence rates for IPR on the visceral surfaces of the ribs of skeletons from each site are presented below. Where sample sizes were large enough, tests of statistical significance were calculated. When the sample sizes were smaller, further statistical analaysis was undertaken once data were pooled into time period groups (Section 7.4.2).

7.4.1.i 4-L-2 (Fourth Cataract)

The crude prevalence of rib IPR for people buried at 4-L-2 is presented in Table 7.34. No statistically significant differences were found between the sex or age groups. The true prevalence rates for rib IPR are presented in Table 7.35 and the outcomes of tests of significant difference are presented in Table 7.36. A significantly higher prevalence of rib IPR was found at the angle and shaft of the right ribs, and on the right side overall, when compared to the left. The right upper-middle rib cage region also demonstrated a significantly higher prevalence than the left upper-middle region. No significant differences were found between the right and left of any other rib cage region or between the right and left neck. Neither was a statistically significant difference found between the total prevalence rate for each rib section, nor between the total prevalence rate for each rib cage region.

Table 7.34 – 4-L-2 (Fourth Cataract) rib IPR crude prevalence, according to sex and age categories and within the total group, and results of tests of significant difference between categories. Frequencies are presented in brackets below.

Category		Crude prevalence	Statistical significance
Sex	**Male**	25.0% (3/12)	P = 0.617 [FET]
	Female	42.9% (3/7)	
Age	**Young Adult**	22.2% (2/9)	P = 1.000 [FET]
	Middle Adult	25.0% (3/12)	
Total		23.1% (6/26)	

Table 7.35 – 4-L-2 (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib cage region. Frequencies are presented in brackets below.

Side	Section	Prevalence by ribcage region					Total prevalence		
		Upper	Upper-Middle	Middle	Lower-Middle	Lower	Section	Side	Ribcage
Right	**Neck**	0.0% (0/41)	2.6% (1/38)	6.3% (7/112)	8.3% (3/36)	6.0% (3/50)	4.9% (10/203)	6.8% (30/441)	4.5% (40/883)
	Angle	7.3% (3/41)	5.4% (2/37)	7.8% (7/90)	6.3% (2/32)	7.3% (3/41)	7.6% (13/172)		
	Shaft	5.0% (1/20)	21.4% (3/14)	14.8% (4/27)	9.1% (1/11)	10.5% (2/19)	10.6% (7/66)		
Left	**Neck**	0.0% (0/36)	0.0% (0/36)	1.9% (2/106)	3.0% (1/33)	5.7% (3/53)	2.6% (5/195)	2.3% (10/442)	
	Angle	0.0% (0/40)	0.0% (0/33)	2.2% (2/89)	0.0% (0/29)	4.2% (2/48)	2.3% (4/177)		
	Shaft	0.0% (0/18)	0.0% (0/13)	3.6% (1/28)	0.0% (0/12)	0.0% (0/24)	1.4% (1/70)		

Table 7.36 – 4-L-2 (Fourth Cataract) tests of significant difference between rib IPR true prevalence rates from the left and right sides, and between all three rib sections and all four rib cage regions, regardless of side. Frequencies are presented in brackets below. Significant results are highlighted in grey.

Section	Prevalence total by side		Statistical significance between sides	Total prevalence	Statistical significance between sections
	Right	Left			
Neck	4.9% (10/203)	2.6% (5/195)	χ^2 (1) = 1.53, P = 0.216	3.8% (15/398)	χ^2 (2) = 1.202, P = 0.548
Angle	7.6% (13/172)	2.3% (4/177)	χ^2 (1) = 5.285, P = 0.022	4.9% (17/349)	
Shaft	10.6% (7/66)	1.4% (1/70)	P = 0.030 [FET]	5.9% (8/136)	
Upper	3.9% (4/102)	0.0% (0/94)	P = 0.122 [FET]	2.0% (4/196)	χ^2 (3) = 3.66, P = 0.301
Upper-Middle	6.7% (6/89)	0.0% (0/82)	P = 0.029 [FET]	3.5% (6/171)	
Lower-Middle	7.6% (6/79)	1.4% (1/74)	P = 0.118 [FET]	4.6% (7/153)	
Lower	7.3% (8/110)	4.0% (5/125)	χ^2 (1) = 1.2, P = 0.273	5.5% (13/235)	
Total	6.8% (30/441)	2.3% (10/442)	χ^2 (1) = 10.522, P = 0.001	4.5% (40/883)	

7.4.1.ii 4-L-88 (Fourth Cataract)

The crude prevalence of rib IPR for people buried at 4-L-88 is presented in Table 7.37 and the true prevalence is presented in Table 7.38. Due to the small sample size at this site, no statistical analysis was undertaken on either crude or true prevalence rates. However, further analysis of these data is presented within the pooled dataset for the Fourth Cataract Kerma Classique time period (Section 7.4.2.i).

Table 7.37 – 4-L-88 (Fourth Cataract) rib IPR crude prevalence, according to sex and age categories and within the total group. Frequencies are presented in brackets below.

Category		Crude prevalence
Sex	Male	0.0% (0/4)
	Female	0.0% (0/1)
Age	Young Adult	0.0% (0/2)
	Middle Adult	0.0% (0/3)
Total		16.7% (1/6)

Table 7.38 – 4-L-88 (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib cage region. Frequencies are presented in brackets below.

Side	Section	Prevalence by ribcage region					Total prevalence		
		Upper	Upper-Middle	Middle	Lower-Middle	Lower	Section	Side	Ribcage
Right	Neck	0.0% (0/11)	0.0% (0/4)	0.0% (0/8)	0.0% (0/4)	0.0% (0/12)	0.0% (0/31)	8.3% (10/120)	5.9% (14/237)
	Angle	0.0% (0/11)	20.0% (1/5)	15.0% (3/20)	11.1% (1/9)	15.4% (2/13)	11.4% (5/44)		
	Shaft	0.0% (0/10)	22.2% (2/9)	9.1% (2/22)	0.0% (0/9)	23.1% (3/13)	11.1% (5/45)		
Left	Neck	0.0% (0/12)	0.0% (0/7)	0.0% (0/18)	0.0% (0/7)	0.0% (0/10)	0.0% (0/40)	3.4% (4/117)	
	Angle	0.0% (0/13)	20.0% (1/5)	5.3% (1/19)	0.0% (0/8)	16.7% (2/12)	6.8% (3/44)		
	Shaft	0.0% (0/7)	0.0% (0/6)	5.9% (1/17)	12.5% (1/8)	0.0% (0/9)	3.0% (1/33)		

7.4.1.iii 4-L-100 (Fourth Cataract)

The crude prevalence of rib IPR for people buried at 4-L-100 is presented in Table 7.39 and the true prevalence is presented in Table 7.40. Due to the small sample size of this site, no statistical analysis was undertaken on either crude or true prevalence. However, further analysis of these data is presented within the pooled dataset for the Fourth Cataract Kerma Classique time period (Section 7.4.2.i).

Table 7.39 – 4-L-100 (Fourth Cataract) rib IPR crude prevalence, according to sex and age categories and within the total group. Frequencies are presented in brackets below.

Category		Crude prevalence
Sex	Male	- (0/0)
	Female	- (0/0)
Age	Young Adult	- (0/0)
	Middle Adult	- (0/0)
Total		0.0% (0/2)

Table 7.40 – 4-L-100 (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib cage region. Frequencies are presented in brackets below.

Side	Section	Prevalence by ribcage region					Total prevalence		
		Upper	Upper-Middle	Middle	Lower-Middle	Lower	Section	Side	Ribcage
Right	Neck	0.0% (0/3)	0.0% (0/4)	0.0% (0/9)	0.0% (0/3)	0.0% (0/3)	0.0% (0/15)	0.0% (0/29)	0.0% (0/63)
	Angle	0.0% (0/3)	0.0% (0/1)	0.0% (0/6)	0.0% (0/1)	0.0% (0/1)	0.0% (0/10)		
	Shaft	0.0% (0/1)	- (0/0)	0.0% (0/2)	- (0/0)	0.0% (0/1)	0.0% (0/4)		
Left	Neck	0.0% (0/3)	0.0% (0/3)	0.0% (0/10)	0.0% (0/2)	0.0% (0/3)	0.0% (0/16)	0.0% (0/34)	
	Angle	0.0% (0/5)	0.0% (0/2)	0.0% (0/7)	0.0% (0/1)	0.0% (0/2)	0.0% (0/14)		
	Shaft	0.0% (0/2)	0.0% (0/1)	0.0% (0/1)	- (0/0)	0.0% (0/1)	0.0% (0/4)		

7.4.1.iv 3-Q-33 (Fourth Cataract)

The crude prevalence of rib IPR for people buried at 3-Q-33 is presented in Table 7.41. No statistically significant differences were found between sex, age, or time period groups. The true prevalence rates of rib IPR are presented in Table 7.42 and outcomes of tests of significant difference are presented in Table 7.43. A significantly higher prevalence of rib IPR was found on the left shaft and the left side of the rib cage in total, when compared to the right side. No significant differences were found between the right and left sides in any other rib cage section or any of the rib cage regions. A significant difference was found between the total prevalence for each type of rib section affected, with the neck displaying a far higher prevalence than the angle or shaft. No significant difference was found between the total prevalence rate for each rib cage region.

Table 7.41 – 3-Q-33 (Fourth Cataract) rib IPR crude prevalence, according to sex, age, and time period categories and within the total group, and results of tests of significant difference between categories. Frequencies are presented in brackets below.

Category		Crude prevalence	Statistical significance
Sex	**Male**	45.5% (5/11)	P = 1.000 [FET]
	Female	50.0% (4/8)	
Age	**Young Adult**	44.4% (4/9)	P = 1.000 [FET]
	Middle Adult	50.0% (5/10)	
Time Period	**Meroitic**	50.0% (7/14)	P = 0.642 [FET]
	Post-Meroitic	33.3% (2/6)	
Total		45.0% (9/20)	

Table 7.42 – 3-Q-33 (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib cage region. Frequencies are presented in brackets below.

Side	Section	Prevalence by ribcage region					Total prevalence		
		Upper	Upper-Middle	Middle	Lower-Middle	Lower	Section	Side	Ribcage
Right	Neck	3.7% (2/54)	7.4% (4/54)	9.1% (10/110)	11.3% (6/53)	7.7% (4/52)	7.4% (16/216)	3.0% (19/642)	4.4% (56/1274)
	Angle	0.0% (0/56)	0.0% (0/55)	0.9% (1/113)	1.8% (1/55)	0.0% (0/55)	0.4% (1/224)		
	Shaft	0.0% (0/46)	0.0% (0/51)	1.0% (1/104)	2.0% (1/51)	1.9% (1/52)	1.0% (2/202)		
Left	Neck	6.4% (3/47)	3.8% (2/53)	11.0% (12/109)	16.7% (10/60)	14.0% (7/50)	10.7% (22/206)	5.9% (37/632)	
	Angle	3.4% (2/59)	3.6% (2/56)	3.5% (4/114)	3.6% (2/56)	0.0% (0/55)	2.6% (6/228)		
	Shaft	6.4% (3/47)	4.1% (2/49)	4.0% (4/100)	2.0% (1/49)	3.9% (2/51)	4.5% (9/198)		

Table 7.43 – 3-Q-33 (Fourth Cataract) tests of significant difference between rib IPR true prevalence rates from the left and right sides, and between all three rib sections and all four rib cage regions, regardless of side. Frequencies are presented in brackets below. Significant results are highlighted in grey.

Section	Prevalence total by side		Statistical significance between sides	Total prevalence	Statistical significance between sections
	Right	Left			
Neck	7.4% (16/216)	10.7% (22/206)	χ^2 (1) = 1.378, P = 0.240	9.0% (38/422)	χ^2 (2) = 32.628, P = <0.001
Angle	0.4% (1/224)	2.6% (6/228)	P = 0.122 [FET]	1.5% (7/452)	
Shaft	1.0% (2/202)	4.5% (9/198)	χ^2 (1) = 4.726, P = 0.030	2.8% (11/400)	
Upper	1.3% (2/156)	5.2% (8/153)	P = 0.059 [FET]	3.2% (10/309)	χ^2 (3) = 5.583, P = 0.134
Upper-Middle	2.5% (4/160)	3.8% (6/158)	P = 0.540 [FET]	3.1% (10/318)	
Lower-Middle	5.0% (8/159)	7.9% (13/165)	χ^2 (1) = 1.083, P = 0.299	6.5% (21/324)	
Lower	3.1% (5/159)	5.8% (9/156)	χ^2 (1) = 1.277, P = 0.258	4.4% (14/315)	
Total	3.0% (19/642)	5.9% (37/632)	χ^2 (1) = 6.351, P = 0.011	4.4% (56/1274)	

7.4.1.v 3-O-1 (Fourth Cataract)

The crude prevalence of rib IPR for people buried at 3-O-1 is presented in Table 7.44. No statistically significant differences were found between sex or age groups. The true prevalence rates for rib IPR are presented in Table 7.45 and outcomes of tests of significant difference are presented in Table 7.46. A significantly higher prevalence of rib IPR was found on the right side, when compared to the left, between all rib sections, between all rib cage regions except the upper region, and between the total prevalence rate by side. A significant difference was also found between the total prevalence rates for different rib sections, but no significant difference was found between the total prevalence rates for each rib cage region.

Table 7.44 – 3-O-1 (Fourth Cataract) rib IPR crude prevalence, according to sex and age categories and within the total group, and results of tests of significant difference between categories. Frequencies are presented in brackets below.

Category		Crude prevalence	Statistical significance
Sex	**Male**	60.0% (6/10)	P = 1.000 [FET]
	Female	50.0% (1/2)	
Age	**Young Adult**	54.5% (6/11)	P = 1.000 [FET]
	Middle Adult	50.0% (3/6)	
	Total	52.9% (9/17)	

Table 7.45 – 3-O-1 (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib cage region. Frequencies are presented in brackets below.

Side	Section	Prevalence by ribcage region					Total prevalence		
		Upper	Upper-Middle	Middle	Lower-Middle	Lower	Section	Side	Ribcage
Right	Neck	10.3% (4/39)	20.0% (7/35)	19.7% (14/71)	20.0% (7/35)	13.5% (5/37)	15.6% (23/147)	11.7% (50/427)	6.9% (59/859)
	Angle	5.0% (2/40)	14.3% (6/42)	12.6% (11/87)	12.2% (5/41)	10.3% (4/39)	10.2% (17/166)		
	Shaft	3.4% (1/29)	11.5% (3/26)	10.9% (6/55)	10.0% (3/30)	10.0% (3/30)	8.8% (10/114)		
Left	Neck	2.9% (1/34)	8.1% (3/37)	4.0% (3/75)	0.0% (0/36)	0.0% (0/32)	2.8% (4/141)	2.1% (9/432)	
	Angle	0.0% (0/41)	5.1% (2/39)	4.8% (4/84)	5.0% (2/40)	2.8% (1/36)	3.1% (5/161)		
	Shaft	0.0% (0/31)	0.0% (0/33)	0.0% (0/68)	0.0% (0/33)	0.0% (0/31)	0.0% (0/130)		

Table 7.46 – 3-O-1 (Fourth Cataract) tests of significant difference between rib IPR true prevalence rates from the left and right sides, and between all three rib sections and all four rib cage regions, regardless of side. Frequencies are presented in brackets below. Significant results are highlighted in grey.

Section	Prevalence total by side		Statistical significance between sides	Total prevalence	Statistical significance between sections
	Right	Left			
Neck	15.6% (23/147)	2.8% (4/141)	χ^2 (1) = 13.899, P = <0.001	9.4% (27/288)	χ^2 (2) =5.766, P = 0.056
Angle	10.2% (17/166)	3.1% (5/161)	χ^2 (1) = 6.631, P = 0.010	6.7% (22/327)	
Shaft	8.8% (10/114)	0.0% (0/130)	P = <0.001 [FET]	4.1% (10/244)	
Upper	6.5% (7/108)	0.9% (1/106)	P = 0.065 [FET]	3.7% (8/214)	χ^2 (3) = 6.677, P = 0.083
Upper-Middle	15.5% (16/103)	4.6% (5/109)	χ^2 (1) = 7.111, P = 0.008	9.9% (21/212)	
Lower-Middle	14.2% (15/106)	1.8% (2/109)	χ^2 (1) = 11.194, P = <0.001	7.9% (17/215)	
Lower	11.3% (12/106)	1.0% (1/99)	χ^2 (1) = 9.163, P = 0.002	6.3% (13/205)	
Total	11.7% (50/427)	2.1% (9/432)	χ^2 (1) = 31.109, P = <0.001	6.9% (59/859)	

7.4.1.vi 4-M-53 (Fourth Cataract)

The crude prevalence of rib IPR for people buried at 4-M-53 is presented in Table 7.47 and the true prevalence is presented in Table 7.48. Due to the small sample size of this site, no statistical analysis was undertaken on either crude or true prevalence rates. However, further analysis of these data are presented within the pooled dataset for the Fourth Cataract Meroitic and Post-Meroitic time period (Section 7.4.2.ii).

Table 7.47 – 4-M-53 (Fourth Cataract) rib IPR crude prevalence, according to sex and age categories and within the total group. Frequencies are presented in brackets below.

Category		Crude prevalence
Sex	**Male**	0.0% (0/4)
	Female	100% (2/2)
Age	**Young Adult**	25.0% (1/4)
	Middle Adult	50.0% (1/2)
Total		42.9% (3/7)

Table 7.48 – 4-M-53 (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib cage region. Frequencies are presented in brackets below.

Side	Section	Prevalence by ribcage region					Total prevalence		
		Upper	Upper-Middle	Middle	Lower-Middle	Lower	Section	Side	Ribcage
Right	**Neck**	0.0% (0/17)	0.0% (0/19)	0.0% (0/37)	0.0% (0/18)	5.3% (1/19)	1.4% (1/73)	0.9% (2/217)	0.9% (4/422)
	Angle	0.0% (0/19)	0.0% (0/20)	0.0% (0/38)	0.0% (0/18)	5.3% (1/19)	1.3% (1/76)		
	Shaft	0.0% (0/16)	0.0% (0/17)	0.0% (0/36)	0.0% (0/19)	0.0% (0/16)	0.0% (0/68)		
Left	**Neck**	0.0% (0/16)	0.0% (0/16)	2.9% (1/35)	5.5% (1/18)	5.3% (1/19)	2.9% (2/70)	1.0% (2/205)	
	Angle	0.0% (0/15)	0.0% (0/18)	0.0% (0/38)	0.0% (0/18)	0.0% (0/19)	0.0% (0/72)		
	Shaft	0.0% (0/15)	0.0% (0/18)	0.0% (0/33)	0.0% (0/14)	0.0% (0/15)	0.0% (0/63)		

7.4.1.vii 3-J-23 (Fourth Cataract)

The crude prevalence of rib IPR for people buried at 3-J-23 is presented in Table 7.49. No statistically significant differences were found between sex or age groups. The true prevalence rates for rib IPR are presented in Table 7.50 and outcomes of tests of significant difference are presented in Table 7.51. No significant differences were found between the right and left sides for any rib section, rib cage region, or for the total prevalence for each side. A significant difference was found both between the total prevalence rates for different rib sections and between the total prevalence rates for each rib cage region.

Table 7.49 – 3-J-23 (Fourth Cataract) rib IPR crude prevalence, according to sex and age categories and within the total group, and results of tests of significant difference between categories. Frequencies are presented in brackets below.

Category		Crude prevalence	Statistical significance
Sex	**Male**	50.0% (15/30)	P = 0.617 [FET]
	Female	42.4% (14/33)	
Age	**Young Adult**	48.6% (17/35)	p = 0.443 [FET]
	Middle Adult	35.7% (10/28)	
Total		43.9% (29/66)	

Table 7.50 - 3-J-23 (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib cage region. Frequencies are presented in brackets below.

Side	Section	Prevalence by ribcage region					Total prevalence		
		Upper	Upper-Middle	Middle	Lower-Middle	Lower	Section	Side	Ribcage
Right	**Neck**	10.1% (19/189)	14.0% (27/193)	13.5% (52/384)	13.2% (25/189)	7.0% (13/185)	11.1% (84/758)	8.4% (191/2266)	8.5% (386/4568)
	Angle	8.3% (16/192)	12.4% (24/193)	10.4% (40/386)	8.4% (16/191)	4.3% (8/186)	8.4% (64/764)		
	Shaft	8.1% (15/186)	8.1% (15/185)	6.7% (25/374)	4.8% (9/188)	1.6% (3/184)	5.8% (43/744)		
Left	**Neck**	8.2% (16/194)	16.6% (32/193)	14.0% (54/387)	11.5% (22/192)	3.7% (7/190)	10.0% (77/771)	8.5% (195/2302)	
	Angle	5.1% (10/195)	13.4% (26/194)	12.8% (50/390)	12.4% (24/194)	5.2% (10/191)	9.0% (70/776)		
	Shaft	4.8% (9/189)	8.5% (16/189)	7.4% (28/378)	6.3% (12/189)	5.9% (11/188)	6.4% (48/755)		

Table 7.51 – 3-J-23 (Fourth Cataract) tests of significant difference between rib IPR true prevalence rates from the left and right sides, and between all three rib sections and all four rib cage regions, regardless of side. Frequencies are presented in brackets below. Significant results are highlighted in grey.

Section	Prevalence total by side		Statistical significance between sides	Total prevalence	Statistical significance between sections
	Right	Left			
Neck	11.1% (84/758)	10.0% (77/771)	χ^2 (1) = 0.486, P = 0.486	10.5% (161/1529)	χ^2 (2) = 19.644, P = <0.001
Angle	8.4% (64/764)	9.0% (70/776)	χ^2 (1) = 0.201, P = 0.654	8.7% 134/1540	
Shaft	5.8% (43/744)	6.4% (48/755)	χ^2 (1) = 0.220, P = 0.639	6.1% 91/1499	
Upper	8.8% (50/567)	6.1% (35/578)	χ^2 (1) = 3.179, P = 0.075	7.4% (85/1145)	χ^2 (3) = 45.215, P = <0.001
Upper-Middle	11.6% (66/571)	12.8% (74/576)	χ^2 (1) = 0.444, P = 0.505	12.2% (140/1147)	
Lower-Middle	8.8% (50/568)	10.1% (58/575)	χ^2 (1) = 0.551, P = 0.458	9.4% (108/1143)	
Lower	4.3% (24/555)	4.9% (28/569)	χ^2 (1) = 0.227, P = 0.634	4.6% (52/1124)	
Total	8.4% (191/2266)	8.5% (195/2302)	χ^2 (1) = 0.003, P = 0.959	8.5% (386/4568)	

7.4.1.viii 3-J-18 (Fourth Cataract)

The crude prevalence rate of rib IPR for people buried at 3-J-18 is presented in Table 7.52. No statistically significant differences were found between sex or age groups. The true prevalence rates of rib IPR are presented in Table 7.53 and outcomes of tests of significant difference are presented in Table 7.54. A significantly higher prevalence on the left side, compared to the right, was found at the angle section and at the upper rib cage region. No significant differences were found between the right and left sides of any other rib section or rib cage region, nor by the total prevalence for each side. A significant difference was found both between the total prevalence rates for different rib sections and for each rib cage region.

Table 7.52 – 3-J-18 (Fourth Cataract) rib IPR crude prevalence, according to sex and age categories and within the total group, and results of tests of significant difference between categories. Frequencies are presented in brackets below.

Category		Crude prevalence	Statistical significance
Sex	Male	22.4% (13/58)	P = 0.823 [FET]
	Female	25.5% (13/51)	
Age	Young Adult	17.4% (8/46)	P = 0.178 [FET]
	Middle Adult	30.2% (19/63)	
Total		24.8% (28/113)	

Table 7.53 – 3-J-18 (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib cage region. Frequencies are presented in brackets below.

Side	Section	Prevalence by ribcage region					Total prevalence		
		Upper	Upper-Middle	Middle	Lower-Middle	Lower	Section	Side	Ribcage
Right	Neck	3.3% (11/329)	7.0% (22/316)	7.4% (48/652)	7.3% (23/315)	2.8% (9/318)	5.2% (68/1299)	3.2% (126/3887)	3.3% (255/7670)
	Angle	0.3% (1/330)	2.5% (8/318)	3.5% (23/663)	3.8% (12/318)	2.2% (7/324)	2.4% (31/1317)		
	Shaft	0.6% (2/316)	2.2% (7/314)	2.4% (15/638)	1.9% (6/312)	3.2% (10/317)	2.1% (27/1271)		
Left	Neck	3.5% (11/318)	5.7% (18/314)	5.3% (34/639)	4.2% (13/308)	2.3% (7/307)	4.1% (52/1264)	3.4% (129/3783)	
	Angle	3.1% (10/325)	3.8% (12/314)	5.0% (32/644)	5.4% (17/312)	2.6% (8/311)	3.9% (50/1280)		
	Shaft	1.9% (6/315)	2.6% (8/302)	2.6% (16/620)	2.6% (8/305)	1.6% (5/304)	2.2% (27/1239)		

Table 7.54 – 3-J-18 (Fourth Cataract) tests of significant difference between rib IPR true prevalence rates from the left and right sides, and between all three rib sections and all four rib cage regions, regardless of side. Frequencies are presented in brackets below. Significant results are highlighted in grey.

Section	Prevalence total by side		Statistical significance between sides	Total prevalence	Statistical significance between sections
	Right	Left			
Neck	5.2% (68/1299)	4.1% (52/1264)	χ^2 (1) = 1.804, P = 0.179	4.7% (120/2563)	χ^2 (2) = 25.784, P = <0.001
Angle	2.4% (31/1317)	3.9% (50/1280)	χ^2 (1) = 5.177, P = 0.023	3.1% (81/2597)	
Shaft	2.1% (27/1271)	2.2% (27/1239)	χ^2 (1) = 0.009, P = 0.925	2.2% (54/2510)	
Upper	1.4% (14/975)	2.8% (27/958)	χ^2 (1) = 4.449, P = 0.035	2.1% (41/1933)	χ^2 (3) = 20.956, P = <0.001
Upper-Middle	3.9% (37/948)	4.1% (38/930)	χ^2 (1) = 0.041, P = 0.840	4.0% (75/1878)	
Lower-Middle	4.3% (41/945)	4.1% (38/925)	χ^2 (1) = 0.061, P = 0.804	4.2% (79/1870)	
Lower	2.7% (26/959)	2.2% (20/922)	χ^2 (1) = 0.579, P =0.447	2.4% (46/1881)	
Total	3.2% (126/3887)	3.4% (129/3783)	χ^2 (1) = 0.169, P = 0.681	3.3% (255/7670)	

7.4.1.ix R12 (comparative site)

The crude prevalence of rib IPR for people buried at R12 is presented in Table 7.55 and true prevalence is presented in Table 7.56. Due to the small sample size of this site and the fact that no individuals demonstrated evidence for rib IPR, no statistical analysis was undertaken on crude prevalence rates within sex and age categories or on true prevalence rates within side, rib section and rib cage region categories. However, the total crude and true prevalence rates for R12 were tested for significant differences against other sites and time periods (Sections 7.4.1.xiii and 7.4.2.vi). Additionally, considerably more individuals could be observed for maxillary sinusitis at this site and the analysis of this data by sex and age is presented in Section 7.3.1.ix.

Table 7.55 – R12 (comparative) rib IPR crude prevalence, according to sex and age categories and within the total group. Frequencies are presented in brackets below.

Category		Crude prevalence
Sex	Male	0.0% (0/8)
	Female	0.0% (0/3)
Age	Young Adult	0.0% (0/5)
	Middle Adult	0.0% (0/2)
Total		0.0% (0/13)

Table 7.56 – R12 (comparative) rib IPR true prevalence by side, rib section, and rib cage region. Frequencies are presented in brackets below.

Side	Section	Prevalence by ribcage region					Total prevalence		
		Upper	Upper-Middle	Middle	Lower-Middle	Lower	Section	Side	Ribcage
Right	Neck	0.0% (0/14)	0.0% (0/24)	0.0% (0/56)	0.0% (0/17)	0.0% (0/13)	0.0% (0/83)	0.0% (0/216)	0.0% (0/411)
	Angle	0.0% (0/25)	0.0% (0/26)	0.0% (0/56)	0.0% (0/15)	0.0% (0/13)	0.0% (0/94)		
	Shaft	0.0% (0/16)	0.0% (0/13)	0.0% (0/18)	0.0% (0/4)	0.0% (0/5)	0.0% (0/39)		
Left	Neck	0.0% (0/20)	0.0% (0/15)	0.0% (0/49)	0.0% (0/13)	0.0% (0/8)	0.0% (0/77)	0.0% (0/195)	
	Angle	0.0% (0/23)	0.0% (0/17)	0.0% (0/52)	0.0% (0/14)	0.0% (0/10)	0.0% (0/85)		
	Shaft	0.0% (0/14)	0.0% (0/5)	0.0% (0/13)	0.0% (0/4)	0.0% (0/6)	0.0% (0/33)		

7.4.1.x P37 (comparative site)

The crude prevalence of rib IPR for people buried at P37 is presented in Table 7.57. No statistically significant differences were found between sex, age, or time period groups. The true prevalence rates of rib IPR are presented in Table 7.58 and the outcomes of tests of significant difference are presented in Table 7.59. No statistically significant differences between true prevalence rates were found when comparing sides, rib sections, or rib cage regions.

Table 7.57 – P37 (comparative) rib IPR crude prevalence, according to sex and age categories and within the total group, and results of tests of significant difference between categories. Frequencies are presented in brackets below.

Category		Crude prevalence	Statistical significance
Sex	**Male**	29.4% (5/17)	P = 1.000 [FET]
	Female	25.0% (2/6)	
Age	**Young Adult**	15.4% (2/13)	P = 0.645 [FET]
	Middle Adult	25.0% (3/12)	
Time Period	**Kerma Ancien**	21.7% (5/23)	P = 1.000 [FET]
	Kerma Moyen	25.0% (2/8)	
Total		22.6% (7/31)	

Table 7.58 – P37 (comparative) rib IPR true prevalence by side, rib section, and rib cage region. Frequencies are presented in brackets below.

Side	Section	Prevalence by ribcage region					Total prevalence		
		Upper	Upper-Middle	Middle	Lower-Middle	Lower	Section	Side	Ribcage
Right	Neck	4.1% (3/74)	4.9% (4/82)	4.4% (7/160)	4.1% (3/73)	3.8% (3/80)	4.1% (13/314)	3.8% (34/886)	3.8% (68/1774)
	Angle	3.0% (2/66)	5.1% (4/78)	3.6% (6/168)	1.2% (1/82)	3.7% (3/82)	3.5% (11/316)		
	Shaft	5.5% (3/55)	6.5% (4/62)	5.3% (7/133)	4.5% (3/67)	0.0% (0/68)	3.9% (10/256)		
Left	Neck	4.5% (3/66)	4.1% (3/73)	3.9% (6/153)	4.1% (3/74)	4.1% (3/73)	4.1% (12/292)	3.8% (34/888)	
	Angle	1.4% (1/71)	5.3% (4/76)	5.0% (8/160)	5.2% (4/77)	3.8% (3/80)	3.9% (12/311)		
	Shaft	3.1% (2/65)	4.5% (3/67)	4.2% (6/142)	4.6% (3/65)	2.6% (2/78)	3.5% (10/285)		

Table 7.59 – P37 (comparative) tests of significant difference between rib IPR true prevalence rates from the left and right sides, and between all three rib sections and all four rib cage regions, regardless of side. Frequencies are presented in brackets below.

Section	Prevalence total by side		Statistical significance between sides	Total prevalence	Statistical significance between sections
	Right	Left			
Neck	4.1% (13/314)	4.1% (12/292)	χ^2 (1) = 0.0004, P = 0.985	4.1% (25/606)	χ^2 (2) = 0.214, P = 0.899
Angle	3.5% (11/316)	3.9% (12/311)	χ^2 (1) = 0.063, P = 0.801	3.7% (23/627)	
Shaft	3.9% (10/256)	3.5% (10/285)	χ^2 (1) = 0.060, P = 0.807	3.7% (20/541)	
Upper	4.1% (8/195)	3.0% (6/202)	χ^2 (1) = 0.374, P = 0.541	3.5% (14/397)	χ^2 (3) = 2.555, P = 0.466
Upper-Middle	5.4% (12/222)	4.6% (10/216)	χ^2 (1) = 0.138, P = 0.710	5.0% (22/438)	
Lower-Middle	3.2% (7/222)	4.6% (10/216)	χ^2 (1) = 0.200, P = 0.654	3.9% (17/438)	
Lower	2.6% (6/230)	3.5% (8/231)	χ^2 (1) = 0.286, P = 0.593	3.0% (14/461)	
Total	3.8% (34/886)	3.8% (34/888)	χ^2 (1) = 0.0001, P = 0.992	3.8% (68/1774)	

7.4.1.xi Gabati (comparative site)

The crude prevalence of rib IPR for individuals buried at Gabati is presented in Table 7.60. Fisher's Exact tests can only be used to compare significant differences between two groups. As there were three time periods for the skeletons from this site, a Pearson's Chi-Square test (with two degrees of freedom) was used to test for statistically significant differences between time periods. No statistically significant differences were found between sex, age, or time period groups. The true prevalence rates of rib IPR are presented in Table 7.61 and the outcomes of tests of significant difference are presented in Table 7.62. A significantly higher prevalence rate of rib IPR was found on the left side at the neck and the shaft, the upper and the upper-middle rib cage regions, and on the left side overall, when compared to the right side. No significant differences were found between the right and left ribs at the angle or in the lower-middle and lower rib cage regions. Neither was a statistically significant difference found between the total prevalence rate for different rib sections or rib cage regions.

Table 7.60 – Gabati (comparative) rib IPR crude prevalence, according to sex, age, and time period categories and within the total group, and results of tests of significant difference between categories. Frequencies are presented in brackets below.

Category		Crude prevalence	Statistical significance
Sex	**Male**	27.0% (10/37)	P = 1.000 [FET]
	Female	27.3% (9/33)	
Age	**Young Adult**	25.0% (9/36)	P = 0.790 [FET]
	Middle Adult	29.4% (10/34)	
Time Period	**Meroitic**	28.9% (13/45)	χ^2 (2) = 0.815, P = 0.665
	Post-Meroitic	20.0% (4/20)	
	Medieval	33.3% (4/12)	
Total		27.3% (21/77)	

Table 7.61 – Gabati (comparative) rib IPR true prevalence by side, rib section, and rib cage region. Frequencies are presented in brackets below.

Side	Section	Prevalence by ribcage region: Upper	Upper-Middle	Middle	Lower-Middle	Lower	Total prevalence: Section	Side	Ribcage
Right	Neck	1.1% (2/174)	1.9% (3/162)	2.3% (9/399)	1.8% (3/165)	0.5% (1/190)	1.6% (12/763)	1.6% (37/2254)	2.7% (119/4439)
	Angle	1.0% (2/193)	1.7% (3/180)	2.7% (12/450)	2.2% (4/178)	1.4% (3/217)	2.0% (17/860)		
	Shaft	0.0% (0/145)	0.0% (0/134)	1.9% (6/323)	2.2% (3/138)	1.2% (2/163)	1.3% (8/631)		
Left	Neck	4.3% (7/163)	4.3% (7/162)	5.4% (20/368)	3.2% (5/157)	2.2% (4/184)	4.3% (31/715)	3.8% (82/2185)	
	Angle	1.6% (3/190)	3.7% (7/191)	4.9% (22/445)	4.0% (7/175)	2.0% (4/200)	3.5% (29/835)		
	Shaft	3.2% (5/155)	4.2% (6/144)	4.2% (14/332)	4.0% (6/150)	2.0% (3/148)	3.5% (22/635)		

Table 7.62 – Gabati (comparative) tests of significant difference between rib IPR true prevalence rates from the left and right sides, and between all three rib sections and all four rib cage regions, regardless of side. Frequencies are presented in brackets below. Significant results are highlighted in grey.

Section	Prevalence total by side: Right	Left	Statistical significance between sides	Total prevalence	Statistical significance between sections
Neck	1.6% (12/763)	4.3% (31/715)	χ^2 (1) = 9.975, P = 0.002	2.9% (43/1478)	χ^2 (2) = 0.773, P = 0.680
Angle	2.0% (17/860)	3.5% (29/835)	χ^2 (1) = 3.593, P = 0.058	2.7% (46/1695)	
Shaft	1.3% (8/631)	3.5% (22/635)	χ^2 (1) = 6.602, P = 0.010	2.4% (30/1266)	
Upper	0.8% (4/512)	3.05 (15/508)	χ^2 (1) = 6.578, P = 0.010	1.9% (19/1020)	χ^2 (3) = 5.948, P = 0.114
Upper-Middle	1.3% (6/476)	4.0% (20/497)	χ^2 (1) = 7.140, P = 0.008	2.7% (26/973)	
Lower-Middle	2.1% (10/481)	3.7% (18/482)	χ^2 (1) = 2.337, P = 0.126	2.9% (28/963)	
Lower	1.1% (6/570)	2.1% (11/532)	χ^2 (1) = 1.867, P = 0.172	1.5% (17/1102)	

Total	1.6% (37/2254)	3.8% (82/2185)	χ^2 (1) = 18.957, P = <0.001	2.7% (119/4439)

7.4.1.xii Soba East (comparative site)

The crude prevalence of rib IPR for people buried at Soba East is presented in Table 7.63. No statistically significant differences were found between sex or age groups. The true prevalence rates of rib IPR are presented in Table 7.64 and outcomes of tests of significant difference are presented in Table 7.65. No significant differences were found between the right and left sides by any rib section, rib cage region, or by the total prevalence rate for each side. A significant difference was found both between the total prevalence rate for different rib sections and between the total prevalence rate for each rib cage region.

Table 7.63 – Soba East (comparative) rib IPR crude prevalence, according to sex and age categories and within the total group, and results of tests of significant difference between categories. Frequencies are presented in brackets below.

Category		Crude prevalence	Statistical significance
Sex	**Male**	31.3% (5/16)	P = 0.119 [FET]
	Female	80.0% (4/5)	
Age	**Young Adult**	36.4% (4/11)	P = 0.414 [FET]
	Middle Adult	58.3% (7/12)	
Total		42.9% (12/28)	

Table 7.64 – Soba East (comparative) rib IPR true prevalence by ribcage region, side and section, and total true prevalence by each section, side and whole ribcage. Frequency of sections observed with rib IPR is presented in brackets.

Side	Section	Prevalence by ribcage region: Upper	Upper-Middle	Middle	Lower-Middle	Lower	Total prevalence: Section	Side	Ribcage
Right	Neck	8.6% (5/58)	14.3% (9/63)	12.2% (16/131)	10.3% (6/58)	9.8% (6/61)	10.8% (27/250)	7.9% (54/680)	7.6% (105/1373)
	Angle	3.2% (2/63)	12.1% (8/66)	9.6% (13/136)	8.5% (5/59)	5.0% (3/60)	6.9% (18/259)		
	Shaft	2.2% (1/46)	13.6% (6/44)	8.0% (7/88)	5.4% (2/37)	2.7% (1/37)	5.3% (9/171)		
Left	Neck	6.2% (4/65)	15.3% (9/59)	12.7% (15/118)	12.5% (6/48)	5.0% (3/60)	9.1% (22/243)	7.4% (51/639)	
	Angle	1.6% (1/64)	8.1% (5/62)	6.1% (8/132)	5.2% (3/58)	3.2% (2/63)	4.2% (11/259)		
	Shaft	4.5% (2/44)	12.8% (5/39)	9.5% (9/95)	8.2% (4/49)	13.5% (7/52)	9.4% (18/191)		

Table 7.65 – Soba East (comparative) tests of significant difference between rib IPR true prevalence rates from the left and right sides, and between all three rib sections and all four rib cage regions, regardless of side. Frequencies are presented in brackets below. Significant results are highlighted in grey.

Section	Prevalence total by side: Right	Left	Statistical significance between sides	Total prevalence	Statistical significance between sections
Neck	10.8% (27/250)	9.1% (22/243)	χ^2 (1) = 0.420, P = 0.517	9.9% (49/493)	χ^2 (2) = 6.764, P = 0.034
Angle	6.9% (18/259)	4.2% (11/259)	χ^2 (1) = 1.790, P = 0.181	5.6% (29/518)	
Shaft	5.3% (9/171)	9.4% (18/191)	χ^2 (1) = 2.263, P = 0.132	7.5% (27/362)	
Upper	4.8% (8/167)	4.0% (7/173)	χ^2 (1) = 0.112, P = 0.738	4.4% (15/340)	χ^2 (3) = 16.553, P = <0.001
Upper-Middle	13.3% (23/173)	11.9% (19/160)	χ^2 (1) = 0.152, P = 0.697	12.6% (42/333)	
Lower-Middle	8.4% (13/154)	8.4% (13/155)	χ^2 (1) = <0.001, P = 0.986	8.4% (26/309)	
Lower	6.3%	6.9%	χ^2 (1) = 0.038,	6.6%	

	(10/158)	(12/175)	P = 0.846	(22/333)	
Total	7.9% (54/680)	7.4% (51/639)	χ^2 (1) = <0.001, P = 0.979	7.6% (105/1373)	

7.4.1.xiii Summary of rib IPR prevalence by site

Table 7.66 displays the outcomes of Fisher's Exact tests between sites to explore whether there were significant differences between crude prevalence rates. 4-L-88, 4-L-100, and 4-M-53 were omitted in this analysis due to small sample sizes. Several sites produced significant differences. R12 had a significantly lower crude prevalence rate of rib IPR than all sites, except 4-L-2 and 3-J-18. However, 3-O-1 had a significantly higher crude prevalence rate than 3-J-18, R12, and Gabati, and 3-J-23 had a significantly higher crude prevalence than 3-J-18, R12, and P37.

Table 7.66 – P-values for Fisher's Exact tests between sites to measure for significant differences in rib IPR crude prevalence. Statistically significant values are highlighted in grey.

Site	4-L-2	3-Q-33	3-O-1	3-J-23	3-J-18	R12	P37	Gabati	Soba East
4-L-2	-								
3-Q-33	0.204	-							
3-O-1	0.057	0.746	-						
3-J-23	0.094	1.000	0.590	-					
3-J-18	1.000	0.101	0.023	0.012	-				
R12	0.152	0.005	0.003	0.003	0.071	-			
P37	1.000	0.126	0.054	0.046	1.000	0.086	-		
Gabati	0.799	0.174	0.049	0.053	0.740	0.034	0.640	-	
Soba East	0.155	1.000	0.552	1.000	0.065	0.007	0.162	0.156	-

Figure 7.21 compares the crude prevalence rates of rib IPR in people buried at the different sites. The sample groups of 4-L-88, 4-L-100, and 4-M-53 contained too few individuals for data from these sites to be considered reliable measures of the frequency of rib IPR in these populations. Therefore, prevalence rates from these sites are not presented in Figure 7.21, but are further analysed when they are pooled into different time period groups (Section 7.4.2). People from 3-O-1 displayed the

highest crude prevalence rate for rib IPR, at 52.9%. No individuals at R12 were observed to display rib IPR, making this the site with the lowest prevalence.

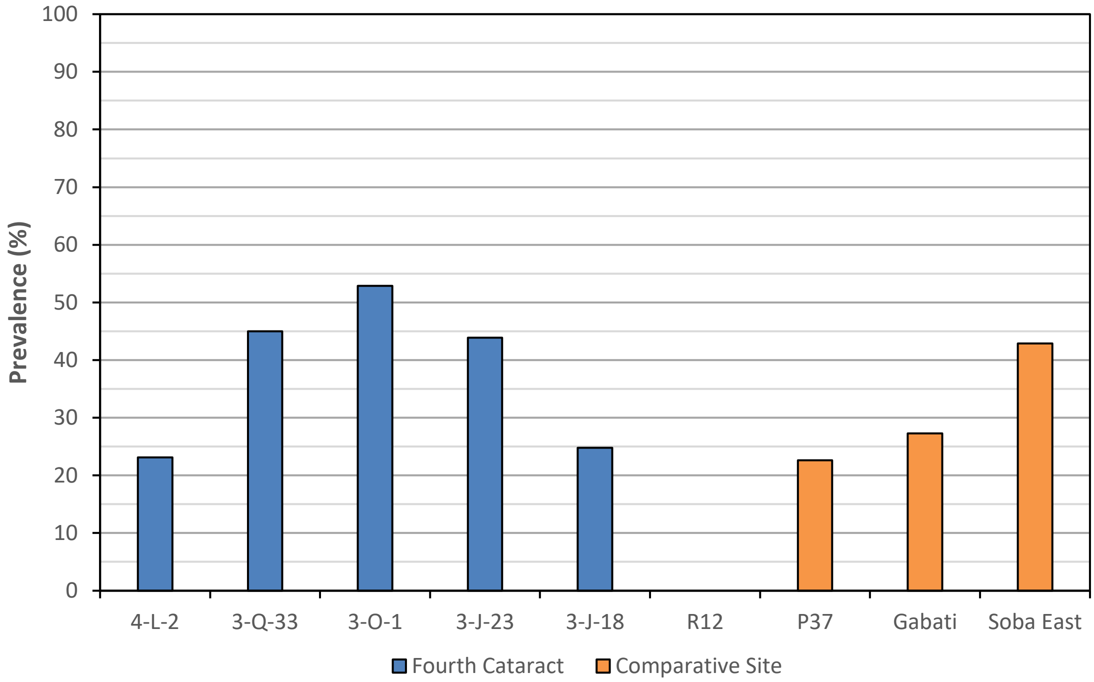


Figure 7.21 – A comparison of the crude prevalence of rib IPR from different sites.

Figure 7.22 compares the crude prevalence rates of rib IPR for males and females at the majority of sites. 4-L-88, 4-L-100, 4-M-53, and R12 were omitted due to small sample sizes. No sites were found to have a significant difference between males and females. A large disparity existed between the sexes at Soba East, with a higher prevalence in females. However, the number of individuals for whom sex was possible to estimate at this site was too small to yield significant results.

Figure 7.23 compares the crude prevalence rates of rib IPR for young and middle adults at the majority of sites. Sites 4-L-88, 4-L-100, 4-M-53, and R12 were omitted due to small numbers. No site presented a significant difference between the prevalence rates for young and middle adults. A higher prevalence in middle adults can be seen at Soba East, but this finding was not significantly different, due to the small number of individuals for whom age could be estimated at this site.

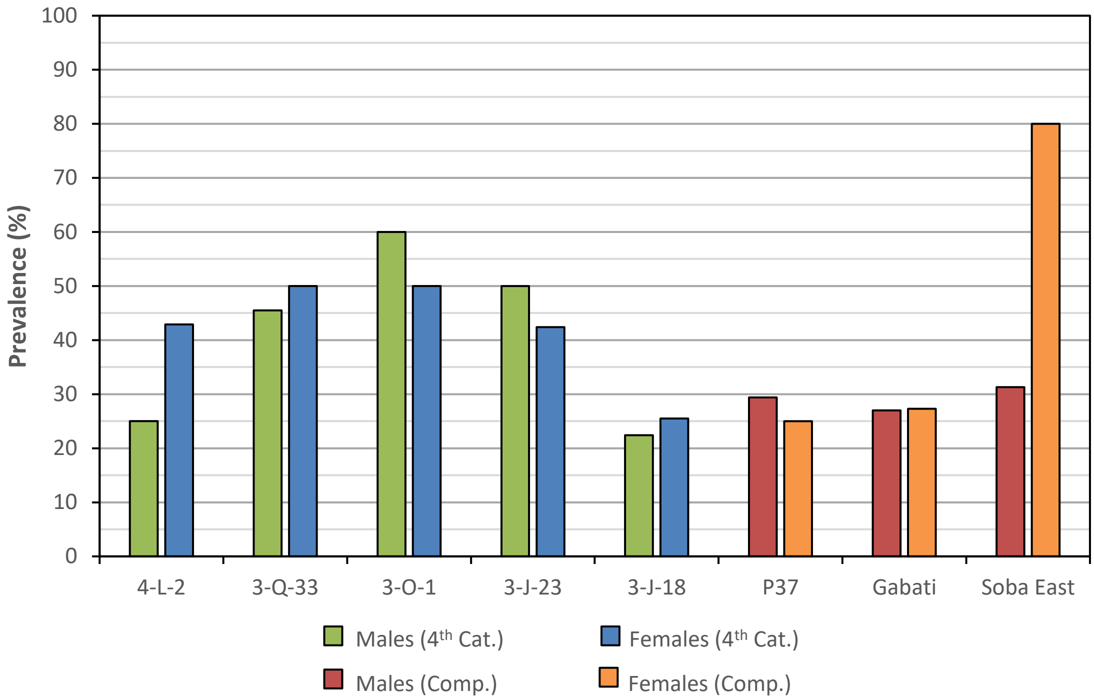


Figure 7.22 – A comparison of the crude prevalence of rib IPR between males and females from different sites.

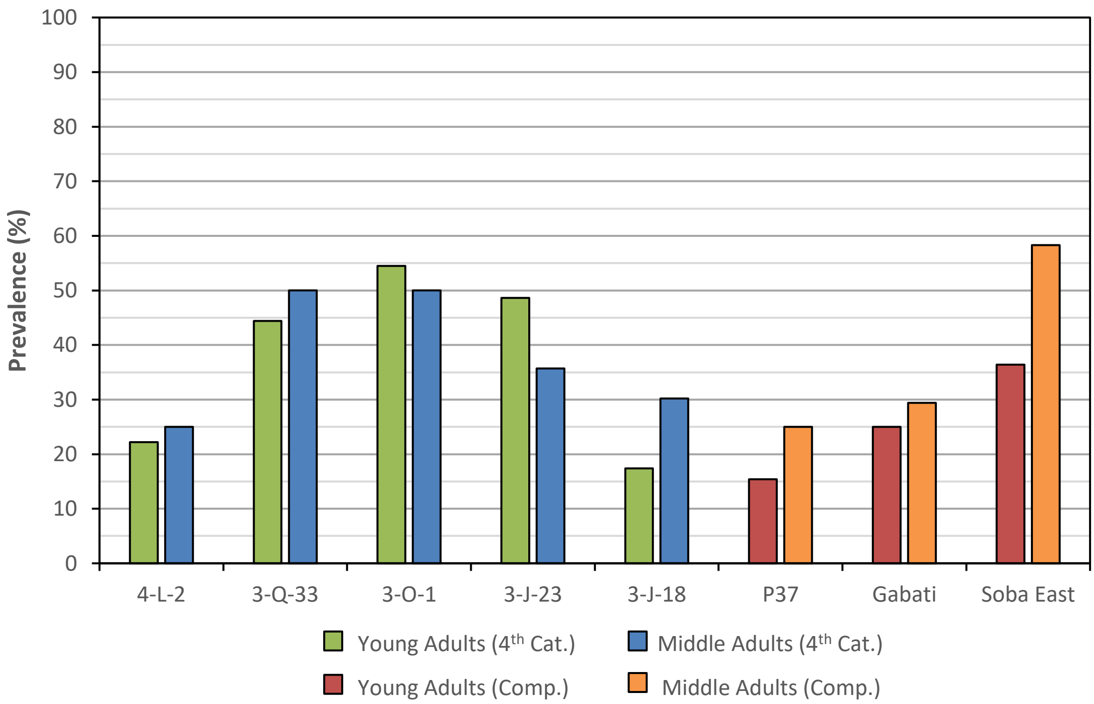


Figure 7.23 – A comparison of the crude prevalence of rib IPR between young adults and middle adults from different sites.

Table 7.67 – P-values for Pearson's Chi-Square tests between sites to measure for significant differences in rib IPR true prevalence. Chi-Square values (χ^2 (1)) are presented in brackets below. Statistically significant values are highlighted in grey.

Site	4-L-2	3-Q-33	3-O-1	3-J-23	3-J-18	R12	P37	Gabati	Soba East
4-L-2	-								
3-Q-33	0.882 (0.022)	-							
3-O-1	0.035 (4.442)	0.013 (6.150)	-						
3-J-23	<0.001 (82.497)	<0.001 (115.894)	<0.001 (50.684)	-					
3-J-18	0.063 (3.455)	0.053 (3.734)	<0.001 (27.358)	<0.001 (532.003)	-				
R12	<0.001 (19.21)	<0.001 (18.69)	<0.001 (29.6)	<0.001 (21.34)	<0.001 (14.11)	-			
P37	0.392 (0.734)	0.438 (0.601)	<0.001 (11.615)	<0.001 (169.361)	0.288 (1.128)	<0.001 (16.26)	-		
Gabati	0.003 (8.690)	0.002 (9.803)	<0.001 (38.873)	<0.001 (434.080)	0.048 (3.894)	<0.001 (11.3)	0.016 (5.766)	-	
Soba East	0.003 (8.684)	<0.001 (12.233)	0.492 (0.471)	<0.001 (61.805)	<0.001 (56.931)	<0.001 (33.4)	<0.001 (21.676)	<0.001 (69.809)	-

Table 7.67 displays the outcomes of Pearson's Chi-Square tests between sites to explore significant differences between true prevalence rates. 4-L-88, 4-L-100, and 4-M-53 were omitted due to small sample size. The majority of sites were significantly different from one another. The sites of 4-L-2, 3-Q-33, P37, and 3-J-18 displayed no significant differences between each other. Additionally, Soba East and 3-O-1 were not significantly different from one another.

Figure 7.24 compares the true prevalence rate of IPR from groups buried at the majority of sites. The sample groups from 4-L-88, 4-L-100, and 4-M-53 were omitted due to small sample sizes, although the true prevalence rate for these sites is further analysed when pooled into time periods (Section 7.4.2). People from 3-J-23 displayed the highest true prevalence rate of rib IPR (8.5%). Skeletons from R12, having displayed no observable rib IPR, had the lowest true prevalence (0.0%). Comparison between Figure 7.21 and Figure 7.24 indicate that the true prevalence rate does not always proportionally correlate with the crude prevalence rate at the same site.

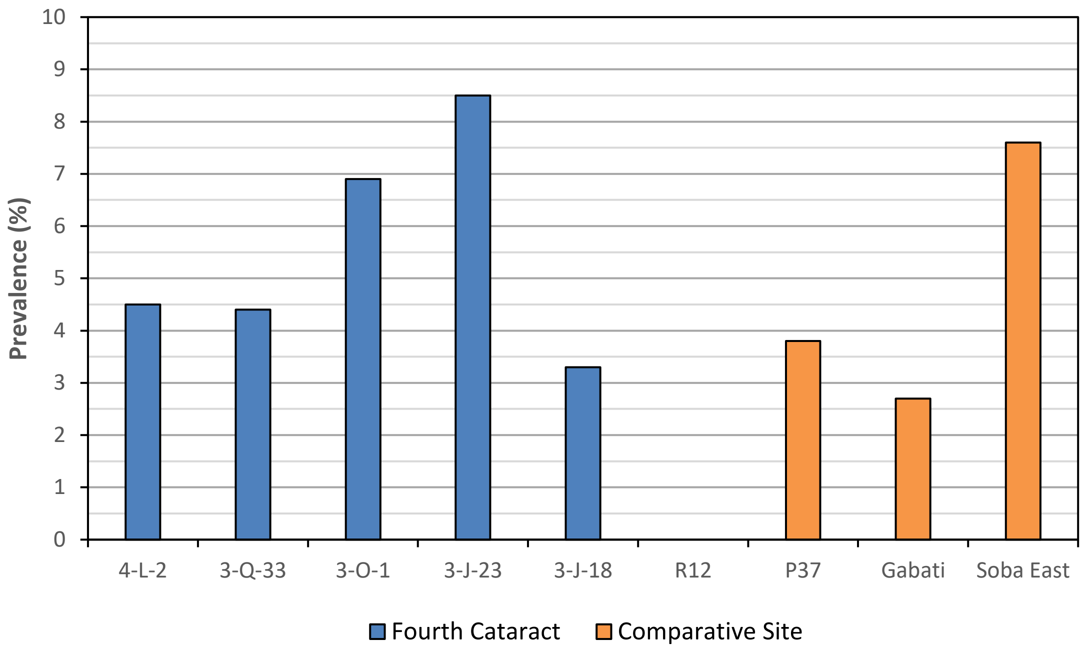


Figure 7.24 – A comparison of the true prevalence of rib IPR between different sites.

Figure 7.25 compares the distribution of true prevalence rates of rib IPR within the rib cage at the majority of sites. Table 7.68 also compares between sites any significant differences in the side of the rib cage affected and any significant differences between the rib sections or rib cage regions affected. The sample groups from 4-L-88, 4-L-100, 4-M-53, and R12 were omitted from both Figure 7.25 and Table 7.68 due to small sample sizes. People buried at 4-L-2 and 3-O-1 displayed a significantly higher prevalence of rib IPR on the right side, and from 3-Q-33 and Gabati on the left side. Groups from all other sites did not display a significant difference in the total true prevalence rate of rib IPR by side, although people buried at 3-J-18 did show a significantly higher prevalence on the left ribs at the angle and on the ribs of the upper rib cage region. People from 3-O-1, 3-J-23, and 3-J-18 all showed a significantly higher total true prevalence rate for the rib neck, followed by the angle, with the shaft displaying the lowest prevalence. People buried at 3-Q-33 and Soba East displayed a significantly higher prevalence rate at the neck, followed by the shaft, with the lowest prevalence rate at the angle. No other groups displayed a significant difference between the total prevalence for each rib section. People from 3-J-23 and Soba East displayed a significantly higher prevalence rate for the upper-middle rib cage region, followed by the lower-middle region, with the lowest prevalence in the upper and lower regions. Skeletons from 3-J-18 displayed a significantly higher prevalence on ribs from the upper-middle and lower-middle regions, with a lower prevalence on the upper and lower regions. No other groups showed a significant difference between the total prevalence rate for each rib cage region.

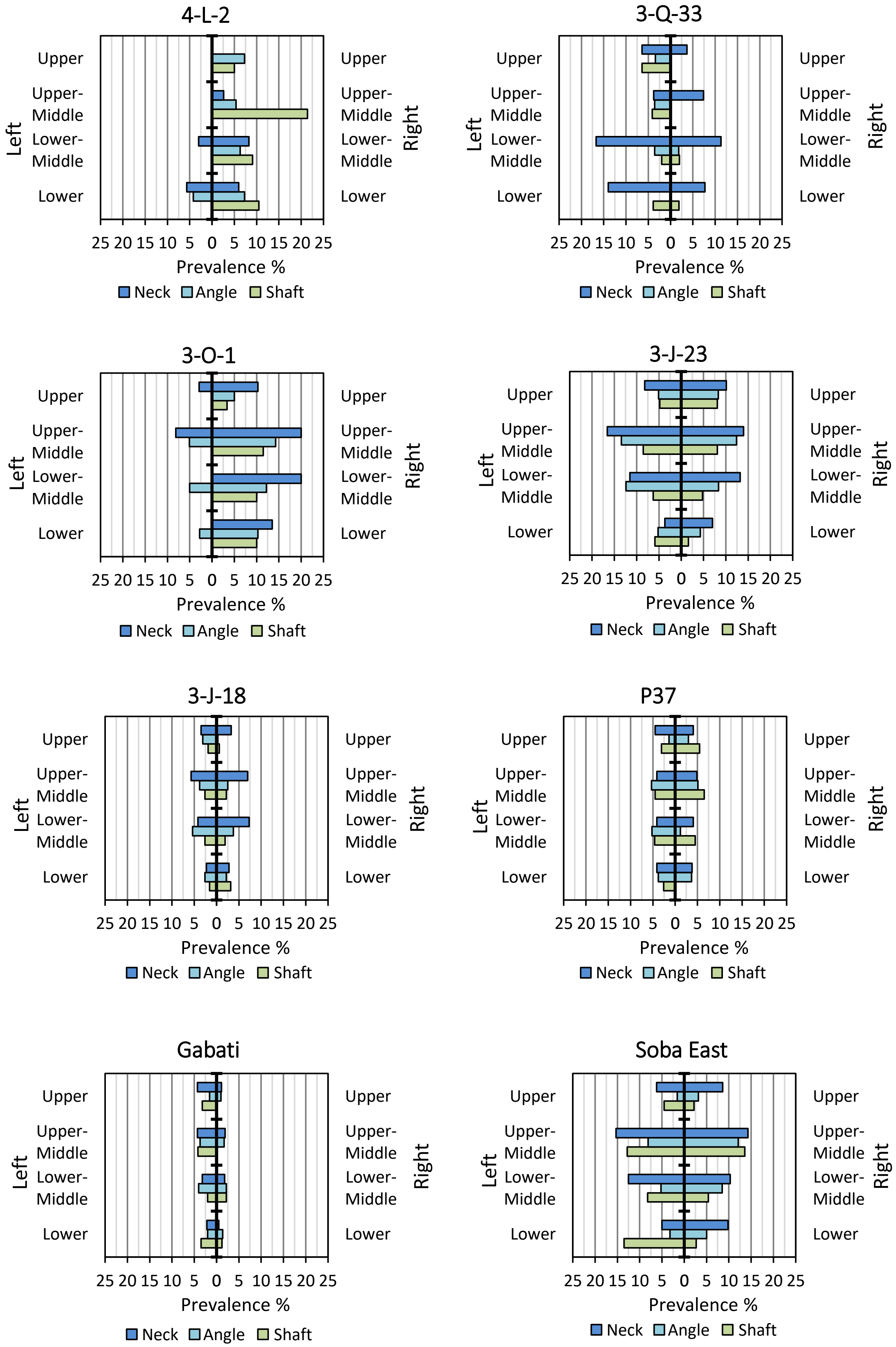


Figure 7.25 – A comparison of the distribution of rib IPR true prevalence within the rib cage at each site, presented by side, rib cage region, and rib section.

Table 7.68 – A comparison of significant differences (if any) between side, between rib sections, and between rib cage regions at different sites. The side given indicates the significantly higher prevalence (U = Upper; U-M = Upper-middle; L-M = Lower-Middle; L = Lower).

Site	Prevalence by side								Total prevalence	
	Neck	Angle	Shaft	Upper	Upper-middle	Lower-middle	Lower	Total	Rib section	Rib cage region
4-L-2	-	Right	Right	-	Right	-	-	Right	-	-
3-Q-33	-	-	Left	-	-	-	-	Left	Neck > Angle < Shaft	-
3-O-1	Right	Right	Right		Right	Right	Right	Right	Neck > Angle > Shaft	-
3-J-23	-	-	-	-	-	-	-	-	Neck > Angle > Shaft	U < U-M > L-M >L
3-J-18	-	Left	-	Left	-	-	-	-	Neck > Angle > Shaft	U < U-M = L-M >L
P37	-	-	-	-	-	-	-	-	-	-
Gabati	Left	-	Left	Left	Left	-	-	Left	-	-
Soba East	-	-	-	-	-	-	-	-	Neck > Angle < Shaft	U < U-M > L-M > L

7.4.1.xiv Type of IPR remodelling (by site)

Table 7.69 presents the percentage of individuals with rib IPR from each site with active, remodelling, or remodelled IPR. Figure 7.26 compares the data between sites. As individuals at R12 and 4-L-100 displayed no evidence for rib IPR, these sites were excluded. People from the majority of the sites displayed a greater proportion of active or remodelling rib IPR. People buried at 3-J-18 and Soba East, however, displayed a higher percentage of remodelled rib IPR. As the type of remodelling of periosteal reaction in different age categories can provide information about the frailty of a population (DeWitte, 2014), the distribution of different phases of remodelling was briefly investigated among age groups for the total sample. Young adults with rib IPR demonstrated a higher proportion of remodelling (47.2%, 25/53) or active (32.1%, 17/53) bone involvement, and only 20.7% (11/53) of individuals had remodelled IPR. Middle adults, however, had a higher proportion of remodelled IPR (46.8%, 29/62) than active (30.6%, 19/62) or remodelling (22.6%, 14/62) bone formation. The proportion of different phases of remodelling in age groups from individual sites was not investigated further as the sample size for individuals with rib IPR at most sites was too small to provide useful information.

Table 7.69 – The percentage of individuals with rib IPR at each site recorded as active, remodelling, or remodelled. Frequencies are presented in brackets below.

Site	Active (woven)	Remodelling (mixed)	Remodelled (lamellar)
4-L-2	16.7% (1/6)	50% (3/6)	33.3% (2/6)
4-L-88	0.0% (0/1)	100% (1/1)	0.0% (0/1)
3-Q-33	33.3% (3/9)	66.7% (6/9)	0.0% (0/9)
3-O-1	11.2% (1/9)	44.4% (4/9)	44.4% (4/9)
4-M-53	66.7% (2/3)	33.3% (1/3)	0.0% (0/3)
3-J-23	34.5% (10/29)	44.8% (13/29)	20.7% (6/29)
3-J-18	17.9% (5/28)	28.6% (8/28)	53.6% (15/28)
P37	71.4% (5/7)	14.3% (1/7)	14.3% (1/7)
Gabati	52.3% (11/21)	4.8% (1/21)	42.9% (9/21)
Soba East	25.0% (3/12)	33.3% (4/12)	41.7% (5/12)
Total	32.8% (41/125)	33.6% (42/125)	33.6% (42/125)

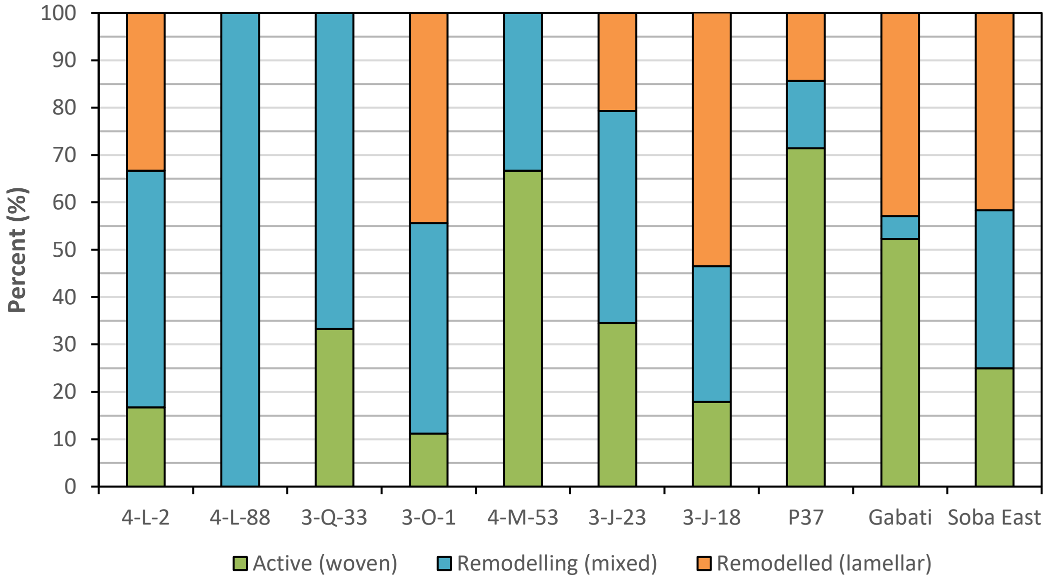


Figure 7.26 – A comparison between the proportion of active, remodelling, and remodelled rib IPR from different sites.

7.4.1.xv Side of ribcage affected by site

Table 7.70 presents the percentage of individuals with rib IPR located within the ribcage on the left side, the right side, or bilaterally at each site. Figure 7.27 compares the data between sites. As individuals at R12 and 4-L-100 displayed no rib IPR, these sites were excluded. The majority of the sites displayed a relatively equal proportion of left, right, or bilateral ribcage involvement. 4-L-2, Gabati, and Soba East, however, displayed a higher percent of bilateral ribcage involvement. 3-O-1 also displayed a high proportion of individuals with rib IPR on the right side of the rib cage.

Table 7.70 – The percentage of individuals at each site with rib IPR located on the left side, right side, bilaterally, or unknown (due to preservation of only one side of the ribcage). Frequencies are presented in brackets below.

Site	Unilateral rib IPR			Bilateral rib	Unknown
	Left	Right	Total	IPR	(only one side observable)
4-L-2	0.0% (0/6)	33.3% (2/6)	33.3% (2/6)	66.7% (4/6)	0.0% (0/6)
4-L-88	0.0% (0/1)	0.0% (0/1)	0.0% (0/1)	100% (1/1)	0.0% (0/1)
3-Q-33	22.2% (2/9)	33.3% (3/9)	55.6% (5/9)	44.4% (4/9)	0.0% (0/9)
3-O-1	33.3% (3/9)	55.6% (5/9)	88.9% (8/9)	11.1% (1/9)	0.0% (0/9)
4-M-53	33.3% (1/3)	33.3% (1/3)	66.7% (2/3)	33.3% (1/3)	0.0% (0/3)
3-J-23	41.4% (12/29)	27.6% (8/29)	69.0% (20/29)	31.0% (9/29)	0.0% (0/29)
3-J-18	28.6% (8/28)	35.7% (10/28)	64.3% (18/28)	32.1% (9/28)	3.6% (1/28)
P37	28.6% (2/7)	42.9% (3/7)	71.4% (5/7)	28.6% (2/7)	0.0% (0/7)
Gabati	28.6% (6/21)	19.0% (4/21)	47.6% (10/21)	52.4% (11/21)	0.0% (0/21)
Soba East	8.3% (1/12)	16.7% (2/12)	25.0% (3/12)	66.7% (8/12)	8.3% (1/12)
Total	28.0% (35/125)	30.4% (38/125)	58.4% (73/125)	40.0% (50/125)	1.6% (2/125)

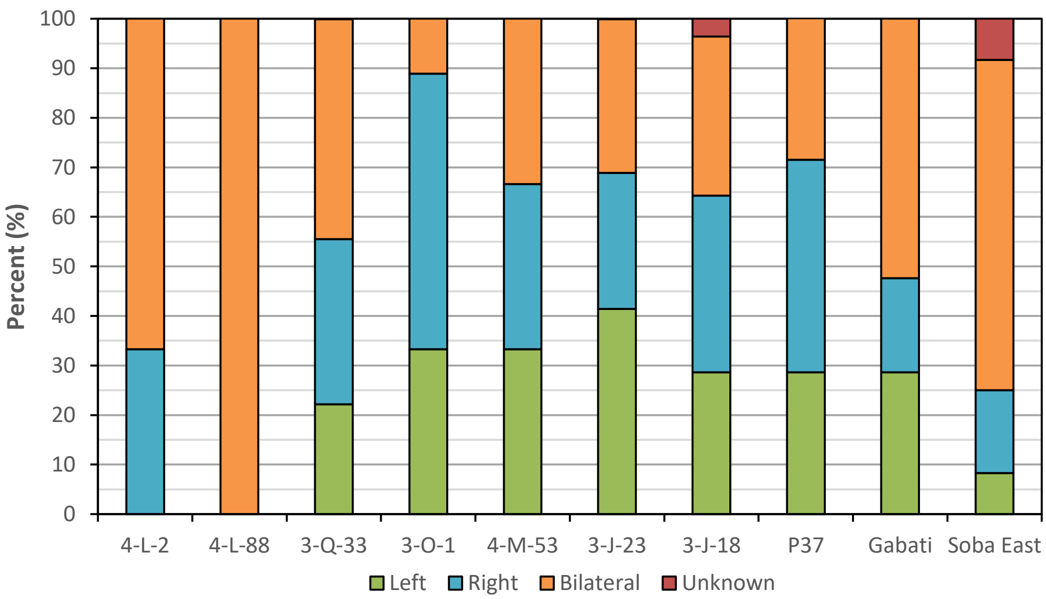


Figure 7.27 – A comparison between the proprotion of individuals at each site with rib IPR located in the ribcage on the left side, the right side, bilaterally, or unknown.

7.4.2 Rib IPR by time period

In order to determine rib IPR prevalence by time period, data from certain sites were pooled together. In addition, certain time periods were grouped to increase the number of individuals within the sample, to enable statistical testing. The crude and true prevalence data for the comparative Neolithic period derived only from R12 and for the comparative Kerma period consisted of pooled data from the Kerma Ancien and Kerma Moyen individuals from P37 only. Therefore, comparative Neolithic crude and true prevalence data, including by sex and age groups, can be found in Section 7.4.1.ix and comparative Kerma crude and true prevalence data can be found in Section 7.4.1.x.

7.4.2.i Kerma Classique (Fourth Cataract)

The Fourth Cataract Kerma Classique group consisted of pooled data from sites 4-L-2, 4-L-88, and 4-L-100. The crude prevalence rate of IPR for people who lived during the Kerma Classique in the Fourth Cataract is presented in Table 7.71. No statistically significant differences were found between sex or age groups. The true prevalence rates of rib IPR are presented in Table 7.72 and outcomes of tests of significant difference are presented in Table 7.73. A significantly higher prevalence of rib IPR was found on the right side of the rib angle and shaft, and on the right side in total, when compared to the left. The right upper-middle rib cage region also showed a significantly higher prevalence than the left upper-middle region. No significant differences were found between the right and left sides of any other rib cage region or between the right and left necks of the ribs. Neither was a statistically significant difference found between the total prevalence rate for different rib sections. However, a significant difference was found between the total prevalence rate for each rib cage region, with the upper region displaying the lowest prevalence, and the lower region the highest prevalence.

Table 7.71 – Kerma Classique (Fourth Cataract) rib IPR crude prevalence, according to sex and age categories and within the total group, and results of tests of significant difference between categories. Frequencies are presented in brackets below.

Category		Crude prevalence	Statistical significance
Sex	**Male**	18.8% (3/16)	P = 0.621 [FET]
	Female	37.5% (3/8)	
Age	**Young Adult**	20.0% (2/10)	P = 1.000 [FET]
	Middle Adult	25.0% (4/16)	
	Total	21.9% (7/32)	

Table 7.72 – Kerma Classique (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib cage region. Frequencies are presented in brackets below.

Side	Section	Prevalence by ribcage region					Total prevalence		
		Upper	Upper-Middle	Middle	Lower-Middle	Lower	Section	Side	Ribcage
Right	**Neck**	0.0% (0/55)	2.1% (1/47)	5.3% (7/133)	7.0% (3/43)	4.5% (3/66)	3.9% (10/254)	6.6% (40/604)	4.5% (54/1208)
	Angle	5.4% (3/56)	6.8% (3/44)	8.2% (10/122)	7.1% (3/42)	8.9% (5/56)	7.7% (18/234)		
	Shaft	3.2% (1/31)	21.7% (5/23)	11.8% (6/51)	5.0% (1/20)	14.7% (5/34)	10.3% (12/116)		
Left	**Neck**	0.0% (0/51)	0.0% (0/46)	1.4% (2/138)	2.4% (1/42)	4.5% (3/67)	2.0% (5/256)	2.3% (14/604)	
	Angle	0.0% (0/58)	2.5% (1/40)	2.5% (3/120)	0.0% (0/38)	6.5% (4/62)	2.9% (7/240)		
	Shaft	0.0% (0/27)	0.0% (0/20)	4.3% (2/47)	5.0% (1/20)	0.0% (0/34)	1.9% (2/108)		

Table 7.73 – Kerma Classique (Fourth Cataract) tests of significant difference between rib IPR true prevalence rates from the left and right sides, and between all three rib sections and all four rib cage regions, regardless of side. Frequencies are presented in brackets below. Significant results are highlighted in grey.

Section	Prevalence total by side		Statistical significance between sides	Total prevalence	Statistical significance between sections
	Right	Left			
Neck	3.9% (10/254)	2.0% (5/256)	χ^2 (1) = 1.758, P = 0.185	2.9% (15/510)	χ^2 (2) = 5.171, P = 0.075
Angle	7.7% (18/234)	2.9% (7/240)	χ^2 (1) = 5.409, P = 0.020	5.3% (25/474)	
Shaft	10.3% (12/116)	1.9% (2/108)	χ^2 (1) = 6.885, P = 0.009	6.3% (14/224)	
Upper	2.85 (4/142)	0.0% (0/136)	P = 0.123 [FET]	1.4% (4/278)	χ^2 (3) = 8.732, P = 0.033
Upper-Middle	7.9% (9/114)	0.9% (1/106)	P = 0.020 [FET]	4.5% (10/220)	
Lower-Middle	6.7% (7/105)	2.0% (2/100)	P = 0.171 [FET]	4.4% (9/205)	
Lower	8.3% (13/156)	4.3% (7/163)	χ^2 (1) = 2.213, P = 0.137	6.3% (20/319)	
Total	6.6% (40/604)	2.3% (14/604)	χ^2 (1) = 13.104, P = <0.001	4.5% (54/1208)	

7.4.2.ii Meroitic and Post-Meroitic (Fourth Cataract)

To increase the sample size to facilitate statistical testing, individuals from both Meroitic and Post-Meroitic time periods from the Fourth Cataract were pooled (Post-/Meroitic group), consisting of data from sites 3-Q-33, 4-M-53, and 3-O-1. However, crude prevalence rates of rib IPR, including by sex and age groups, and true prevalence rates have been presented separately for the Meroitic and the Post-Meroitic periods within Appendices G and H, respectively. The crude prevalence of rib IPR for people buried during the Post-/Meroitic period in the Fourth Cataract are presented in Table 7.74. No statistically significant differences were found between sex or age groups. The true prevalence rates of rib IPR are presented in Table 7.75 and outcomes of tests of significant difference are presented in Table 7.76. No significant differences were found between the left and right sides for any rib section or rib cage region. However, the total prevalence rate for the right side of the rib cage was significantly higher than for the left. A significant difference was also found between the total prevalence rate for different rib sections, with the neck displaying a far higher prevalence rate than the angle or shaft sections. No significant difference was found between the total prevalence rate for each rib cage region.

Table 7.74 – Post-/Meroitic (Fourth Cataract) rib IPR crude prevalence, according to sex and age categories and within the total group, and results of tests of significant difference between categories. Frequencies are presented in brackets below.

Category		Crude prevalence	Statistical significance
Sex	**Male**	44.0% (11/25)	P = 0.495 [FET]
	Female	58.3% (7/12)	
Age	**Young Adult**	45.8% (11/24)	P = 1.000 [FET]
	Middle Adult	50.0% (9/18)	
	Total	47.7% (21/44)	

Table 7.75 – Post-/Meroitic (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib cage region. Frequencies are presented in brackets below.

Side	Section	Prevalence by ribcage region					Total prevalence		
		Upper	Upper-Middle	Middle	Lower-Middle	Lower	Section	Side	Ribcage
Right	**Neck**	5.5% (6/110)	10.2% (11/108)	11.0% (24/218)	12.3% (13/106)	9.3% (10/108)	9.2% (40/436)	5.5% (71/1286)	4.7% (119/2555)
	Angle	1.7% (2/115)	5.1% (6/117)	5.0% (12/238)	5.3% (6/114)	4.4% (5/113)	4.1% (19/466)		
	Shaft	1.1% (1/91)	3.2% (3/94)	3.6% (7/195)	4.0% (4/100)	4.1% (4/98)	3.1% (12/384)		
Left	**Neck**	4.1% (4/97)	4.7% (5/106)	7.3% (16/219)	9.6% (11/114)	7.9% (8/101)	6.7% (28/417)	3.8% (48/1269)	
	Angle	1.7% (2/115)	3.5% (4/113)	3.4% (8/236)	3.5% (4/114)	0.9% (1/110)	2.4% (11/461)		
	Shaft	3.2% (3/93)	2.0% (2/100)	2.0% (4/201)	1.0% (1/96)	2.1% (2/97)	2.3% (9/391)		

Table 7.76 – Post-/Meroitic (Fourth Cataract) tests of significant difference between rib IPR true prevalence rates from the left and right sides, and between all three rib sections and all four rib cage regions, regardless of side. Frequencies are presented in brackets below. Significant results are highlighted in grey.

Section	Prevalence total by side		Statistical significance between sides	Total prevalence	Statistical significance between sections
	Right	Left			
Neck	9.2% (40/436)	6.7% (28/417)	χ^2 (1) = 1.758, P = 0.185	8.0% (68/853)	χ^2 (1) = 31.940 P = <0.001
Angle	4.1% (19/466)	2.4% (11/461)	χ^2 (1) = 2.117 P = 0.146	3.2% (30/927)	
Shaft	3.1% (12/384)	2.3% (9/391)	χ^2 (1) = 0.498 P = 0.480	2.7% (21/775)	
Upper	2.8% (9/316)	3.0% (9/305)	χ^2 (1) = 0.006 P = 0.939	2.9% (18/621)	χ^2 (1) = 7.234 P = 0.065
Upper-Middle	6.3% (20/319)	3.4% (11/319)	χ^2 (1) = 2.746 P = 0.097	4.9% (31/638)	
Lower-Middle	7.2% (23/320)	4.9% (16/324)	χ^2 (1) = 1.432 P = 0.232	6.1% (39/644)	
Lower	6.0% (19/319)	3.6% (11/308)	χ^2 (1) = 1.956 P = 0.162	4.8% (30/627)	
Total	5.5% (71/1286)	3.8% (48/1269)	χ^2 (1) = 4.347 P = 0.037	4.7% (119/2555)	

7.4.2.iii Medieval (Fourth Cataract)

The Medieval group from the Fourth Cataract consisted of pooled data from sites 3-J-23 and 3-J-18. The crude prevalence of rib IPR for people living during the Medieval period in the Fourth Cataract is presented in Table 7.77. No statistically significant differences were found between sex or age groups. The true prevalence rates of rib IPR are presented in Table 7.78 and outcomes of tests of significant difference are presented in Table 7.79. No significant differences were found between the right and left sides by any rib section, rib cage region, or by the total prevalence rate for each side. A significant difference was found both between the total prevalence rate for different rib sections and between the total prevalence rate for each rib cage region.

Table 7.77 – Medieval (Fourth Cataract) rib IPR crude prevalence, according to sex and age categories and within the total group, and results of tests of significant difference between categories. Frequencies are presented in brackets below.

Category		Crude prevalence	Statistical significance
Sex	Male	31.8% (28/88)	P = 1.000 [FET]
	Female	32.1% (27/84)	
Age	Young Adult	30.9% (25/81)	P = 1.000 [FET]
	Middle Adult	31.9% (29/91)	
	Total	31.8% (57/179)	

Table 7.78 – Medieval (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib cage region. Frequencies are presented in brackets below.

Side	Section	Prevalence by ribcage region					Total prevalence		
		Upper	Upper-Middle	Middle	Lower-Middle	Lower	Section	Side	Ribcage
Right	Neck	5.8% (30/521)	9.6% (49/513)	9.6% (100/1043)	9.5% (48/507)	4.3% (22/506)	7.3% (152/2070)	5.1% (317/6180)	5.2% (641/12292)
	Angle	3.2% (17/525)	6.2% (32/515)	6.0% (63/1056)	5.5% (28/512)	2.9% (15/513)	4.5% (95/2094)		
	Shaft	3.4% (17/502)	4.4% (22/500)	3.9% (40/1013)	3.0% (15/500)	2.6% (13/501)	3.5% (70/2016)		
Left	Neck	5.2% (27/515)	9.8% (50/510)	8.5% (88/1033)	7.0% (35/503)	2.8% (14/500)	6.35 (129/2048)	5.3% (324/6112)	
	Angle	3.8% (20/523)	7.4% (38/511)	7.9% (82/1041)	8.1% (41/509)	3.6% (18/505)	5.8% (120/2069)		
	Shaft	3.0% (15/504)	4.9% (24/491)	4.4% (44/999)	4.0% (20/494)	3.3% (16/492)	3.8% (75/1995)		

Table 7.79 – Medieval (Fourth Cataract) tests of significant difference between rib IPR true prevalence rates from the left and right sides, and between all three rib sections and all four rib cage regions, regardless of side. Frequencies are presented in brackets below. Significant results are highlighted in grey.

Section	Prevalence total by side		Statistical significance between sides	Total prevalence	Statistical significance between sections
	Right	Left			
Neck	7.3% (152/2070)	6.3% (129/2048)	χ^2 (1) = 1.765, P = 0.184	6.8% (281/4118)	χ^2 (2) = 42.354, P = <0.001
Angle	4.5% (95/2094)	5.8% (120/2069)	χ^2 (1) = 3.390, P = 0.066	5.2% (215/4163)	
Shaft	3.5% (70/2016)	3.8% (75/1995)	χ^2 (1) = 0.237, P = 0.626	3.6% (145/4011)	
Upper	4.1% (64/1548)	4.0% (62/1542)	χ^2 (1) = 0.026, P = 0.873	4.1% (126/3090)	χ^2 (3) = 59.279, P = <0.001
Upper-Middle	6.7% (103/1528)	7.4% (112/1512)	χ^2 (1) = 0.514, P = 0.474	7.1% (215/3040)	
Lower-Middle	6.0% (91/1519)	6.4% (96/1506)	χ^2 (1) = 0.192, P = 0.661	6.2% (187/3025)	
Lower	3.3% (50/1520)	3.2% (48/1497)	χ^2 (1) = 0.017, P = 0.898	3.2% (98/3017)	
Total	5.1% (317/6180)	5.3% (324/6112)	χ^2 (1) = 0.183, P = 0.669	5.2% (641/12292)	

7.4.2.iv Meroitic and Post-Meroitic (comparative site)

To increase the sample size to facilitate statistical testing, individuals from both Meroitic and Post-Meroitic time periods from the comparative site of Gabati were pooled. However, crude prevalence rates of rib IPR, including by sex and age groups, and true prevalence rates have been presented separately for the Meroitic and the Post-Meroitic periods within Appendices G and H, respectively. The crude prevalence of rib IPR for people living during the Post-/Meroitic period at the comparative site of Gabati is presented in Table 7.80. No statistically significant differences were found between sex or age groups. The true prevalence rates of rib IPR are presented in Table 7.81 and outcomes of tests of significant difference are presented in Table 7.82. A significantly higher prevalence of rib IPR was found on the left side at the neck and shaft rib sections, in the upper-middle and lower-middle rib cage regions, and on the left side overall, when compared to the right side. No significant differences were found between the right and left ribs at the angle and in the upper and lower rib cage regions. A significant difference in the total prevalence rate was also found between each rib cage region, with the upper-middle and lower-middle regions displaying a higher prevalence than the upper and lower regions. No significant difference was found between the total prevalence rate according to the different rib sections.

Table 7.80 – Post-/Meroitic (comparative) rib IPR crude prevalence, according to sex and age categories and within the total group, and results of tests of significant difference between categories. Frequencies are presented in brackets below.

Category		Crude prevalence	Statistical significance
Sex	Male	22.6% (7/31)	P = 0.766 [FET]
	Female	28.6% (8/28)	
Age	Young Adult	24.1% (7/29)	P = 1.000 [FET]
	Middle Adult	27.6% (8/29)	
Total		26.2% (17/65)	

Table 7.81 – Post-/Merotic (comparative) rib IPR true prevalence by side, rib section, and rib cage region. Frequencies are presented in brackets below.

Side	Section	Prevalence by ribcage region					Total prevalence		
		Upper	Upper-Middle	Middle	Lower-Middle	Lower	Section	Side	Ribcage
Right	Neck	1.4% (2/141)	1.6% (2/129)	2.1% (7/331)	1.5% (2/133)	0.0% (0/156)	1.4% (9/628)	1.6% (30/1863)	2.6% (97/3672)
	Angle	1.3% (2/160)	2.0% (3/148)	2.9% (11/384)	2.1% (3/145)	1.6% (3/182)	2.2% (16/726)		
	Shaft	0.0% (0/117)	0.0% (0/106)	1.5% (4/262)	0.9% (1/109)	0.8% (1/130)	1.0% (5/509)		
Left	Neck	3.8% (5/131)	4.5% (6/132)	5.6% (17/304)	2.4% (3/126)	0.7% (1/152)	3.9% (23/587)	3.7% (67/1809)	
	Angle	1.3% (2/158)	3.8% (6/159)	5.5% (21/379)	4.9% (7/142)	1.2% (2/167)	3.6% (25/704)		
	Shaft	3.2% (4/124)	3.4% (4/117)	4.4% (12/273)	5.1% (6/118)	2.5% (3/121)	3.7% (19/518)		

Table 7.82 – Post-/Meroitic (comparative) tests of significant difference between rib IPR true prevalence rates from the left and right sides, and between all three rib sections and all four rib cage regions, regardless of side. Frequencies are presented in brackets below. Significant results are highlighted in grey.

Section	Prevalence total by side		Statistical significance between sides	Total prevalence	Statistical significance between sections
	Right	Left			
Neck	1.4% (9/628)	3.9% (23/587)	χ^2 (1) = 7.307, P = 0.007	2.6% (32/1215)	χ^2 (2) = 0.654, P = 0.721
Angle	2.2% (16/726)	3.6% (25/704)	χ^2 (1) = 2.330, P = 0.127	2.9% (41/1430)	
Shaft	1.0% (5/509)	3.7% (19/518)	χ^2 (1) = 8.113, P = 0.004	2.3% (24/1027)	
Upper	1.0% (4/418)	2.7% (11/413)	χ^2 (1) = 3.413, P = 0.065	1.8% (15/831)	χ^2 (3) = 8.164 P = 0.043
Upper-Middle	1.3% (5/383)	3.9% (16/408)	χ^2 (1) = 5.232, P = 0.022	2.7% (21/791)	
Lower-Middle	1.6% (6/387)	4.1% (16/386)	χ^2 (1) = 4.705, P = 0.030	2.8% (22/773)	
Lower	0.9% (4/468)	1.4% (6/440)	χ^2 (1) = 0.539, P = 0.463	1.1% (10/908)	
Total	1.6% (30/1863)	3.7% (67/1809)	χ^2 (1) = 15.639, P = <0.001	2.6% (97/3672)	

7.4.2.v Medieval (comparative site)

The comparative Medieval group consisted of pooled data from Gabati and Soba East. The crude prevalence of rib IPR for people living during the Medieval period from comparative sites is presented in Table 7.83. No statistically significant differences were found between sex or age groups. The true prevalence rates of rib IPR are presented in Table 7.84 and outcomes of tests of significant difference are presented in Table 7.85. No significant differences were found between the right and left sides by any rib section, rib cage region, or by the total prevalence rate for each side. A significant difference was found both between the total prevalence rate for different rib sections and between the total prevalence rate for each rib cage region.

Table 7.83 – Medieval (comparative) rib IPR crude prevalence, according to sex and age categories and within the total group, and results of tests of significant difference between categories. Frequencies are presented in brackets below.

Category		Crude prevalence	Statistical significance
Sex	**Male**	36.4% (8/22)	P = 0.699 [FET]
	Female	50.0% (5/10)	
Age	**Young Adult**	33.3% (6/18)	P = 0.315 [FET]
	Middle Adult	52.9% (9/17)	
Total		40.0% (16/40)	

Table 7.84 – Medieval (comparative) rib IPR true prevalence by side, rib section, and rib cage region. Frequencies are presented in brackets below.

Side	Section	Prevalence by ribcage region					Total prevalence		
		Upper	Upper-Middle	Middle	Lower-Middle	Lower	Section	Side	Ribcage
Right	**Neck**	5.5% (5/91)	10.4% (10/96)	9.0% (18/199)	7.8% (7/90)	7.4% (7/95)	7.8% (30/385)	5.7% (61/1071)	5.9% (127/2140)
	Angle	2.1% (2/96)	8.2% (8/98)	6.9% (14/202)	6.5% (6/92)	3.2% (3/95)	4.8% (19/393)		
	Shaft	1.4% (1/74)	8.3% (6/72)	6.0% (9/149)	6.1% (4/66)	2.9% (2/70)	4.1% (12/293)		
Left	**Neck**	6.2% (6/97)	11.2% (10/89)	9.9% (18/182)	10.1% (8/79)	6.5% (6/92)	8.1% (30/371)	6.2% (66/1069)	
	Angle	2.1% (2/96)	6.4% (6/94)	4.5% (9/198)	3.3% (3/91)	4.2% (4/96)	3.8% (15/390)		
	Shaft	4.0% (3/75)	10.6% (7/66)	7.1% (11/154)	4.9% (4/81)	8.9% (7/79)	6.8% (21/308)		

Table 7.85 – Medieval (comparative) tests of significant difference between rib IPR true prevalence rates from the left and right sides, and between all three rib sections and all four rib cage regions, regardless of side. Frequencies are presented in brackets below. Significant results are highlighted in grey.

Section	Prevalence total by side		Statistical significance between sides	Total prevalence	Statistical significance between sections
	Right	Left			
Neck	7.8% (30/385)	8.1% (30/371)	χ^2 (1) = 0.022, P = 0.881	8.3% (60/756)	χ^2 (2) = 9.196, P = 0.010
Angle	4.8% (19/393)	3.8% (15/390)	χ^2 (1) = 0.460, P = 0.497	4.9% (34/783)	
Shaft	4.1% (12/293)	6.8% (21/308)	χ^2 (1) = 2.145, P = 0.143	6.0% (33/601)	
Upper	3.1% (8/261)	4.1% (11/268)	χ^2 (1) = 0.413, P = 0.521	3.6% (19/529)	χ^2 (3) = 14.376, P = 0.002
Upper-Middle	9.0% (24/266)	9.2% (23/249)	χ^2 (1) = 0.007, P = 0.933	9.1% (47/515)	
Lower-Middle	6.9% (17/248)	6.0% (15/251)	χ^2 (1) = 0.161, P = 0.689	6.4% (32/499)	
Lower	4.6% (12/260)	6.4% (17/267)	χ^2 (1) = 0.778, P = 0.378	5.5% (29/527)	
Total	5.7% (61/1071)	6.2% (66/1069)	χ^2 (1) = 0.219, P = 0.640	5.9% (127/2140)	

7.4.2.vi Summary of rib IPR prevalence by time period

Table 7.86 displays the outcomes of Fisher's Exact tests between time periods to explore significant differences between crude prevalence rates. Several sites produced significant differences. People living during the Neolithic period had a significantly lower crude prevalence of rib IPR than during the Fourth Cataract Post-/Meroitic, Fourth Cataract Medieval, and comparative Medieval periods. People living during the Fourth Cataract Post-/Meroitic period had a significantly higher crude prevalence rate than all other time periods, except during both the Fourth Cataract and comparative Medieval periods. No other time periods displayed any significant differences to one another.

Table 7.86 – P-values for Fisher's Exact tests between time periods to measure for significant differences in rib IPR crude prevalence. Statistically significant values are highlighted in grey.

Site	Kerma Classique (4th Cat.)	Meroitic and Post-Meroitic (4th Cat.)	Medieval (4th Cat.)	Neolithic (Comp.)	Kerma (Comp.)	Meroitic and Post-Meroitic (Comp)	Medieval (Comp.)
Kerma Classique (4th Cat.)	-						
Post-/Meroitic (4th Cat.)	0.030	-					
Medieval (4th Cat.)	0.302	0.054	-				
Neolithic (Comp.)	0.089	0.002	0.011	-			
Kerma (Comp.)	1.000	0.031	0.399	0.086	-		
Post-/Meroitic (Comp.)	0.803	0.025	0.434	0.060	0.804	-	
Medieval (Comp.)	0.130	0.515	0.358	0.012	0.135	0.194	-

Figure 7.28 compares the crude prevalence rates of IPR in people living during the different time periods. The Fourth Cataract Post-/Meroitic period displayed the highest crude prevalence rate, at 47.7%. No individuals during the Neolithic had rib IPR, making this the site with the lowest (0.0%) prevalence. Figure 7.29 compares the crude prevalence rate of rib IPR for males and females during different time periods. The Neolithic period was omitted due to a small sample size. There were no significant differences between males and females during any time period. Figure 7.30 compares the crude prevalence rates of rib IPR in young adults and middle adults during different time periods. Again, the Neolithic period was omitted due to the small sample size. There were no significant differences between young adults and middle adults during any time period.

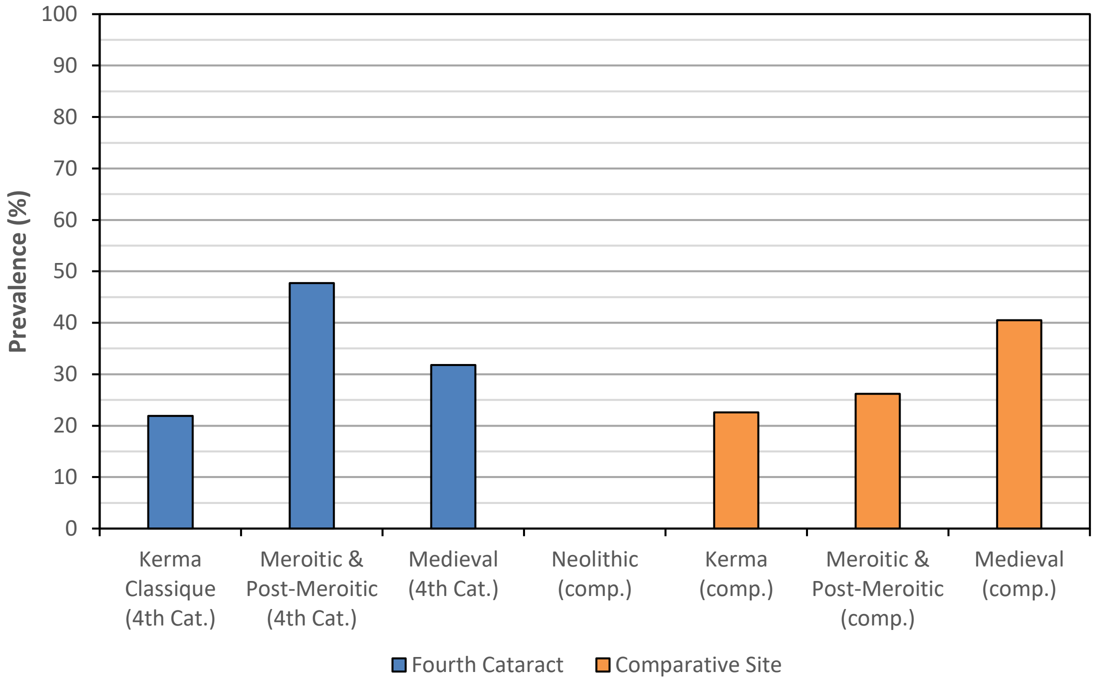


Figure 7.28 – A comparison of the crude prevalence of rib IPR during different time periods.

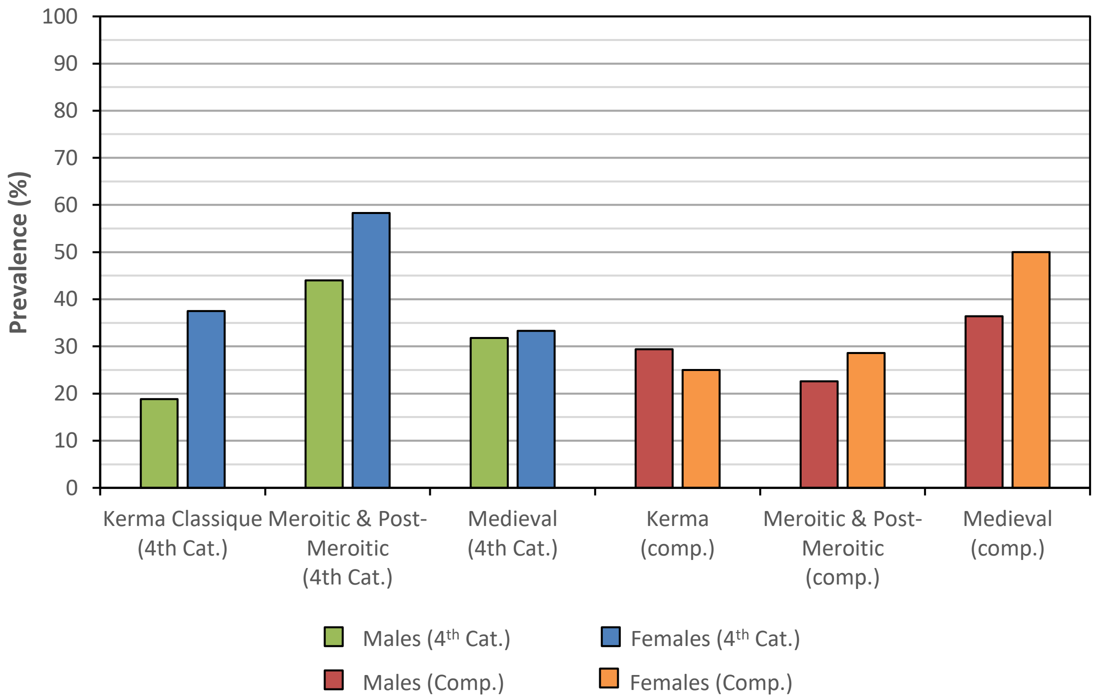


Figure 7.29 – A comparison of the crude prevalence of rib IPR between males and females during different time periods.

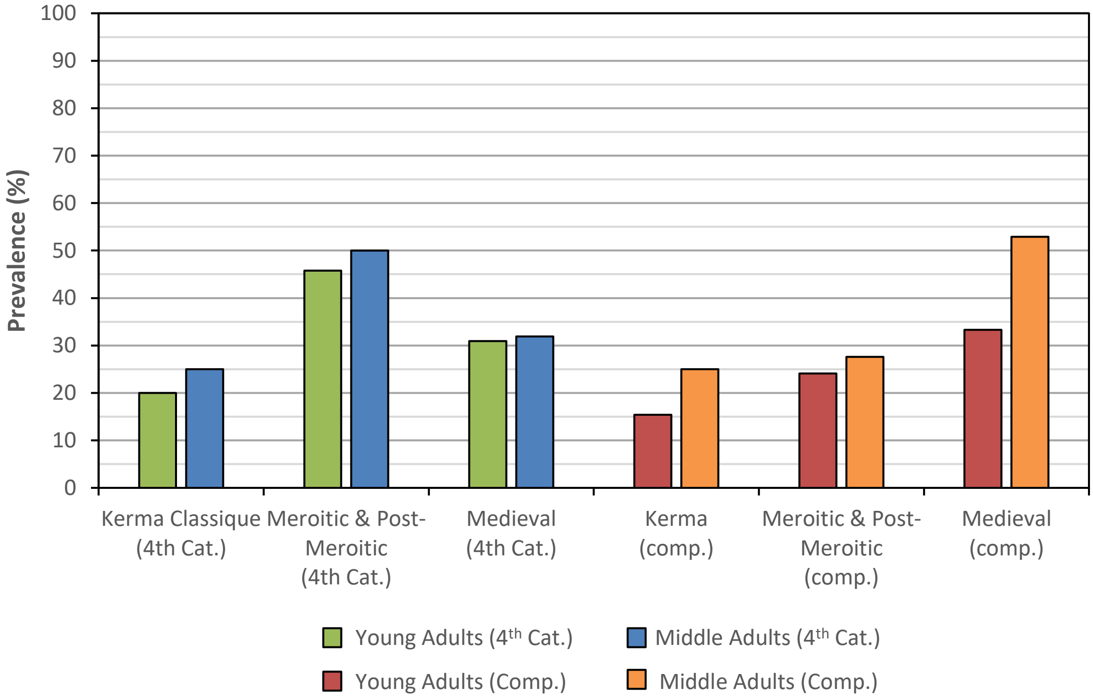


Figure 7.30 – A comparison of the crude prevalence of rib IPR between young adults and middle adults during different time periods.

Table 7.87 displays the outcomes of Pearson's Chi-Square tests between time periods to explore significant differences between true prevalence rates. The majority of time periods were significantly different from one another. The true prevalence rate for the Neolithic and comparative Post-/Meroitic periods were significantly lower than for all other time periods, while the people from the Neolithic period also had a significantly lower prevalence rate than people from the comparative Post-/Meroitic period. Additionally, the true prevalence rate for people from the Comparative Medieval period was significantly higher than for the Fourth Cataract Post-/Meroitic and the comparative Kerma periods. The true prevalence rate for people from the Fourth Cataract Medieval period was also significantly higher than for the comparative Kerma period.

Figure 7.31 compares the true prevalence rates of rib IPR for people living during the different time periods. People from the comparative Medieval period displayed the highest rate, at 5.9%. The Neolithic, having displayed no observable rib IPR, had the lowest true prevalence. Comparison between Figure 7.28 and Figure 7.31 indicate that the true prevalence rate does not always proportionally correlate with the crude prevalence rate for the same time period.

Table 7.87 – P-values for Pearson's Chi-Square tests between time periods to measure for significant differences in rib IPR true prevalence. Chi-Square values (χ^2 (1)) are presented in brackets below. Statistically significant values are highlighted in grey.

Site	Kerma Classique (4th Cat.)	Post-/Meroitic (4th Cat.)	Medieval (4th Cat.)	Neolithic (Comp.)	Kerma (Comp.)	Post-/Meroitic (Comp)	Medieval (Comp.)
Kerma Classique (4th Cat.)	-						
Post-/Meroitic (4th Cat.)	0.791 (0.067)	-					
Medieval (4th Cat.)	0.264 (1.249)	0.245 (1.352)	-				
Neolithic (Comp.)	<0.001 (19.01)	<0.001 (19.94)	<0.001 (22.57)	-			
Kerma (Comp.)	0.389 (0.743)	0.189 (1.722)	0.013 (6.183)	<0.001 (16.26)	-		
Post-/Meroitic (Comp.)	0.001 (10.136)	<0.001 (18.286)	<0.001 (42.458)	<0.001 (11.12)	0.016 (5.780)	-	
Medieval (Comp.)	0.072 (3.238)	0.050 (3.825)	0.171 (1.874)	<0.001 (25.67)	0.003 (9.048)	<0.001 (39.565)	-

Figure 7.32 compares the distribution of true prevalence rates of rib IPR within the rib cage during different time periods. Table 7.88 also compares between time periods any significant differences in the side the rib cage affected and any significant differences between the rib sections or rib cage regions affected. The Neolithic time period was omitted from both Figure 7.32 and Table 7.88 due to the small sample size. The Fourth Cataract Kerma Classique and Post-/Meroitic periods displayed a significantly higher prevalence of rib IPR on the right side, and the comparative Post-/Meroitic on the left. There was no significant difference in the total true prevalence rate for rib IPR by side during any other time period. The Fourth Cataract Post-/Meroitic and Medieval periods showed a significantly higher total true prevalence rate at the neck section of the rib, followed by the angle, with the shaft displaying the lowest prevalence. People from the comparative Medieval period displayed a significantly higher prevalence at the neck, followed by the shaft, with the lowest prevalence at the angle. No other sites displayed a significant difference between the total prevalence rate for different rib sections. The Fourth Cataract Medieval and comparative Post-

/Meroitic periods displayed a significantly higher prevalence in the upper-middle rib cage region, followed by the lower-middle region, with the lowest prevalence at the upper and lower regions. People living during the Fourth Cataract Kerma Classique period displayed a significantly higher prevalence in the lower rib cage region, followed by the upper-middle and lower-middle regions, with the lowest prevalence in the upper region. There was no significant difference during any other time period between the total prevalence rate in each rib cage region.

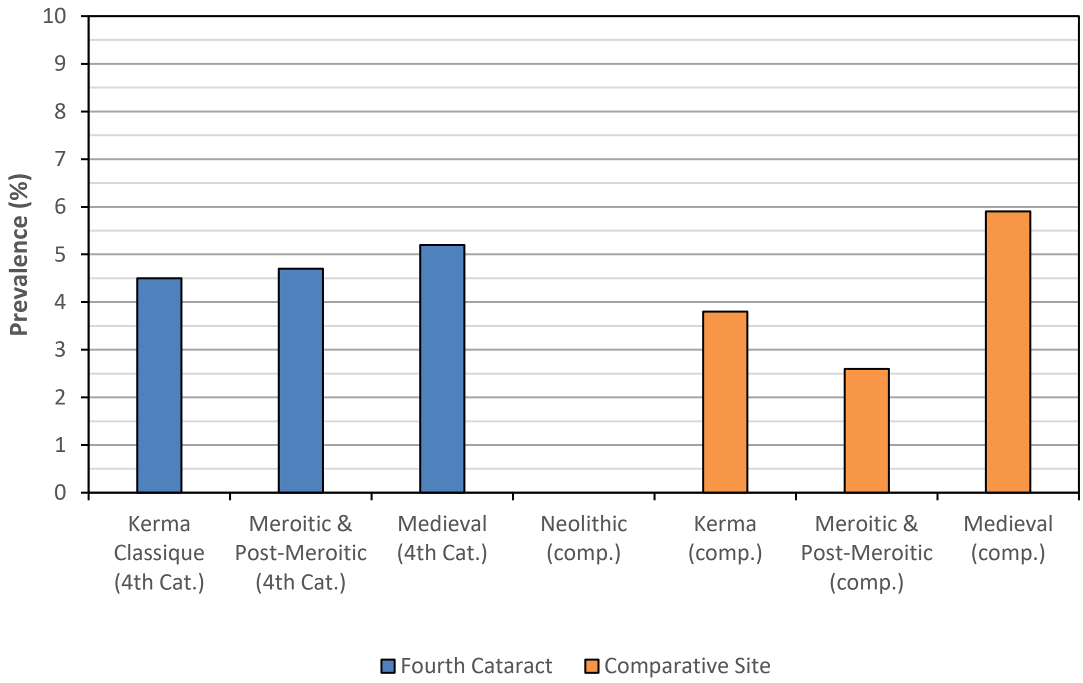


Figure 7.31 – A comparison of the true prevalence of rib IPR during different time periods.

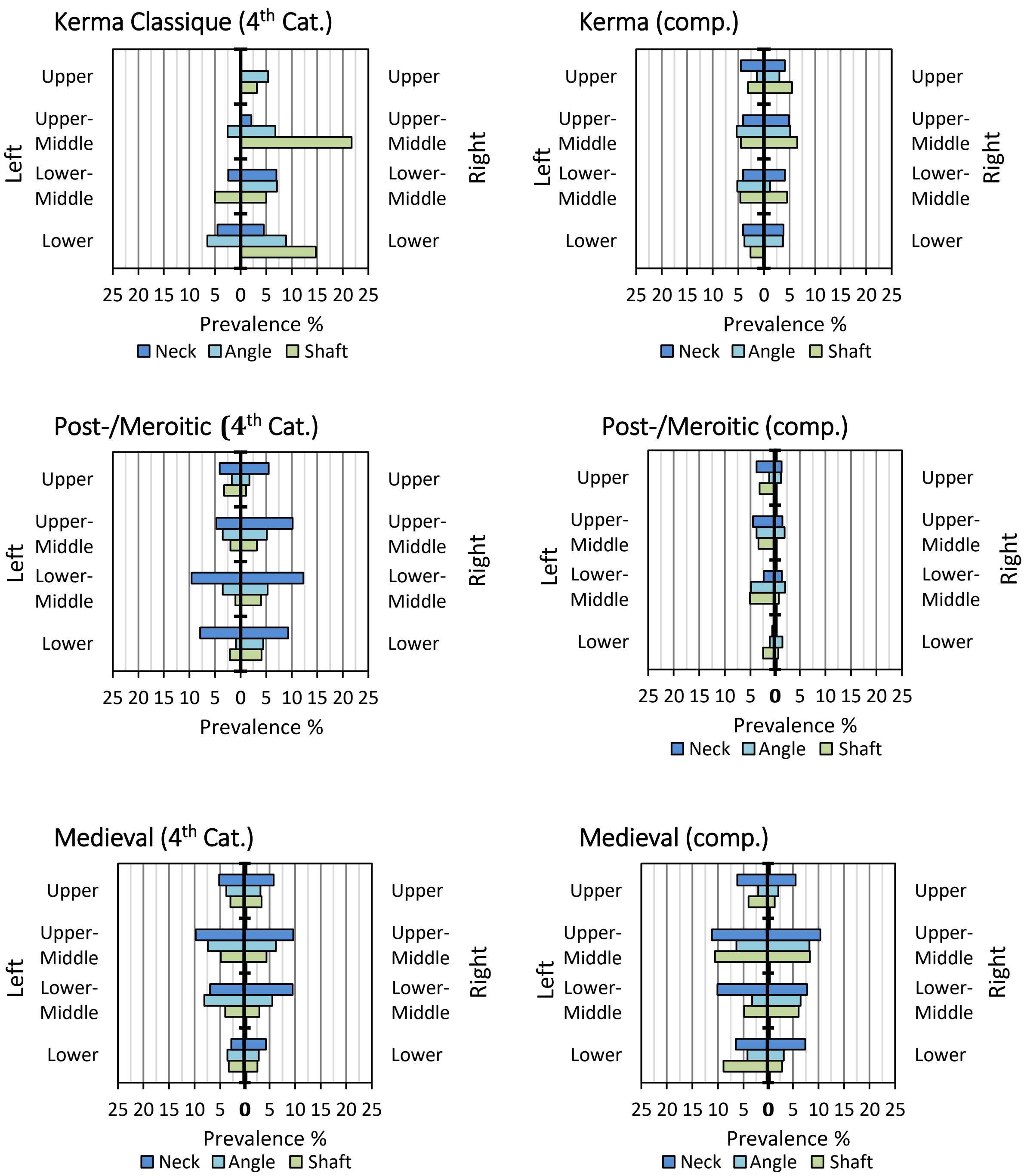


Figure 7.32 – A comparison of the distribution of rib IPR true prevalence within the rib cage during each time period, presented by side, rib cage region, and rib section.

Table 7.88 – A comparison of significant differences (if any) between side, between rib sections, and between rib cage regions during different time periods. The side given indicates the significantly higher prevalence (U = Upper; U-M = Upper-middle; L-M = Lower-Middle; L = Lower).

Site	Prevalence by side								Total prevalence	
	Neck	Angle	Shaft	Upper	Upper-Middle	Lower-Middle	Lower	Total	Rib section	Rib cage region
Kerma Classique (4th Cat.)	-	Right	Right		Right	-	-	Right	-	U < U-M = L-M < S
Post-/Meroitic (4th Cat.)	-	-	-	-	-	-	-	Right	Neck > Angle > Shaft	-
Medieval (4th Cat.)	-	-	-	-	-	-	-	-	Neck > Angle > Shaft	U < U-M > L-M > L
Kerma (comp.)	-	-	-	-	-	-	-	-	-	-
Post-/Merotic (comp.)	Left	-	Left	-	Left	Left	-	Left	-	U < U-M > L-M > L
Medieval (comp.)	-	-	-	-	-	-	-	-	Neck > Angle < Shaft	U < U-M > L-M > L

7.4.2.vii Remodelling rib IPR (by time period)

Table 7.89 presents the percentage of individuals with rib IPR during each time period with active, remodelling, or remodelled IPR. Figure 7.33 compares the data between time periods. People from the different Fourth Cataract time periods display a higher percentage of remodelling rib IPR. People living during the comparative Kerma period display the highest prevalence of active rib IPR, at 71.4%. The comparative Post-/Meroitic and Medieval periods both display an equal proportion of active and remodelled rib IPR, with a lower percentage of remodelling rib IPR.

Table 7.89 – The percentage of individuals with rib IPR during each time period recorded as active, remodelling, or remodelled. Frequencies are presented in brackets below.

Site	Active (woven)	Remodelling (mixed)	Remodelled (lamellar)
Kerma Classique (4th Cat.)	14.3% (1/7)	57.1% (4/7)	28.6% (2/7)
Post-/Meroitic (4th Cat.)	28.6% (6/21)	52.4% (11/21)	19.0% (4/21)
Medieval (4th Cat.)	26.3% (15/57)	36.8% (21/57)	36.8% (21/57)
Kerma (comp.)	71.4% (5/7)	14.3% (1/7)	14.3% (1/7)
Post-/Meroitic (comp.)	47.1% (8/17)	5.8% (1/17)	47.1% (8/17)
Medieval (comp.)	37.5% (6/16)	25.0% (4/16)	37.5% (6/16)
Total	32.8% (41/125)	33.6% (42/125)	33.6% (42/125)

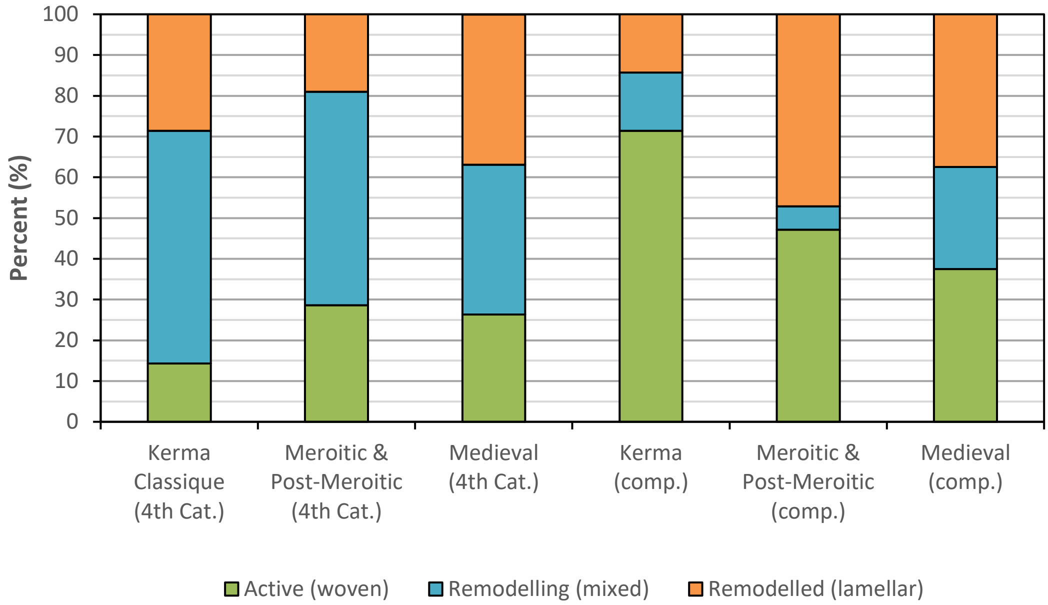


Figure 7.33 – A comparison between the proportion of active, remodelling, and remodelled rib IPR during each time period.

7.4.2.viii Side of ribcage affected (by time period)

Table 7.90 presents the percentage of individuals with rib IPR located within the ribcage on the left side, the right side, or bilaterally during each time period. Figure 7.34 compares the data between sites. People from the Fourth Cataract Post-/Meroitic and Medieval and the comparative Kerma periods display relatively equal percentages of left, right, and bilateral ribcage involvement. The Fourth Cataract Kerma Classique and the comparative Medieval periods demonstrate a high percentage of bilateral involvement. Additionally, the comparative Post-Meroitic group demonstrates a low percentage of right rib cage involvement.

Table 7.90 – The percentage of individuals during each time period with rib IPR located on the left side, right side, bilaterally, or unknown (due to preservation of only one side of the ribcage). Frequencies are presented in brackets below.

Time Period	Unilateral rib IPR			Bilateral rib IPR	Unknown (only one side observable)
	Left	Right	Total		
Kerma Classique (4th Cat.)	0.0% (0/7)	28.6% (2/7)	28.6% (2/7)	71.4% (5/7)	0.0% (0/7)
Post-/Meroitic (4th Cat.)	28.6% (6/21)	42.9% (9/21)	71.4% (15/21)	28.6% (6/21)	0.0% (0/21)
Medieval (4th Cat.)	35.1% (20/57)	31.6% (18/57)	66.6% (38/57)	31.6% (18/57)	1.8% (1/57)
Kerma (comp.)	28.6% (2/7)	42.9% (3/7)	71.4% (5/7)	28.6% (2/7)	0.0% (0/7)
Post-/Meroitic (comp.)	35.3% (6/17)	17.6% (3/17)	52.9 (9/17)	47.1% (8/17)	0.0% (0/17)
Medieval (comp.)	6.3% (1/16)	18.8% (3/16)	25.0% (4/16)	68.7% (11/16)	6.3% (1/16)
Total	28.0% (35/125)	30.4% (38/125)	58.4% (73/125)	40.0% (50/125)	1.6% (2/125)

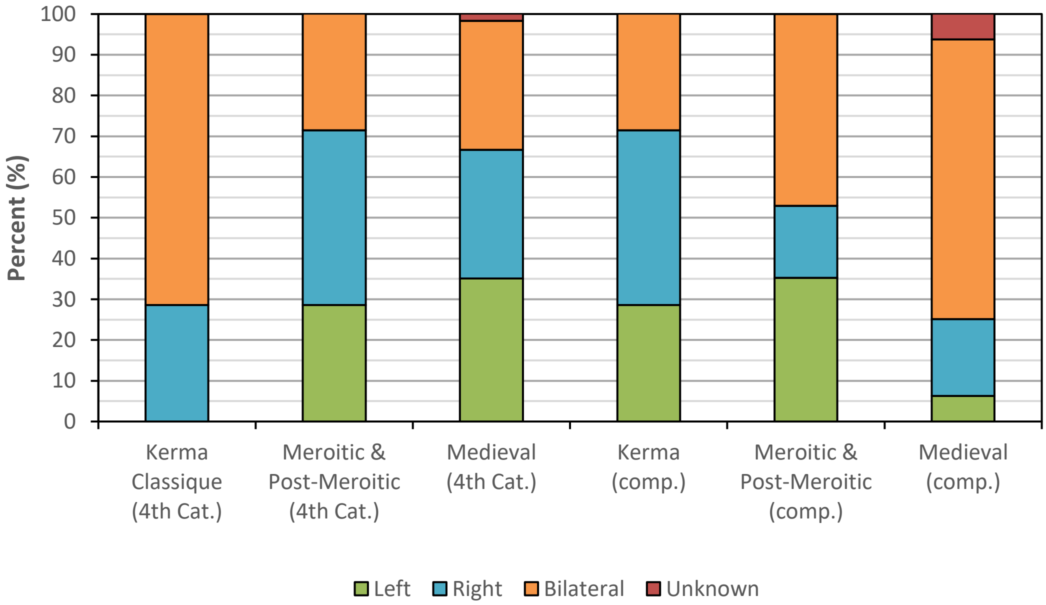


Figure 7.34 – A comparison between the proportion of individuals during each time period with rib IPR located in the ribcage on the left side, the right side, bilaterally, or unknown

7.5 Potential specific causes of maxillary sinusitis and rib IPR

All skeletons in the current study were observed for evidence of potential specific identifiable diseases that could be considered as a cause of maxillary sinusitis or IPR on the visceral surfaces of the ribs. Due to time and preservation constraints, the prevalence of each potential causative disease could not be systematically produced. However, identifying the presence of specific diseases is useful for providing evidence of the potential causes of respiratory disease at certain sites or during specific time periods. As this study was not focused on the extensive identification and diagnosis of non-respiratory related diseases, potential diagnoses of diseases have been given only tentatively unless pathognomonic changes were apparent. Unfortunately, full analysis and publication of the pathological changes present in individuals in the Fourth Cataract have not yet been undertaken. General palaeopathological analyses of the comparative sites have been published (Filer, 1998; Judd, 2001, 2008, 2012) but skeletons from these sites were also analysed separately as part of the current research. A general summary of pathological changes potentially related to respiratory disease, observed during the course of the current research, is presented below and detailed descriptions of the pathological changes observed in individual skeletons can be found in Appendix I.

Several instances of possible leprosy and tuberculosis were identified according to the established diagnostic criteria presented in Section 6.7, which also discusses the potential differential diagnoses that may also have resulted in the observed lesions. Only the Medieval site of 3-J-18 demonstrated any evidence for individuals with skeletal changes consistent with leprosy. Two skeletons (Sk2097 and Sk2193) displayed extensive pathological changes to both the nasal cavity and hands/feet typical of leprosy, including concentric resorption of the digits (see Figure 6.17). The co-occurrence of rhino-maxillary syndrome and atrophic loss of bone in the digits is highly suggestive of a diagnosis of leprosy in these two individuals. Additionally, Skeleton 2224 displayed only slight resorption around the nasal aperture and anterior nasal spine, but was observed to have resorption of the phalanges of both the hands and feet, accompanied by diffuse woven bone on the metatarsals, tibiae, and fibulae, and possible osteomyelitis of the phalanges of the hands. Similarly, Skeleton 4235 demonstrated resorption of the phalanges of the feet and of the right 5th metatarsal and periosteal reaction on the tibiae and the right fibula. Skeleton 2106 presented very slight resorption of the distal heads of the distal phalanges of the hands and resorption of the anterior base of the nasal spine and vomer, but these changes were not pronounced.

At 3-Q-33, one individual (Sk67) demonstrated almost complete resorption of several unsided proximal, intermediate, and distal hand phalanges, accompanied by localised mixed new bone formation around the areas of resorption that may indicate osteomyelitis of the hand. While bone resorption due to osteomyelitis occurs during leprosy, without the accompanying concentric diaphyseal bone loss of the digits of the hands or feet, or rhino-maxillary syndrome, these pathological bone changes cannot be differentiated from other conditions that cause bone resorption, such as trauma, general infection, or rheumatoid arthritis, among other conditions (Destouet & Murphy, 1983; Antunes-Ferreira et al., 2013:156).

At 3-J-18, destructive lesions potentially caused by tuberculosis were noted on the vertebrae of a number of individuals. Skeleton 2002 demonstrated destructive lesions on the right lateral aspects of the first thoracic, and fourth and fifth lumbar vertebral bodies, with some remodelling and lamellar bone formation around the margins of the lesions. The fifth lumbar vertebra also had complete destruction of the spinous process. Skeleton 2248 displayed extensive lytic lesions on the vertebral bodies from the third thoracic vertebra to the third lumbar vertebra, which was likely to have caused the extreme destruction of the rib heads also observed. Similarly, Skeleton 4019 also presented destructive lesions of the thoracic vertebrae one to eight, with minimal bone formation. These lesions also occurred on the neural arches. Skeleton 2273 presented destructive lesions on the inferior end plate of the twelfth thoracic vertebra and on the superior end plate of second lumbar vertebra, accompanied by minimal bone formation. Skeleton 4284 demonstrated small destructive lesions on the anterior surface of the vertebral bodies of the first and fifth thoracic vertebrae, and on the postero-inferior surface of the first lumbar vertebral body, accompanied by minimal lamellar bone formation at the margins of the lesions. In all these instances, lesions had scalloped margins, destroying the cortical surface and exposing the trabeculae beneath, and were accompanied by very little new bone formation. These changes are often related to tuberculosis, but can also be caused by other conditions (see Section 6.7.1). Additionally, a middle adult (Sk4348) displayed a destructive lesion on the inferior surface of the end plate of the second lumbar vertebra and also demonstrated erosive and cyst-like lesions on the right 2nd metacarpal and right 1st distal foot phalanx, which was accompanied by destruction of the proximal base. The 1st distal foot phalanx on the left was also completely destroyed, leaving only the proximal base present.

One instance of Pott's disease of the spine (tuberculosis) in a young woman (Sk75) was observed at Medieval 3-J-23, consisting of large destructive lesions from the fifth thoracic vertebra to the first lumbar vertebra (see Figure 6.16A). Complete destruction of thoracic vertebrae 10 to 12 had resulted in collapse and considerable kyphosis of the spinal column. One other individual at 3-J-23 (Sk59) had scalloped lytic lesions on the inferior end plates of the first and second lumbar vertebrae.

Evidence for lytic lesions of the spine in other cemeteries in the Fourth Cataract represent isolated instances. At 4-M-53, one individual (Sk52) demonstrated a destructive lesion on the superior end plate of a lower lumbar vertebra, accompanied by remodelling of the margins and lamellar bone formation on the right lateral aspect of the vertebral body, close to the destructive lesion. At 3-Q-33, a Meroitic individual (Sk71) displayed destructive lesions of the anterior, superior, and inferior surfaces of the ninth to twelfth vertebral bodies. This was accompanied by prolific and diffuse new bone formation on all surfaces, with an irregular porous 'honeycomb' texture. At 3-O-1 a young adult male (Sk60) presented with an unusual extremely large destructive lesion between the bodies of the first and second lumbar vertebrae, causing complete destruction of the cortical surfaces of the inferior end plate of L1 and of the superior end plate of L2. The interior trabecular structure of the affected vertebrae had been almost completely destroyed, but the morphology of the vertebrae had been maintained. This lesion likely resulted in the prolific wax-like osteophytes observed on the anterior bodies of L1, L2, and T12, causing fusion between all three vertebrae. A similar, yet smaller destructive lesion was also present on the superior surface of the fifth thoracic vertebra, with minimal new bone formation. A lytic lesion on the posterior aspect of the lateral facet of the right clavicle, with remodelling but partial exposure of the trabecular bone, was also present. While the pathological changes observed could be the result of tuberculosis, it should be noted that maintenance of the morphology of the vertebral bodies and the formation of anterior osteophytes, rather than collapse and kyphosis, occurs in brucellosis (Al-Shahed et al., 1994:340) and this disease can also affect joints, such as the clavicle (e.g. Ebrahimpour et al., 2017).

Only one individual during the Kerma period, from P37, demonstrated evidence for destructive lesions on the vertebrae. Skeleton 43-50 was observed to have almost complete destruction of the anterior vertebral body of the first sacral vertebra. This was accompanied by prolific lamellar new bone formation on the lateral aspect of the vertebral body. The sacrum was also observed to have diffuse spiculated lamellar bone formation on the anterior aspects of the sacral bodies.

At Gabati, one Post-Meroitic young adult (Sk37-1061) presented two shallow circular erosive lesions on the superior surface of the body of the first sacral vertebra, with no new bone formation. This individual also had an unidentified lumbar vertebra with a possible shallow lytic lesion on the superior surface of the vertebral body, but preservation hindered further observation. These lesions could represent Schmorl's nodes, pressure defects on the end plates caused by herniation of the intervertebral discs (e.g. Roberts & Manchester, 2010:140). However, they do not have the rounded margins or dense floor usually observed for Schmorl's nodes. Two Medieval individuals from Gabati also demonstrated lytic lesions on the vertebrae. Skeleton 20-20 had a scalloped lytic lesion on the anterior aspect of the body of the fourth lumbar vertebra, with minimal new bone formation, accompanied by porosity and irregular lamellar bone formation on the anterior surface of the body of the third lumbar vertebra. Skeleton 61-67 demonstrated crenulated lytic lesions on the inferior end plate of fourth cervical vertebra and the superior surface of fifth cervical vertebra. The involvement of the cervical vertebrae is rare, although not unheard of, in both tuberculosis and brucellosis (e.g. Garg & Somvanshi, 2011). A Post-Meroitic young adult male (Sk94-156) from Gabati presented extreme destruction of the anterior portion of the superior surfaces of the endplates of the third and fourth lumbar vertebrae, with some lamellar bone formation around the margins. This pattern of destruction has been described in focal brucellosis (see Section 6.7.1). Extreme vascularity and widening of the foramina, that may possibly have represented the early stages of cavitating lesions, was also present on the anterior surfaces of all the lumbar vertebrae and this has been noted in skeletons with brucellosis identified by molecular analysis, but is difficult to differentiated from changes related to tuberculosis (Mutolo et al., 2012).

Diffuse woven bone on the visceral surfaces of the ribs in one individual (Gr22A) from 3-J-23 was also accompanied by bilateral prolific diffuse woven bone on all long bones and on the bones of the hands and feet. This individual likely had hypertrophic osteoarthropathy (HOA) (see Section 6.7.1). HOA is commonly caused by pulmonary conditions (Yap et al., 2017:160) and has been significantly associated with individuals who died from pulmonary tuberculosis in a study of the Coimbra human identified skeletal collection (Assis et al., 2011:160). However, there are a wide range of diseases that can cause this condition (Yap et al., 2017:Table 2) and it is not possible to definitively say whether bone changes in this individual, and the rib IPR likely associated with it, resulted from a respiratory disease.

Evidence for pathognomonic changes related to leprosy and tuberculosis at 3-J-18 and 3-J-23 demonstrates that these infectious diseases were present in the Fourth Cataract during the Medieval period. Additionally, destructive lesions of the vertebrae were also present in the Kerma period at P37, during the Meroitic and Post-Meroitic periods at 3-O-1, 3-Q-33, 4-M-53, and in the Post-Meroitic and Medieval periods at Gabati. However, in all instances the potential differential diagnoses should not be ignored. In the case of isolated destructive lesions of the spine, it is particularly difficult to differentiate the processes of tuberculosis from other conditions such as brucellosis, osteomyelitis, malignant bone tumours, actinomycosis, and sarcoidosis (Aufderheide & Rodríguez-Martín, 1998:140-141; Ortner, 2003:263; Roberts & Buikstra, 2003:Table 3.3). Additionally, the absence of pathological changes related to diseases potentially causing maxillary sinusitis or rib IPR, for example at R12 and Soba East, do not indicate that these diseases were not present but may also be a reflection of poor preservation of the skeletal remains, hindering identification of disease processes.

Chapter 8: Discussion

8.1 Introduction

The following chapter discusses the results presented in Chapter 7 within the context of the available archaeological, historical, clinical, and palaeoenvironmental data. Differences in the prevalence rates of respiratory disease between sites and time periods are addressed, to determine if changes over time or in different regions of the Middle Nile Valley can be identified and contextualised. Comparisons between the data from the current study and from other populations in the Middle Nile Valley and other regions of the world are made, including a discussion of the similarities and differences in the prevalence rates of respiratory disease between different sex and age groups. This chapter also addresses the prevalence of odontogenic sinusitis recorded in the current study, the distribution of rib IPR within the rib cage at different sites and its diagnostic potential, as well as the correlation between the prevalence of maxillary sinusitis and rib IPR. A summary of the limitations of the current study and the potential avenues for future research are also presented. Firstly, the effect that preservation may have had on the reliability of the data produced in this study is discussed.

8.2 Preservation

Prior to discussing the prevalence of evidence for respiratory disease in populations analysed in the current study, the effect preservation has on the recording of pathological changes in skeletons from different sites must be considered. Lower prevalence rates of rib IPR in studies of skeletons from archaeological sites, when compared to well-preserved 'modern' (i.e. 19th – 20th Century) identified human skeletal collections, have been attributed to the poorer preservation of skeletal remains from archaeological contexts (Santos & Roberts, 2006:47). Additionally, a significant correlation has been found between the level of preservation and the frequency with which sinusitis has been identified, with poorly preserved sinuses displaying evidence for maxillary sinusitis less frequently (Sundman & Kjellström, 2013:451). Therefore, it is important to identify sites in the current study where preservation or other factors may have affected the recorded prevalence rates.

Preservation varied greatly between sites, from severely fragmented and incomplete skeletal remains to very well-preserved and naturally mummified individuals. R12 consistently displayed the poorest preservation of the ribs, with the highest mean scores for rib fragmentation (2.57) and cortical preservation (2.79) and the largest number of ribcages that were below five percent complete (73.8%). Only thirteen of forty-three individuals analysed at this site had at least 5% or more of one half of a rib cage complete and so only this small number could be observed for rib IPR. The fact that cortical preservation of the rib cage was so poor at this site and rib fragmentation so high may have affected the observability of the rib surfaces. Thus, while no individuals at R12 presented evidence for rib IPR, this may not be wholly related to the absence of lower respiratory tract disease or other diseases producing rib IPR at this site, but also to the poor preservation of the ribs. Other sites with poor rib preservation scores include 4-L-2, 4-L-88, 4-L-100, and Soba East. Although rib IPR was observed at these sites, the crude prevalence rates recorded in these groups may also have been affected by the poor preservation.

Fragmentation and cortical preservation scores for maxillary sinuses were not recorded in the current study as the delicate nature of the sinus walls means that poor preservation usually leads to disintegration or lack of recovery of the fragments, making it difficult to determine the extent of fragmentation and cortical preservation. In those sinuses that were preserved, cortical preservation was not observed to affect the surfaces of the sinuses in the same way that it did the rest of the skeleton, perhaps because the sinuses remain enclosed for some time after burial or because the regions of the sinus that have poor cortical preservation simply do not survive. However, maxillary sinus completeness was recorded and tended to correlate loosely with the rib cage completeness scores from each site (Figure 8.1). Individuals from 4-L-88 had the highest number of sinuses that were below 5% complete (43.8%), with low levels of completeness also observed in skeletons from R12, 4-L-100, and P37.

Additionally, when looking at completeness scores for both the rib cage and the maxillary sinuses, after excluding any in the category of <5%, the majority of rib cages and sinuses in skeletons from the poorly preserved sites (4-L sites, R12, P37 and Soba East) were below 50% complete. For example at R12 and 4-L-88, 93.8% and 100%, respectively, of all observable maxillary sinuses were below 50% complete. While rib IPR and maxillary sinusitis could still be recorded in these groups, fifty percent or more of the surface area of the sinuses or rib cage were not present to be analysed for the majority of these skeletons. This may have negatively impacted the ability to observe all bony changes related to sinusitis or rib IPR and could have affected prevalence rates in the poorly preserved sites. This also effects the comparability between poorly preserved sites and those sites with high levels of skeletal completeness, for which a more representative prevalence rate can be determined.

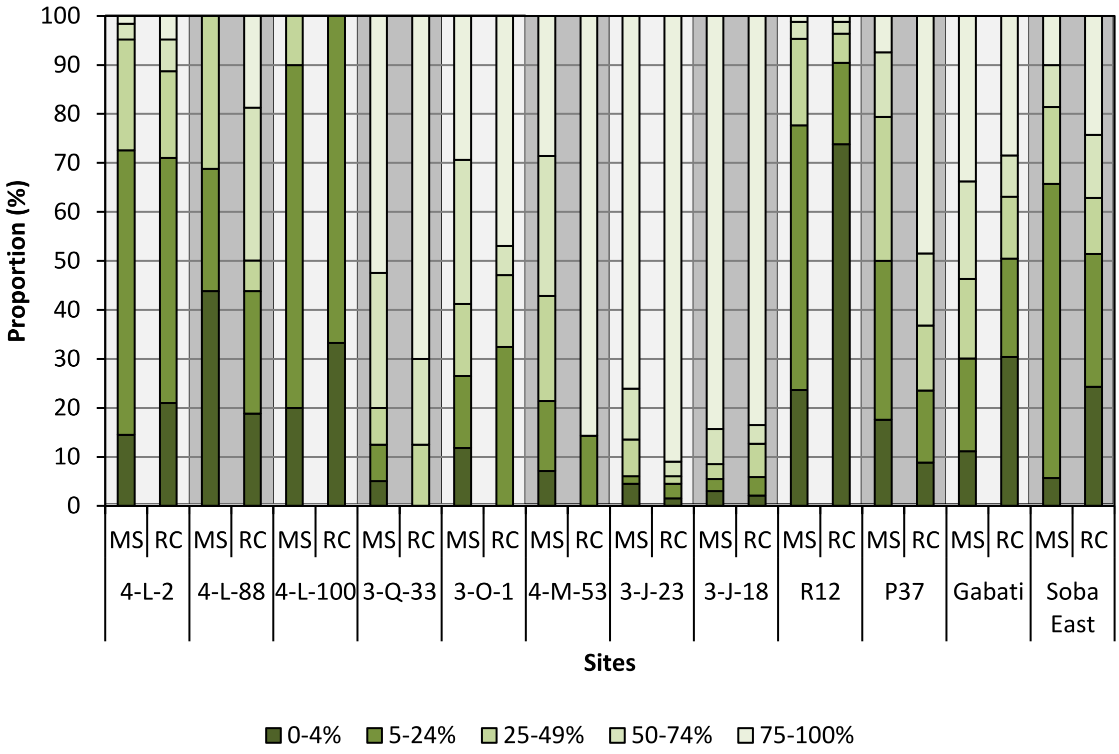


Figure 8.1 – A comparison of the proportion of maxillary sinuses (MS) and rib cages (RC) within the different completeness categories at each site, demonstrating a general correlation between the completeness of different elements at the same site.

To improve comparability of rib IPR between sites with different levels of preservation, a new method for recording the true prevalence of rib IPR was produced in the current study. This method accounted for fragmentation and element completeness by recording rib IPR on three separate sections of each individual rib. Although this method provides a means of calculating true prevalence at different sites and allows for the analysis of the distribution of rib IPR in the ribcage, it does not provide information on the number of individuals with rib IPR. Neither was a method for recording the true prevalence of maxillary sinusitis applied to sinuses, as the size and shape of the maxillary sinus is very variable, making it difficult to accurately record the presence or absence of separate areas of the sinus.

While cortical preservation, rib fragmentation, and element completeness at the same sites tended to correlate, surface observability did not. Mean rib cage observability scores were higher, indicating poorer surface observability, in skeletons from 3-J-18 (1.97) and 3-J-23 (1.74), while other preservation scores suggested good levels of preservation at these sites (Figure 8.2). For the most part, these high scores are likely due to the adherence of soft tissues to the rib cage, as many of the individuals at these sites had been, to some extent, naturally mummified. This result is not surprising considering that the method for scoring surface observability was created in the current study to take into consideration the inability to observe the entire rib cage in some of the naturally mummified skeletons. This affected the accuracy of recording the prevalence of rib IPR and could not be accounted for simply by scoring cortical preservation. Skeletons from 4-L-2 also displayed a high mean rib surface observability score (1.76) despite having poor preservation scores in other categories but, in this instance, is likely due to the adherence of soil and the deposition of crystallised minerals to the bones rather than to the preservation of soft tissues.

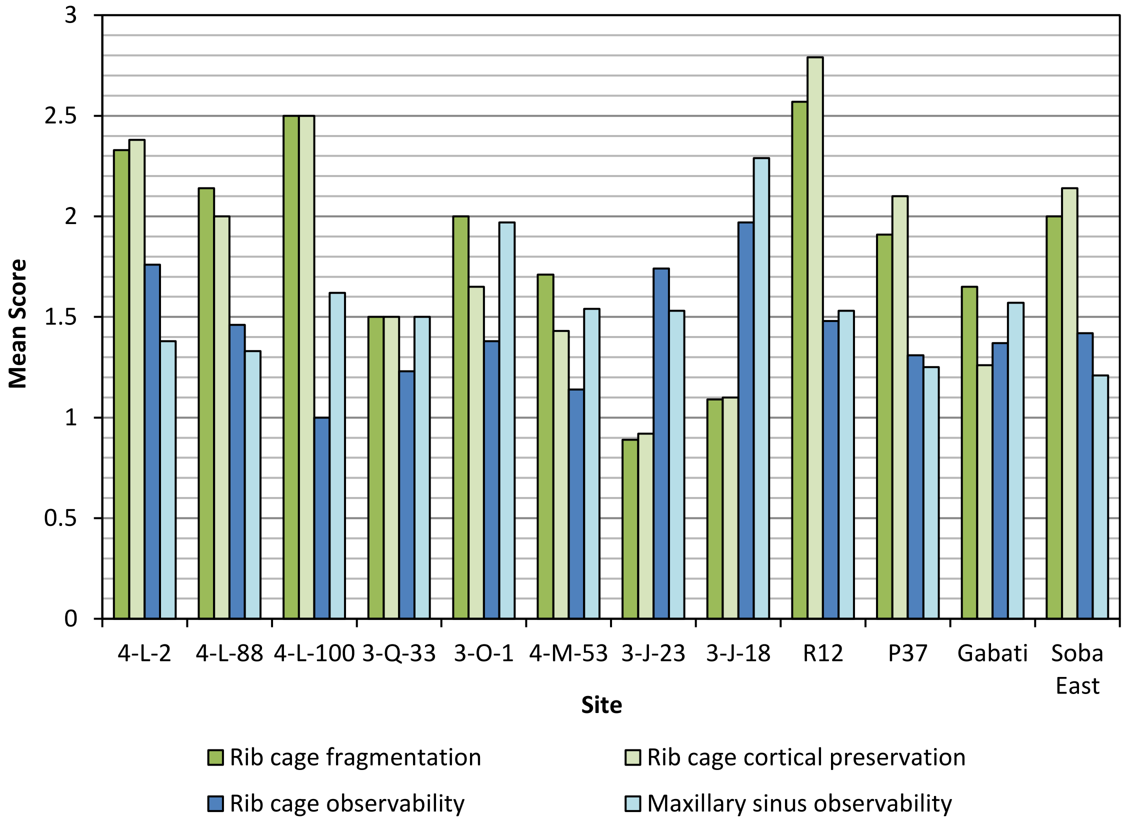


Figure 8.2 – A comparison of the mean scores for rib cage fragmentation, rib cage cortical preservation, rib cage observability, and maxillary sinus observability at each site.

Maxillary sinus observability scores were also higher in skeletons from the well-preserved site of 3-J-18. This is likely due to some soft tissue preservation within the sinuses, but also to the high level of completeness of the skeletons at this site. The more intact sinuses at 3-J-18 could only be viewed using an endoscope and could not be fully accessed to clean. If soil was particularly adherent to the sinus walls and could not be dislodged without causing damage to the skull, a higher observability score was recorded. At more fragmented sites, maxillary sinus fragments were easily accessed and cleaned, resulting in lower (i.e. better) observability scores. Despite being exceptionally well-preserved, with many intact sinuses requiring an endoscope to be viewed, 3-J-23 did not have a particularly poor observability score compared to other sites. This may be due to the many burials at 3-J-23 that were excavated from a sandy soil that was easier to dislodge from the sinuses without causing damage.

The preservation scores demonstrate that factors, such as fragmentation, cortical preservation, completeness, type of soil matrix, and the presence of naturally mummified soft tissues, all have implications for the recording of maxillary sinusitis and rib IPR in skeletons. These factors have been taken into consideration when interpreting the data from the current study, particularly when comparing sites with different levels of preservation. At sites with poor preservation, where element completeness, fragmentation, and cortical preservation could all have contributed to the inability to observe and record instances of bony changes related to respiratory disease, it should be remembered that only the very minimum prevalence rates have been observed. Conversely, this also holds true for the very well-preserved sites where the presence of soft tissue also hindered observation.

Preservation also affected the ability to assess the sex and age of skeletons. This is reflected in the high percentage of individuals from the poorly preserved sites for whom age and sex were recorded as unknown, in particular from 4-L-100 (80.0% for both age and sex) and R12 (67.4% for age and 58.2% for sex). Poor preservation of the sinuses and ribs also excluded many individuals, for whom sex and age could be estimated, from meeting the inclusion criteria of this study. This has implications for the comparison of prevalence rates between age or sex groups from different sites. At several of the poorly preserved sites the low number of individuals with an estimated sex or age meant that tests of statistical significance could not be applied or that sample sizes were too small to yield any meaningful results. This was accommodated for in part by the pooling of sites into time period groups.

8.3 Respiratory disease in the Middle Nile Valley

The following section discusses the crude prevalence rates of respiratory disease recorded in the current study in the context of the available archaeological and palaeoenvironmental data for each time period. As there was very little difference between the prevalence rates of maxillary sinusitis only in individuals with both sinuses present (2SP) compared to the group for individuals with one or both sinuses present (1+SP) (see Section 7.3), data for the prevalence of maxillary sinusitis in the 1+SP group is presented below. The prevalence of respiratory disease in groups from different time periods and sites, including the identification of patterns and differences that may be related to changes in environment, habitation, subsistence strategy, and activities related to occupation, among other factors, is summarised at the end.

8.3.1 The Neolithic period (6000 – 4000 BC)

The individuals from R12 (4900 – 4300 BC), making up the only Neolithic group in the current study, demonstrated the lowest prevalence rate of maxillary sinusitis (32.5%, 13/40). This prevalence was significantly lower than all other groups, except for 3-O-1, 3-J-23, and the Fourth Cataract Post/-Meroitic period. R12 also had the highest percentage of sinuses with evidence for an odontogenic origin of sinusitis (18.8%, 3/16). When only those sinuses with undamaged alveolar bone were considered, odontogenic sinusitis was present in 37.5% (3/8) of sinuses with sinusitis. This suggests that a large proportion of sinusitis may have been caused by dental disease, rather than by environmental particulates or pathogens breathed in via the nose. Skeletons from R12 also presented no evidence for rib IPR (0/13). This was significantly lower than groups from all other sites except for 4-L-2, 3-J-18, and P37. When compared by time period the rib IPR crude prevalence rate for the Neolithic time period was significantly lower than for the Fourth Cataract Post-/Meroitic and Medieval periods and the comparative Medieval period.

The significantly lower prevalence rates of rib IPR and maxillary sinusitis at R12, when compared to most other groups, and the high percentage of sinusitis potentially caused by dental disease, could suggest that individuals buried at this site were less exposed to environmental particulate matter (PM) or other factors causing respiratory disease than in later time periods. The environment during the Neolithic period in Sudan was the wettest and most humid of all periods represented in the current study (Haaland, 1981:46-47; Lario et al., 1997:587; L. Krzyżaniak, 2011:20-21; Woodward et al., 2015:133). A certain level of humidity can be beneficial for the health of the upper respiratory tract (e.g. Arundel et al., 1986; Wolkoff & Kjærgaard, 2007). Additionally, the relatively high levels of humidity and precipitation during this period led to a greater coverage of vegetation (Lario et al., 1997:587) and was likely to have yielded a lower concentration of dust and sand particulates in the air. However, the greater vegetation cover present in the Neolithic period may also have produced higher levels of pollen and plant spores in the environment, which can also increase susceptibility to respiratory diseases (Ayers et al., 2009:297; Bernstein & Rice, 2013:1456; D'Amato et al., 2015:2; Yusa et al., 2015:8372).

'Char' markers in dental calculus from Neolithic individuals buried at Al Khiday II, in Central Sudan, demonstrate that people, at least from this site, were likely to have been exposed to smoke from fires for extended periods of time, perhaps during cooking (Buckley et al., 2014:7). Hearths have been found at a number of Neolithic sites (e.g. Arkell, 1953:79-80; McHugh et al., 1989:328;

Honegger, 2001:17). However, the only substantial evidence for hearths in relation to habitation structures, at the Kerma East Cemetery approximately 50km north of R12, places them outside in areas protected from the wind (Honegger, 2001:18-19). In addition to this, the lack of evidence for substantial housing has led to the suggestion that organic materials, such as woven grass, may have been utilised in construction (e.g. Arkell, 1953:102). These temporary forms of housing, such as those seen in modern day nomadic examples from the Fourth Cataract, constructed of branches, mats, palm fronds, and straw bundles, could have been well ventilated (Reshetnikova, 2012:94-96; 2014:VI, XIX). Therefore, Neolithic individuals cooking inside wooden huts or using outside hearths may have been exposed to lower concentrations of PM from smoke than in later periods, when more substantial forms of construction were also used and hearths were predominantly located inside.

Wild animal remains from the graves at R12 indicate hunting was a prized activity for this community (Pöllath, 2008:73). A greater reliance on hunter-gathering and fishing during the Neolithic period, compared to later periods, may have resulted in lower exposure to PM from agrarian activities, such as ploughing, threshing, and winnowing. However, there is also evidence for animal husbandry and some cultivation of cereal grains. Domesticated wheat and barley, as well as wild grasses, legumes, and starchy plants, have been found at R12 and at the Neolithic site of Ghaba (Madella et al., 2014). Wild grasses at Ghaba may have been processed with some form of threshing tool (Out et al., 2016:44). Additionally, grinding stones were used to process plant material for consumption, as evidenced by a Neolithic grinding stone at Conical Hill in the Wadi Howar that retained wild grass material on its surface (Radomski & Neumann, 2011:163). Grindstones of sandstone and limestone have been found in six graves from R12 (Usai, 2008:57). The grinding of gains on stone grinders has been shown to produce particulates that can be detrimental to respiratory health (Grobbelaar & Bateman, 1991:338). Additionally, palettes stained with red and yellow ochre were common at R12, found in twenty-seven graves, and were used to grind ochre into a pigment for application on people, animals, and pottery (Usai, 2008:56-57). Regular grinding of pigments could also have exposed individuals to PM.

At R12 bucrania were found in at least thirty-six graves and, to a lesser degree, sheep and goat were also included in grave assemblages at this site (Pöllath, 2008:62-63, Table 6.1). The importance of cattle in Neolithic ideology has been demonstrated by the inclusion of bucrania in graves at other cemetery sites, such as at el-Barga, Ghaba, Kadruka, and el-Kadada (Reinold, 2001:8; Honegger, 2014:24; Usai, 2016:17). If animals, in particular cattle, were prized as indicators of the accumulation of wealth or power (Haaland, 2012:331; Chaix, 2017:422), they may have been kept in close proximity to settlements. The only substantial evidence for Neolithic settlement organisation, at the Kerma East Cemetery, displayed possible animal enclosures close to habitation structures (Honegger, 2001:18). This proximity may have increased exposure to animal allergens and zoonotic infectious diseases and may also have lowered levels of sanitation and increased disease load within occupation sites. However, the possible transient nature of Neolithic settlements, suggested by the lack of evidence for habitation structures (Usai & Salvatori, 2005:480), may indicate that groups moved on before an occupation area could become too polluted.

The preservation of human remains at R12 was particularly poor, as has been discussed in Section 8.2. The fact that rib IPR was absent in the individuals buried there may have as much to do with the small sample size and poor preservation of the rib cages as it does a lack of factors causing respiratory disease. Neither was potential rhinogenic maxillary sinusitis completely absent, indicating that there may have been some exposure to factors causing respiratory disease. However, other sites, such as Soba East, also display poor preservation scores but still demonstrate high prevalence rates of maxillary sinusitis and rib IPR. The significantly lower prevalence rates at R12, in particular of maxillary sinusitis which was not as greatly affected by the poor preservation, does suggest that this population was not being exposed to the same level of PM or infectious pathogens that may have been present in later periods. This was likely due in part to the more humid climate, ventilated housing, and a greater reliance on a hunter-gatherer lifestyle.

8.3.2 The Kerma period (2500 – 1500 BC)

8.3.2.i Fourth Cataract sites

The Fourth Cataract Kerma Classique period (1750 – 1500 BC) group had a maxillary sinusitis prevalence rate of 56.4% (22/39). By individual site, people buried at 4-L-2 and 4-L-88 displayed a higher prevalence of 60.7% (17/28) and 66.7% (4/6), respectively. However, individuls from 4-L-100 displayed a considerably lower prevalence rate of 20.0% (1/5). The number of individuals that it was possible to analyse from 4-L-88 and 4-L-100 was extremely small, indicating that the prevalence rates for these two groups may not be reliable when considered solely by individual site. The prevalence of maxillary sinusitis at 4-L-2, the only Kerma Classique site with a large enough sample size to apply statistical testing to, was significantly higher than R12 but showed no significant differences with any other site. The same result was achieved when the combined Fourth Cataract Kerma Classique group was compared against all other time periods. Odontogenic sinusitis was low in the combined Fourth Cataract Kerma Classique group at 3.5% (1/29), with only one oroantral fistula observed. However, the percentage of sinuses with damaged or absent alveolar bone was the highest of all time period groups analysed (65.5%, 19/29), indicating that evidence for sinusitis caused by dental infection could have been higher, but poor preservation of the alveolar bone and sinuses prevented observation.

The prevalence rate for rib IPR was lower than for maxillary sinusitis. The combined crude prevalence rate for the Fourth Cataract Kerma Classique period was 21.9% (7/32). This was the second lowest rib IPR prevalence rate recorded by time period after the Neolithic site of R12. People buried at 4-L-100 displayed no evidence for rib IPR (0/2), at 4-L-88 a prevalence rate of 16.7% (1/6), and at 4-L-2 a rate of 23.1% (6/26). While the prevalence rate at 4-L-2 was not significantly different to any other site, the combined Fourth Cataract Kerma Classique group was significantly lower than the Fourth Cataract Post-/Meroitic group only.

8.3.2.ii P37

People buried at the Kerma Ancien (2500 – 2050 BC) and Kerma Moyen (2050 – 1750 BC) site of P37 had the second highest prevalence rate of maxillary sinusitis by site, after Soba East, with a prevalence rate of 76.6% (23/30). When considered by time period, the comparative Kerma group, representing individuals from both the Kerma Moyen and Kerma Ancien periods at P37, displayed the highest prevalence rate of maxillary sinusitis. This was significantly higher than the prevalence rates for groups from 3-J-23, R12, and Gabati, and from the Neolithic and Fourth Cataract Medieval periods. No significant difference was found between the prevalence for Kerma Ancien individuals at P37 (76.2%, 16/21) and Kerma Moyen individuals (77.8%, 7/9). Additionally, P37 displayed no evidence for odontogenic sinusitis (0/35), suggesting that the majority of sinusitis was possibly caused by PM or pathogens breathed in via the nose. However, 45.7% (16/35) of sinuses were damaged and could not be observed for an oroantral fistula.

Considering that individuals from P37 displayed one of the highest rates for maxillary sinusitis in the current study, the prevalence rate of rib IPR was low, at 22.6% (7/31). This was the second lowest prevalence rate by site, after R12, and the third lowest rate by time period, after the comparative Neolithic and Fourth Cataract Kerma Classique periods. However, P37 only had a significantly lower prevalence rate than groups from 3-J-23 and the Fourth Cataract Post-/Meroitic period. The minimal difference between prevalence rates of rib IPR for the Kerma Ancien individuals (21.7%, 5/23) and Kerma Moyen individuals (25.0%, 5/23) at P37 was not statistically significant.

While the rate of rib IPR was very similar between the Fourth Cataract Kerma Classique and comparative Kerma period groups, the maxillary sinusitis prevalence rate for the comparative Kerma group was higher by 20.2%. This result was not significantly different, but it may suggest that factors at P37 were causing an increased susceptibility to maxillary sinusitis compared to the Kerma period sites from the Fourth Cataract.

8.3.2.iii Kerma sites in context

The Kerma period, in both the Fourth Cataract and the Northern Dongola Reach, sees a significant rise in maxillary sinusitis compared to the previous Neolithic period. There is also a considerably lower prevalence of odontogenic sinusitis in both Kerma period groups when compared to the Neolithic period. This suggests that changes between the two time periods may have caused a rise in susceptibility to maxillary sinusitis, in particular from environmental pathogens and particulates breathed in via the nose. One of the major shifts between the Neolithic and Kerma periods was an increase in the aridity of the environment. By the start of the Kerma Ancien period (*c.* 2500 BC) the wadi systems of the Nile were drying up and populations may have been exposed to increasing concentrations of aeolian sands (Nicoll, 2004:571; Woodward et al., 2015:138). In the Northern Dongola Reach, in which P37 is located, subsidiary Nile channels were also beginning to dry and settlements were clustering along the banks of the Alfreda, Dongola, and Hawawiya Niles, demonstrating a dependence on proximity to a main body of water (Welsby, 2001:589; Welsby et al., 2002:32). Isotopic analysis of human and faunal remains from the Eastern Cemetery at Kerma, dating to the Kerma Moyen and Kerma Classique periods, found elevated nitrogen isotope ratios consistent with an arid environment (Iacumin et al., 2001:44; Thompson et al., 2008:383). The increase in aridity would have reduced vegetational cover and introduced a higher concentration of dust and sand particles into the air (Field et al., 2010; Ravi et al., 2011:7). The southward shift of precipitation, and consequently of the vegetation belt, over time (Kuper & Kröpelin, 2006:807; Gatto & Zerboni, 2015:311-312; Out et al., 2016:37) meant that the northern region of the Middle Nile Valley became more arid at an earlier date. The higher maxillary sinusitis prevalence rate at P37, compared to Fourth Cataract Kerma Classique group, may be due to the slightly more northerly position of this site and its exposure to windblown sand and dust from the western desert. However, floral evidence from Kerma period sites in the Northern Dongola Reach indicate that the environment was not completely arid, with a lightly wooded savannah and a riparian zone near the river, likely to have had greater vegetal cover (Cartwright, 2001:561; Welsby, 2001:589).

The Kerma period also provides the first substantial evidence for housing structures. During the Kerma Ancien period, at the city of Kerma and nearby Gism el-Arba, circular huts seem to have been predominant (Gratien, 1999:10; Bonnet, 2014b:238). From around 2000 BC onwards rectilinear mudbrick buildings became a popular form of habitation at these sites (Gratien, 1999:10-11; Bonnet, 2004b:79, 2014b:238) and in the Northern Dongola Reach remains of Kerma period rectilinear mudbrick walls and stone foundations have also been found, for example at the site of L12 (Welsby, 2001:577). While these mudbrick buildings may have served as a more substantial barrier to environmental PM from the outside, they were also likely to have reduced ventilation within the home, retaining particulates from smoke and other sources. In the Northern Dongola Reach the use of daub was noted at some sites (Welsby, 2001:577) and this may have reduced ventilation in the walls further. The weak walls of Kerma mudbrick buildings were likely only able to support light roofs of organic materials (Gratien, 1999:10; Bonnet, 2014b:Fig. 146). Some form of ventilation may have been achieved through the roof if the materials used were fairly insubstantial. However, in recent houses in the Fourth Cataract the roofs were constructed from wooden poles and palm leaves, plastered with mud and animal dung, and were quite insulated (Welsh, 2005:21, 2013:x; Reshetnikova, 2014:XVIII-XIX). A similar technique may have been used in the Kerma period to provide waterproofing for the houses. At the city of Kerma it appears that kitchen facilities were located outside, providing greater dissipation of smoke from cooking fires (Bonnet, 2004b:79, 2014b:239, Fig. 146), but at more rural sites, such as Gism el-Arba, cooking may have taken place within the dwelling (Gratien, 1999:10-11). The roof area over the kitchen, however, may have been left unplastered or with lighter roofing materials, to allow for ventilation, as has been noted in recent Fourth Cataract housing (Welsh, 2005:19, 2013:xi).

It is difficult to say what type of housing the Kerma populations from this study were occupying as no settlements have been associated with the cemeteries. As a cemetery serving possible rural agricultural settlements, the Kerma Moyen individuals at P37 may have inhabited brick buildings similar to those at Kerma, Gism el-Arba, and the building found nearby at L12 in the Northern Dongola Reach. Additionally, if P37 was similar to rural Gism el-Arba, then cooking fires may have been located indoors. However, if the earlier Kerma Ancien individuals at P37 inhabited huts, as has been found at other Kerma Ancien sites, the more ventilated structures did not appear to protect them from developing respiratory disease, as this group displayed very similar prevalence rates to the Kerma Moyen group.

In the Fourth Cataract there is little evidence for mudbrick structures. Kerma Moyen period huts constructed from wood and other organic materials have been found at HP221, in Wadi Umm Rahau, and singular circular huts of possible Kerma date have been noted in the vicinity of the 4-L cemetery sites included in this study (Welsby, 2005:3; 2006a:9; Paner & Pudło, 2010:136; Paner, 2014:60). While the absence of evidence for mudbrick buildings in the Fourth Cataract does not preclude their presence (e.g. Welsby, 2014a:192), the rocky terrain in the Fourth Cataract region may have made the construction of smaller circular huts more practical. Additionally, prior to the Medieval period, the lack of settlements in comparison to the presence of cemeteries in the Fourth

Cataract region has been used to suggest a more nomadic lifestyle in this area (Paner, 2014:62; Żurawski, 2014:149) and may indicate that more temporary structures, such as ventilated huts, were used. This could indicate why the prevalence rate of maxillary sinusitis is lower in people from the Fourth Cataract Kerma group than for people buried at P37. However, while the use of organic materials for the construction of huts may have provided ventilation in the home, it will also have increased exposure to environmental PM from outside.

The Kerma period also saw the intensification of agrarian activities. The hunter-gathering practices of the Neolithic do not appear to have continued to any substantial degree into the Kerma period, and wild animal remains in Kerma faunal assemblages are poorly represented (Chaix, 2006:27-28; 2017:416). Instead, a greater reliance on the growing of cereal crops may have increased the exposure of farmers to PM. Agricultural activities such as ploughing, tilling, harvesting, and winnowing produce airborne particulates (Kirkhorn & Garry, 2000:706; Schenker, 2000:664), particularly in arid, windy environments where disturbances of dust, sand, or other particles can easily be introduced into the air (Schenker, 2010:110). These activities were all likely to have been undertaken by farmers during this period. For example, at Kerma City a field dating to the Kerma Classique was discovered with evidence for ploughing using oxen (Bonnet, 2003:viii). At the city the baking of bread was also likely to have been undertaken on an industrial scale (Bonnet, 2004b:79) and large volumes of grain would have had to be ground for this purpose. Bread ovens have also been found at Gism el-Arba (Gratien, 1999:11) and the grinding of grain and the baking of bread on a local scale may have been the staple of the diet. If grain grinding was undertaken on a regular basis, people responsible for the task may have been commonly inhaling grain and stone dust, perhaps even daily. Women in the region of Darfur in Western Sudan have recently been observed to spend two or three hours a day grinding grains (Haaland, 2017:4). Furthermore, the same activity undertaken by women in the Transkei district of South Africa is thought to have contributed to the presence of pneumoconiosis in women from this region (Grobbelaar & Bateman, 1991:339).

One continuation that can be identified from the Neolithic period is the retention of cattle as an important part of Kerma ideology, as represented by the inclusion of cattle in iconography from this period and the presence of large numbers of bucrania around important graves at Kerma City (Chaix & Grant, 1993:403; Chaix, 2017:422). The potential importance of cattle at rural sites is also demonstrated by the large numbers of clay cattle figurines discovered at Gism el-Arba (Chaix, 2006:27). Animal deposits were present within twelve of the thirteen Kerma Moyen graves at P37, including complete animals and meat cuts from sheep, goat, and dog (Grant, 2001:545). Cattle bones were not found within the graves, but approximately twenty cattle bucrania were discovered placed around one burial (Grant, 2001:547-548). It is evident that livestock were an important part of the lives of the people buried at P37. At 4-L-2 animal remains were recovered (Welsby, 2010:I), but reports on the species composition and quantity of the assemblage is still ongoing.

As noted above, the lack of settlement sites in the Fourth Cataract region for the Kerma period may also indicate that nomadic pastoralism was an important activity for some groups in the region during this time (Paner, 2014:62), particularly as grave goods related to the Pan-Grave culture indicate possible connections to eastern desert nomadic cultures (Welsby, 2008:37; Emberling et al., 2014:333-334). Close contact with cattle and other animals may have increased exposure to allergens and infectious zoonotic diseases, such as bovine tuberculosis and brucellosis. These diseases can be spread through inhalation of infected aerosols or dust particles shed by the animal, transmission through cuts on the skin, or from the handling and consumption of animal products, such as infected milk or meat (Young, 1995:283; Cosivi et al., 1998:63; Ayele et al., 2004:927; Corbel, 2006:4-5). The sharing of living environments and dwellings with animals in rural developing areas today has been noted as an important factor in the spread of bovine tuberculosis (Shitaye et al., 2007:318). In recent pastoralist societies in Africa diets consist largely of milk, while raw meat and blood may also be consumed, and cattle urine can be used for a number of functions, all of which can cause the transmission of tuberculosis and other infectious diseases (Daborn et al., 1996:30S-31S).

At P37 one Kerma Ancien individual (Sk 43-50, GrK3) presented destruction of a lower lumbar vertebral body and prolific new bone formation on this vertebra and on the sacrum. This individual also presented evidence for maxillary sinusitis and rib IPR, although the three types of pathological change may be unrelated. While a number of diseases may be responsible for the vertebral lesions, one potential cause is that of brucellosis, which can cause lytic lesions on the vertebral plates, particularly in the lumbar spine, as well as new bone formation (Alp & Doganay, 2008:574; Waldron, 2009:96; Mutolo et al., 2011:2). Although today bovine tuberculosis is usually transmitted to humans by cattle (Ayele et al., 2004:925), brucellosis can be transmitted by a number of animals including cattle, goats, sheep, and dogs (Young, 1995:283), all of which were recovered from P37. While pulmonary complications and pleural effusion are rare in brucellosis (Pappas et al., 2003:e98), the presence of the disease in archaeological populations may indicate that hygiene was poor, and, thus, immune systems were compromised and exposure to other zoonotic diseases, including bovine tuberculosis, could have also been elevated. This provides potential evidence that close contact with animals and the transmission of zoonotic infections, such as those causing lower respiratory tract disease, may have been a factor in the prevalence of rib IPR in people buried at P37.

Pastoralism also requires the long-distance travel of livestock to find continuing sources of pasture for large herds and cattle may have been transported to centres of trade or religious significance. For example, isotopic analysis of bucrania from graves at Kerma revealed that cattle were brought to the city from various regions (Iacumin et al., 2001:45), perhaps even from as far as the Mediterranean (Bonnet, 2014a:88; Chaix, 2017:421), and as many as 5000 bucrania could be included in the most prestigious graves (Emberling, 2014:134; Chaix, 2017:420). Regions like the Northern Dongola Reach and the Fourth Cataract may have provided the capital with cattle or other livestock during important funerary or religious events. In arid environments the driving of cattle over the earth can produce considerable amounts of dust in the air (Baddock et al., 2011) and may have exposed herders on long journeys to high levels of PM for sustained periods of time.

The transport of cattle, other livestock, and agricultural produce to Kerma or other central places of trade may have been part of the economy of the people in the Northern Dongola Reach and the Fourth Cataract. Located close to the major city in the region, Kerma, people buried at P37 could have been more exposed to the transmission of infectious diseases, particularly if people in the Northern Dongola Reach were travelling to densely populated areas to trade in produce and other items. Individuals within the Fourth Cataract were also likely to have maintained trade contacts with the wider region. Fine imports from Kerma, such as scarabs and ceramics, have been found at el-Widay in the Fourth Cataract (Emberling & Williams, 2010:27). Such trade could also have facilitated the spread of infectious diseases to this region.

The Kerma period also provides the first evidence for object production taking place on an industrial scale. Several pottery workshops and metalworking areas have been identified in Kerma City, containing complex kilns and furnaces (Bonnet, 2014a:89-90). At Gism el-Arba pottery kilns and possible copper-smelting furnaces have been identified (Gratien, 1999:11), indicating that these production activities were also taking place on a rural scale. It is likely that production of everyday objects, such as roughware ceramics, were occurring locally and the use of fire for sustained periods to either smelt metal or to fire pottery may have exposed craft specialists to smoke. However, in rural contexts, these activities may have only been undertaken on a part-time basis around agricultural production (e.g. Fuller, 2014:174).

In the Fourth Cataract it has been suggested that the site of Hosh el-Guruf may represent a gold mining centre, where small particles of gold were extracted by grinding local quartz or alluvial gravel (Emberling & Williams, 2010; Meyer, 2010; Emberling, 2014:144; Paner, 2014:65). This process could have produced considerable amounts of inorganic dust, which when inhaled for sustained periods of time can lead to pneumoconiosis and can greatly increase the risk of contracting lower respiratory tract diseases, such as tuberculosis (Calvert et al., 2003:126; Tjo Nij et al., 2003:415; Ross & Murray, 2004:307; Sirajuddin & Kanne, 2009:311). Ethnographic research reveals the practice of gold extraction by washing sand for gold particulates has a long history in the Fourth Cataract region and was still practiced along the river in recent times (Salih, 1999:49; Weschenfelder, 2012a:81). While there is no evidence to link the people from the 4-L sites to particular activities, their cemeteries were located close to the river and, thus, to the potential source of gold, and these groups may also have taken part in gold mining. This may also be true of populations from different time periods in the Fourth Cataract region, although no evidence exists for gold mining during the other periods represented in the current study.

8.3.3 The Meroitic and Post-Meroitic period (300 BC – AD 550)

8.3.3.i Fourth Cataract sites

The combined Fourth Cataract Meroitic (300 BC – AD 350) and Post-Meroitic (AD 350 – 550) group displayed a maxillary sinusitis prevalence rate of 53.8% (21/39). The Meroitic group from 3-Q-33 had a prevalence rate of 53.8% (7/13) and the Post-Meroitic group a rate of 80.0% (4/5), giving a total prevalence of 61.1% (11/18) in people buried at this site. There was no significant difference between the two time period groups. Skeletons from the Post-Meroitic sites of 4-M-53 and 3-O-1 displayed prevalence rates of 28.6% (2/7) and 57.1% (8/14), respectively. The variability of prevalence rates in the different Post-Meroitic groups could potentially be due to the small size of the sample groups from these sites. The prevalence of maxillary sinusitis for the combined Fourth Cataract Post-/Meroitic group was not significantly different to any other time period group in this study. Nor was the site of 3-O-1 significantly different to any other site. 3-Q-33, however, did display a significantly higher prevalence of maxillary sinusitis than R12. 4-M-53 was not statistically tested against any other site due to the small number of skeletons recovered. Evidence for odontogenic sinusitis was low in the Fourth Cataract for the Post-/Meroitic group (3.0%, 1/33). Only one sinus from 3-Q-33 had an oroantral fistula. Additionally, 81.8% (27/33) of sinuses with sinusitis had undamaged alvealor bone and no oroantral fistulae, representing possible rhinogenic sinusitis.

The crude prevalence rate of rib IPR in the Fourth Cataract Post-/Meroitic group, at 47.7% (21/44), was comparable to the rate of maxillary sinusitis in the region during this time period. This was the highest prevalence rate for rib IPR according to time period recorded in this study. People buried at 3-Q-33 displayed a prevalence rate of 50.0% (7/14) for the Meroitic period and 33.3% (2/6) for the Post-Meroitic, giving a total rate of 45.0% (9/20). Individuals from 3-O-1 displayed a prevalence rate of 52.9% (9/17) and 4-M-52 a rate of 42.9% (3/7). The prevalence rates for rib IPR in people buried at 3-O-1 and 3-Q-33 were the highest and second highest rates recorded in this study, respectively. As with maxillary sinusitis, the variability in the prevalence rates of rib IPR in groups from different sites in the Fourth Cataract during the Post-Meroitic may be due to the small sample sizes from 3-Q-33 and 4-M-53. The rib IPR prevalence rate for the Fourth Cataract Post-/Meroitic group was significantly higher than all other time period groups except for the Fourth Cataract and comparative Medieval periods. People from 3-Q-33 and 3-O-1 both had significantly higher prevalence rates than R12, while individuals from 3-O-1 also had a significantly higher prevalence rate than 3-J-18 and Gabati.

8.3.3.ii Meroitic and Post-Meroitic Gabati

The individual comparative Meroitic (200 BC – AD 200) and Post-Meroitic (AD 400 – 700) groups, made up of individuals from Gabati, showed only a minor variation in prevalence, with rates of 56.3% (40/71) and 50.0% (9/18), respectively. These two groups were not significantly different from one another and, when combined into the comparative Post-/Meroitic time period group, displayed a maxillary sinusitis prevalence rate of 55.1% (49/89). This was significantly higher than the Neolithic period and significantly lower than the comparative Medieval period. Evidence for odontogenic sinusitis in the comparative Post-/Meroitic group was low with only 2.9% (2/69) of sinuses displaying an oroantral fistula. Potential rhinogenic sinusitis was recorded in 72.5% (50/69) of all sinuses with sinusitis. This was a similar result to the potential causes of sinusitis in the Fourth Cataract Post-/Meroitic group.

The prevalence rate of rib IPR for the combined comparative Meroitic and Post-Meroitic group from Gabati was 26.2% (17/65). Individually, the Meroitic group had a prevalence rate of 28.9% (13/45) and the Post-Meroitic a rate of 20.0% (4/20), which, when statistically tested, were not significantly different from one another. The prevalence rate of rib IPR for the combined comparative Post-/Meroitic group was significantly lower than the Fourth Cataract Post-/Meroitic group, but did not demonstrate a significant difference with any other time period.

8.3.3.iii Meroitic and Post-Meroitic sites in context

The similar results for maxillary sinusitis from both the Fourth Cataract and comparative Post-/Meroitic groups suggests that in both regions individuals may have been similarly susceptible to upper respiratory tract disease. The high level of rhinogenic sinusitis indicates that this could have been through exposure to particulates or pathogens in the air breathed in through the nose. The prevalence of maxillary sinusitis at both sites was also similar to the preceding Kerma period in the Fourth Cataract. Similar practices to the Kerma period may be responsible for the comparable prevalence rates of maxillary sinusitis. Agricultural activties may have remained relatively unchanged. The cultivation of plants, such as barley and sorghum, have been identified from Meroitic contexts in the Fourth Cataract region and at Gabati (Clapham & Edwards, 1998:241-242; Edwards & Fuller, 2005:27-28) and animal husbandry was also an important part of Meroitic subsistence (Edwards, 1996:22, 1998a:185; Chaix, 2010:524). Plant cultivation was also likely to have been undertaken for longer periods of time in the north after the introduction of the saqia at the end of the Meroitic period (Fuller, 2014:172). As discussed in Section 8.3.2.iii for the Kerma period, particulate matter produced by animal husbandry and agrarian practices and exposure to zoonotic diseases may also have been a factor in the prevalence of maxillary sinusitis observed in the Post-/Meroitic groups.

There was also a continuation in the construction of mudbrick housing from the Kerma to Meroitic periods and hearths and ovens appear to be more consistently located indoors (e.g. W. Y. Adams, 1984a:272; Payne, 2005:11-12; Wolf et al., 2014:728). While vaulted roofs also became popular during this period, they are observed for the most part in the north where access to plant materials to construct roofs may have been limited due to the desert conditions (D. Welsby, pers. comm., 2018). In the Fourth Cataract the only large Meroitic settlement site is found on the island of Umm Muri and consists of a mudbrick building with a cluster of rooms, some of which contained pots used as ovens and areas dedicated to burning (Payne, 2005:11-12). During the Post-Meroitic period in this region clusters of huts, possibly constructed from organic materials and containing fireplaces, have been found at 3-Q-14 and 3-Q-102 (Wolf & Nowotnick, 2005a:25), close to 3-Q-33. A stone enclosure at 3-Q-14 may also indicate that livestock were penned close to the habitations (Wolf & Nowotnick, 2005a:26). A similar hamlet at 3-R-103 contained both rectangular and circular housing, likely constructed from organic materials, with indoor hearths (Wolf & Nowotnick, 2006b:26-27). Rectangular and circular stone dwellings have also been noted at a number of sites during this period in the Fourth Cataract region, some of which contained evidence for indoor hearths (Paner, 2003b:179-180; Paner & Borcowski, 2005b:214; Wolf & Nowotnick, 2006b:27, 29; Welsby, 2007:17-18). Thus, Meroitic and Post-Meroitic groups in the Fourth Cataract may have been using a range of housing structures depending on factors such as material availability or location. The position of hearths indoors in the majority of cases, however, was likely to have led to exposure to smoke.

In the south, approximately 50km south of Gabati, the town of Hamadab provides the most complete evidence for habitation. Dense multi-roomed buildings, constructed of mudbrick, contained kitchens with indoor ovens and fireplaces and some buildings may have accommodated several separate living units at once (Wolf et al., 2014:723-728). However, while Hamadab is of a definite urban nature, the lack of typical ‘elite’ Meroitic burials at Gabati may represent a cemetery serving a more rural population (Edwards, 1998:201), who could have had different housing. The southern site of Abu Geili also consisted of a large cluster of more than eighty small rooms, likely making up several living units, containing ovens or fireplaces (Crawford & Addison, 1951:9; W. Y. Adams, 1984a:272). Albeit, this site is located some distance from Gabati, further south on the Blue Nile, and may not be a reliable indication of the type of housing that might have been used by the individuals buried at Gabati. The only evidence for Post-Meroitic habitation in the south is that of squatters' remains, including indoor hearths, at Meroe and Hamadab (Shinnie & Anderson, 2004:32-34, 64; Wolf et al., 2014:736). Although settlement information from Gabati is absent, the use of mudbrick and indoor hearths in other areas may indicate that people at this site were exposed to smoke inhalation within the home. For example, at Al Khiday, in the south, calculus recovered from individuals from Meroitic burials contained 'char' particles that indicate people buried at this site were inhaling smoke (Buckley et al., 2014:2).

While the prevalence rates of maxillary sinusitis within the Fourth Cataract and comparative Post-/Meroitic groups show no significant differences to the preceding Kerma period, the Fourth Cataract Post-/Meroitic sees a significant rise in the prevalence of rib IPR compared to the previous Kerma period groups and is also significantly higher than the comparative Post-/Meroitic group. This could suggest that changes in the Fourth Cataract between the Kerma and Meroitic periods significantly affected susceptibility to lower respiratory tract diseases, but that differences in environmental and socio-cultural factors at the more southern site of Gabati did not lead to a similar increased rate of rib IPR.

Fine PM below 10μm in size can penetrate beyond the upper respiratory tract into the lungs, where it can cause lung tissue damage and increased susceptibility to infection (see Section 8.8). A higher prevalence of rib IPR may indicate exposure to greater concentrations of fine particulates. While Saharan desert dust tends to be coarse, smaller lighter particles can be suspended in the air and travel further during dust storms (Mahowald et al., 2014:53-54; van der Does et al., 2016:13704). A correlation between dust storms and a rise in hospital admissions for respiratory disease has been noted in a number of studies from different countries (e.g. Hefflin et al., 1994; Meng & Lu, 2007; Bell et al., 2008; Lai & Cheng, 2008; de Longueville et al., 2013; Ebrahimi et al., 2014; Trianti et al., 2017). Dust storms are common in Sudan and today, near Khartoum, an average of twenty dust storms occur per year (Nicholson, 2011:305). Aridification progressed throughout the Kushite period but varied according to geographic region. While desert conditions and the influx of aeolian sand may have been serious issues by the early Kushite period in more northerly regions of Upper Nubia, as seen at Amara West and Kawa (Welsby, 2000a:6, 2011; Spencer et al., 2012:41-42), the southern regions of the Butana and Keraba had higher levels of precipitation and vegetal ground cover (e.g. Gabriel, 1997:28), although even in this region the availability of water may still have been declining (Berking et al., 2012:166; Welsby, 2003a:73-76). By the beginning of the Kushite period, in the Northern Dongola Reach, the Alfreda and Hawawiya Nile paleochannels had dried up, leaving only the Dongola Nile still active (Woodward et al., 2015:Fig. 12). The inhospitable environment is reflected in the lack of evidence for Kushite settlements in the area, with those few sites present confined to the banks of the main Dongola Nile (Welsby, 2001:591). The more northerly position of the Fourth Cataract may have exposed inhabitants to fine particulates in dust storms from the encroaching deserts, resulting in a significantly higher prevalence rate of rib IPR compared to the comparative Post-/Meroitic group from Gabati.

A number of other sources create particulate emissions below 10 µm, including metallurgic dusts and biomass smoke (Lapple 1961:59). A greater exposure to fine particulate matter from smoke within the home or whilst undertaking activities related to occupation, such as pottery production or metallurgy, may also have increased susceptibility to lower respiratory tract diseases. Pottery production may have been undertaken at a number of sites during the Meroitic and Post-Meroitic periods and Meroitic production centres have been identified in the south at Meroe, Hamadab, Muweis, and Musawwarat es Sufra (Török, 1997b:174; Edwards, 1999; Baud, 2008:53; Wolf et al., 2014:728-730). While evidence of iron working during the Meroitic period is limited to Meroe, during the Post-Meroitic period Hamadab also has evidence for the mass production of iron (Ting & Humphris, 2017) and the deposition of iron objects in late Meroitic and Post-Meroitic graves became more regular (Edwards, 2004:189), which may indicate that iron production may have been more widespread. However, if there is an increased exposure to particulates in a population, particularly of smoke which tends to have a range of particulate sizes (Hosseini et al., 2010), a correlated increase in susceptibility to sinusitis might also be expected.

Lower respiratory tract disease can be caused by a range of other factors, not all of which relate to exposure to particulate matter. Increased rib IPR could be the result of higher incidences of infectious pulmonary disease within the Fourth Cataract. Studies of identified human skeletal collections have found a significant correlation between the presence of rib IPR and individuals who were recorded to have died from pulmonary tuberculosis (Roberts et al., 1994:172; Santos & Roberts, 2001:41, 2006:42; Matos & Santos, 2006:193). Other infectious pulmonary diseases can cause pleural effusion and pleurisy, leading to inflammation underlying the ribs, including pneumonia, actinomycosis, and viral infection (Kass et al., 2007:Table 1; Light, 2013:267). While these diseases may be exacerbated by the inhalation of particulate matter (e.g. Perez-Padilla et al., 2010:1083), risk factors such as poor sanitation, crowding, and malnutrition can all increase the prevalence (Garg and Somvanshi, 2011:441; van der Poll & Opal, 2009:1544). A significantly higher prevalence of rib IPR in the Fourth Cataract may indicate poorer levels of sanitation or nutrition and a higher disease load. There could also have been a greater reliance on animals as part of the subsistence economy. Infectious diseases may have been transmitted through close contact with animals or through the consumption of infected animal products, while the presence of animals in close vicinity to living quarters will also have reduced sanitary conditions (Daborn et al., 1996:30S-31S). In the Fourth Cataract during the Post-Meroitic period stone enclosures at 3-Q-14 may have been used to pen animals in the vicinity of huts (Wolf & Nowotnick, 2005a:26). Similar enclosures made of wood or other organic materials could have been present at other sites but may no longer be visible in the archaeological record.

Domestic faunal assemblages show a dominance of cattle bones at Kushite settlement and temple sites (Carter & Foley, 1980:Fig. B2; Chaix, 2010:521; Nowotnick et al., 2014:10). The role of cattle and other domestic animals in the spread of tuberculosis and brucellosis has been discussed above in Section 8.3.2.iii. Both diseases can cause destructive lesions on the vertebrae in infected humans (e.g. Alp & Doganay, 2008:574; Garg & Somvanshi, 2011:442) and all Meroitic and Post-Meroitic sites in the current study contained at least one individual with destructive lesions of the vertebral bodies that could potentially be related to these zoonotic diseases (see Section 7.5). Additionally, skeletal and mummified human remains from Egypt have provided macroscopic and molecular evidence for tuberculosis from as early as the predynastic period (*c.* 3500 BC onwards) (e.g. Nerlich et al., 1997; Zink et al., 2003, 2004; Dabernat & Crubézy, 2010). In Sudan, molecular evidence for tuberculosis has been found in 34% of samples analysed from naturally mummified early Medieval individuals from Kulubnarti, dating to around AD 550 to 750 (Spigelman et al., 2005:94). This indicates that TB was likely to have been present in Sudan during the Meroitic and Post-Meroitic periods and may be responsible for the prevalence rates of rib IPR recorded in the groups dating to this period.

Gabati was located fairly close to the major centre of Meroe and, during the Meroitic period, may have benefitted economically from a proximity to the city. A higher socio-economic status could have allowed for better housing with more ventilation, cleaner burning fuel, and better sanitation. However, close contact with the city and other more populated areas, such as Hamadab, may also have increased the risk of exposure to infectious diseases. Additionally, Meroitic grave goods within burials at Gabati do not indicate that elite burials such as those seen at Meroe were present, although this may simply reflect cultural differences in burial practices (Edwards, 1998:201). Factors, such as variation in socio-economic status between Gabati and the Fourth Cataract region, may have differentially affected susceptibility to lower respiratory tract, but the lack of settlement data for Meroitic and Post-Meroitic sites in this study makes it extremely difficult to interpret differences in the data.

In addition to this, while the grouping of individuals from Meroitic and Post-Meroitic sites is useful for a wider analysis of respiratory disease and allows for further statistical testing, it should be considered that the Post-Meroitic period was a transitional one. During this time there were certain governmental, cultural, socio-economic, and religious changes from the Meroitic period, and also some continuation of Post-Meroitic practices into the Early Medieval period (Welsby, 1996:202-203; Edwards, 2004:189-191). Therefore, the arbitrary grouping of Meroitic and Post-Meroitic groups, in this case to increase sample size, may falsely create the impression that the Post-Meroitic was distinct in culture and practices from the Medieval period and was, in turn, more alike with the Meroitic period. This distinction is not necessarily so clear-cut, and the grouping of Meroitic and Post-Meroitic individuals in the current study may mask differences in the prevalence of respiratory disease brought about by changes during the transitional Post-Meroitic period. Thus, prevalence data has been presented separately for both the Meroitic and Post-Meroitic periods in Appendices G and H, respectively, should future studies be able to combine larger sample groups for the individual time periods.

8.3.4 The Medieval period (AD 550 – 1500)

8.3.4.i Fourth Cataract sites

The Fourth Cataract Medieval group displayed a maxillary sinusitis prevalence rate of 53.8% (77/143). When compared to other time periods, this rate was significantly higher than for the Neolithic period, but was significantly lower than the comparative Kerma and Medieval groups. Individuals from the sites making up the Fourth Cataract Medieval group, 3-J-23 (AD 550 – 1500) and 3-J-18 (AD 1000 – 1500), had similar prevalence rates of 50.0% (29/58) and 56.5% (48/85), respectively. While both sites had significantly lower prevalence rates of maxillary sinusitis than Soba East, 3-J-23 also had a significantly lower rate than P37 and 3-J-18 had a significantly higher prevalence rate than R12. The prevalence for odontogenic sinusitis in the Fourth Cataract Medieval group was 10.7% (12/112), which was higher than all other groups, except for the Neolithic group. However, preservation at the Medieval sites in the Fourth Cataract was particularly good, and 84.8% (95/112) of sinuses with sinusitis may have had a potential rhinogenic origin.

The crude prevalence rate of rib IPR for the Fourth Cataract Medieval group was 31.8% (57/179). This was only significantly higher than the prevalence rate for the Neolithic period. However, people from the two sites making up this group displayed prevalence rates of 43.9% (29/66) at 3-J-23 and 24.8% (28/113) at 3-J-18. These rates were significantly different from one another, making the combination of the two sites into the Fourth Cataract Medieval group unsuitable for further discussion of lower respiratory tract disease in this region. 3-J-18 also had a rib IPR prevalence rate significantly lower than 3-O-1 and 3-J-23 displayed a significantly higher prevalence rate compared to R12 and P37.

8.3.4.ii Comparative sites

The combined prevalence rate for maxillary sinusitis for individuals from the comparative Medieval period was 73.9% (34/46). This was the second highest rate of maxillary sinusitis from all time period groups, after the comparative Kerma period, and was significantly higher than the Fourth Cataract Medieval group and the comparative Neolithic and Post-/Meroitic groups. However, individuals from the two sites making up the comparative Medieval group, Gabati (AD 800 – 1200) and Soba East (AD 550 – 1500), had prevalence rates that were significantly different from one another. People buried at Soba East presented the highest prevalence rate of maxillary sinusitis recorded in this study at 82.4% (28/34), which was significantly higher than in groups from Gabati, R12, 3-J-23, and 3-J-18. The Medieval individuals at Gabati had a prevalence rate of 50.0% (6/12), which was significantly higher than in people from R12, but significantly lower than in those from P37 and Soba East. Although the difference between the two comparative Medieval sites may be due to the small sample size from Gabati, the potential different subsistence economies of the two sites may play a major role. Therefore, as with rib IPR for the Medieval Fourth Cataract sites, the combination of Medieval individuals from Gabati and Soba East into one group was not considered useful when discussing the potential causes of maxillary sinusitis during this period. No evidence for odontogenic sinusitis was present in skeletons from either site (0/55 of sinuses) and potential rhinogenic sinusitis was fairly high, making up a total of 70.9% (39/55) of all sinuses with sinusitis for both sites.

The prevalence rate of rib IPR for the combined comparative Medieval group was 40.0% (16/40), which was the second highest rate after the Fourth Cataract Post-/Meroitic group. This prevalence rate was only significantly higher than the Neolithic group. Medieval individuals from Gabati displayed a rib IPR prevalence rate of 33.3% (4/12). People buried at Soba East had a higher prevalence rate of 42.9% (12/28), which was significantly higher than R12.

8.3.4.iii Medieval sites in context

Maxillary sinusitis prevalence rates during the Medieval period in the Fourth Cataract and in Medieval people from Gabati were similar and are comparable to rates of sinusitis during the previous Fourth Cataract Kerma and Post-/Meroitic periods, all of which fall in the range of between 50% and 60%. This may indicate that these groups, all assumed to be rural agricultural populations, were similarly exposed to factors that can increase susceptibility to upper respiratory tract disease.

Despite the rise in odontogenic sinusitis in the Fourth Cataract Medieval sites, potential rhinogenic sinusitis remained high, suggesting that the majority of instances of sinusitis may have continued to be caused by particulates or pathogens breathed in through the nose.

Many of the factors present in the Meroitic and Post-Meroitic periods that may have caused a susceptibility to maxillary sinusitis remained similar in the Medieval period. The environment in Upper Nubia during this time was that of desert. The constant threat of in-blown sand, which can be seen in more northerly sites from the end of the New Kingdom and the beginning of the Early Kushite period onwards (Welsby, 2000a:6; Spencer et al., 2012:41-42), continued into the Medieval period at numerous sites as far south as Banginarti, near the Fourth Cataract region (e.g. W. Y. Adams, 1961:43; Hajnóczi, 1974:341-342; W. Y. Adams, 1984b:492; Welsby, 2002:117-118, 126; Drzewiecki, 2014:901). In Central Sudan, wetter conditions with semi-desert and grassland would have been present (J. Adams, 2002; Welsby, 2002:8, 2006b:21), but in areas of dense occupation, such as at Soba East, land may have become overgrazed, leading to increased desertification (Cartwright, 1999:256; Welsby, 2002:9).

A reliance on grains, such as sorghum, as a staple of the diet continued and the saqia appeared to be particularly important during this period (Welsby, 2002:185). The use of the irrigation tool led to a greater proportion of land use and extended periods of cultivation that meant people were likely to have spent more time on agricultural-related activities (Fuller, 2014:174). Animal husbandry was also an important part of the Medieval diet and a variety of animals may have been consumed in Upper Nubia, such as cattle, caprines, pigs, and camels, which were all recorded from faunal assemblages at Banginarti and Old Dongola (Osypińska, 2014:Table 1). Faunal remains of mostly cattle and caprine bones were also present at Soba East (Chaix, 1998:234). Exposure to particulates from the environment, agricultural-related activities, and animal husbandry, as well as increased exposure to infectious zoonotic diseases are all likely to have increased susceptibility to respiratory tract diseases (see Section 8.3.2.iii).

The use of a variety of housing styles also continued into the Medieval period, although the greatest evidence exists for mudbrick housing. These rectilinear buildings, containing hearths or ovens, have been identified in the Medieval kingdoms of Makuria and Alwa at Old Dongola, Hambukol, and Soba East (Anderson, 1994:225, 2001:101; Godlewski, 1997:183-184, 1998:173-175; Welsby, 1998:273-275) and at numerous sites in the north in Nobadia (e.g. Welsby, 2002:166). In the Fourth Cataract region evidence for dense Medieval settlement comes from 3-Q-62, which consisted of more than 230 houses. Constructed of stone and possibly mudbrick, excavation of a typical dwelling at this site revealed indoor hearths and a potential second storey, thought to be roofed with a light wooden material (Wolf & Nowotnick, 2005b:191-193). A close cluster of rooms in one part of the site in proximity to the church has been suggested to possibly represent a monastic complex (Wolf & Nowotnick, 2005b:192), but could also signify increased utilisation of settlement space for habitation due to a larger population. Medieval rectangular structures and the stone foundations of circular huts have also been found on Tibet Island, in the Fourth Cataract region (Näser, 2005:81). While flat roofs of wooden poles and organic materials were likely to have been used for many buildings, at Old Dongola and Hambukol there is evidence for the barrel-vaulted ceiling (Godlewski, 1990:16, 1991; Anderson, 1994:225, 2001:101). This type of roof, constructed using brick, became popular in the Medieval period, chiefly in the north in Nobadia. As in previous periods, mudbrick walls, particularly in conjunction with vaulted roofs and indoor hearths and ovens, were likely to have significantly reduced ventilation within the home, increasing exposure to particulate matter from smoke and other sources.

Toilets also became popular in the Medieval period and have been found within houses in Nobadia and at Old Dongola (W. Y. Adams, 1984b:491; Godlewski, 1997:183-184, 1998:173-175). Toilets may have been introduced as a way to control poor sanitation and pollution within settlements that were increasing in size and population density. However, having the toilet indoors can encourage household vermin and pests and facilitate the spread of diseases, particularly if the toilet is located close to the kitchen or food stores (e.g. Scobie, 1986:410; Taylor, 2005:59, 62). The penning of animals within settlements, and even within houses, has also been noted during the Medieval period, for example at Qasr Ibrim, Debeira West, Old Dongola, and Hambukol (Shinnie & Shinnie, 1978:440; Grzymski, 1990:155; Godlewski, 1991:89; W. Y. Adams, 1996:101). This will have also introduced a number of pests and vermin into the settlement, exposing individuals to infectious diseases, and will have produced animal dander and allergens into the living environment that could have led to sinusitis (e.g. Shitaye et al., 2007:318; Milgrom, 2003:318).

Pathological changes in the human skeleton related to infectious diseases certainly appear to become more visible during the Medieval period. Within the current study one instance at 3-J-23 (Gr75) of a collapsed spine resulting from destruction of the vertebrae, which is indicative of tuberculosis, suggests that the disease was present in this population. Other instances of destructive lesions on the vertebrae in people buried at 3-J-23, 3-J-18, and Medieval Gabati may also all be the result of tuberculosis or brucellosis. Additionally, the first evidence for leprosy in the Middle Nile Valley becomes apparent during the Medieval period at 3-J-18, where two individuals display pathognomonic changes consistent with the disease (see Section 7.5). One individual buried at the Medieval site of 3-J-11, also located on Mis Island in the Fourth Cataract, presented pathological changes that may be evidence for leprosy (Soler, 2012:215). In particular, leprosy has been linked to the development of maxillary sinusitis (e.g. Hauhnar et al., 1992; Sharma et al., 1998; Kiris et al., 2007) and both tuberculosis and leprosy may have contributed to the prevalence rates of respiratory disease recorded for the Medieval period. However, the increased observation of pathological changes related to infectious diseases during the Medieval period may be due to the high level of preservation at Medieval cemetery sites, such as 3-J-18 and 3-J-23, and the same diseases may have also been present during earlier periods, but skeletal evidence may now be unobservable as a result of poor preservation.

While there is little change in the prevalence of maxillary sinusitis between the rural agricultural Post-/Meroitic and Medieval sites, Soba East displays a remarkably high prevalence rate of maxillary sinusitis and also of rib IPR, which could be the result of these people living in an urban environment. The city was of considerable size (Welsby, 1998:20) and increased population density, resulting in crowded housing, poor ventilation, lower levels of sanitation, and a higher disease load, are likely to have affected susceptibility to respiratory diseases. Crowding in houses, with a greater number of inhabitants per square meter, and more social mixing have been linked to increased prevalence rates of lower respiratory tract diseases, such as tuberculosis or pneumonia (e.g. Alves Cardoso et al., 2004; Baker et al., 2013; Ferraro et al., 2014; Pelissari & Diaz-Quijano, 2017). In the early phases at Soba East, buildings may have been constructed from timber, with a later shift to include the use of mudbrick (Welsby, 1998:20). Possible round huts have been identified, one of which contained evidence for activities related to burning on its floor (Welsby, 1998:273). In another area a possible 'official' mudbrick building was later partitioned and expanded into smaller domestic rooms containing hearths and storage bins (Welsby, 1998:275). This might indicate that domestic space was at a premium in the city and that individuals may have been exposed to smoke within the home.

Other major cities in the Middle Nile Valley during the Medieval period have demonstrated evidence for large-scale industrial pottery production, such as at Faras and Old Dongola (W. Y. Adams, 1986:22; Pluskota, 2001:365). It is likely, considering descriptions of Soba East as being prosperous and powerful in historical texts (Welsby & Daniels, 1991:7), that this city also had competing production facilities. While only a single kiln has been found at the site (Welsby & Daniels, 1991:105, 245), excavations have been largely limited to the investigation of churches and a large palatial building. Additionally, some areas had large amounts of evidence for the metalworking of copper-alloys and precious metals, including crucibles and moulds (Welsby, 1998:273). Individuals may have been exposed to smoke from kilns, furnaces, or bonfires while undertaking activities related to occupation. Indirect exposure of the general populace to industrial air pollution may also have increased susceptibility to respiratory diseases at Soba East. In other bioarchaeological studies high prevalence rates of maxillary sinusitis in urban contexts, particularly in males, have also been attributed to air pollution from industrial activities (Lewis et al., 1995:503-504; Sundman and Kjellström, 2013:455).

Soba East has also been described in historical texts as having strong trading links with the Arab world and was likely to have served as a trade hub for the wider region (Welsby & Daniels 1991:9). The presence of trade networks and increased movement of people may have played a major role in the introduction of infectious diseases to the city, such as tuberculosis and leprosy (e.g. Tatem et al., 2006; Yue et al., 2017). Those living in worse conditions within the city may have also been more susceptible to contracting these diseases. While no skeletal evidence for infectious diseases were observed in individuals from Soba East during the current study or in the previous osteological analysis (Filer, 1998), the poorer preservation of human skeletal remains from this site, compared to other Medieval cemeteries, may have been a factor.

Rib IPR prevalence rates in individuals from 3-J-23 and the comparative Medieval group were similar to one another and comparable to the rate for the Fourth Cataract Post-/Meroitic group. However, a significantly lower prevalence rate of rib IPR in individuals from 3-J-18 compared to those from 3-J-23 suggests that, despite their geographical proximity, the people at these two sites may have undertaken different socio-economic or cultural activities that had differing impacts on their susceptibility to lower respiratory tract disease. The island lifestyle of the inhabitants of 3-J-18 may have limited the amount of livestock the land could support, while people from 3-J-23 on the main bank could have engaged in a wider range of pastoralist activities, including the easier transportation and grazing of animals. A greater number of livestock in the living vicinity and more time spent in pastoralist activities may have increased exposure to infectious zoonotic diseases, such as tuberculosis (e.g. Daborn et al., 1996:30S-31S), at 3-J-23. Due to greater proximity to water on all sides, 3-J-18 may have also supported a denser vegetation cover that could have protected the land from soil erosion and the generation of aeolian dust (e.g. Field et al., 2010). If the individuals buried at 3-J-23 had lived close to their cemetery, they may have been exposed to greater levels of fine particulate matter from the desert to the south. However, the body of water between the two sites was unlikely to have provided a great deal of protection from aeolian dust for the inhabitants buried at 3-J-18, as fine airborne particulates are known to travel great distances (e.g. Mahowald et al., 2014:53-54).

Although there is little evidence for any major settlement associated with either 3-J-18 or 3-J-23, differences in the type of housing, levels of sanitation, or production activities at these sites may have been a factor in the disparity between prevalence rates of rib IPR. However, without more information on associated settlements, it is difficult to suggest potential differences. Both cemeteries also had excellent preservation, so this is unlikely to have influenced the observed differences. It should also be noted that a lower prevalence rate of rib IPR in people from 3-J-18 may not necessarily indicate that living conditions were more favourable for the individuals at this site compared to 3-J-23. Lower respiratory tract diseases can often be fatal (e.g. Troeger et al., 2017:1153) and a compromised immune system, poor nutritional intake, poor sanitary conditions, and other environmental factors can all affect the frailty (likelihood of mortality) of a population, or certain groups within a population (DeWitte & Stojanowski, 2015:406). If a person buried at 3-J-18 had a high level of frailty, they may have died from a lower respiratory tract disease before inflammatory new bone could begin to form (see Section 8.6).

8.3.5 Summary

Figure 8.3 and Figure 8.4 display the prevalence rates of maxillary sinusitis and rib IPR, respectively, recorded in groups from each site, according to subsistence economy, approximate geographical location, and time period. Individuals from the smaller Kerma Classique and Post-/Meroitic Fourth Cataract sites have been grouped by time period. There is an evident rise in the prevalence of maxillary sinusitis between the Neolithic (site R12) and later time periods. A combination of a more humid climate and a subsistence practice that relied more on hunter-gathering, fishing, and pastoralism, and less on plant cultivation and agricultural activities, may have resulted in a lower exposure to particulate matter. In addition to this, the potential use of more ventilated huts with hearths located outside may have also been a factor. However, evidence for Neolithic housing, besides the settlement found in the Eastern Cemetery at Kerma, is still lacking. Additionally, while the prevalence rate of rib IPR displays the same trend as maxillary sinusitis, with no individuals showing evidence for lower respiratory tract disease during the Neolithic period, followed by a rise in prevalence in later periods, the reliability of the rib IPR prevalence data from R12 is questionable considering the poor preservation of the rib cages and the small sample included in the current study (only 13 individuals).

Roberts (2007:799) found that rural sites tended to be more consistently affected by sinusitis than urban sites, which showed greater variations in prevalence. During all time periods in the Fourth Cataract and at Gabati there appears to be a remarkable consistency in the prevalence of maxillary sinusitis, with a range of only 6.5%. This may suggest similar levels of exposure to particulate matter or infectious diseases from the environment, socio-cultural practices, and subsistence activities. Although associated settlement data is absent for these sites, they are all assumed to contain individuals who were likely to have taken part in a rural agricultural mode of subsistence. The similarity in subsistence economy, which may have determined the level of exposure people had to infectious diseases and particulate matter from agrarian activities, may be responsible for the relatively equal prevalence rates between sites. While these prevalence rates are lower than that of P37 and Soba East, this does not detract from the fact that maxillary sinusitis was common in these populations. A minimum of 50% of all individuals from these sites displayed evidence for bony changes related to chronic maxillary sinusitis. This does not take into account individuals with incomplete sinuses that may have presented changes that were not observable or individuals who suffered from acute maxillary sinusitis but did not manifest bony changes. The potential for a greater percentage of the population to have had some form of maxillary sinusitis, therefore, may have been even higher.

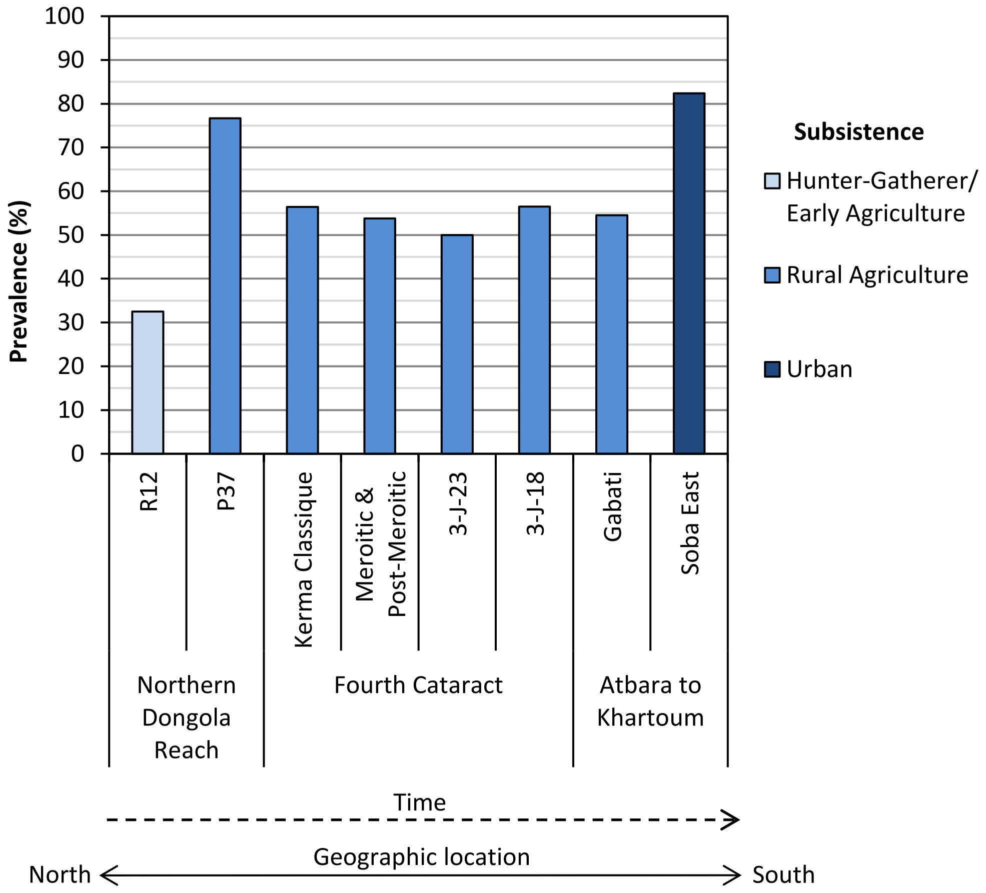


Figure 8.3 – A comparison of the prevalence rates of maxillary sinusitis recorded in the current study, according to subsistence strategy, approximate geographic location, and time period.

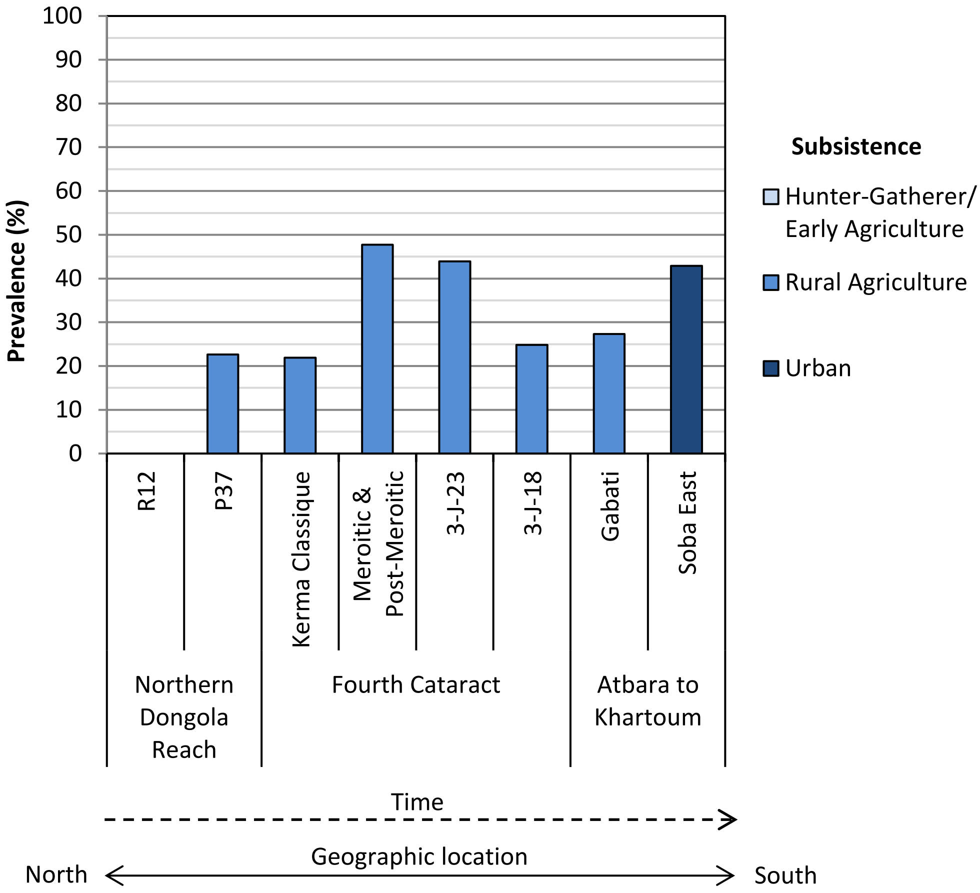


Figure 8.4 – A comparison of the crude prevalence rates of rib IPR recorded in the current study, according to subsistence strategy, approximate geographic location, and time period.

This suggests that certain risk factors must have been impacting susceptibility to upper respiratory tract disease in individuals buried at these sites. Between the Kerma and Medieval periods, the environment was becoming increasingly arid, particularly in the north. This was likely to have exposed individuals to aeolian dust and sand. People during these periods also relied to a greater degree on agriculture and animal husbandry. Agricultural activities, such as ploughing, harvesting, burning, winnowing, threshing, grinding, and cattle driving, can produce dust in large quantities, exposing those undertaking these activities and increasing susceptibility to maxillary sinusitis. Other activities that produce particulate matter may also have been taking place within settlements, although there is, as yet, no associated evidence for this. More substantial housing made of mudbrick, with decreased levels of ventilation, and the use of indoor hearths and ovens, were employed during these time periods, and may have increased the concentration of smoke within the home. However, a mix of housing types, including those made of organic materials and stone, may have also been used. Additionally, sites from these time periods demonstrate evidence for infectious diseases, such as tuberculosis and leprosy, which may have affected the sinuses.

The prevalence of rib IPR at the same rural agricultural sites show greater variation, demonstrating that the factors causing maxillary sinusitis and lower respiratory tract disease may not have always been related (see Section 8.8). While a general exposure to particulates from the arid environment may have affected people buried at all sites and equally predisposed them to the development of maxillary sinusitis, activities causing lower respiratory tract disease may have differed from site to site. The Post-/Meroitic group and site 3-J-23 display particularly high prevalence rates of rib IPR and the similarity between the prevalence rates within the two Kerma groups, and the subsequent rise in the Fourth Cataract Post-/Meroitic period may indicate a change in conditions through time, causing an increase in susceptibility to lower respiratory tract disease. Increased sedentism and lower levels of hygiene and sanitation within settlements may have contributed to this. Exposure of people buried at 3-J-23 and in the Post-/Meroitic group to fine particulates that can penetrate deep into the lungs or a high pathogen load causing infectious lower respiratory tract disease may also be responsible for these elevated prevalence rates. Variations in these factors could also explain the significant difference between rib IPR at 3-J-18 and 3-J-23, despite their proximity, both geographically and temporally.

Of interest is site P37, which, although thought to be a rural agricultural site, displays an elevated prevalence of maxillary sinusitis. The location of P37 in a slightly more northerly position, exposed to the western desert, may have increased exposure to aeolian sand and dust storms. Additionally, inhabitants may have had close contact with the city of Kerma, which could have facilitated the spread of infectious diseases. Activities that individuals buried at P37 may have undertaken, such as pottery production or metallurgy, could also have exposed people to particulate matter. The prevalence of rib IPR, however, was one of the lowest of all sites in this study. This could indicate that despite exposure to factors causing upper respiratory tract disease, diseases affecting the lungs, such as tuberculosis or pneumonia, were less common. It may also indicate, however, that frailty at this site was high and individuals were not surviving lower respiratory tract diseases long enough to manifest bony changes (see Section 8.6).

People buried at Soba East displayed an elevated prevalence rate of both maxillary sinusitis and rib IPR. The urban environment of Soba East may have been particularly conducive to the development of respiratory diseases. The increased population density found in urban contexts can lead to household crowding (more people per household), lower levels of sanitation, poor air quality, and a higher disease load. Increased trade within cities, including the long-distance travel of goods and people, and greater levels of social mixing, could also lead to the ready transmission of infectious diseases. Therefore, individuals at Soba East may have been highly exposed to pathogens within the living environment. Additionally, industrial centres producing smoke, such as pottery production or metallurgy, located within or near to the city may have reduced the general air quality in the surrounding environment.

It is evident that, after the Neolithic period, respiratory diseases were a common occurrence for people buried in Middle Nile Valley cemeteries, although how common varied among different populations. A comparison of the results from the current study and those from other Middle Nile Valley sites and from other regions of the world can help to further contextualise these findings.

8.4 Comparisons with other bioarchaeological studies

The prevalence data from the current study are compared below with those from other sites from the Middle Nile Valley and from other regions of the world. Additionally, the similarities and differences in the prevalence rates of respiratory disease between sex and age groups are presented from sites both within the current research and from other published studies with comparable data. The potential causes of similarities and differences in the current study are then discussed.

8.4.1 Comparisons with other Middle Nile Valley sites

Until now, few studies have reported the prevalence rates of respiratory disease in human skeletal remains from Middle Nile Valley sites. However, three other systematic studies of the prevalence of maxillary sinusitis have been undertaken, from Amara West (New Kingdom and Post-New Kingdom/Early Kushite periods), Kulubnarti (Medieval period), and a combined sample group from two sites located on Mis Island in the Fourth Cataract region (Medieval period) (Roberts, 2007; Soler, 2012; Binder, 2014). Figure 8.5 compares the prevalence rates of maxillary sinusitis from all Middle Nile Valley sites analysed, according to subsistence strategy. The systematic study of rib IPR has been undertaken on one other Middle Nile Valley population, Amara West (Binder, 2014).

Table 8.1 and Table 8.2 display the outcomes of Fisher's Exact tests to explore the significance of differences between prevalence rates of maxillary sinusitis and rib IPR, respectively, between sites from the current research and those of other studies from the Middle Nile Valley. People buried at Kulubnarti had a significantly lower rate of maxillary sinusitis than all other groups in the current study, except for R12. The prevalence rate of maxillary sinusitis for people from the combined Mis Island group was significantly lower when compared with 3-J-18, P37, Gabati, Soba East, and Amara West, and was significantly higher than in people from Kulubnarti. Individuals from Amara West had a significantly higher rate of maxillary sinusitis compared to all sites except P37 and Soba East and had a significantly higher prevalence of rib IPR than all groups except for 3-J-23, Soba East, and the Fourth Cataract Post-/Meroitic period. The potential reasons for similarities and differences between the data in the current research and those from other studies are discussed below by site.

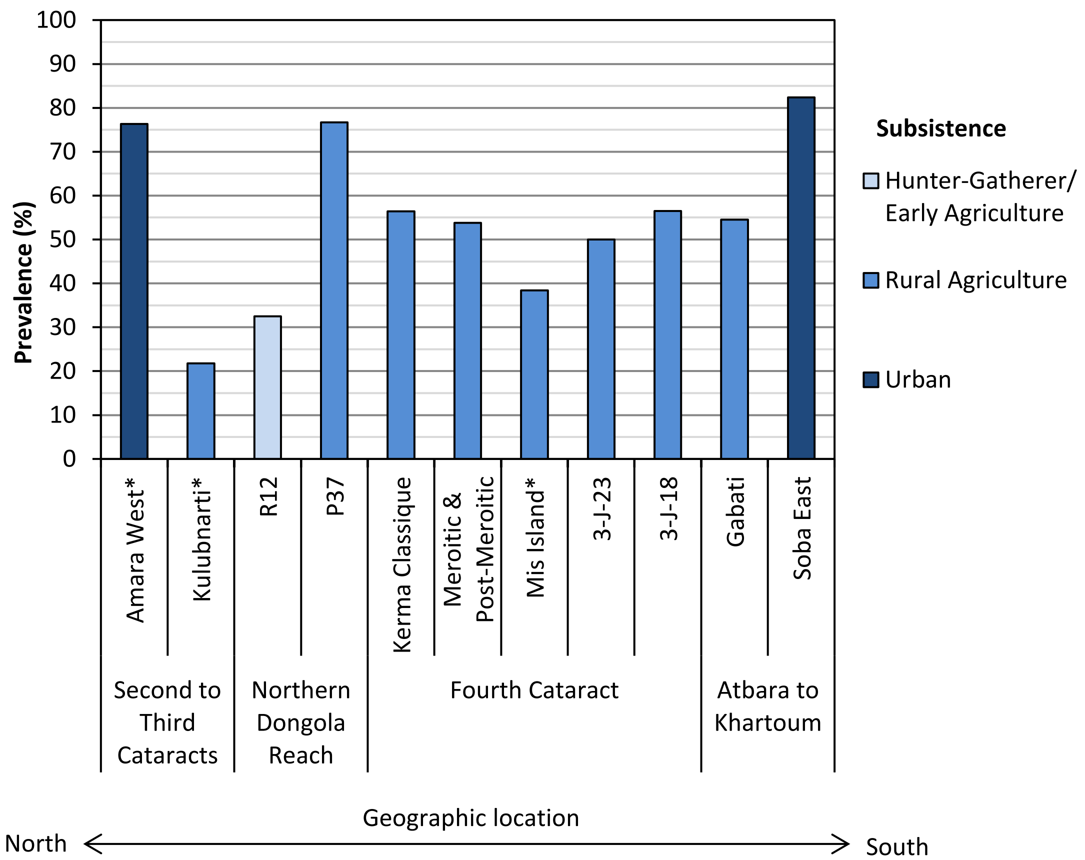


Figure 8.5 – A comparison of prevalence rates of maxillary sinusitis from sites in the Middle Nile Valley, according to subsistence strategy and approximate geographical location, retrieved from the current research and from other studies (* = sites from other studies).

Table 8.1 – The P-values of Fisher's Exact tests between sites from the current research and from other studies of Middle Nile Valley sites, to measure for significant differences in the prevalence rates of maxillary sinusitis. Statistically significant values are highlighted in grey (KC = Kerma Classique; P-/M = Post-/Meroitic).

	KC (4th Cat.)	P-/M (4th Cat.)	3-J-23	3-J-18	R12	P37	Gabati	Soba East	Amara West	Mis Island
Kulubnarti	<0.001	<0.001	<0.001	<0.001	0.200	<0.001	<0.001	<0.001	<0.001	0.027
Mis Island	0.076	0.161	0.216	0.026	0.683	<0.001	0.046	<0.001	<0.001	
Amara West	0.047	0.028	0.004	0.021	<0.001	1.000	0.007	0.604		

Table 8.2 – The P-values of Fisher's Exact tests between sites from the current research and from other studies of Middle Nile Valley sites to measure for significant differences in the crude prevalence rates of rib IPR. Statistically significant values are highlighted in grey (KC = Kerma Classique; P-/M = Post-/Meroitic).

	KC (4th Cat.)	P-/M (4th Cat.)	3-J-23	3-J-18	R12	P37	Gabati	Soba East
Amara West	0.014	1.000	0.755	0.001	<0.001	0.022	0.009	0.832

8.4.1.i Amara West

The Egyptian-founded town of Amara West was occupied during the New Kingdom and Post-New Kingdom/Early Kushite periods, from c. 1280 to 800 BC. It is located between the Second and Third Cataracts, near Saï Island (see Figure 4.4). Bioarchaeological analysis of the skeletons from the town's cemetery provides a prevalence rate of 76.3% (45/59) for maxillary sinusitis (calculated from Binder, 2014:Table 8.46) and a crude prevalence rate for rib IPR of 46.7% (49/105) (calculated from Binder, 2014:Table 8.49). A number of factors have been suggested to have had an effect on the high prevalence rates of respiratory disease observed in the people from Amara West, including smoky environments caused by bread ovens and fire pits inside enclosed rooms and industrial kilns located in high walled courtyards with poor ventilation, along with exposure to sand and dust in the arid environment (Binder, 2014:304-305). Houses within the town walls at Amara were densely packed, had thick brick walls, and contained hearths, bread ovens, and areas for the grinding of grain. Many rooms, including those containing ovens and hearths, were entirely roofed with organic matting, and there was a lack of light penetrating into buildings (Binder & Spencer, 2014:124; Spencer, 2015:190). Sanitation may have also been poor inside the town. Alleys between buildings had channels filled with organic waste, which was also deposited around house entrances, alongside occupational debris (Binder & Spencer, 2014:124; Spencer, 2015:188). Dung and charcoal were burned as fuels in ovens and hearths (Binder & Spencer, 2014:125). Sand was noted to have been a particular problem during the lifespan of the town and large deposits of aeolian sand have been recovered in occupation levels (Spencer et al., 2012:41-42; Spencer, 2015:195-196). For example, the doorway of one house was completely blocked by the rising ground level caused by in-blown sand and a set of stairs was constructed so that occupants could step down into the original floor of the house (Spencer, 2009:51). In other buildings doorways were located away from the direction of the wind and barriers were constructed in front of them from old stonework, mudbrick, and plaster to stop sand from the rising street level from flowing into houses (Spencer, 2015:196).

The prevalence rate of maxillary sinusitis at Amara West was significantly higher than rates from all sites in the current study except for P37 and Soba East, which had higher rates but were not significantly different to Amara West. The crude prevalence rate of rib IPR was also significantly higher than for most sites in the current study, but was comparable again to Soba East and to 3-J-23 and the Fourth Cataract Post-Meroitic group (Figure 8.6).

Most closely related to Amara West in both time and location is the Kerma Ancien and Kerma Moyen cemetery of P37, which had a very similar maxillary sinusitis prevalence rate of 76.7%. Although the two sites are separated by a time span of around one thousand years, these data may indicate that the environment in northern Upper Nubia exposed the people living there to aeolian dust and sand as early as the Kerma Ancien period, which then continued into the New Kingdom period. There are no significant differences between the prevalence of maxillary sinusitis for males and females at either Amara West (Binder, 2014:214) or P37, suggesting that the entire population at both sites may have been equally exposed to particulates in the general environment (see Section 8.4.3). The similar prevalence rates could also indicate that populations at both sites were involved in activities that exposed them to high levels of particulate matter, causing susceptibility to sinusitis. Mudbrick housing containing hearths were found at Amara and at the rural Kerma site of Gism el-Arba, and similar houses may have been present in the Northern Dongola Reach. Similarly, kilns and bread ovens have been located at both Amara West and Gism el-Arba (Gratien, 1999:11; Binder & Spencer, 2014:125). Agrarian activities, including animal husbandry, were also likely to have been taking place at both sites. Animals were commonly included in Kerma Moyen graves at P37 (Grant, 2001:545) and animal waste was found outside houses at Amara West (Binder & Spencer, 2014:124), suggesting that animals were often located within the town itself. The proximity of animals may have introduced zoonotic diseases and animal allergens into the living environment. All these factors may have contributed to similar prevalence rates of maxillary sinusitis in people from both sites. However, there is a disparity between the prevalence of rib IPR at the two sites, with Amara West having a significantly higher prevalence rate. This suggests that certain factors affecting lower respiratory tract disease may have differed at each site.

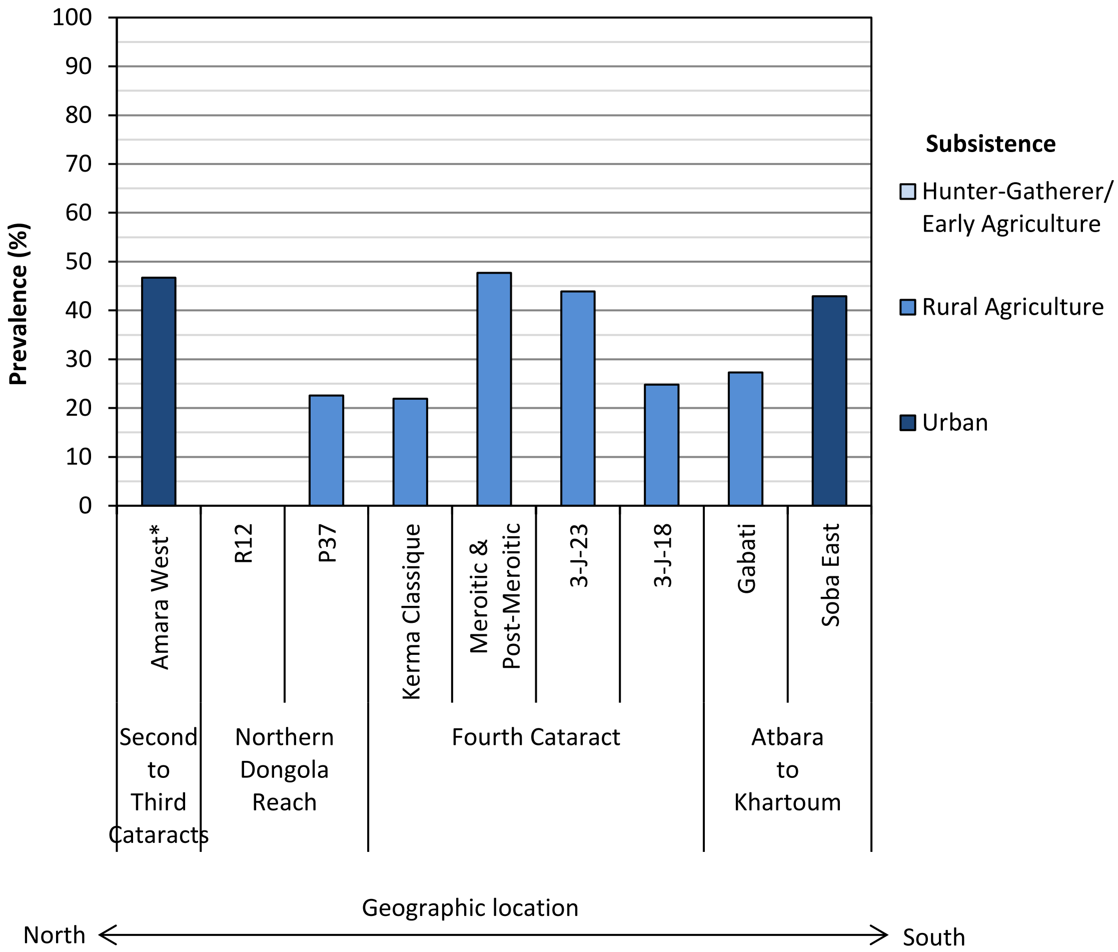


Figure 8.6 – A comparison of the crude prevalence rates of rib IPR from sites in the Middle Nile Valley, according to subsistence strategy and approximate geographical location, retrieved from the current research and from Binder (2014) (* = sites from other studies).

Although distant from one another both in location and in time, the urban nature of Amara West draws parallels with Soba East, which also had very similar prevalence rates of respiratory disease. Urban features, such as increased population density and household crowding, leading to an increased disease load, lack of ventilation, and lower levels of sanitation, can all occur in urban environments and many of these features were present at Amara West (Binder & Spencer, 2014). Thus, disease load in the people living there may have been considerably high. Evidence for non-specific infection in the form of periosteal reaction on the lower limb bones was common, with 61.4% (43/70) of all individuals displaying some form of new bone formation on one or both tibiae (Binder, 2014:Table 8.43). However, it should be remembered that periosteal reaction of the limb bones has numerous other aetiologies, such as trauma or mechanical stress (Weston, 2012:504; Binder, 2014:298-299).

The fact that animal dung was recovered from outside houses in the town (Binder & Spencer, 2014:124) suggests that animals were regularly found within the settlement and may have been in close contact with humans in habitation spaces, potentially introducing pathogens and vermin, and reducing sanitation within the settlement. Animals were also likely to have been present at Soba East, where faunal assemblages of predominantly cattle and caprine bones were recovered from domestic contexts (Chaix, 1998). The inhalation of smoke and general poor air quality due to industrial activities in the towns, such as pottery firing, metalworking, or other production activities, may also have resulted in high prevalence rates of respiratory disease. At Amara West kilns in small courtyards with high walls, that would have been poorly ventilated, may have been used for pottery, metalworking, or potentially for faience production (Binder, 2014:304). A kiln and plentiful evidence for metalworking, in the form of crucibles and moulds, have also been recovered from Soba East (Welsby & Daniels, 1991:105, 245; Welsby, 1998:273). Dung was used as a fuel at Amara West (Binder & Spencer, 2014:125), which, when burnt, can produce fine particulates with a high oxidising potential (Mudway et al., 2005:8) that is particularly damaging to the lungs (e.g. Becker, 2002; Lee et al., 2015) (see Section 8.8). Similar types of fuel may have also been used at Soba East if resources were limited, although vegetation was more plentiful in this region, even into the Medieval period (van der Veen, 1991:270-271). Unfortunately, there is little evidence for the types of fuel used during different periods in the Middle Nile Valley.

The high prevalence of respiratory disease at both urban Soba East and Amara West may indicate, however, that sites with comparable results, such as rib IPR prevalence rates at 3-J-23 and the Fourth Cataract Post-/Meroitic group, may reflect settlements that were more urban in nature. Large, potentially crowded settlements, have been identified in the Fourth Cataract during the Meroitic and Medieval periods. For example, the Meroitic settlement at Umm Muri (Payne, 2005:11-12) and the large Medieval settlement at 3-Q-62, with more than 230 houses (Wolf & Nowotnick, 2005b:191-193), provide evidence that large settlements and even towns could have been supported in this region. Additionally, skeletal evidence for infectious diseases such as tuberculosis, leprosy, and possibly brucellosis has been identified, affecting skeletons from the Fourth Cataract during the Medieval period and possibly even earlier. Although these diseases may not be observable in skeletons from earlier periods due to poorer preservation, the rise in visibility of skeletal changes related to these diseases may indicate a higher rate of infectious disease overall, due to a more urban environment, including poorer sanitation, household crowding, and greater social mixing from trade and travel. Unfortunately, the lack of preservation of occupation features associated with Fourth Cataract cemeteries and at Soba East severely limits these kinds of interpretations. A high number of confounding factors could also have been independently present at each site, resulting in the high prevalence of maxillary sinusitis or rib IPR within each population.

8.4.1.ii Kulubnarti

The Medieval site of Kulubnarti is located in the north of Upper Nubia, between the Second and Third Cataracts (see Figure 4.6). Although Kulubnarti is now an island, before the construction of the Aswan High Dam in the 1960s it consisted of headlands projecting into the river, separated from the main west bank by a small channel which was dry for most of the year (W. Y. Adams, 2011:1). A study of maxillary sinusitis of Early Medieval individuals from two cemeteries at Kulubnarti has provided a combined prevalence rate of 21.8% (22/101) (Roberts, 2007:Table 3). The individuals in this study were recovered from 21-S-46, located on the west region of the island, dating to the Early Christian phase (AD 600 – 850), and 21-R-2, located on the west bank of the Nile just below the southern tip of the island, and dating to the Early and early Classic Christian phases (AD 600 – 1100) (W. Y. Adams, 1999:7, 15, 26). Only approximately one eighth of 21-R-2 was excavated, at the far west of the site on the highest ground, and therefore was not a representative sample of the whole cemetery (W. Y. Adams, 1999:24-26). Architectural remains on the island, dating to the Medieval period, included stone huts, rough stone houses that may have been used as outdoor cooking and working areas, mudbrick unit houses, 'castle' houses, and ‘flimsy’ houses with lower walls of stone or mudbrick and possible upper storeys with walls of an organic material (W. Y. Adams, 2011). No buildings were contemporary with the Early Christian cemetery burials and the unit and castle houses represented the latest Medieval types (W. Y. Adams, 2011:Fig. 1.1). Therefore, it is more likely that Early Christian houses may have resembled the earlier ‘flimsy’ and rough stone houses, which were likely to have had better ventilation and organic roofing, but also contained fireplaces and ovens (W. Y. Adams, 2011:11-21). Firing pits for handmade pottery dating to the Post-Meroitic were also present on the island (W. Y. Adams, 2011:119).

The prevalence rate of maxillary sinusitis at Kulubnarti is the lowest recorded in any population from the Middle Nile Valley with a sample group containing over ten individuals. This is unusual considering that Kulubnarti is located in the north of Sudan, which, by the time of the Post-Meroitic and Medieval Periods, was likely to have consisted of desert with some small cultivatable areas on the river banks and islands, such as Kulubnarti itself. The area today consists of barren alluvial plains and sand drifts, with only some small areas of sparse desert vegetation (W. Y. Adams, 2011:1). It might be expected that the inhalation of dust and sand at Kulubnarti would have increased the prevalence rate of maxillary sinusitis. Both the northern sites of Amara West, where aeolian sand from the desert was known to have an impact on the occupation site, and P37 have considerably higher prevalence rates. Additionally, individuals from the Medieval sites of 3-J-18, 3-J-23, and Gabati were located further south than Kulubnarti, in regions perhaps slightly more protected from the western desert sands, yet these sites still had significantly higher prevalence rates.

A number of reasons might be given for the large disparity between the prevalence rates of maxillary sinusitis at Kulubnarti and other Middle Nile Valley sites. The location of sites on islands may act as a buffer against windblown dust and sand from the main banks, particularly as islands are more likely to support a greater cover of vegetation due to the proximity of water on all sides. Amara West, for example, was once located on an island but later increasing aridity caused the northernmost channel around the island to dry up, allowing the encroachment of sand from the main banks, destroying the fertility of the island, and acting as a major factor in the ultimate abandonment of the town (Spencer et al., 2012: 41-42; Binder & Spencer, 2014:26). While Kulubnarti was not a true island during the Medieval period, its position as a headland projecting into the river may have protected the inhabitants from excesses of windblown sand. However, Medieval 3-J-18 was also located on Mis Island, opposite other sites from the Fourth Cataract which were situated on the west bank of the Nile, and no significant differences were found between the prevalence rates of maxillary sinusitis at any of these sites.

Socio-economic and/or cultural factors may have protected certain inhabitants of Kulubnarti from particulate matter. For example, individuals buried in these two cemeteries may have had a high level of socio-economic status that precluded them from exposure to particulate matter from sustained activities, such as those related to agrarianism, pastoralism, pottery making, or metallurgy. One of the cemetery sites used to make up part of the Kulubnarti sample (21-R-2) was not fully excavated and the majority of recovered skeletons were buried on the highest ground within the cemetery (W. Y. Adams, 1999:24-26). It is possible that individuals were buried in a position overlooking the rest of the cemetery due to their high status in the community. For example, it has been speculated that a small Medieval cemetery on Mis Island located on the top of a hill and visible from much of the surrounding region may have been an exclusive cemetery for those of higher social standing (Ginns, 2010d:II). The architectural remains on Kulubnarti do little to support this hypothesis, however, as the flimsy and rough stone houses of the late Classic and early Late Christian periods are rather insubstantial and suggest a population with little in the way of material goods (W. Y. Adams, 2011:65). However, these settlements are later in date compared to the cemetery sites and the personal circumstances of the inhabitants of Kulubnarti may have changed substantially over time.

Inter-observer error in recording the prevalence of maxillary sinusitis should also be taken into account when considering differences between studies conducted by different researchers. Although the study of Kulubnarti employed the same diagnostic criteria laid out by Boocock et al. (1995) that the current research used, small differences in the criteria used by each researcher may have been a factor in the significant difference in prevalence rates between studies. For example, while Boocock et al. (1995) provide criteria for identifying bony changes related to sinusitis, the extent or severity of the changes required before maxillary sinusitis could be recorded as present was not described and may vary by researcher.

Importantly, the curation of the human remains after excavation can have a major impact on the ability to observe the presence of maxillary sinusitis. In the current study, unremodelled spicules were one of the most common forms of bony changes related to maxillary sinusitis, found in 42.7% (102/239) of sinuses with sinusitis. The bone formed is, however, extremely delicate and can be easily dislodged and lost by the cleaning of sinuses. Fortunately, in the current study the majority of individuals analysed had not been thoroughly cleaned and it was possible to take extra care when cleaning and analysing the sinuses to ensure spicules were not dislodged. However, the human skeletal remains from Kulubnarti were excavated in 1969 and 1979, before the presence of bony changes related to maxillary sinusitis had become better understood and systematically recorded within palaeopathology and before the publication of diagnostic criteria by Boocock et al. (1995). Therefore, it is very possible that broken sinuses at Kulubnarti were vigorously cleaned by well-meaning curators and evidence for maxillary sinusitis has unfortunately been lost. This may also pose a problem for recording maxillary sinusitis in other collections of human remains that have been curated before the publication of the diagnostic criteria for maxillary sinusitis.

8.4.1.iii Mis Island

The Medieval cemetery sites of 3-J-10 and 3-J-11 (AD 550 – 1500 AD) are situated on Mis Island, close to 3-J-18, and were excavated between 2005 and 2007 during the archaeological rescue campaigns carried out in the Fourth Cataract region (Ginns, 2006, 2007). A palaeopathological analysis of adult skeletons from these sites included data on the prevalence of maxillary sinusitis (Soler, 2012). 3-J-10 was located 300m north-west of the church at 3-J-18 and may have contained the latest Medieval burials on the island (Ginns, 2006:17). As the entire cemetery could not be excavated, a representative sample of skeletons from across the whole site was recovered (Ginns, 2010e:I). People from this cemetery had a maxillary sinusitis prevalence rate of 42.9% (15/35) (Soler, 2012:192). 3-J-11 was the largest cemetery on the island, located midway along the northern bank (Ginns, 2010f:I). As with 3-J-10, the entire 3-J-11 cemetery could not be excavated and skeletons were recovered from across the whole site in equal density (Ginns, 2010f:I). 3-J-11 had been in use since the Meroitic period, which was only represented by two burials (Ginns, 2010f:I). Very early Medieval burials contained ceramic vessels and blocking stones in the grave cut over the body (Ginns, 2006:17, 2007:21), and were designated by Soler (2012:86) as Transitional Medieval burials. Later Medieval graves were identified by a lack of grave goods and no blocking stones (Ginns, 2006:17-18, 2007:21). People from transitional burials at 3-J-11 had a prevalence rate of 33.3% (3/9) and individuals from later Medieval burials a rate of 34.5% (10/29), with a total of 34.2% (13/38) for the combined group (Soler, 2012:200, 210).

The total prevalence rate for maxillary sinusitis for the two Mis Island sites combined was 38.4% (28/73). This was lower than the rates for the majority of groups in the current study. While there were no significant differences between the Mis Island group and the Fourth Cataract Kerma Classique and Post-/Meroitic groups, or the nearby contemporaneous site of 3-J-23, there was a significant difference between the Mis Island group and 3-J-18, also located on the same island. 3-J-18 had a maxillary sinusitis prevalence 18.1% higher than the Mis Island group. This may indicate that, although individuals were living in the same environment at similar times, they may have been engaged in different activities or practices that differentially affected susceptibility to maxillary sinusitis. Unfortunately, the only Medieval settlement identified on Mis Island was that of 3-J-19, which provided little evidence of housing or activities taking place within the settlement, although animal pens and areas of burning were identified (Ginns, 2007:25, 2010c).

Ginns (2007:22-23) noted that all three island cemeteries may have been in use contemporaneously and that the location a person was buried in could have been dependent on factors such as age or status. For example, much higher proportions of infants and children were identified at 3-J-10 and 3-J-11 than at 3-J-18 (Ginns, 2007:22). The cemetery of 3-J-18 was suggested to perhaps contain higher status individuals, based on the proximity of the cemetery to the church (Ginns, 2007:22-23). If the population on Mis Island was divided by status, individuals at 3-J-18 may have lived in more substantial stone or mudbrick housing with indoor hearths that could have exposed people to higher levels of smoke, and subsequent poor air quality, within their homes. Social divisions based on the type of activities people undertook may have led to the inclusion of more individuals in 3-J-18 that were exposed to higher levels of particulates or pathogens as part of their occupation and/or subsistence practices. Unfortunately, the Fourth Cataract region, including Mis Island, has now been flooded by the construction of the Merowe Dam and further archaeological data for this region, which might have provided information about the differences between the sites, is no longer obtainable.

As discussed above, although the diagnostic criteria of Boocock et al. (1995) were used to identify maxillary sinusitis in the Mis Island group, variation in methods used by different researchers may have affected differences in the recorded prevalence rates. Additionally, an endoscope was not used to access intact maxillary sinuses in the Mis Island group and only those sinuses that were broken could be observed (Soler, 2012:192, 210). As conditions on Mis Island led to particularly well-preserved Medieval burials, many of the individuals from 3-J-10 and 3-J-11 had intact crania and could not be observed for maxillary sinusitis. The fact that only broken sinuses were included in the study by Soler (2012), which may have been exposed to damage and the destruction of evidence for sinusitis, and an endoscope was employed to study 3-J-18 and 3-J-23, may explain the disparity in results. Intact sinuses are far more likely to protect and retain evidence for sinusitis. However, this also raises implications for the comparability of results between groups in different states of preservations within the current study (see Section 8.9).

8.4.2 Sudanese prevalence in a worldwide context

8.4.2.i Maxillary sinusitis

Published studies of maxillary sinusitis in adults using the diagnostic criteria of Boocock et al. (1995) have been limited to the geographic regions of England, northern mainland Europe, North America, and Sudan (Figure 8.7). Within and between each geographic region there is a considerable amount of variation in the prevalence of maxillary sinusitis. This is not surprising, considering the range of locations and time periods represented in these studies, which may have been considerably different in climate, subsistence economy, housing, socio-cultural practices, and exposure to infectious diseases, among other factors affecting respiratory disease. When sites are ranked by increasing prevalence (Figure 8.8), a higher number of Sudanese sites (7/11), are located in the top half of prevalence rates. This could indicate that conditions in Sudan predisposed people to higher prevalence rates of maxillary sinusitis than in other regions of the world. From the Kerma period onwards, Sudan was considerably more arid than the other regions presented here, regardless of time period.

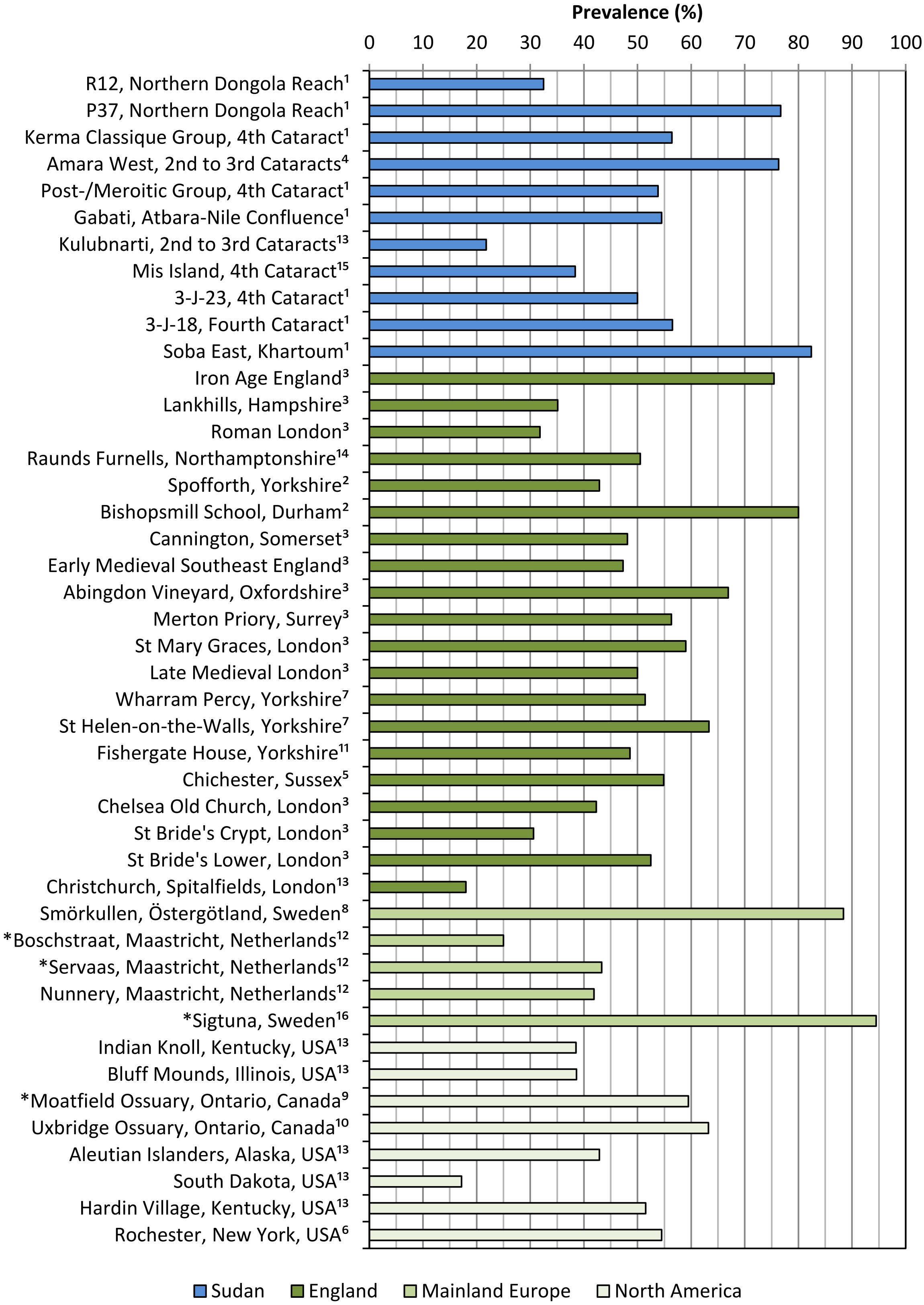


Figure 8.7 – A comparison of the prevalence rates of maxillary sinusitis in adults from various studies, according to geographical region and then by approximate time period (* = mixed adult and non-adult population).

[1]Current study; [2]Bernofsky (2006); [3]Bernofsky (2010); [4]Binder (2014); [5]Boocock et al. (1995); [6]DiGangi and Sirianni (2017); [7]Lewis et al. (1995); [8]Liebe-Harkort (2012); [9]Merrett (2003); [10]Merrett and Pfeiffer (2000); [11]Papapelekanos (2003); [12]Panhuysen et al. (1997); [13]Roberts (2007); [14]Roberts, Lewis, & Boocock (1998); [15]Soler (2012); [16]Sundman & Kjellström (2013)

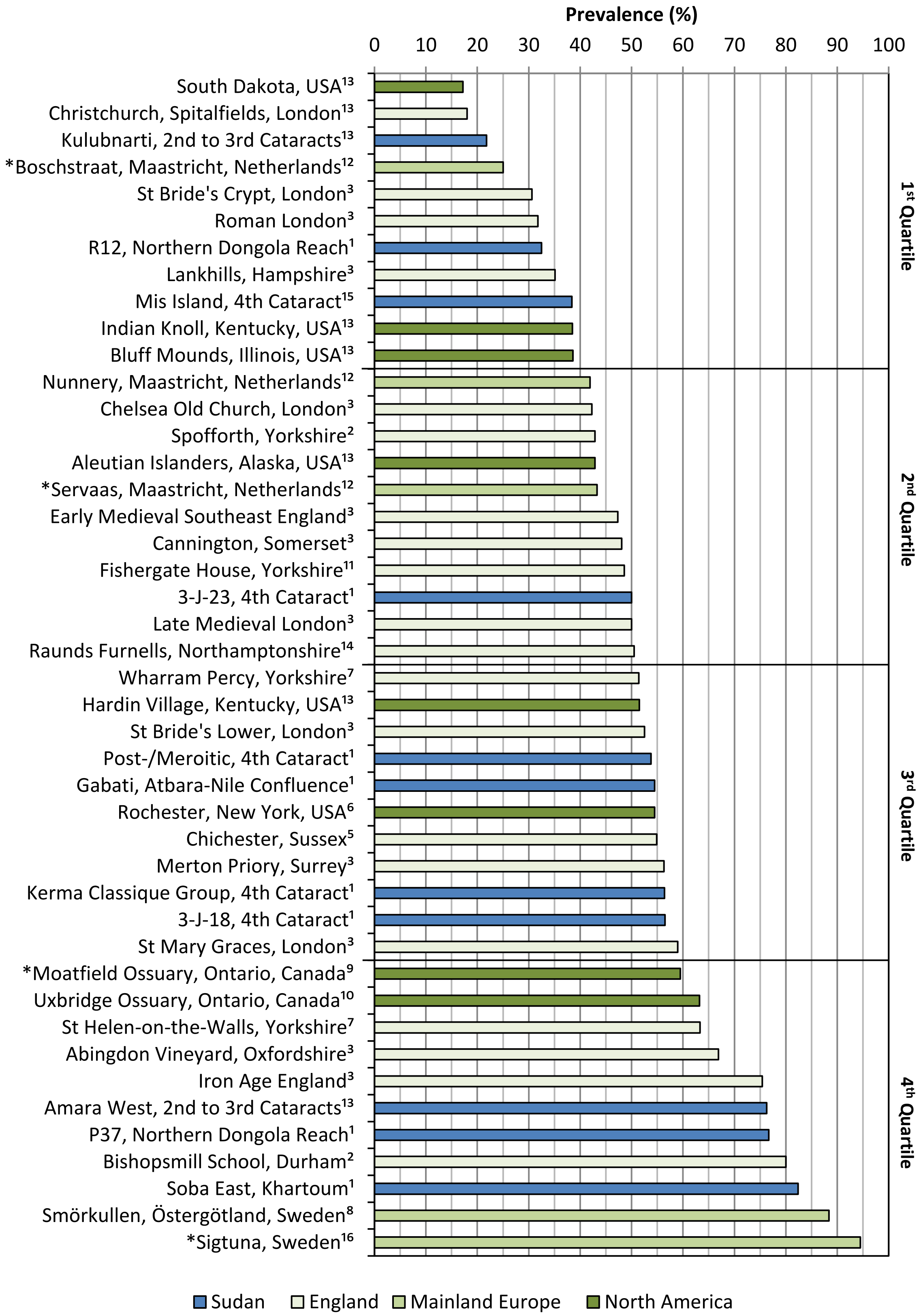


Figure 8.8 – The ranking of all prevalence rates of maxillary sinusitis from various studies, from lowest to highest values (* = mixed adult and non-adult population).

[1]Current study; [2]Bernofsky (2006); [3]Bernofsky (2010); [4]Binder (2014); [5]Boocock et al. (1995); [6]DiGangi and Sirianni (2017); [7]Lewis et al. (1995); [8]Liebe-Harkort (2012); [9]Merrett (2003); [10]Merrett and Pfeiffer (2000); [11]Papapelekanos (2003); [12]Panhuysen et al. (1997); [13]Roberts (2007); [14]Roberts, Lewis, & Boocock (1998); [15]Soler (2012); [16]Sundman & Kjellström (2013)

When comparing prevalence rates of maxillary sinusitis from around the world, ranked first by subsistence strategy and then by time period (Figure 8.9), it is difficult to see any pattern by subsistence, except for a consistently lower prevalence rate in hunter-gatherers and early agriculturalists. This group shows the lowest mean prevalence rate (33.9%) and smallest range of any other subsistence group (Table 8.3), which is consistent with the findings of Roberts (2007). However, this group also included one of the lowest numbers of sites, indicating that the limited range in prevalence rates may also be due to the small sample size. The rural and urban groups show similar mean prevalence rates (52.7% and 55.9%, respectively) and a far greater range.

Table 8.3 – Mean prevalence rates and ranges for maxillary sinusitis within different subsistence economies.

Subsistence	Number of sites	Mean Prevalence	Range
Hunter-Gatherer/ Early Agriculture	5	33.9%	17.2% – 42.9%
Rural Agriculture	22	52.7%	21.8% – 88.4%
Semi-Urban	3	39.1%	31.8% – 43.3%
Urban	13	55.9%	18.0% – 94.5%

The wide range in prevalence rates makes it evident that other site-specific factors, besides these broad and general subsistence categories, have an effect on susceptibility to maxillary sinusitis. Cultural factors such as the type of housing constructed, including the levels of ventilation and sanitation within, the number of individuals or families living in one building, the use of space within those buildings, the proximity of animals to the living environment, the reliance on fire for cooking and production activities, the type of hearth, oven, or fuel used, and other factors related to particulate production and inhalation, can all have an impact on susceptibility to maxillary sinusitis. For example, an Iroquoian population from Uxbridge Ossuary, in Canada, had a maxillary sinusitis prevalence of 63.2%. It has been suggested that the continual burning of multiple wood fires within Iroquoian longhouses, in winter for heat and in the summer to repel insects, and the housing of between twenty and a hundred people within one structure were likely to have predisposed this population to developing maxillary sinusitis (Merrett & Pfeiffer, 2000:306, 314-315). However, the lack of settlement data for many Middle Nile Valley sites makes it difficult to compare the potential risk factors affecting a susceptibility to maxillary sinusitis with already published studies.

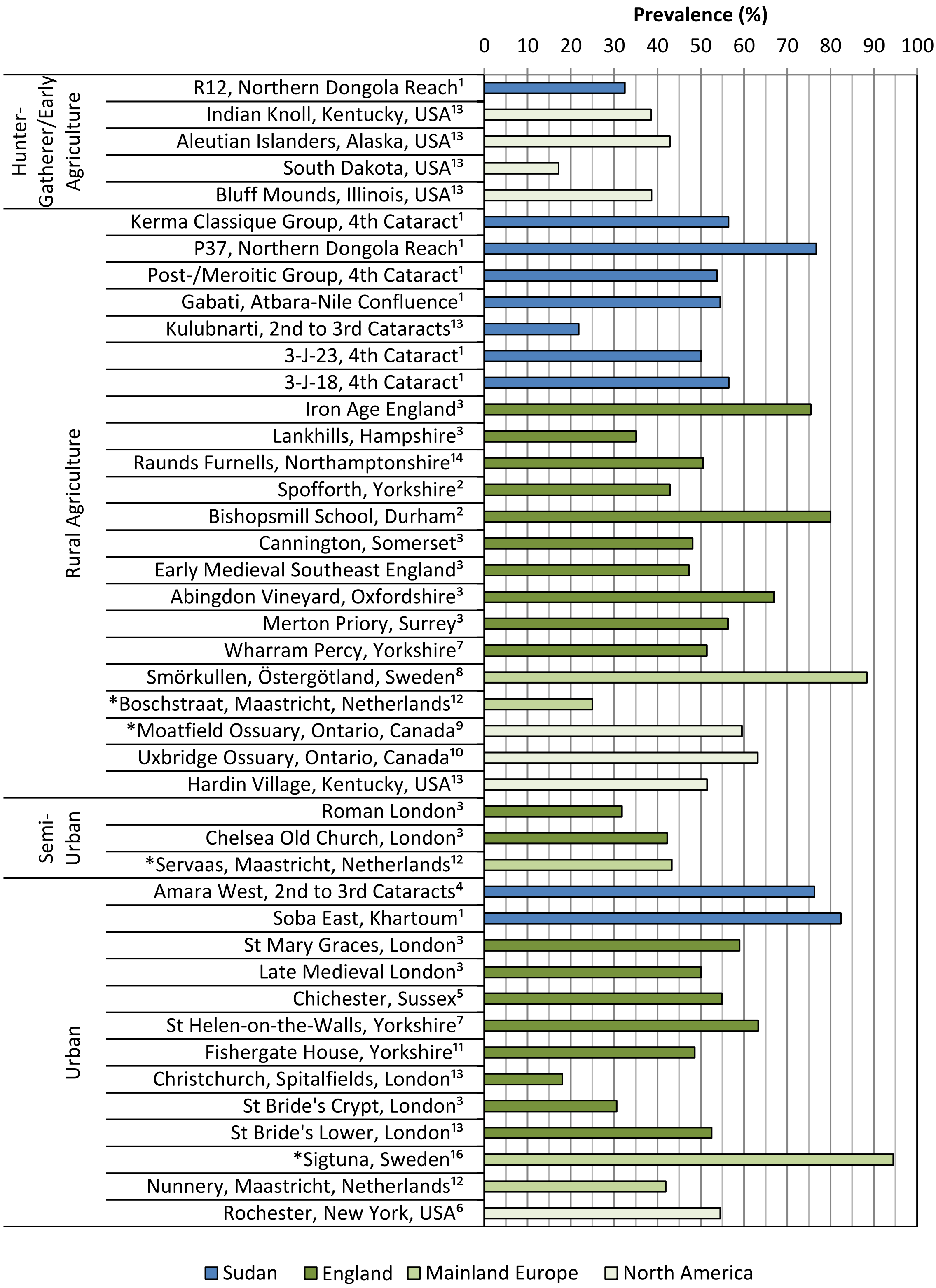


Figure 8.9 – A comparison of prevalence rates of maxillary sinusitis from various studies, according to subsistence strategy, geographical region, and then by approximate time period (* = mixed adult and non-adult population).

[1]Current study; [2]Bernofsky (2006); [3]Bernofsky (2010); [4]Binder (2014); [5]Boocock et al. (1995); [6]DiGangi and Sirianni (2017); [7]Lewis et al. (1995); [8]Liebe-Harkort (2012); [9]Merrett (2003); [10]Merrett and Pfeiffer (2000); [11]Papapelekanos (2003); [12]Panhuysen et al. (1997); [13]Roberts (2007); [14]Roberts, Lewis, & Boocock (1998); [15]Soler (2012); [16]Sundman & Kjellström (2013)

Both Roberts (2007) and Bernofsky (2010) have also noted that high status may act as a buffer against exposure to particulate pollution in urban environments. For example, Bernofsky (2010:164) found a statistically significant difference in frequency rates between the Post-Medieval British sites of St Bride's Crypt and St Bride's Lower, in London, despite the fact that the two cemeteries served the same urban parish. St Bride's crypt was likely to have contained the wealthier members of the parish and had a prevalence rate that was 21.9% lower than the poorer population at St Bride's Lower (Bernofsky, 2010: Tables 5.36 & 5.39). It was also found that people buried in the relatively high status crypt of Post-Medieval Spitalfields in London had a particularly low prevalence rate of 18.0% (Roberts, 2007:Table 3). In these cases, access to cleaner burning fuels, greater ventilation within homes, and better sanitation for the wealthier portion of society may have lowered prevalence rates in people buried at high-status cemeteries (Roberts, 2007:803; Bernofsky, 2010: 216).

However, one of the limitations of the current study is that the status of burials could not be inferred from the cemetery, grave goods, or burial-type. For example, while urban Soba East has been described as a powerful and affluent city (Welsby & Daniels, 1991:7), and certain people were buried wearing fine clothes (Vogelsang-Eastwood, 1991:307), it was not possible to determine the socio-economic status of the individuals in the sample studied. The high prevalence rate of maxillary sinusitis in the people buried at this site suggests that either high status was not acting as a buffer against other factors predisposing to maxillary sinusitis at Soba East, or that the individuals within the study were from lower status cemeteries.

8.4.2.ii Rib IPR

Studies of the prevalence of rib IPR are rare and, outside of the current study, have been mainly limited to the geographical regions of Europe, in particular England, and to a small number of studies in North and South America (Figure 8.10). While there is some variation within geographical regions, it is evident that Sudan has consistently higher prevalence rates of rib IPR when compared to other areas of the world. When sites are ranked by increasing prevalence (Figure 8.11), eight out of nine Sudanese sites are found in the highest half for all rates of rib IPR and Sudanese sites make up 50% (5/10) of the highest quartile. This indicates that certain risk factors in the ancient Middle Nile Valley were likely to have been increasing susceptibility to lower respiratory tract disease, when compared to other regions of the world.

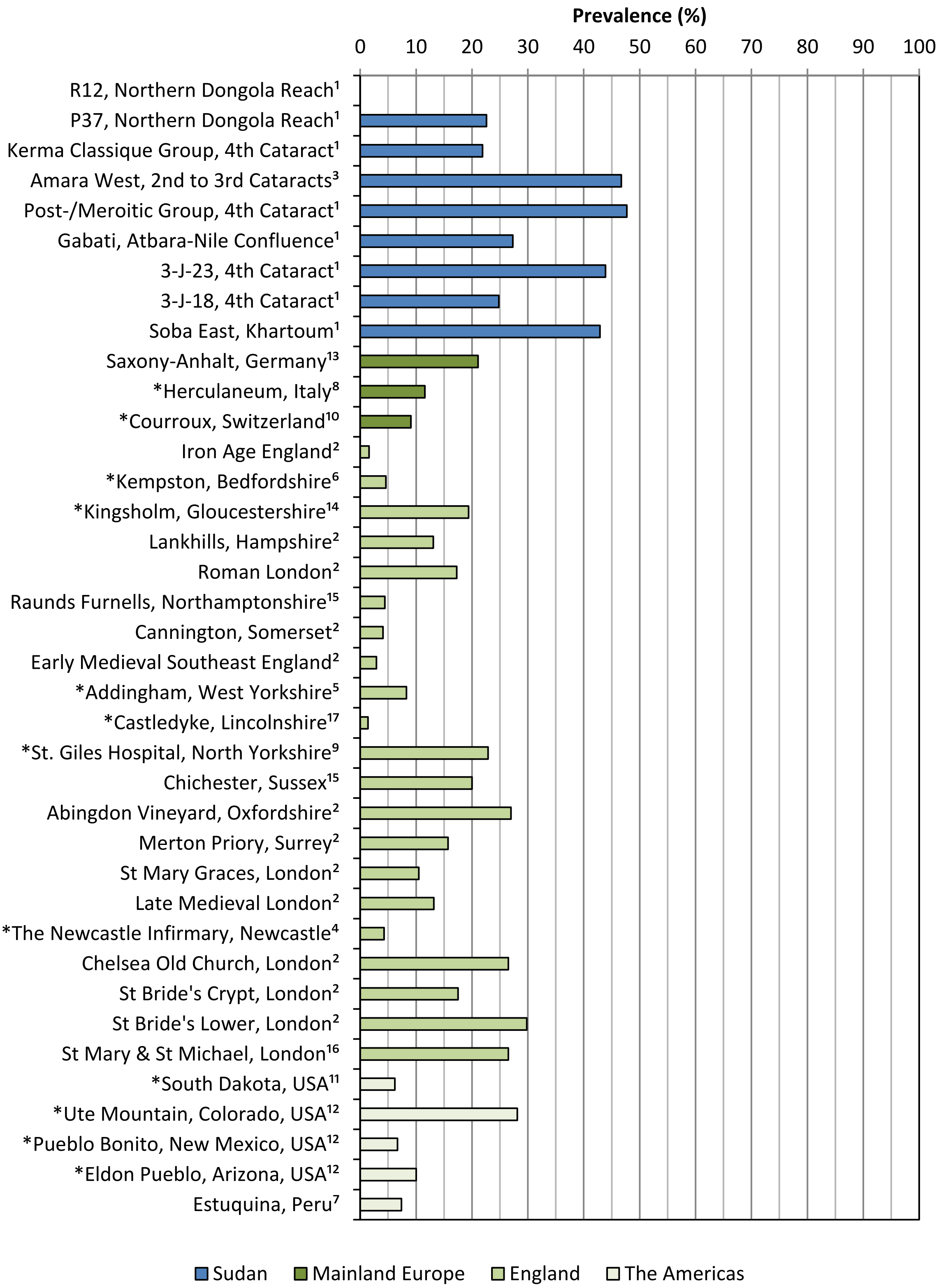


Figure 8.10 – A comparison of the prevalence rates of rib IPR in adults from various studies, according to geographical region and then by approximate time period (* = mixed adult and non-adult population).

[1]Current study; [2]Bernofsky (2010); [3]Binder (2014); [4]Boulter et al. (1998); [5]Boylston (1991); [6]Boylston & Roberts (1996); [7]Buikstra & Williams (1991); [8]Capasso (2000); [9]Chundun (1992); [10]Cooper et al. (2016); [11]Kelley et al. (1994); [12]Lambert (2002); [13]Nicklisch et al. (2012); [14]Roberts (1989); [15]Roberts, Lewis, & Boocock (1998); [16]Walker & Henderson (2010); [17]Wiggins et al. (1993)

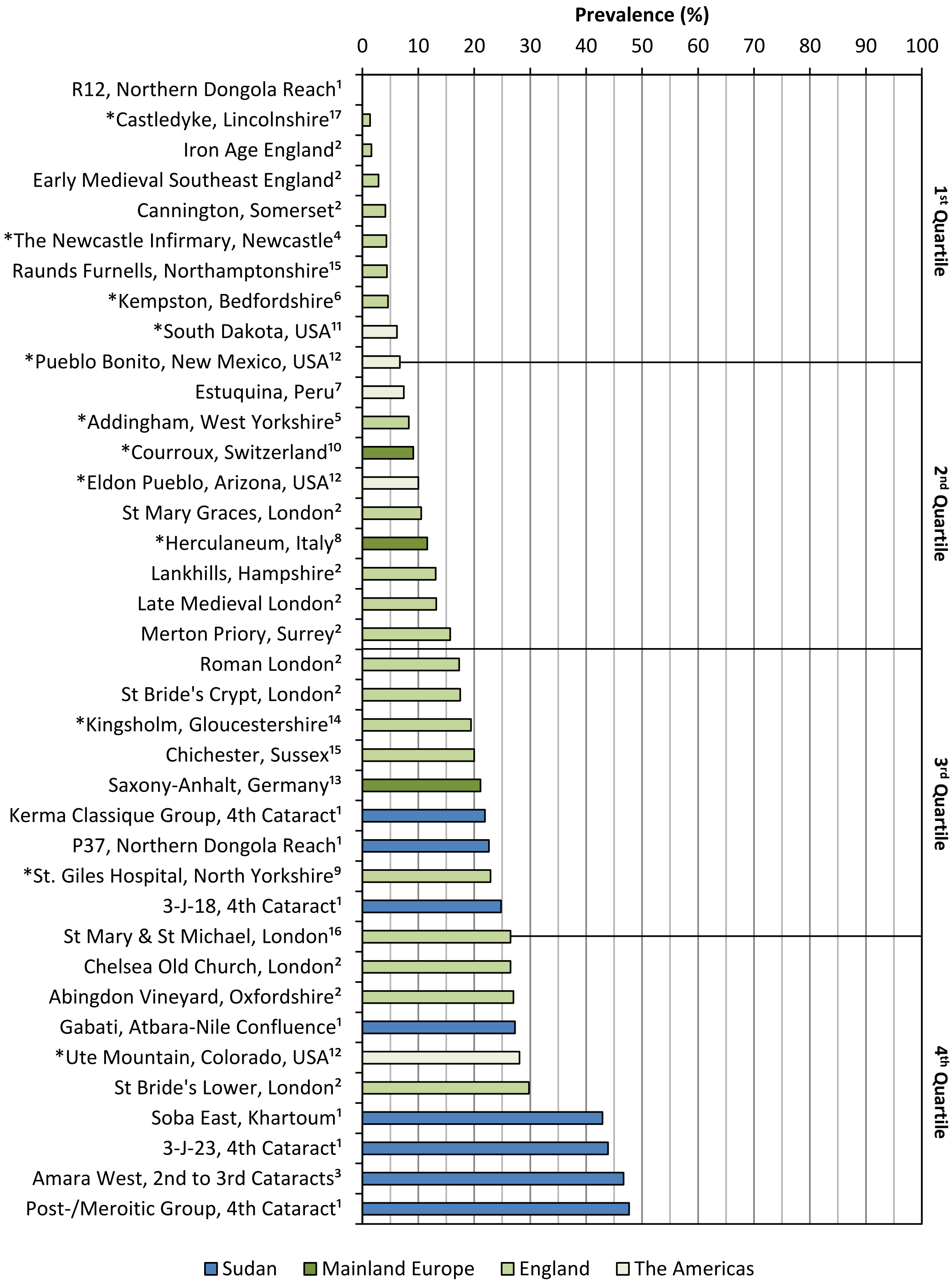


Figure 8.11 – The ranking of all prevalence rates of rib IPR from various studies, from lowest to highest values (* = mixed adult and non-adult population).

[1]Current study; [2]Bernofsky (2010); [3]Binder (2014); [4]Boulter et al. (1998); [5]Boylston (1991); [6]Boylston & Roberts (1996); [7]Buikstra & Williams (1991); [8]Capasso (2000); [9]Chundun (1992); [10]Cooper et al. (2016); [11]Kelley et al. (1994); [12]Lambert (2002); [13]Nicklisch et al. (2012); [14]Roberts (1989); [15]Roberts, Lewis, & Boocock (1998); [16]Walker & Henderson (2010); [17]Wiggins et al. (1993)

Studies of the specific pathological causes of rib IPR using identified human skeletal collections with documented causes of death have found a significant association between the presence of rib IPR in individuals who died from tuberculosis, when compared to individuals reported to have died from other diseases (Roberts et al., 1994:172; Santos & Roberts, 2001:41, 2006:42; Matos & Santos, 2006:193; Mariotti et al., 2015:394). Archaeological studies have also successfully extracted the DNA of *Mycobacterium tuberculosis* from bone samples obtained from individuals with rib IPR (e.g. Mays et al., 2002; Raff et al., 2006; Nicklisch et al., 2012; Cooper et al., 2016), demonstrating a possible relationship between the two. Therefore, many studies of rib IPR have discussed prevalence rates in relation to tuberculosis (e.g. Pfeiffer, 1991; Kelley et al., 1994; Roberts, 1999; Lambert, 2002; Raff et al., 2006; Nicklisch et al., 2012).

Studies of rib IPR in samples of adult skeletons from the human identified skeletal collections curated at Coimbra University and the Museu Bocage, both in Portugal, revealed prevalence rates of 49.7% and 55.8%, respectively (Matos & Santos, 2006:Table 4; Santos & Roberts, 2006: Table 1). Although the prevalence rates of these groups are biased, as the majority of the sample have been selected specifically for the presence of tuberculosis or some other respiratory disease (with an accompanying control group), they are most comparable to the higher prevalence rates observed in populations from the Middle Nile Valley sites of Amara West, Soba East, 3-J-23, and the Fourth Cataract Post-/Meroitic group. The similarity between prevalence rates of samples containing a high number of individuals who were known to have died from tuberculosis and those of people from Sudanese sites could indicate that this disease was also common in the Middle Nile Valley during certain time periods.

Skeletons with destructive vertebral lesions that could have potentially been caused by tuberculosis have been identified from Post-Meroitic and Medieval sites included in the current research (see Section 7.5). Risk factors for tuberculosis include crowding, poor ventilation, and poor air quality (Narasimhan et al., 2013: Fig. 1), which may have been present at certain Middle Nile Valley sites. The prevalence of tuberculosis may also have been exacerbated by the inhalation of dust and sand. In a study of silicosis in desert dwellers in the Thar Desert of India, it was noted that a higher prevalence of tuberculosis was recorded in certain districts located close to the desert. This was thought to be unusual considering that tuberculosis bacilli do not survive well when exposed to sunlight or aridity. Thus, the higher prevalence of tuberculosis in the desert populations was attributed to an increased risk of contracting the disease, caused by sand inhalation and resultant lung damage (Mathur & Choudhary, 1997:560-561).

However, pleural disease, causing inflammatory periosteal reaction on the ribs, can be caused by several lower respiratory tract diseases other than TB, and some non-pulmonary diseases (see Table 2.1). For example, although identified skeletal collections have found a significant correlation between pulmonary tuberculosis and rib IPR, these colletions may not always have completely accurate documentation about the cause of death or any co-morbidities for all individuals concerned (Roberts, Boylston et al., 1998:57; Santos & Roberts, 2001:46; Matos & Santos, 2006:191). For example, tuberculosis is known to increase the risk of pneumonia (e.g. Moreira et al., 2011; Chang et al., 2016:3) and the two can have similar clinical manifestations, potentially leading to confusion in diagnosis (e.g. Naderi et al., 2017:Table 2). Thus, some individuals with rib IPR, whose cause of death was recorded as tuberculosis, may instead have had pneumonia or a combination of the two diseases. This may also be the case, vice versa, for individuals with a recorded cause of death of pneumonia.

Nevertheless, the factors increasing susceptibility to tuberculosis, like poor air quality and crowding in urban contexts, are often similar to those for other infectious lower respiratory tract diseases, such as pneumonia (e.g. Van der Poll & Opal, 2009:1544). Therefore, while it may not be possible to identify the specific pathogen causing rib IPR, prevalence rates may indicate the level of exposure of a population to general risk factors causing lower respiratory tract disease.

One of the major differences between sites from Sudan and those from other regions of the world is the arid desert environment present in northerly regions of the Middle Nile Valley from the Kerma period onwards. While there is still a lack of clinical studies of respiratory diseases in Sudan in populations today, the implications of dust inhalation from arid environments are well recorded. Ambient dust and dust-storms are known to cause a rise in hospital admissions for respiratory-related problems (e.g. Hefflin et al., 1994; Meng & Lu, 2007; Lai & Cheng, 2008; Tam et al., 2012; de Longueville et al., 2013; Uduma & Jimoh, 2013; Ebrahimi et al., 2014; Esmaeli et al., 2014; Trianti et al., 2017; Reed and Nugent, 2018) and a rise in respiratory diseases can be seen in modern soldiers deployed to desert environments (e.g. Richards et al., 1993; Korzeniewski et al., 2015; Singh et al., 2016; Saers et al., 2017).

Although other risk factors, such as exposure to pathogens, smoke, and allergens, may have contributed to respiratory disease in all regions of the world, the persistent inhalation of dust and sand from a desert environment in Sudan may have substantially affected the lungs in past populations, increasing the likelihood of contracting infectious respiratory diseases and of developing other pulmonary diseases, such as silicosis (e.g. Hirsch et al., 1974; Mathur & Choudhary, 1997). Most other studies of rib IPR have analysed skeletons from sites from fairly temperate regions of the world. However, in a study of rib IPR prevalence in contemporary Puebloan sites from southwestern USA, it was also suggested that dust and pollen from the arid landscape, particularly at the site of Ute Mountain (with the highest prevalence of rib IPR recorded at any site from the Americas), may have contributed to an increased susceptibility to lower respiratory tract disease in this region (Lambert, 2002:288).

When ranking prevalence rates by subsistence strategy, region, and then by time period, groups in England appear to display a slight rise in prevalence in later urban contexts (Figure 8.12). It is notable that two of the highest prevalence rates for rib IPR from Sudanese sites are also from urban contexts: Amara West and Soba East. When frequencies of rib IPR are grouped according to subsistence strategy, the urban-based subsistence group demonstrates the highest mean prevalence rate (24.0%), while the rural agricultural group displays a lower rate (19.7%) but a wider range (Table 8.4). As discussed above, urban environments have the potential for poor air quality, high population density, household crowding, high disease load, and poor sanitation, all of which can lead to an increased susceptibility to respiratory diseases.

However, status may also be a confounding factor in lower respiratory tract disease. For example, Bernofksy (2010:Table 5.63) found that individuals inhumed in the high status crypt of St. Bride's had a significantly lower prevalence rate of rib IPR (17.5%, 22/126) compared to individuals buried at the contemporary low status cemetery of St. Bride's Lower (29.8%, 36/121), although the two cemeteries served the same parish. This could indicate that despite living in proximity to one another, within an urban environment, the lifestyles of the two groups were sufficiently dissimilar to differentially affect exposure to pathogens and particulates (Bernofsky, 2010:244-245). Higher status individuals were likely able to afford better housing with less crowding, better ventilation and sanitation, and cleaner burning fuels, and may have engaged in occupations that did not expose them to high levels of particulates or pathogens (Roberts, 2007:803; Bernofsky, 2010: 216). While status cannot be inferred from the cemeteries included in the current research, differences in socio-economic circumstances may have contributed to the disparities in rib IPR prevalence seen between contemporaneous Middle Nile Valley sites that are in close proximity to one another, such as 3-J-23 and 3-J-18.

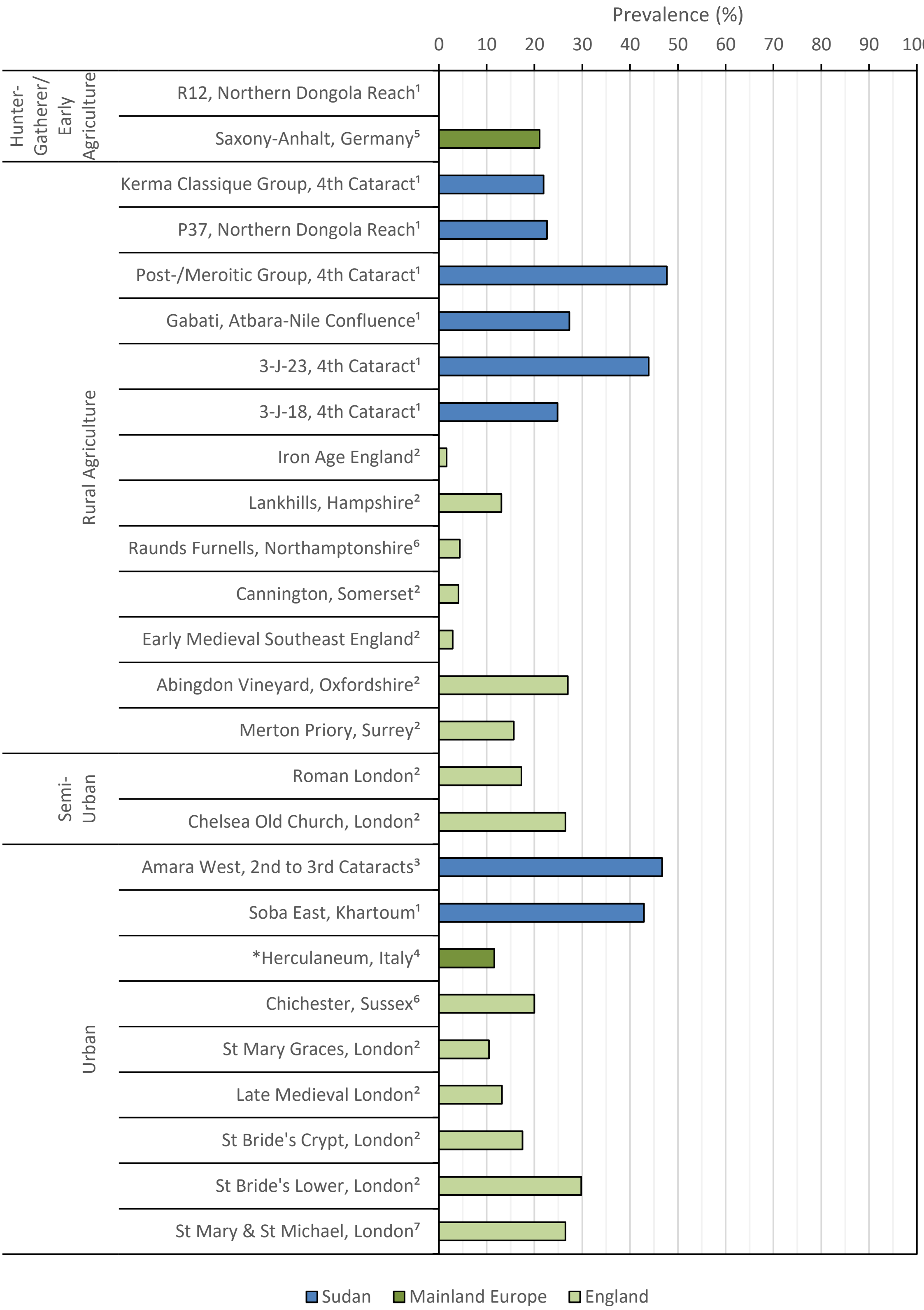


Figure 8.12 – A comparison of prevalence rates of rib IPR from various studies, according to subsistence strategy, geographical region, and then by time period (* = mixed adult and non-adult population).
Note: information regarding the subsistence economy in some studies could not be easily obtained and these sites were excluded from the analysis of rib IPR prevalence according to subsistence.

[1]Current study; [2]Bernofsky (2010); [3]Binder (2014); [4]Capasso (2000); [5]Nicklisch et al. (2012); [6]Roberts, Lewis, & Boocock (1998); [7]Walker & Henderson (2010)

Table 8.4 – Mean prevalence rates and ranges for rib IPR within different subsistence economies. Note: information regarding the subsistence economy in some studies could not be easily obtained and these sites were excluded from the analysis of rib IPR prevalence according to subsistence.

Subsistence	Number of sites	Mean Prevalence	Range
Hunter-Gatherer/ Early Agriculture	2	10.6%	0.0% – 21.1%
Rural Agriculture	13	19.7%	1.6% – 47.7%
Semi-Urban	2	23.5%	17.3% – 29.7%
Urban	9	24.0%	10.5% – 46.7%

It should also be noted that previously published methods for recording IPR on the visceral surfaces of the ribs were developed on relatively well-preserved human identified skeletal collections (e.g. Kelley & Micozzi, 1984; Roberts et al., 1994; Santos & Roberts, 2001, 2006; Matos & Santos, 2006). These methods are not always as easily applicable to skeletons from archaeological sites, whose ribs often have variable preservation. Furthermore, prior to the current study, there has been no research that has published criteria for identifying rib IPR and differentiating it from other bony changes on the ribs. This could, therefore, lead to under- or over-estimations of the prevalence of rib IPR, depending on the individual researcher's own diagnostic criteria. These factors may have affected the comparability of results between studies. For example, if only a small portion of the rib cage for each individual is observable at a site, due to poor preservation, then it is not possible to identify all rib IPR, resulting in lower crude prevalence rates. A relatively low rate recorded at the majority of archaeological sites may be due to this phenomenon. Attempts to account for the preservation of human skeletal remains, in particular the rib cage, and to record true as well as crude prevalence rates in the current study are discussed in Section 8.7.

8.4.3 Comparison between males and females

The uniform exposure of both men and women to poor air quality or pathogens in the general lived environment, or through performing similar tasks, may be reflected in comparable prevalence rates of respiratory disease. This has been suggested for the similar prevalence rates of maxillary sinusitis observed between males and females at the English Medieval sites of Chichester, Wharram Percy, and St. Helen-on-the-Walls, and at the 19th Century Almshouse in Rochester, New York, USA

(Boocock et al., 1995:493; Lewis et al., 1995:502; DiGangi & Sirianni, 2017:162). Most of the groups in this study (with large enough sample sizes to apply statistical tests) did not display a significant difference in either maxillary sinusitis or rib IPR between males and females (Figure 8.13). This may indicate that general exposure in the environment and within the home, rather than sex-specific risk factors, was increasing susceptibility to maxillary sinusitis, or that both sexes were undertaking similar tasks that led to an equal exposure to risk factors.

No significant differences between males and females have been found in other systematic studies of maxillary sinusitis in the Middle Nile Valley, from the Medieval sites of Kulubnarti and Mis Island and the New Kingdom/Post-New Kingdom site of Amara West, although there was a slightly higher prevalence in females at all sites (Roberts, 2007:798; Soler, 2012:242; Binder, 2014:214). In the current study, at P37 and 3-J-18 and in the Fourth Cataract Post-/Meroitic group, female maxillary sinusitis prevalence exceeded that of males, while at Soba East and in the Fourth Cataract Kerma Classique group sinusitis in males exceeded females. However, when statistically tested, none of these results were significantly different.

At 3-J-23 and Gabati a statistically significant difference in maxillary sinusitis between the sexes was present. In people buried at 3-J-23 the male prevalence rate exceeded the female rate by 28.7%. At Gabati females had a prevalence rate 26.8% higher than males. When grouped by time period, the comparative Meroitic and Post-Meroitic period, consisting of individuals from Gabati, displayed a significantly higher prevalence in females, with a difference of 26.7%. Interestingly, the Fourth Cataract Post-/Meroitic group mirrored this pattern, with females displaying a prevalence rate 24.2% higher than males. However, this sample group was too small to produce a statistically significant difference. This may suggest that during the Meroitic and Post-Meroitic, at Gabati in particular, females were more exposed to particulate matter or pathogens that may have caused maxillary sinusitis, while at 3-J-23 males buried during the Medieval period may have had a higher exposure to risk factors.

For the prevalence of rib IPR, a difference of 48.7% existed between males (5/16) and females (4/5) at Soba East. This may have been due to a greater exposure of females to infectious diseases or particulate matter, leading to lower respiratory tract disease. However, due to the small sample size, this difference was not statistically significant. A slightly higher prevalence of rib IPR in females was identified in the Fourth Cataract Kerma Classique and Post-/Meroitic periods and at 3-J-18. At 3-J-23 and P37 male prevalence slightly exceeded female prevalence, and at Gabati the prevalence of both sexes was almost equal. However, no statistically significant differences exist between the sexes in any population. The only other study of the prevalence of rib IPR in the Middle Nile Valley

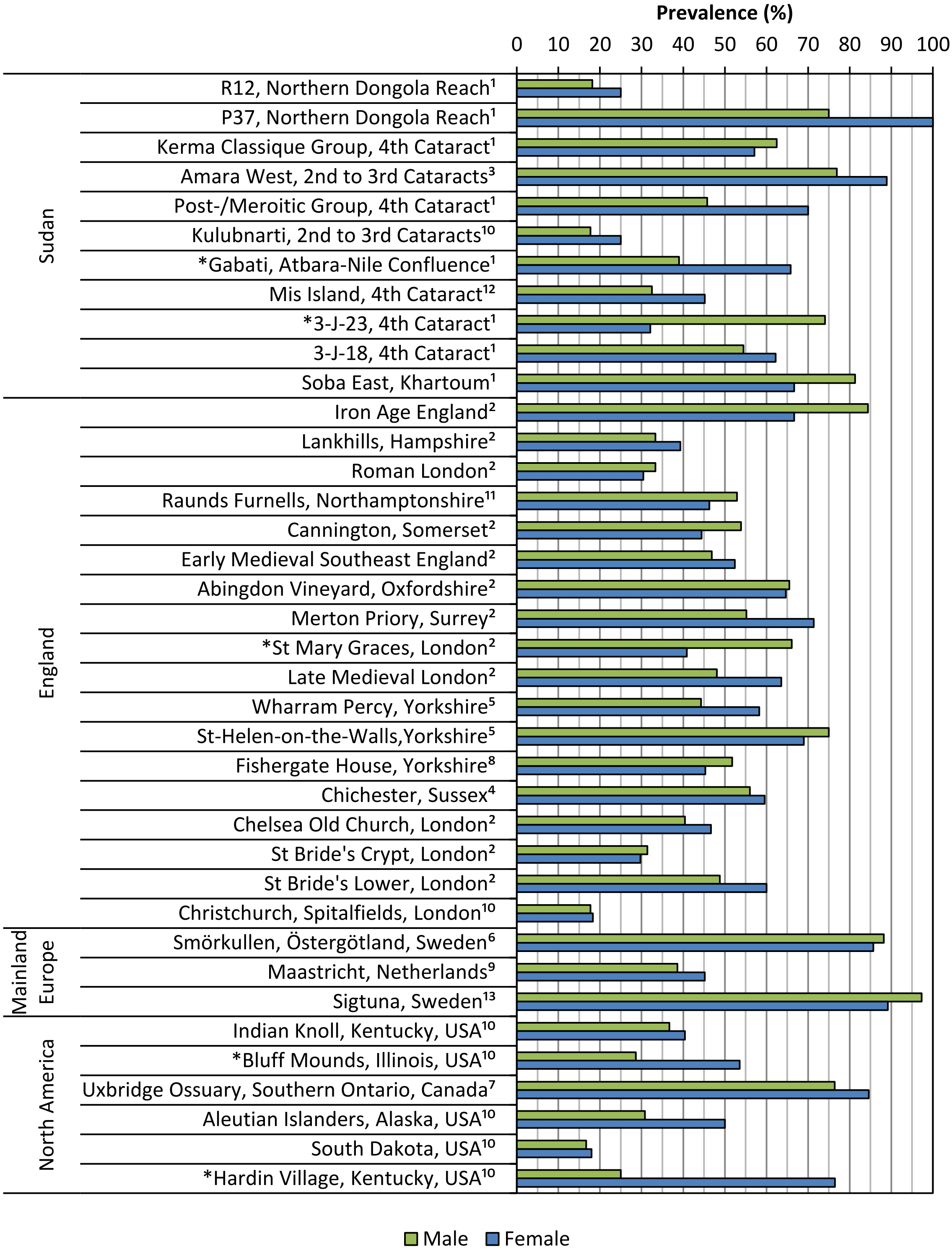


Figure 8.13 - A comparison of the prevalence rates of maxillary sinusitis in males and females from various studies (* = significant difference between males and females, p = <0.05).

[1]Current study; [2]Bernofsky (2010); [3]Binder (2014); [4]Boocock et al. (1995); [5]Lewis et al. (1995); [6]Liebe-Harkort (2012); [7]Merrett and Pfeiffer (2000); [8]Papapelekanos (2003); [9]Panhuysen et al. (1997); [10]Roberts (2007); [11]Roberts, Lewis, & Boocock (1998); [12]Soler (2012); [13]Sundman & Kjellström (2013)

(Amara West) also had equal prevalence rates between males and females (Binder, 2014:Table 8.50). Very few other studies of rib IPR have investigated differences between males and females (Figure 8.14). As with maxillary sinusitis, equal prevalence rates of rib IPR between the sexes may indicate equal exposure to risk factors involved in increasing susceptibility to lower respiratory tract diseases (Roberts, Lewis, & Boocock, 1998:108).

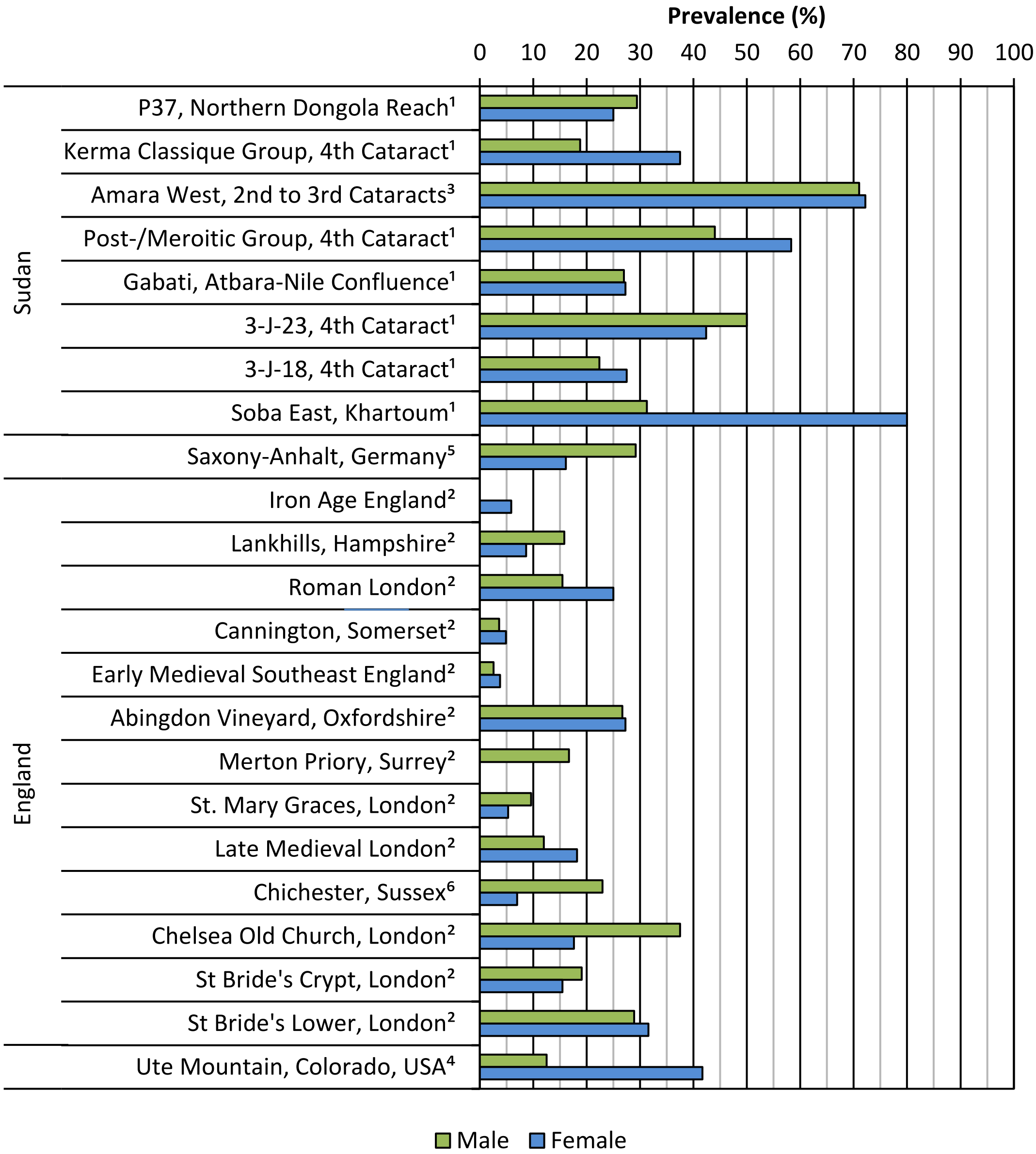


Figure 8.14 - A comparison of the prevalence rates of rib IPR in males and females from various studies. Data from studies other than the current one, consisting of percentages and frequencies of rib IPR in males and females, can be found in Table A.5 in Appendix A).

[1]Current study; [2]Bernofsky (2010); [3]Binder (2014); [4]Lambert (2002); [5]Nicklish et al. (2012); [6]Roberts, Lewis, & Boocock (1998)

It is difficult to suggest potential reasons for any differences observed in the prevalence of respiratory disease between males and females as archaeological and historical evidence for sex-specific tasks in the Middle Nile Valley is severely limited. However, different types of pottery production have been attributed to males and females based on ethnographic parallels. It has been suggested that women may have made rough hand-made pottery fired over open bonfires, while men may have produced fine wheel-made ceramics fired in kilns (W. Y. Adams, 1986:38-39; Welsby, 2002:190). If women were responsible for firing as well as shaping hand-made ware, they may have been exposed to greater concentrations of smoke from the open bonfires. However, in many instances, particularly in rural areas, the production of hand-made pottery was likely to have been undertaken on a part-time, small-scale basis. The wheel-made ware of the Meroitic and Medieval periods may have been undertaken at specialist pottery production centres by artisans, and if this constituted a role for men, then they may have been exposed to particulates from this activity on a more regular or daily basis.

For example, at the Medieval site of Sigtuna, in Sweden, the significantly higher prevalence of maxillary sinusitis in males was suggested to be due to the men being bronze casters and ironsmiths within the industrial workshops located in the town (Sundman & Kjellström, 2013:455). The significant difference ($p = <0.1$) between males from the rural site of Wharram Percy (44%), in the Yorkshire Wolds, England, and males from the nearby contemporary urban site of St. Helen-on-the-Walls (75%), York, was also suggested to be due to the exposure of men living in the city to poor air quality while working in industrially-based occupations (Lewis et al., 1995:504). A role in industrial production may be a factor in the higher prevalence of sinusitis in males at the city of Soba East (although not significantly so), which may have had industrial centres for the production and trade of pottery, metalwork, or other objects. While no settlement evidence has been recovered that is associated with 3-J-23, men buried at this site may also have had roles in the production of pottery or other objects, resulting in a significantly higher prevalence of maxillary sinusitis. However, despite the use of ethnographic paralells, there is no archaeological or historical evidence to discount women from a role in the production process either.

Changes in religion between each major time period in Sudan may have also affected the cultural and economic practices of men and women. Little can be speculated about the roles of the sexes in the Kerma and Kushite periods. However, during the Christian Medieval period a religious class made up of male monks may have played a role in specialised crafts, such as pottery, wall painting, and the production of parchment and written materials (Edwards, 2004:247; Obłuski, 2018). While some production roles may have exposed monks to particulates, their religious status could also have enabled them to avoid other occupations that the majority of people relied on, such as agriculture or the raising of livestock. This possibly protected them from a number of sources of PM or infectious disease.

In a rural agricultural context, ethnographic research on the Manâsîr women, who until recently lived in Kirbekân in the Fourth Cataract, has demonstrated more recent sex-specific activities (e.g., Salih, 1999; Weschenfelder, 2012a, 2012b). Women were responsible for the cultivation of land by the riverbanks and for the daily care of livestock, including the raising of goats and sheep, the collection of dairy products, the cutting of fodder, the procurement of drinking water, and the preparation of food for their families (Weschenfelder, 2012a:78-81, 2012b:253-254). Men, on the other hand, were responsible for the preparation of land, including ploughing and levelling, the cultivation and irrigation of cash crops, and of harvesting, including the cutting, binding into bundles, and threshing of crops (Salih, 1999:Table 5.14; Weschenfelder, 2012a:82). Women also aided in the threshing of straw and in winnowing (Salih, 1999:Table 5.14; Haberlah, 2012:Pl. 13). Another interesting activity of the Manâsîr women, and of married women from many other areas of northern Sudan, is the application of a 'smoke bath', known as a *duhkan*, to the face and body. This is done by burning acacia wood in the kitchen or courtyard and sitting over the smoke below a fabric covering. For the Manâsîr women, this regular exposure to smoke took place once a week and was used for cosmetic purposes (Haberlah, 2012:59). Exposure of women to particulates from wood smoke as part of the *duhkan* can have adverse health effects. For example, these smoke baths have been implicated in the development of dermatitis due to dust and smoke exposure (Ozturk et al., 2018), and have been discussed in relation to carbon inhalation causing oesophageal cancer (ElHassan et al., 2015). However, it is not evident how long this tradition has been practiced in Sudan and if it would have taken place in the time periods represented in the current study. A potential parallel to the modern *duhkan* has been noted in a Meroitic building at Musawwarat es Sufra, where a jar set into the floor was found filled with ash (Eigner, 2002:21), but this vessel may have served another function.

In the Darfur region of western Sudan women have also been observed to spend two to three hours a day grinding sorghum grain (Haaland, 2017:4). The grinding of maize using grinding rocks for just forty-five minutes a day by women from the Transkei district of South Africa, resulting in the inhalation of maize and stone dust, was thought to contribute to pneumoconiosis in women from this area (Grobbelaar & Bateman, 1991). As grains like sorghum, barley, and wheat were relied upon as a major staple of the diet from the Kerma to the Medieval period, it is likely that large portions of time were spent on the grinding of grain. If it was the role of women to undertake this activity, as has been recorded for the modern Darfur region, this may be a contributory factor to the slightly elevated prevalence rates of respiratory disease seen in females at some sites and to the significantly higher prevalence rates of maxillary sinusitis in females at Gabati.

Similarly, the issue of female exposure to particulate matter from cooking fires in developing countries today is of great concern as, traditionally, women are usually responsible for the preparation of food, spending long hours by the cooking fire (Bruce et al., 2000:1080; Fullerton et al., 2008:845; Perez-Padilla et al., 2010:1081; Sood, 2012:651; Amegah & Jaakkola, 2016:215). It has been noted by Weschenfelder (2012a:78-81, 2012b:253-254) that the Manâsîr women of the Fourth Cataract in recent times had the responsibility of preparing food, including cooking over fires. In a study of maxillary sinusitis from various populations from around the world with different subsistence economies, females were found to have a higher prevalence at hunter-gatherer and rural agricultural sites, but at urban sites men and women tended to have relatively equal prevalence rates (Roberts, 2007:Table 6). A significantly higher prevalence rate of maxillary sinusitis was found in females from the agricultural site of Hardin Village, Kentucky, and in the hunter-gatherer/early agricultural site of Bluff Mounds, Illinois, both in the USA (Roberts, 2007:798). It was suggested that female rates were higher in these instances due to longer time spent indoors exposed to particulate matter within the home, among other factors (Roberts, 2007:801, 803). At the Medieval site of Maastricht in the Netherlands, when individuals with dental disease were removed from the sample, females displayed a significantly higher prevalence of maxillary sinusitis than males. It was suggested this may be due to a higher exposure in women to smoke fires and also, in the case of the women from a nunnery cemetery, to infection whilst caring for the sick (Panhuysen et al., 1997:613-614).

Other sex-specific domestic roles may also have affected the prevalence of respiratory disease. One clinical study has suggested that a preponderance for pneumoconiosis caused by silica inhalation in Bedouin women from the Negev Desert, Israel, could be explained by their role in cleaning the tents, grinding coffee, and in particular preparing sheep wool into cloth. All these activities would have exposed women to dust from various sources (Hirsch et al., 1974:510). Additionally, Norboo et al. (1991:343) suggested that a higher prevalence of silicosis found in women from Himalayan villages was the result of their role in sweeping houses and undertaking farming work, exposing them to environmental dust. If past women in the Middle Nile Valley had undertaken similar roles, such as cooking, cleaning, and grinding grains, this may have contributed to the prevalence rates of respiratory disease observed in females in the majority of groups.

Certain gender-specific cultural behaviours may also have differentially affected the prevalence of respiratory disease between the sexes. For example, in a study of rib IPR in skeletons from the 19th

Century cemetery site of St Mary and St Michael, Whitechapel, London, Walker and Henderson (2010:214) concluded that males in early and middle adulthood were more frequently effected than females (although they do not provide any prevalence rates to support this) and discuss this in relation to the habit for men in Victorian London to smoke more frequently than women. They noted that individuals with evidence on the teeth for smoking, in the form of pipe facets or lingual tobacco staining, of which women made up a very small percentage, had a rib IPR prevalence rate 40.9% higher than individuals with no evidence for smoking (Walker & Henderson, 2010:215, Table 1). Therefore, males may have been demonstrating a higher prevalence rate of rib IPR than females due to the gendered cultural practice of smoking. Evidence for smoking pipes have been found in sub-Saharan Africa as early as 600 BC, and pipe bowls for smoking cannabis have been found in nearby Ethiopia dating from around AD 1325. However, there is as yet little evidence for any form of smoking, such as pipes, from Sudan prior to the Islamic period (Duvall, 2017:4-5) and no evidence for staining or pipe facets related to smoking have been noted in the skeletons during the current research.

Other factors, such as wearing protective clothing around the nose or mouth or the division of households and sleeping areas, may have buffered a specific sex from the inhalation of particulates. For example, recent ethnographic research on village architecture in the et-Tereif region of the Fourth Cataract has noted that men's living quarters were separate from those occupied by the women and children (Welsh, 2012:117). Wolf & Nowotnick (2005:29) also noted similar living situations for nomadic people recently living in the Fourth Cataract. Differences in ventilation and levels of crowding and sanitation in male and female living quarters could lead to differences in prevalence rates for respiratory disease. The prevalence rate of maxillary sinusitis for females at 3-J-23 was much lower compared to females from other groups in the Fourth Cataract. Considering how consistently populations in this study appear to have been affected in this region regardless of time period, this lower rate in females at 3-J-23 is unusual. While men at this site may have been engaged in activities that exposed them to greater concentrations of particulate matter or pathogens, women may also have been protected in some manner, although it is difficult to propose the mechanism by which this occurred without further settlement data. Unfortunately, there may be a whole host of cultural behaviours and practices in the Middle Nile Valley that could have differentially affected the exposure of certain groups to particulate matter, for which there is no evidence.

8.4.4 Comparison among age groups

As for comparisons of prevalence rates between the sexes, similar prevalence rates of maxillary sinusitis between different age groups have been used to suggest an equal exposure to factors causing a susceptibility to sinusitis (Boocock et al., 1995:493; Sundman & Kjellström, 2013:455). Within the current study the majority of groups displayed relatively equal prevalence rates of maxillary sinusitis between people in the young adult and middle adult age categories. The comparative Post-/Meroitic group had a slightly higher prevalence of maxillary sinusitis in middle adults, and the Fourth Cataract Kerma Classique period displayed a marked increase of 45.6% in middle adults. However, no statistically significant differences were found between frequencies for young and middle adults buried at any site or during any time period in the current study. In the Mis Island group a slight rise can be seen in prevalence between the young adult group (26.7%, 4/15) and the middle (42.9%, 12/28) and older adult (43.8%, 7/16) groups (Soler, 2012: calculated from Tables 47, 55, & 69). At Amara West prevalence in the young (79.2%, 19/24), middle (75.0%, 22/30), and older adults (85.7%, 6/7) was relatively equal, although there was a slight rise between middle and older adults (calculated from Binder, 2014:Table 8.46). Using a Chi-square test, neither study displayed a significant difference in frequency between age groups (Mis Island: χ^2 (2) = 1.61, p = 0.447; Amara West: χ^2 (2) = 0.59, p = 0.745).

The relatively equal prevalence rates for maxillary sinusitis between age categories in the majority of groups from the Middle Nile Valley might indicate that individuals of different ages were being equally exposed to sources of particulate matter or infectious diseases. However, if all ages were being equally exposed to factors causing a susceptibility to maxillary sinusitis, it might be expected that age groups consisting of older individuals would display a higher prevalence, as they would have had a longer duration of exposure to particulate matter and more time to develop the disease. Studies from other regions of the world have demonstrated an increase in sinusitis with age (Panhuysen et al., 1997:612; Merrett & Pfeiffer, 2000:310; Bernofksy, 2010:184; Liebe-Harkort, 2012:392). However, while Panhuysen et al. (1997:612) and Merrett and Pfeiffer (2000:310-311) found a significant increase in maxillary sinusitis with age, when individuals affected by dental disease were removed from the age groups, the significant difference was lost. In the study by Merrett and Pfeiffer (2000), the prevalence of sinusitis actually declined with age. Other studies have revealed no significant differences in the prevalence of maxillary sinusitis among different age groups (Boocock et al., 1995:486-487; Digangi & Sirianni, 2017:160). This is not consistent with an expected increase in sinusitis with age.

By measuring the extent of the surface of the sinus affected by bony changes, a study of maxillary sinusitis at the Medieval site of Sigtuna, Sweden, found that, while there was no significant difference in the prevalence of maxillary sinusitis between age groups, older individuals were significantly more likely to show a greater degree of bone change (Sundman & Kjellström, 2013:454, 455). Once developed, chronic sinusitis can often reoccur throughout life (Hamilos, 2000:213, 215), and this continued cycle of inflammation may contribute to a greater degree of bone change in older individuals. Due to the variability in preservation of the sinuses, this study did not measure the extent or degree of bony changes observed as it was not considered possible to accurately measure this without being able to observe 100% of the sinus surface. It should also be noted that a lack of clinical studies of the bone changes related to maxillary sinusitis makes it problematic to assume that more proliferative bone changes are associated with prolonged or repeated instances of sinusitis (Boocock et al., 1995:493).

However, an equal prevalence between ages and increased severity of bone changes in older individuals could indicate that exposure was occurring from an early age, and that by the time a person reached the age range of young adult they were already likely to have developed maxillary sinusitis. In a longitudinal study of sinusitis in childhood and adulthood, Chang et al. (2018:1294) found that one of the strongest independent risk factors for adult sinusitis, with a four-fold odds increase, was a diagnosis of sinusitis as a child. Although not the case for all adult instances of sinusitis, allergic sensitisation during childhood, with a susceptibility to asthma, colds, and viral infection, was also found to be a contributory factor in the development of the disease in later life. This may indicate that individuals can be predisposed to chronic maxillary sinusitis from an early age and that prevalence rates of sinusitis may reflect childhood exposure to particulates, pathogens, and allergens. This has implications for the interpretation of prevalence rates of maxillary sinusitis based on exposure to risk factors during adult life, for example through specific occupational roles. However, Chang et al. (2018:1296) also identified a type of late onset sinusitis occurring only in adults, with no risk factors from childhood, that suggests other influences during adult life can also increase susceptibility to the development of maxillary sinusitis (as has been demonstrated in numerous clinical studies – see Section 2.2.3). Further clinical studies of the correlation between childhood and adult sinusitis may help to elucidate this.

Furthermore, those with a compromised immune system earlier in life, including an increased risk of death in early adulthood, may have been the portion of the population more likely to contract sinusitis at an earlier age and, thus, the prevalence of maxillary sinusitis may be overrepresented in the younger adult age group (DeWitte & Stojanowski, 2015:407). Those with lower frailty, surviving into later life, may have contracted sinusitis later in middle adulthood, leading to the relatively equal prevalence rates observed between those dying in earlier and later adult life. Therefore, the observations of the prevalence of maxillary sinusitis by age, and the following interpretations made of exposure to particulate matter, may be secondary to factors affecting the immune system and risk of death, although the two can be closely correlated.

While maxillary sinusitis very rarely causes death and was not likely to have contributed to the mortality of the individual, many of the diseases causing rib IPR, such as tuberculosis or pneumonia, can be fatal and were particularly so in the pre-antibiotic era (e.g. Frost, 1995; Troeger et al., 2017:1153). Therefore, interpretations of the prevalence of maxillary sinusitis and rib IPR according to age-at-death should be considered separately. An equal prevalence of rib IPR between young and middle adult groups may indicate an equal risk of mortality from a respiratory infection. This may be due to general exposure to particulates and pathogens across all age groups. While no sites in this study showed a significant difference between the prevalence of rib IPR in young adult and middle adult age groups, the majority of sites displayed a slight increase in the prevalence of rib IPR in middle adults. The largest difference was at Soba East, where the middle adult group had an IPR prevalence rate 21.9% higher than in the young adult group. Only 3-J-23 showed a higher prevalence in the young adult age group. At Amara West, young (64.7%, 22/34) and middle adult (64.0%, 16/25) age groups showed similar prevalence rates. However, the old adult age group displayed a much lower prevalence of 13.9% (5/36). A significant difference was observed between these groups (χ^2 (2) = 23.0, p = <0.001). It should be noted that, although there is a risk of mortality with certain lower respiratory tract diseases, an individual may also survive. Therefore, a consideration of the extent of remodelling of rib IPR, indicating whether or not an individual began to recover from the disease causing inflammation, can help to elucidate this (see Section 8.6). Certain age groups may have had higher frailty, meaning they were less likely to survive a lower respiratory tract disease long enough to develop new bone on the visceral surfaces of the ribs (Wood et al., 1992:345; DeWitte & Stojanowski, 2015:407). This could indicate why the prevalence of rib IPR in the older adult age group at Amara West was significantly lower than that of the younger age categories.

Data from late nineteenth century Massachusetts, before the introduction of a vaccine for tuberculosis, indicate that peak mortality for the disease occurred in early adult life, from between 20 and 29 years of age (Frost, 1995). In a study of rib lesions from the Smithsonian Institution's Terry Collection of identified human skeletons, Roberts et al. (1994:172-173) found a significantly higher prevalence of rib IPR in younger adult individuals who died from tuberculosis, compared to individuals who died from a non-pulmonary cause of death. Several studies of archaeological skeletons have suggested that the higher prevalence of rib IPR observed in young adults is consistent with an increased susceptibility to tuberculosis in this age group (e.g. Buikstra & Williams, 1991:167; Kelley et al., 1994:126-127; Lambert, 2002:285). For example, Kelley et al. (1994:Fig. 10) compared the demographic profile of individuals with rib IPR from native Arikara skeletons (South Dakota, USA) with clinical demographic data from hospital admissions for tuberculosis and pneumonia. The age distribution for both hospital admissions for tuberculosis and for the Arikara series showed a peak in the adolescent age groups, while pneumonia prevalence was very low in adolescents and rose in later age groups. Based on the age distribution and the location of lesions within the rib cage, Kelley et al. (1994:129) suggested that tuberculosis was the most likely respiratory disease to have caused the rib IPR in this population. Walker and Henderson (2010:214) also found the prevalence of rib IPR peaked in the age category of 18-25 years in people buried in the nineteenth century London cemetery of St Mary and St. Michael. While it was suggested that the higher prevalence in young adults, particularly in males, may be related to the habit of smoking in this age group, the results could also reflect a demographic group susceptible to tuberculosis (Walker & Henderson, 2010:214-215).

An important issue to consider when comparing prevalence rates for respiratory disease in age groups between archaeological studies is that different researchers use different age group parameters. For example, the studies by Binder (2014) and Soler (2012) on other Middle Nile Valley sites present three separate adult age groups: young adult (21-35/20-35), middle adult (36-50/35-50), and old adult (50+). However, in the current study, adolescents (16-19) and young adults (20-34) were grouped into a young adult category, and middle (34-50) and older adults (50+) into a middle adult category in order to increase the size of the sample groups. It may be that the allocation of individuals in the current research into groups with such large age ranges may have obscured differences in prevalence rates between the different ages-at-death. However, it is often challenging to accurately estimate the age-at-death of a skeleton using current macroscopic osteological methods (especially when skeletons are poorly preserved) and different methods often provide scores with associated age ranges that overlap with one another (see Section 6.4). Furthermore, increasing the number of adult age categories reduces the sample size for each group and the ability to apply statistical testing and risks increasing the chance of inaccurately allocating an individual into the wrong age group.

8.5 Odontogenic sinusitis

Odontogenic sinusitis was relatively low in the majority of groups in the current study, affecting 0-6% of sinuses in most populations. However, a distinct rise in frequency was evident in skeletons from R12 (18.8% of all sinuses), 3-J-23 (11.4%), and 3-J-18 (10.3%). This may be related to increased instances of dental disease in these groups. In individuals from Neolithic R12 there was a high prevalence of non-carious pulp-exposure, possibly due to dental wear, leading to peri-apical infection. The high level of wear may have been due to the tough consistency of food or gritty inclusions in the diet, although it will have also increased with age. At the Fourth Cataract Medieval sites an increased rate of dental disease may also have been due to high levels of wear and the type of food consumed, such as sticky carbohydrates or increased availability of sugars, which can lead to caries and periapical lesions (R. Whiting, pers. comm., 2018).

When studies of maxillary sinusitis present data for odontogenic sinusitis it is usually according to the frequency of individuals affected, rather than by sinuses involved (e.g. Roberts, 2007; Liebe-Harkort, 2012; Sundman & Kjellström, 2013). It is not stipulated in the methods of these publications whether individuals were excluded from the sample group used to calculate odontogenic sinusitis prevalence if the alveolar bone of one or more of the sinuses was damaged or absent. Thus, it has to be assumed that in the majority of cases individuals were not excluded when preservation was poor as the sample size would have then been greatly reduced.

Figure 8.15 displays a comparison of the proportion of people affected by odontogenic and rhinogenic sinusitis in various studies, including the results from the Middle Nile Valley. For comparative purposes with other studies, the data for odontogenic sinusitis in the current research was presented according to the number of individuals affected, without removing individuals that had damaged alveolar bone in one or more of the sinuses. However, presenting the data in this manner does not take into account the fact that an oroantral fistula may be unobservable (because the part of the alveolar bone affected was not preserved) rather than absent, nor the fact that one sinus may be affected by odontogenic sinusitis due to an oroantral fistula, while the other sinus may be affected by rhinogenic sinusitis. A more nuanced understanding of the prevalence of odontogenic and rhinogenic sinusitis is likely to be gained in bioarchaeology by presenting data by sinus rather than by individual and by reporting a group for sinuses that could not be assigned a definite cause of sinusitis due to damage, as has been presented in the results in the current study.

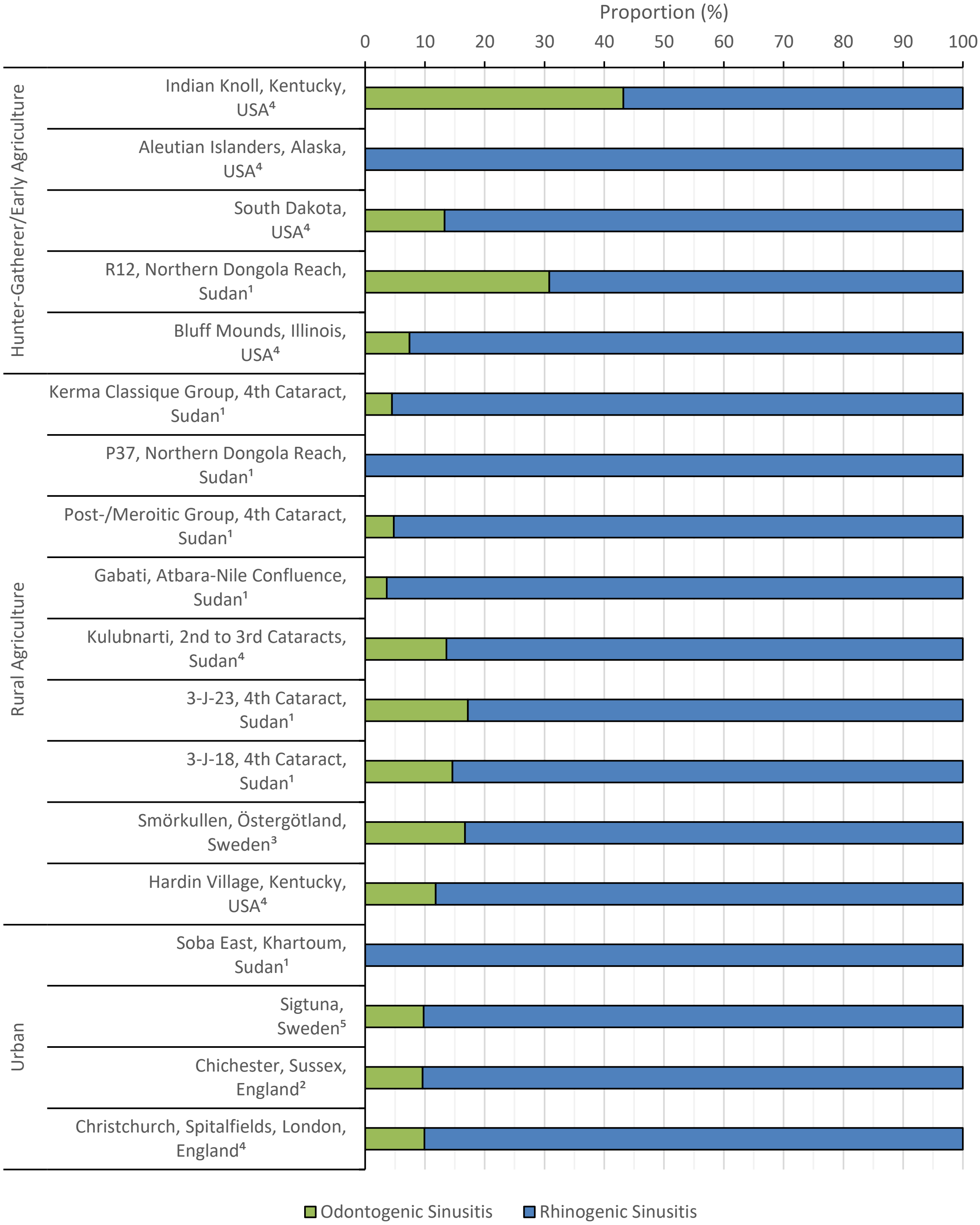


Figure 8.15 – A comparison of the proportion of odontogenic and rhinogenic sinusitis observed at various sites. Note: Studies have been included if only the presence of an oroantral fistula was used as evidence for odontogenic sinusitis.

[1]Current study; [2]Boocock et al. (1995); [3]Liebe-Harkort (2012); [4]Roberts (2007); [5]Sundman & Kjellström (2013)

At the Medieval Middle Nile Valley site of Kulubnarti, 13.6% (3/22) of individuals with sinusitis also displayed evidence for an oroantral fistula (Roberts, 2007:Table 7). This is comparable to the Fourth Cataract Medieval sites in the current study. At 3-J-18 and 3-J-23 14.6% (7/48) and 17.2% (5/29) of individuals displayed evidence for an oroantral fistula, respectively. However, the comparative Medieval group (comprised of individuals from Soba East and Medieval Gabati) displayed no evidence for odontogenic sinusitis (0/55). Dental analysis of the individuals from Soba East has also demonstrated a lower prevalence of other types of dental disease, such as caries, compared to the Fourth Cataract Medieval sites (R. Whiting, pers. comm., 2018). This may be the result of differences in diet between the more northern sites found within the Christian kingdoms of Nobadia and Makuria, and the southern kingdom of Alwa, where Soba East and Gabati were situated.

The proportion of odontogenic sinusitis in individuals buried at Neolithic R12 is the second highest frequency from any study (30.8%, 4/13), second only to Indian Knoll, Kentucky (43.2%, 16/37). People buried at both Indian Knoll and R12 practiced hunter-gathering, although at R12 early agricultural practices such as pastoralism and plant cultivation were also utilised. It is possible that similar subsistence strategies or approaches to food preparation led to increased rates of dental disease and oroantral fistulae in these two groups. However, other hunter-gatherer and early agricultural sites show much lower proportions of odontogenic sinusitis. The proportion of odontogenic sinusitis at rural Medieval Sudanese sites from the Fourth Cataract is comparable to rural agricultural and urban sites in other parts of the world. However, earlier rural agricultural sites from the Middle Nile Valley and from Medieval Soba East have lower frequencies of odontogenic sinusitis. Thus, it is likely that geographically distinct cultural practices and types of food available, in addition to subsistence activties, had an effect on the prevalence of odontogenic sinusitis at different sites.

In the clinical literature, studies tend to cite the prevalence of odontogenic sinusitis at around 10-12% of all instances of maxillary sinusitis, without any substantial evidence to support this claim (e.g. Brook, 2006:349, 2009:132; Mehra and Jeong, 2009:238). However, more recent clinical studies suggest an odontogenic cause may in fact be present in around 30-40% of all people who have chronic maxillary sinusitis (Simuntis et al., 2014:42), and has been recorded as high as 51.8% (Maillet et al., 2011:756-757). In the current study, odontogenic sinusitis was generally much lower, but the only evidence used to determine a dental origin was the presence of an oroantral fistula. Although oroantral fistulae have been noted as the most common cause of odontogenic chronic maxillary sinusitis (Akhlaghi et al., 2015:4), it has been found that, while 95% (20/21) of patients with odontogenic sinusitis had periapical abscesses, only 24% (5/21) displayed an oroantral fistula (Longhini & Ferguson, 2011:411). Lee and Lee (2010:934) also found that only 25.9% of instances of odontogenic sinusitis were proved to be caused by an oroantral fistula. The fact that the average prevalence rates of odontogenic sinusitis recorded in clinical studies are higher than those found in archaeological studies indicates that odontogenic sinusitis in archaeological populations is not always detectable from the available evidence.

For example, in a study of maxillary sinusitis in skeletons from southeast English archaeological sites, Bernofsky (2010:171, 251-252) found that periapical abscesses that resulted in a medial or lateral oral sinus had a significant association with maxillary sinusitis. Liebe-Harkort (2012:392) also found that maxillary sinusitis and periapical lesions were significantly likely to co-occur in an archaeological population from Iron Age Sweden. However, using a range of statistical tests, DiGangi and Sirianni (2017:160) found no correlation between the presence of maxillary sinusitis and dental diseases. The results from these studies are complicated by the fact that, while oroantral fistulae provide evidence for the direct route of infection into the maxillary sinus, periapical abscesses may not always lead to the spread of infection and are, therefore, not direct evidence of odontogenic maxillary sinusitis (Roberts, 2007:797). Further research into the correlation between the prevalence of maxillary sinusitis and the prevalence of various forms of dental disease in archaeological populations may help to clarify this point.

Another factor that could explain the disparity between prevalence rates of odontogenic sinusitis in bioarchaeological and clinical studies is that current dental healthcare may have an impact on the incidence of odontogenic sinusitis. Some of the most common causes of odontogenic sinusitis today include displaced tooth roots after extraction, other foreign bodies introduced to the sinus (such as dental fillings), and complications with dental implants (Lopatin et al., 2002:Table 1). One meta-analysis found that odontogenic sinusitis was the result of medical complications in 56% of cases (Arias-Irimia et al., 2010:e71). Another study recorded that 66.6% (18/27) of incidences of odontogenic sinusitis were related to dental implants or dental extractions and only 7.4% (2/27) were caused by dental caries (Lee & Lee, 2010:Fig. 2). Thus, the frequency of odontogenic sinusitis in archaeological populations may be lower if less invasive medical treatments for dental diseases were utilised in the past. However, without modern healthcare practices, the rate of odontogenic sinusitis caused by caries, periapical abscesses, and oroantral fistulae may have actually been higher.

While Longhini and Ferguson (2011:414) found that dental disease was associated with bilateral sinusitis just as frequently as in unilateral sinusitis, other clinical studies have shown that odontogenic sinusitis commonly causes unilateral symptoms (Lee & Lee, 2010:934; Patel & Ferguson, 2012:26; Simuntis et al, 2014:40). Chronic unilateral sinusitis may be of dental origin in around 30% of cases (Patel & Ferguson, 2012:27), but has been recorded as high as 72.6% (138/190) (Matsumoto et al., 2015:289). If unilateral sinusitis is more common in instances of odontogenic sinusitis, it might be expected that groups with a high proportion of odontogenic sinusitis, such as R12, might also have a high proportion of unilateral sinusitis.

Figure 8.16 compares the proportion of individuals with unilateral and bilateral sinusitis and the proportion of individuals with odontogenic and rhinogenic sinusitis from groups in the current study. No evident pattern is apparent between the type or laterality of the sinusitis. For example, Gabati displays a very low prevalence of odontogenic sinusitis but has a relatively high proportion of unilateral sinusitis. However, this could indicate that certain groups had a higher prevalence of odontogenic sinusitis but did not always have, or due to damage did not always display, evidence for an oroantral fistula. The number of individuals making up the sample groups in this study were also small. Further research of larger groups with a higher proportion of individuals with evidence for odontogenic sinusitis may provide further information. It should also be considered that the observation of unilateral sinusitis does not preclude an individual from having had bilateral sinusitis. Instead, bony changes may have never manifested in one of the sinuses or these changes may be unobservable due to damage to the sinus.

In CT scans of patients with maxillary sinusitis, Bomeli et al. (2009:Table 2) found that patients were 86% more likely to have odontogenic maxillary sinusitis when mucosal thickening was at its most severe. This may suggest that more extensive changes in the maxillary sinus may be due to odontogenic sinusitis. However, the degree or extent of bony changes to the maxillary sinus were not recorded in the current study. Additionally, while proliferative bone formation in the sinus is assumed to be related to a prolonged experience of sinusitis or greater levels of inflammation, this cannot be verified until clinical studies can provide more detailed evidence of the processes of bone changes related to maxillary sinusitis (Boocock et al., 1995:493).

When relying on evidence for rhinogenic sinusitis to make suggestions about the exposure of a population to environmental factors, it is important to bear in mind the confounding influence of odontogenic sinusitis. It may not always be possible to determine the origin of the sinus infection. In archaeological populations prevalence rates of odontogenic sinusitis may be higher than can be detected simply by the presence of an oroantral fistula. It is also important to note that rhinogenic and odontogenic sinusitis are not mutually exclusive and a person may have had both forms at some point in their life (Wells, 1977:175; Merrett & Pfeiffer, 2001:312; Sundman & Kjellström, 2013:448). Thus, differentiating between the two types of sinusitis is problematic for bioarchaeologists. However, further research into the correlation between maxillary sinusitis and different types of dental disease and a careful consideration of the clinical literature on odontogenic sinusitis may help to improve methods of differentiating the origins of the disease in human skeletal remains in the future.

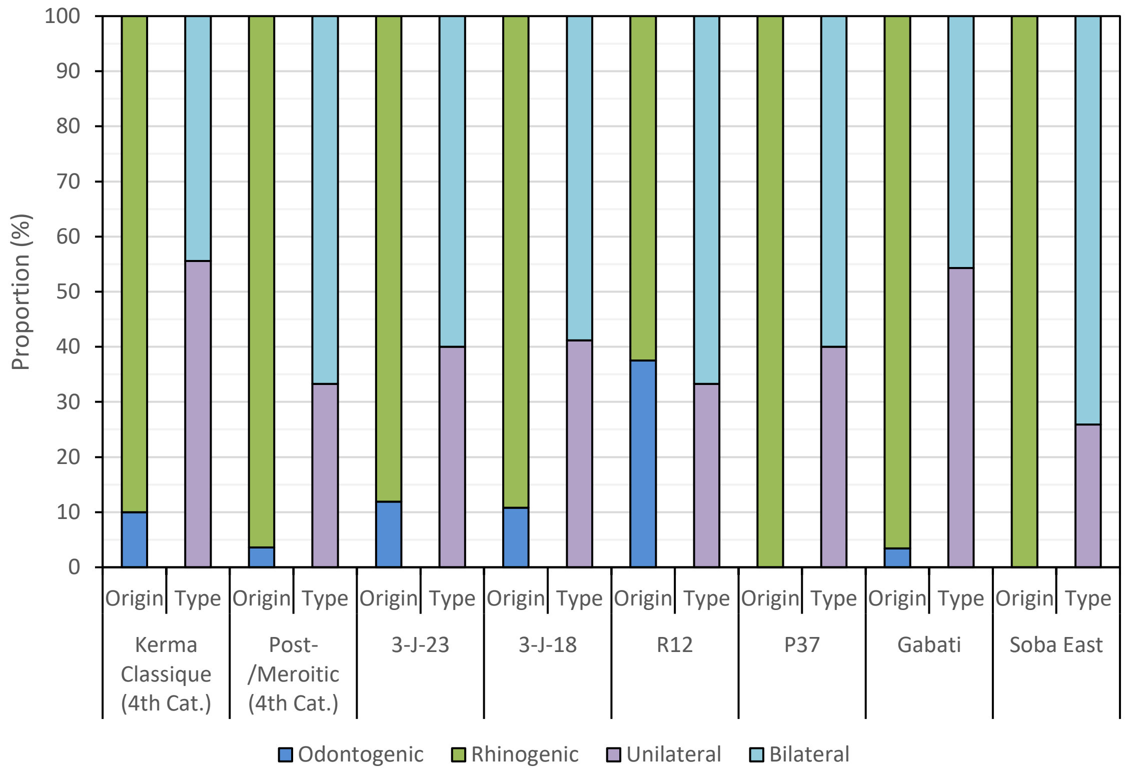


Figure 8.16 – A comparison between the proportion of individuals with rhinogenic or odontogenic sinusitis and the proportion of individuals with unilateral or bilateral sinusitis within each group in the current study, after individuals with an unobservable origin or unknown type of sinusitis have been removed from the sample.

8.6 Phase of rib IPR remodelling

The phase of remodelling of periosteal reaction can indicate whether an individual died whilst inflammation was occurring or after the inflammation had been resolved or quiesced. Active (woven bone) and remodelling (a mix of woven and lamellar bone) lesions indicate that the individual died not long after the bone had been formed, suggesting that inflammation was still present or the disease was recently active. In the case of remodelling lesions, the individual was likely to have survived long enough for the bone to begin ‘reorganising’ itself. Remodelled (lamellar) bone indicates that the disease was no longer active and that the bone had had time to remodel (Weston, 2008:51-52; Roberts & Manchester, 2010:8). Although little is written about the time frame for periosteal new bone formation, bone is thought to begin to form if the inflammatory response persists for more than two weeks (Weston, 2008:49). The time taken to remodel into lamellar bone is unknown. In the case of fractures this can take a few weeks to a few months depending on the skeletal element and the type of fracture (Lovell, 1997:144-145, Table 3). For periosteal reaction only, the time taken to remodel could be just as variable. Thus, a person must survive the disease for at least two weeks in order to display any observable bone changes, and must live some time longer to begin to display signs of remodelling or completely healed IPR.

Researchers have suggested that the phase of remodelling of skeletal lesions could provide information about the frailty of a population (e.g. Wood et al., 1992; Mays et al., 2002:30; DeWitte, 2014). In a study of periosteal reaction in relation to survivorship in individuals from Medieval London, DeWitte (2014:42, Table 2) found that those individuals displaying healed periosteal lesions had higher survivorship (i.e. lived longer) than people with active lesions or those with no periosteal reaction at all. Mixed reaction (woven and lamellar) lesions also indicated higher survivorship, although this was lower than individuals with healed periosteal reaction. This indicated that those with active lesions had a higher frailty, but also that some individuals without any lesions may have been so frail that they did not survive a disease long enough to begin to form new bone (DeWitte, 2014:42), although it is impossible to tell what proportion.

Figure 8.17 displays the proportion of individuals with rib IPR who had active (woven bone), remodelling (woven and lamellar bone), and remodelled (lamellar bone) lesions. The majority of individuals from most sites were observed to have IPR that was either active or remodelling. This suggests that inflammation of the pleura and of the lower respiratory tract may have been active not long prior to death and could also indicate that lower respiratory tract disease may have contributed towards the death of the individual. Infectious lower respiratory tract diseases, such as pneumonia, can be deadly and even today are responsible for 2.74 million deaths per year (Troeger et al., 2017:1153). Although it is not possible to determine if the respiratory disease itself was the sole cause of death, it can be suggested that it may have contributed towards mortality (Roberts & Manchester, 2010:8).

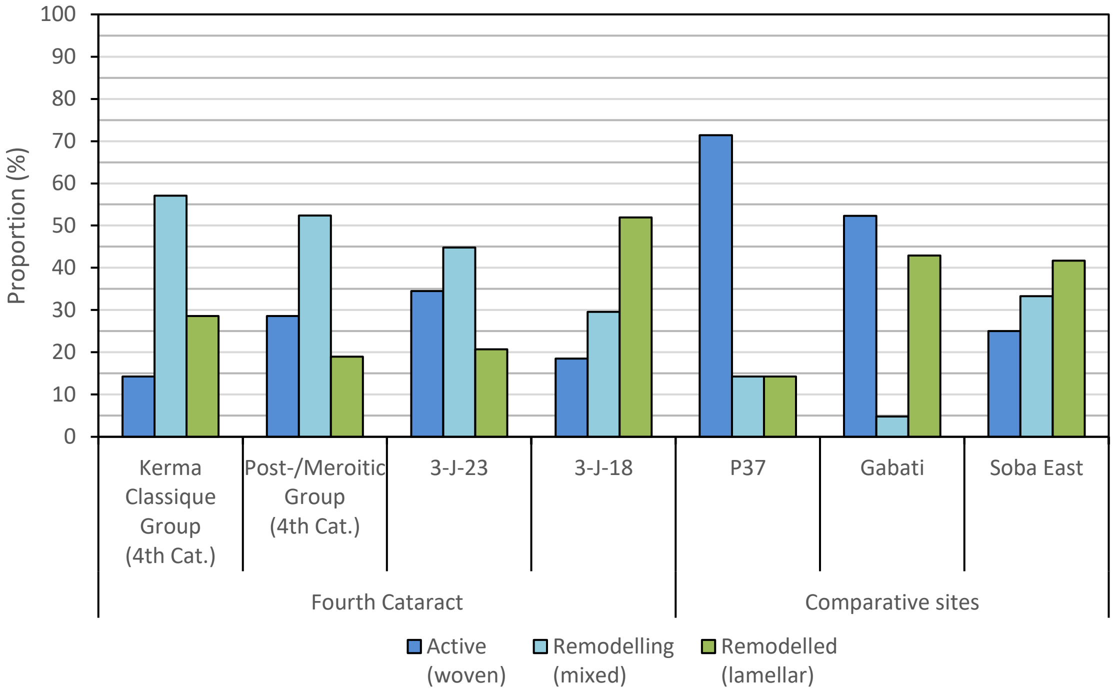


Figure 8.17 – A comparison of the proportion of individuals with active, remodelling, and remodelled rib IPR in different groups from the current study.

In particular, a large proportion of individuals with rib IPR from P37 and Gabati displayed lesions consisting of woven bone. This could suggest that individuals at these sites had compromised immune systems due to a number of factors, such as poor nutrition, low levels of hygiene, or the presence of comorbidities. These sites also displayed fairly low crude prevalence rates of rib IPR, which might indicate that, rather than there being fewer people who had lower respiratory tract diseases, these groups were so frail that individuals were dying before they could manifest bony changes related to inflammation (e.g. Wood et al., 1992:345; DeWitte & Stojanowski, 2015:407; DeWitte, 2014:42). However, Gabati also demonstrated a relatively high proportion of individuals with remodelled rib IPR. This might suggest that different groups at the site had different levels of frailty or that conditions for the population buried at Gabati changed over time.

At 3-J-18 over 50% of individuals displayed completely remodelled IPR. If the low prevalence of rib IPR at this site was because people were so frail that they were dying before they could manifest bony changes, then it would also be expected that a higher proportion of the skeletons that did have rib IPR would display active lesions. As the majority of lesions at this site consisted of remodelled IPR, this could instead indicate that people buried at this site had lower frailty, that the lower respiratory tract diseases affecting individuals were not as acute or deadly (DeWitte, 2014:43), or that the low crude prevalence of rib IPR could simply indicate that respiratory disease prevalence at the site was indeed relatively low.

An investigation into the age distribution of individuals with rib IPR that had different stages of remodelling could add further context to this interpretation (DeWitte, 2014:43). For example, it might be expected that the very young and the very old would demonstrate higher frailty. In the current study a higher proportion of remodelled rib IPR was observed in the entire sample in the middle adult age category (46.8%, 29/62), compared to young adults (20.7%, 11/53), consistent with enhanced survivability in individuals with remodelled lesions (DeWitte, 2014:43). Unfortunately, the age categories employed in this study were too broad, non-adults were not included, and sample sizes for each site too small to allow for a detailed examination of the demographic distribution of phases of rib IPR remodelling in different populations. It should also be considered that as lamellar bone integrates with the cortical surface as it heals, it is much harder to observe and differentiate from normal bone than woven or remodelling IPR. This may have resulted in lower proportions of remodelled IPR from being observed in the current research.

Populations are not static, conditions change, and the factors affecting the mortality of individuals at a site are highly complex and cannot simply be generalised using three categories of bone remodelling. However, a high proportion of individuals with remodelled rib IPR, such as at 3-J-18, could broadly indicate a population with lower frailty, perhaps due to better nutrition and environmental conditions, such as improved sanitation. Similarly, a high proportion of individuals with active rib IPR, for example at P37 and Gabati, could indicate the opposite. Identifying these general differences among sites can help to identify further avenues for more detailed research.

8.7 True prevalence and rib IPR distribution

It has been hypothesised that a careful consideration of the specific distribution of rib IPR within the rib cage in relation to the underlying anatomical structures could help to identify specific diseases (Santos & Roberts, 2006:47; Waldron, 2009:117). For example, in tuberculosis the upper lobe of the lung is affected most commonly (e.g. Chang et al., 1967:230; Berger & Granada, 1974:522; Moreira et al., 2011:236; Capone et al., 2017:3-4; Kim et al., 2017:112). If the lower lobe is involved it tends to be caused by spread of the disease from the upper lobe (Berger & Granada, 1974:522). In 1,276 hospital admissions for pulmonary tuberculosis, only 5.1% presented solely lower lung involvement (Chang et al., 1967:239). Similar studies have found lower lung involvement in 5.4% (Kourbatova et al., 2006:Table 1) and 7% (Berger and Granada, 1974:522-523) of patients with pulmonary tuberculosis. However, it has also been noted that pleural effusion occurs more often in lower lung disease than in upper lobe involvement (Berger & Granada, 1974:525), which could lead to a greater prevalence of rib IPR in instances of lower lung tuberculosis. It has also been observed that while immunocompetent individuals are likely to have upper lobe involvement in pulmonary tuberculosis, the lower lung is more commonly affected in the immunocompromised, who are also more likely to develop pleural effusions (Jabbar, et al., 2006:526; Rozenshtein et al., 2015:974-975; Kim et al., 2017:112).

Unilateral involvement of the lower lobe is most common in pneumonia, except in the case of the pathogen *Klebsiella pneumoniae,* which tends to affect the right upper lobe, and in *Legionella* or severe pneumococcal pneumonia, which can cause multilobar involvement (Heffron, 1939:108-111; Sadashivaiah & Carr, 2009:88; Nambu et al., 2014:783, 785). In a study of 4,644 patients diagnosed with pneumonia, Liapikou et al. (2016:1) found that only 23% of all instances of pneumonia involved more than one lobe and only 13% of all instances were bilateral. This could suggest that IPR related to inflammation caused by pneumonia may be more localised. In cases of pneumonia caused by tuberculosis, the upper lobes and in particular the right (in 67.8% of incidences), appeared to be primarily affected (Moreira et al., 2011:234). In actinomycosis, the lower lobe of the lung is more likely to be affected, which is often the case for pulmonary diseases caused by aspiration of pathogens (Mabeza & Macfarlane, 2003:548; Farrokh et al., 2014:55), such as aspiration pneumonia (Beigelman-Aubry et al., 2012:433).

Bilateral lung involvement in tuberculosis appears to be more common than in pneumonia, although the frequency can vary considerably (e.g. Kourbatova et al., 2006:Table 1; Capone et al., 2017:2; Kim et al., 2017). Kim et al. (2017:Table 2) found bilateral involvement in 41% of individuals with just tuberculosis and in 58% of immunocompromised individuals with diabetes and TB. In an analysis of the risk factors for mortality, Kourbatova et al. (2006:Table 1) found that 80.4% of those who died from pulmonary tuberculosis had bilateral involvement, whereas only 38.6% of those who survived the disease presented the same. If bilateral tuberculosis was more likely to lead to death then a high prevalence of active (woven bone) bilateral lesions in a skeletal population could be caused by tuberculosis. It has also been noted that bilaterality in tuberculosis may increase with the duration of the disease (Sant'Anna et al., 2011:41), suggesting that bilateral lesions may be more common in those who survive the disease for a prolonged amount of time (i.e. long enough to manifest bone changes).

The greater involvement of either the left or right lung in certain diseases varies by study, which will reflect the study sample. Capone et al. (2017:2) found a higher left lobe involvement (56%) than right lobe involvement (38%) in CT scans of individuals with pulmonary tuberculosis, although the difference was only small. In a study of tuberculosis in children, a greater involvement of the right side was found in 65% of patients, with the involvement of the left side in only 23% of patients, the remaining percentage being bilateral (Boloursaz et al., 2010:Fig. 4). Moreira et al. (2011:234) also found that in instances of pneumonia caused by tuberculosis, involvement of the right upper lobe was most common. However, Seiscento et al. (2011:1080) found that individuals with pleural tuberculosis, resulting in pleural effusion, were more likely to be affected on the left side (62.5% of patients, 55/67). Additionally, several studies have found that the left side is more commonly affected in cases of lung destruction caused by tuberculosis (e.g Ashour et al., 1990; Ashour 1995; Porres et al., 2017:272; Salami et al., 2018:84). This has been suggested to be due to the presence of the heart on the left side of the thoracic cavity, resulting in altered anatomy of the left bronchus leading to bronchial obstruction and impaired lymph drainage (Ashour, 1995; Porres et al., 2017:274; Salami et al., 2018:84). In CT scans of lung destruction caused by tuberculosis, Porres et al. (2017:274-275) found that 85% of their patients were affected on the left side and also noted hypertrophy of the ribs in all their patients, suggesting that the chronic inflammation related to the disease resulted in periosteal reaction and new bone formation that led to the enlargement of the ribs. If lung destruction as a result of tuberculosis is more likely to cause rib IPR, and this condition has a predominance on the left side, then it might be expected that rib IPR might form more commonly on the left side in tuberculosis. Lobar pneumonia may affect the right lung more often than the left (Heffron, 1939:107), but little has been written about side involvement in more recent clinical texts on the disease. One study by Song et al. (2010:Table 2) found that thoracic actinomycosis affected the right side (58%) more commonly than the left (37%). Unfortunately, again there is very little other clinical data on the involvement of different sides of the lungs in actinomycosis, perhaps due to the rarity of the disease today.

The duration of the disease should also be considered. Pneumonia, in particular bacteremic pneumococcal pneumonia, has a high early mortality rate, with a large percentage of people dying within 24 and 48 hours of hospital admission (Marrie, 1993:659). Many individuals may, thus, die before they can form new bone. However, tuberculosis has a long disease duration, lasting an average of 3 years before death (Tiemersma et al., 2011:10), providing plenty of time for multiple layers of bone to form if inflammation is ongoing.

Although the recording of rib IPR in this study did allow for the reconstruction of the distribution of periosteal reaction within the rib cage of specific individuals, in order to narrow the scope of differential diagnoses, too many skeletons had rib IPR for this to be realistically undertaken. The combined distribution of rib IPR across the ribcage, however, could be used to identify potential broad differences between groups, which ultimately may help to identify different IPR aetiologies.

A similar approach has also been utilised in previous studies of identified human skeletal collections to compare the distribution of rib IPR in groups with different causes of death (Roberts et al., 1994; Santos & Roberts, 2001, 2006; Matos & Santos, 2006; Mariotti et al., 2015).

Unfortunately, there is a lack of consistency in the type of data presented by different studies. Some have presented vague descriptions of the distribution of IPR within their populations, while others have presented percentages without corresponding frequency data. The frequency of IPR found in different sections of the rib have been presented in various non-comparable ways: by percent of affected ribs with a certain section involved, by the number of affected ribs with a certain section involved (without any corresponding prevalence data), or by number of affected individuals with a certain section involved. Additionally, different sections of the rib have been recorded by different researchers, which can include the neck (sometimes referred to as the vertebral end), angle, shaft (sometimes referred to as the body), and sternal end. No criteria for what constitutes a specific rib section have been given. The lack of consistency between studies hinders the ability to draw in-depth comparisons. However, the rib IPR distribution data presented by different studies have been summarised as best as possible in Table 8.5 (identified human skeletal collections) and Table 8.6 (archaeological studies).

Additionally, the true prevalence rates of rib IPR recorded in this study have been presented in Table 8.7 by the side affected, the rib cage region affected, and by the rib section affected. Although these true prevalence calculations are not comparable to previous studies, they do take into account the preservation of different sections of the rib and different regions of the rib cage, which can vary considerably according to site. For example, previous studies have presented the number of rib necks or shafts affected by IPR, without presenting the corresponding data for the number of rib necks or shafts present but unaffected. This does not take into account the variable preservation of the rib, for which the neck often preserves better than the shaft. Therefore, lower numbers of rib shafts with rib IPR compared to rib necks may simply be the result of a reduced number of observable rib shafts.

Table 8.5 – Data for rib IPR distribution within the rib cage from various studies of human identified skeletal collections. (+) = most frequent; (n) = number of ribs affected.

[1]Kelley & Micozzi (1984); [2]Roberts et al. (1994); [3]Santos & Roberts (2001); [4]Santos & Roberts (2006); [5]Matos & Santos (2006); [6]Mariotti et al. (2015)

Collection	Cause of death	Side affected (proportion of affected individuals)			Most commonly affected ribs	Zone affected on rib (percent of affected ribs)			
		Left	Right	Bilateral		Neck	Angle	Shaft	Sternal
Hamann-Todd Collection[1]	Tuberculosis	2 :	1	-	4th to 8th			(+)	
Robert J. Terry Collection[2]	Tuberculosis	25%	30%	45%	5th to 8th	25%	28%	20%	-
	Pulmonary disease (non-TB)	37%	37%	26%	-	-	-	-	-
	Non-pulmonary disease	20%	30%	50%	5th to 8th	23%	24%	29%	-
Coimbra Collection (non-adults)[3]	Pulmonary tuberculosis	40% (4/10)	20% (2/10)	40% (4/10)	4th to 6th	40 (n)	-	10 (n)	5 (n)
Coimbra Collection (adults)[4]	Pulmonary tuberculosis	34.4% (22/64)	21.9% (14/64)	43.7% (28/64)	4th to 6th	275 (n)	-	61 (n)	63 (n)
Luís Lopes (Lisbon) Collection[5]	Tuberculosis	17.1% (13/76)	23.7% (18/84)	59.2% (45/84)	3rd to 7th	85.6% (477/557)	-	37.5% (208/555)	32.2% (494/159)
	Pulmonary disease (non-TB)	33.3% (6/18)	33.3% (6/18)	33.3% (6/18)	8th	52% (39/75)	-	42.7% (32/75)	59.4% (41/69)
	Extrapulmonar y disease (non-TB)	31.3% (5/16)	25.0% (4/16)	43.8% (7/16)	4th to 8th	81.3% (100/123)	-	54.0% (67/124)	42.7% (41/96)
Certosa Cemetery Collection[6]	Various	20% (6/30)	40% (12/30)	40% (12/30)	2nd to 10th	126 (n)	-	4 (n)	47 (n)

Table 8.6 – Data for rib IPR distribution within the rib cage from various studies of archaeological human remains. (+) = most frequent; (n) = number of ribs affected; (n*) = number of individuals affected.

[1]Kelley et al. (1994); [2]Lambert (2002); [3]Nicklisch et al. (2012); [4]Pfeiffer (1991); [5]Bernofsky (2010); [6]Current study

Study	Side affected (proportion of affected individuals)			Most commonly affected ribs	Zone affected on rib			
	Left	Right	Bilateral		Neck	Angle	Shaft	Sternal
South Dakota, USA[1]	Fairly equal		13.0% (6/46)	Upper and middle ribs	-	-	-	-
Ute Mountain, Colorado, USA[2]	Left < Right		-	6th to 10th	(+)	(+)		
Saxony-Anhalt, Germany[3]	46%	54%	-	Middle ribs	(+)			
Uxbridge Ossuary, Ontario, Canada[4]	136 (n)	123 (n)	-	3rd to 10th	(+)			
Southeast England[5]	90 (n*)	79 (n*)	-	4th and 8th	39 (n*)	-	140 (n*)	8 (n*)
Kerma Classique Group, Fourth Cataract, Sudan[6]	0.0% (0/7)	28.6% (2/7)	71.4% (5/7)	-	See Table 8.7			
Post-/Meroitic Group, Fourth Cataract, Sudan[6]	28.6% (6/21)	42.9% (9/21)	28.6% (6/21)	-				
3-J-23, Fourth Cataract, Sudan[6]	41.4% (12/29)	27.6% (8/29)	31.0% (9/29)	-				
3-J-18, Fourth Cataract, Sudan[6]	28.6% (8/28)	35.7% (10/28)	32.1% (9/28)	-				
P37, Northern Donogla Reach, Sudan[6]	28.6% (2/7)	42.9% (3/7)	28.6% (2/7)	-				
Gabati, Atbara-Nile Confluence, Sudan[6]	28.6% (6/21)	19.0% (4/21)	52.4% (11/21)	-				
Soba East, Khartoum, Sudan[6]	8.3% (1/12)	16.7% (2/12)	66.7% (8/12)	-				

Table 8.7 – Data for the distribution of the true prevalence of rib IPR within the ribcage in different groups in the current study, according to the rib section affected, the rib cage region affected, and the side affected.

Site	Prevalence by rib section			Prevalence by ribcage region				Prevalence by side	
	Neck	Angle	Shaft	Upper	Upper-Middle	Lower-Middle	Lower	Left	Right
Kerma Classique Group, Fourth Cataract	2.9% (15/510)	5.3% (25/474)	6.3% (14/224)	1.4% (4/278)	4.5% (10/220)	4.4% (9/205)	6.3% (20/319)	6.6% (40/604)	2.3% (14/604)
Post-/Meroitic Group, Fourth Cataract	8.0% (68/853)	3.2% (30/927)	2.7% (21/775)	2.9% (18/621)	4.9% (31/638)	6.1% (39/644)	4.8% (30/627)	5.5% (71/1286)	3.8% (48/1269)
3-J-23, Fourth Cataract	10.5% (161/1529)	8.7% (134/1540)	6.1% (91/1499)	7.4% (85/1145)	12.2% (140/1147)	9.4% (108/1143)	4.6% (52/1124)	8.5% (195/2302)	8.4% (191/2266)
3-J-18, Forth Cataract	4.7% (120/2563)	3.1% (81/2597)	2.2% (54/2510)	2.1% (41/1933)	4.0% (75/1878)	4.2% (79/1870)	2.4% (46/1881)	3.4% (129/3783)	3.2% (126/3887)
P37, Northern Dongola Reach	4.1% (25/606)	3.7% (23/627)	3.7% (20/541)	3.5% (14/397)	5.0% (22/438)	3.9% (17/438)	3.0% (14/461)	3.8% (34/886)	3.8% (34/888)
Gabati, Atbara-Nile Confluence	2.9% (43/1478)	2.7% (46/1695)	2.4% (30/1266)	1.9% (19/1020)	2.7% (26/973)	2.9% (28/963)	1.5% (17/1102)	1.6% (37/2254)	3.8% (82/2185)
Soba East, Khartoum	9.9% (49/493)	5.6% (29/518)	7.5% (27/362)	4.4% (15/340)	12.6% (42/333)	8.4% (26/309)	6.6% (22/333)	7.9% (54/680)	7.4% (51/639)
Total	6.0% (481/8032)	4.4% (368/8378)	3.6% (257/7177)	3.4% (196//5734)	6.1% (346/5627)	5.5% (306/5572)	3.4% (201/5847)	4.7% (560/11795)	4.7% (546/11738)

The findings of Roberts et al. (1994:Fig. 6) correlate with the clinical data for the regions of the lungs affected by tuberculosis and pneumonia. The group of individuals with tuberculosis who also had rib IPR displayed a higher frequency of bilateral IPR (45%) than the group of individuals dying from a non-tuberculosis related pulmonary disease (26%). The upper (30%) and middle (57%) regions of the rib cage were also more affected than the lower region in the group who died from tuberculosis (Roberts et al., 1994:Fig. 8). Analysis of the adult and non-adult individuals from the Coimbra Collection who were recorded to have died from tuberculosis displayed a fairly high percentage of bilateral involvement (40% for non-adults, 43.7% for adults) and the 4th to 6th ribs were most frequently involved, which is consistent with greater upper lobe involvement (Santos & Roberts, 2001:41, Table 4, 2006:Table 4). A similar result was noted in the Lisbon collection, which had a significantly higher bilateral lung involvement (59.2%) compared to unilateral involvement in the group that died from tuberculosis, with ribs 3 to 7 most commonly affected. In the group with a death caused by a non-TB-related pulmonary disease, bilaterality was lower (33%) and the most common rib involved was the 8th, suggesting involvement of the lower lung. However, the number of individuals with rib IPR making up the non-tuberculous pulmonary disease group was relatively small (18 individuals) (Matos & Santos, 2006:Table 7). Kelley et al. (1994:126) use the more frequent presence of rib IPR on the upper and middle ribs in an Arikara native American archaeological group to suggest that tuberculosis may have been the most common disease to cause rib IPR in this population.

In the results from the current research, the majority of sites show a greater prevalence of IPR in the middle rib cage regions. 3-J-23 and Soba East both had significant differences between the prevalence of rib IPR in different rib cage regions, with a notably higher rate in the upper-middle rib cage region. This is consistent with the more frequent involvement of the upper lobes in tuberculosis. Additionally, 3-J-18 displays a significant difference in frequency between rib cage regions, with a higher prevalence in both the upper-middle and lower-middle regions. The Fourth Cataract Kerma Classique group also demonstrates a significant difference between rib cage regions. However, the most commonly affected region in this group was the lower, followed by the middle, rib cage regions. This could perhaps indicate a different disease process affecting individuals at this site. For example, pneumonia and actinomycosis are suggested to affect the lower lobes more frequently (Heffron, 1939:108-111; Mabeza & Macfarlane, 2003:548; Sadashivaiah, 2009:88; Farrokh et al., 2014:55; Nambu et al., 2014: 783, 785).

The Fourth Cataract Kerma Classique group, and people from Gabati and Soba East, also demonstrate a high number of individuals with bilateral lung involvement (71.4%, 52.4%, 66.7%, respectively). A high percentage of bilateral involvement could indicate a more chronic form of tuberculosis or pneumococcal pneumonia. Gabati demonstrated a significantly higher total true prevalence rate on the left side, whilst the Fourth Cataract Kerma Classique and Post-Meroitic groups demonstrated a higher prevalence on the right. However, the lack of consistency in the side of the lung affected between clinical studies of tuberculosis, and the sparse clinical data presented to support the suggestions for a more common right side involvement in actinomycosis and pneumonia, makes it currently difficult to suggest the causes of this difference.

The majority of sites in this study had a higher true prevalence rate of IPR in the neck region, followed by the angle, with the lowest prevalence on the shaft. Sites 3-J-23, 3-J-18, Soba East and the Fourth Cataract Post-Meroitic group demonstrated significant differences between the prevalence of rib IPR on different sections of the rib, with a higher prevalence in the neck region.

This is consistent with the general findings of other studies from identified human skeletal collections (e.g. Santos & Roberts, 2001:41; 2006:Table 4; Matos & Santos, 2006:193-194; Mariotti et al., 2015:398). Although these studies do not record prevalence at the angle (except for Roberts et al., 1994), in general the neck region is affected to a greater extent than the shaft. Archaeological studies also describe the neck as being more commonly involved than other regions of the rib (Pfeiffer, 1991:195; Lambert, 2002:284; Nicklisch et al., 2012:395), except for Bernofksy (2010: Fig. 5.7), who found a greater number of individuals with shaft involvement when combining all south-east English sites in the study into one group.

Matos & Santos (2006:198) suggest that the formation of IPR on the vertebral ends of the ribs could be due to the presence of the posterior intercostal lymph nodes. These lymph nodes are located in the region of the heads and necks of the ribs and are the pathway of drainage for the lymphatic vessels of the thoracic wall and the parietal pleura (Drake et al., 2010:154; Harisinghani, 2013:51). The lymph nodes of the thoracic cavity are commonly involved in tuberculosis (e.g. Haringsahani, 2000; Prasoon, 2003; Gupta, 2004). However, the involvement of the posterior intercostal lymph nodes in tuberculosis is not frequently reported in the clinical literature, but can often occur in geographical regions with a high incidence of the disease (Prasoon, 2003:51-52). The involvement of these lymph nodes includes the formation of pus, abscesses, or granulomatous inflammation (Prasoon, 2003:54). Inflammation related to the posterior intercostal lymph nodes, particularly in relation to tuberculosis, could be responsible for the high prevalence of rib IPR on the rib necks in the majority of studies. It should also be noted, however, that lymph nodes can be affected in a number of diseases, including sarcoidosis (causing the formation of inflammatory granulomatous tissue), brucellosis, leprosy, syphilis, and fungal infection (Asano, 2012:Table 1).

In the Lisbon Collection, in the group with a cause-of-death recorded as non-tuberculous pulmonary disease, a higher prevalence was found at the sternal end of the ribs, rather than at the neck region, and also a higher involvement of the shaft (Matos & Santos, 2006:194). Although in the current study the prevalence of rib IPR was not systematically recorded for the region of the sternal end, because this area of the rib was often absent or damaged, the shaft was found to have a greater involvement than the neck and angle in the Fourth Cataract Kerma Classique group. This might indicate that a different aetiology could have caused some of the instances of rib IPR in this group compared to other populations. People from Soba East also demonstrated a relatively high prevalence in the shaft, which was the only group to exceed the prevalence in the angle, other than the Fourth Cataract Kerma Classique.

Figure 8.18 displays the distribution within the ribcage of the true prevalence rates for rib IPR in different populations. The groups from 3-J-18, P37, and Gabati, which had generally lower crude prevalence rates, demonstrated a fairly equal distribution across the rib cage. As would be expected, people buried at 3-J-23 and Soba East, who had higher crude prevalence rates, also demonstrated a wider distribution of rib IPR across the rib cage, with a higher total true prevalence (8.5% and 7.6%, respectively). However, the Fourth Cataract Meroitic and Post-Meroitic group, which had the highest crude prevalence of rib IPR, had a fairly low prevalence distribution across the rib cage and a lower total true prevalence (4.7%). This suggests that individuals were only manifesting bony changes in a small number of ribs, thus reducing the true prevalence. This might indicate that either individuals were overcoming the disease before inflammation could spread to involve a greater number of ribs, or that individuals were dying from the disease before they could manifest a greater degree of bone formation. The high proportion of individuals with active and remodelling, but not healed, rib IPR in this group perhaps suggests the latter (see Section 8.6). Alternatively, individuals at this site could have been affected by a more localised form of pulmonary inflammation that only produced new bone formation on a small number of ribs per individual.

The Fourth Cataract Kerma Classique group also demonstrated relatively high true prevalence rates in certain regions of the rib cage, despite having a low crude prevalence. The preservation of the skeletal remains from the Fourth Cataract Kerma Classique sites was poor and the ribs were often very fragmented. The high prevalence rate for certain rib cage regions may be the result of the small sample size. A fewer number of individuals in the whole sample, and more ribs involved per affected person, could result in elevated true prevalence rates. However, it could also indicate that fragmentation resulted in many rib cages being only partially observable and that the crude prevalence of respiratory disease may have been originally higher than was observable.

Santos and Roberts (2006:44) found that two individuals dying from peritoneal tuberculosis displayed rib IPR on the lower ribs on their shafts and sternal ends. This is consistent with inflammation of the peritoneum (the membrane lining the abdominal cavity), which can be caused by bacterial infection, appendicitis, pancreatitis, or injury to the stomach, among other factors (NHS, 2017). Although rare, peritonitis can cause pleural effusion (e.g. Marel et al., 1993:Table 2) as well as peritoneal effusion, but the proximity of the peritoneum to the lower rib shafts, which are not entirely covered by the pleurae (Drake et al., 2010:Fig. 3.104) could stimulate new bone formation independently of pleural effusion. The Fourth Cataract Kerma Classique group and people from Soba East demonstrated elevated true prevalence rates for the shafts of the lower ribs, which could indicate an inflammatory aetiology originating from the abdominal cavity.

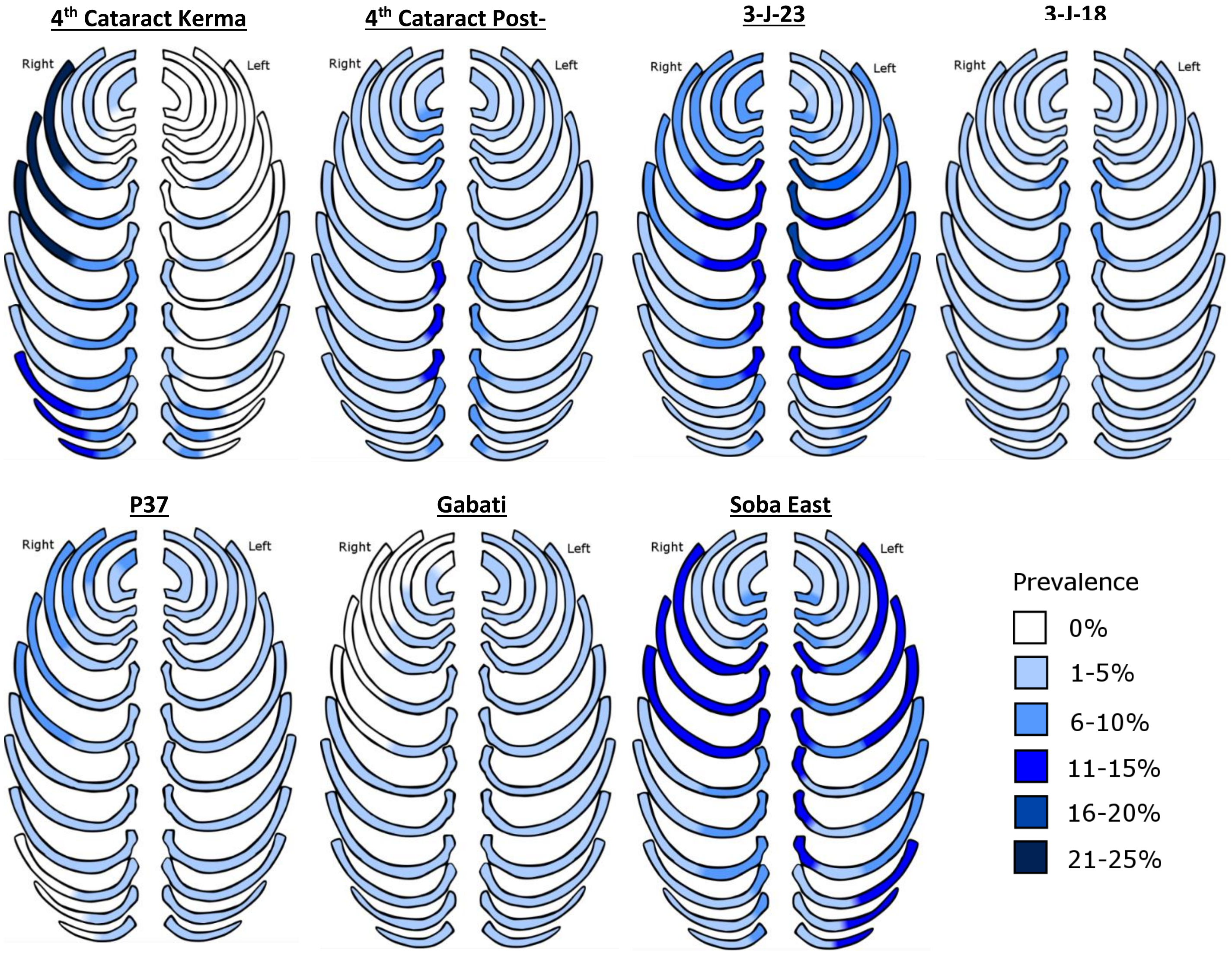


Figure 8.18 – A comparison of the distribution of true prevalence rates of rib IPR within the rib cage in groups from the current study. Prevalence rates have been presented by side, rib section affected, and by rib cage region (e.g. upper, upper-middle, lower-middle, lower) affected.

Note: as these images categorise rib IPR prevalence rates into groups increasing in increments of 5%, subtle differences in the prevalence of different rib sections may be lost.

The body is not neatly separated into isolated units and diseases often affect individuals in unpredictable ways, so that it is not always easy to separate the pathological processes of one disease from another. The presence of multiple types of lower respiratory tract disease with different distribution patterns at one site may confound the picture. However, the study of the distribution of rib IPR within the rib cage has the potential to provide useful diagnostic aid. First, consistency between studies must be achieved so that data can be reliably compared. With an increased consistency in the recording of rib IPR distribution in the rib cage among different studies, a combination of other evidence for diseases (such as biomolecular analysis), and a greater review of medical texts regarding how different pulmonary diseases affect the lungs, it may be possible to identify general differences between groups and investigate the potential aetiology of rib IPR in greater depth.

8.8 Comparison of maxillary sinusitis and rib IPR

Figure 8.19 demonstrates that the prevalence rates of inflammatory periosteal reaction on the ribs and of maxillary sinusitis do not always correlate. For example, while P37 has one of the highest prevalence rates for maxillary sinusitis, it also has one of the lowest for rib IPR. Bernofsky (2010:187) also investigated the correlation between maxillary sinusitis and rib IPR in English archaeological skeletons from a number of sites and found no statistical correlation between the two types of respiratory disease. The potential causes and factors involved in the development of upper and lower respiratory tract disease may, therefore, differ.

Although particulate matter (PM) affects susceptibility to both upper and lower respiratory tract disease, different sizes and types of PM affect the respiratory tract differently. Particles larger than 10µm are removed from the airstream in the nasal cavity and sinuses and are, therefore, more likely to cause irritation and inflammation in the maxillary sinuses than in the lower respiratory tract. Particulate matter of 10µm or smaller (PM_{10}) can pass into the lower respiratory tract airways and particles smaller than 2.5µm ($PM_{2.5}$) can penetrate even further into the gas exchange region of the alveoli. The smallest particulates of less than 1.0µm can make their way from the alveoli into the blood stream and have been linked to vascular diseases and cancer (Bruce et al., 2000:1079; Clerico, 2001:108; Brunekreef & Holgate, 2002:1235; Li et al., 2003:455; Sood, 2012:650; Marino et al., 2015:286).

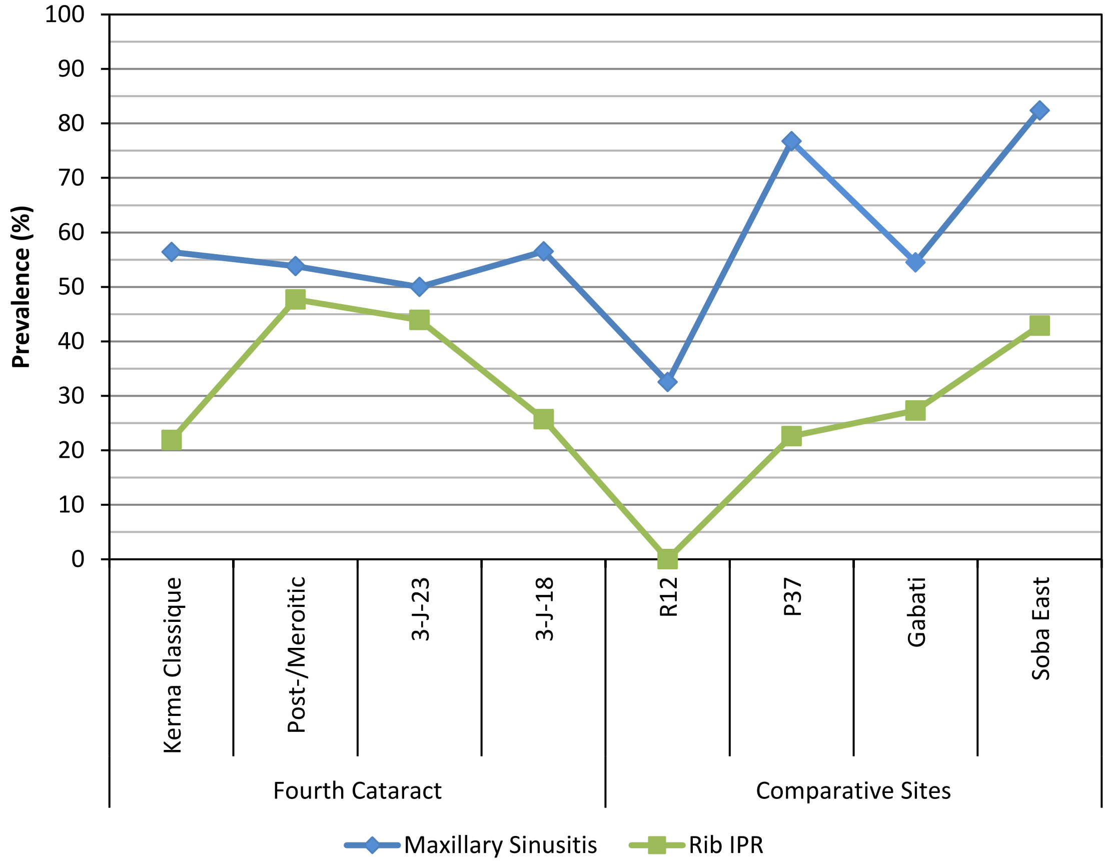


Figure 8.19 – A comparison of the crude prevalence of maxillary sinusitis and rib IPR in different groups within the current study.

Figure 8.20 presents the approximate size ranges of particulates from a variety of sources. A higher prevalence of maxillary sinusitis over rib IPR may indicate a greater exposure to coarser environmental particulates, such as coarse sand, pollens, plant spores, and larger dust particles, while a high prevalence of rib IPR might also suggest additional inhalation of smaller particles, particularly of $PM_{2.5}$ and smaller, which can cause inflammation in the alveoli underlying the ribs (Bruce et al., 2000:1079; Brunekreef & Holgate, 2002:1235; Perez-Padilla et al., 2010:1081). These types of particles might be related more to occupational or human-made sources of PM, such as animal allergens, metallurgic dusts and fumes, and smoke from various fuels, although atmospheric and desert dusts can also consist of smaller particulates (e.g. Mahowald et al, 2014:67). A study of aeolian Saharan dust deposition found that the modal grain size of particulates was relatively coarse, between 4 and 32µm (van der Does et al., 2016:13704). This could suggest that environmental dusts affected the sinuses more than the lungs. However, smaller dust particulates

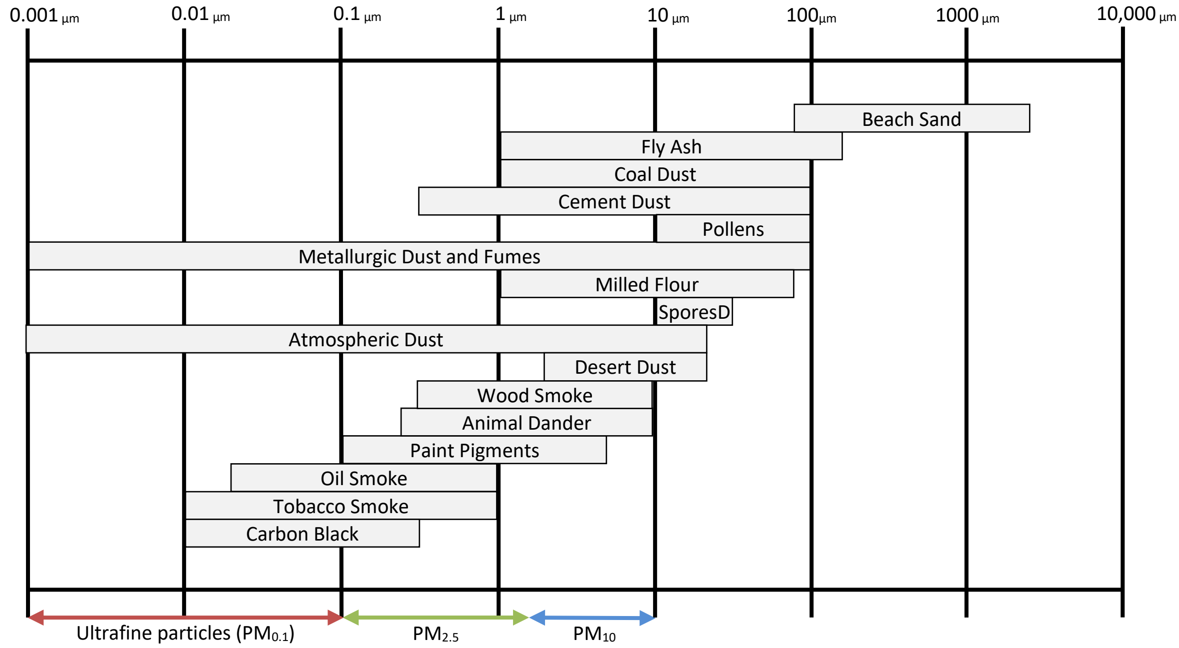


Figure 8.20 – The approximate size ranges of various sources of particulate matter (after Lapple, 1961:59 and Hosseini et al. 2010:8075). Desert dust size was taken from the model grain size recorded for Saharan dust by van der Does et al. (2016:13704).

can be suspended in the air for longer and will travel further, for example during dust storms (Mahowald et al., 2014:53-54; van der Does et al., 2016:13704) and could affect people exposed to windblown sands. The composition of the particles may also have an effect. Toxic gases like nitrogen dioxide, ozone, and formaldehyde are usually removed from inspired air in the upper respiratory tract, but when combined with smoke can adhere to carbon particles and penetrate the lungs, where they are highly irritant (Schlesinger, 1995:317; Seaton et al., 1995:177).

Exposure to a variety of sources of particulate matter, with different size ranges and compositions, could affect both the upper and lower respiratory tracts. This may explain why in urban environments, where there is the potential for exposure to different sources of air pollution from a range of activities, like at Soba East and Amara West, both maxillary sinusitis and rib IPR are relatively high. Different biomass fuels may generate different sizes and concentrations of particulates. The weight of PM produced in grams per one kilogram of fuel burned is known as the emission factor (EF) (Amaral et al., 2016). For example, charcoal produces a fairly low emission factor (EF = 0.9) compared to untreated woods (average EF = 10.5) (Amaral et al., 2016:Table 10). In laboratory tests, acacia wood, which is common in Sudan, has been found to have an emission factor of 6.06. Dung has been found to have a significantly higher emission factor than other fuels (Amaral et al., 2016:14) and emits a high proportion of PM with a size below 1µm, particularly at higher heats (Park et al., 2013:Table 2). Dung also has a high metal content, which can be extremely oxidative (Mudway et al., 2005). This can cause oxidative stress in the lungs, which can affect the immune response of alveolar macrophages and the regulation of inflammation within the lungs, increasing susceptibility to infection (e.g. Becker, 2002; Lee et al., 2015). Vegetation for burning was likely to have been scarce in the more arid regions of Sudan and dung may have been a valuable resource for fuel. Although there is very little evidence for the type of fuel used at most Sudanese settlement sites, the burning of both dung and charcoal was found at Amara West (Binder & Spencer, 2014:125). Groups with a higher status may have enjoyed privileged access to cleaner burning fuels such as charcoal, while poorer groups may have used dung. Therefore, the types of fuels available to certain groups may have determined the size, type, and concentration of particulates inhaled, differentially affecting the sinuses and the lungs.

Additionally, one of the major differences between maxillary sinusitis and lower respiratory tract disease is the risk of death. Maxillary sinusitis is not a disease that causes mortality and fatal complications are extremely rare (Wagenmann & Nacleiro, 1992:554). Lower respiratory tract diseases, however, can often be deadly. As described in Section 8.6, if an individual has a higher level of frailty they may die from a lower respiratory tract disease before new bone can form, leaving no evidence that the disease was ever present (e.g. Wood et al., 1992:345; DeWitte & Stojanowski, 2015:407; DeWitte, 2014:42). The higher risk of mortality may indicate why the prevalence of upper and lower respiratory tract disease may not always correlate. If a population, such as P37, had a high level of frailty, individuals buried at this site may have been more likely to develop maxillary sinusitis but could also have been more likely to die from an acute episode of lower respiratory tract disease before new bone could form on the ribs, resulting in a high prevalence of maxillary sinusitis but a low prevalence of rib IPR.

The sinuses act as the first line of defence against particulates and pathogens in inspired air and are one of the first regions of the body to be affected by toxic pollutants, particulates, and pathogens in the environment (Clerico, 2001:107; Marino et al., 2015:286). It is likely, therefore, that the frequency of maxillary sinusitis in a population can provide a useful indication of the air quality that an individual is exposed to, although other unrelated factors certainly may affect prevalence rates. However, the lower respiratory tract is affected by a far greater range of risk factors. While poor air quality has been proven to cause inflammation of the lungs and to increase susceptibility to respiratory diseases (e.g. Li et al., 2003:455; Jang, 2012:154; Hiraiwa & van Eeden, 2013:1), other common causes of pleural disease include malignancy, heart failure, and pulmonary embolism (Porcel & Light, 2006:1211; Light, 2013:128). Additionally, although poor air quality increases susceptibility to infectious lower respiratory tract diseases, a number of other factors such as population crowding, low levels of sanitation, disease load, malnutrition, underlying diseases, and age can play a considerable part in a population's susceptibility. Thus, while maxillary sinusitis may be a useful barometer for air quality, greater caution should be taken with the interpretation of the presence of rib IPR, which presents a more complex picture.

8.9 Limitations

The interpretations presented here are limited by the lack of contextual evidence. While care was taken to interpret differences in prevalence rates of respiratory disease in the Middle Nile Valley in view of the available archaeological, environmental, historical, and clinical data, in the future evidence may be presented that will further contextualise the results presented in the current study. For example, the majority of cemetery sites included in this study lack any corresponding archaeological data for associated settlements, habitation structures, subsistence practices, potential occupations, and other valuable evidence related to the possible causes of respiratory disease. One of the limitations brought about by the lack of archaeological data was the inability to identify the socioeconomic status of people buried at the different sites, and of different groups buried at the same site. As discussed above, the socioeconomic status of a group may have had an effect on the prevalence rate of respiratory disease, but without further evidence it is impossible to predict how this status may have affected the individuals in the current study. Additionally, certain information about specific populations, such as their subsistence strategy, had to be assumed based on data from nearby contemporary sites. Unfortunately, the flooding of the Fourth Cataract region makes it unlikely that further archaeological material will be recovered from this area. In other regions, however, new evidence of settlements and subsistence practices during different time periods may emerge, providing further context for the prevalence data presented in the current study.

This research has also been limited by the availability of skeletons to those currently curated at the British Museum. While the Sudanese skeletons represent a large and valuable collection, certain time periods, such as the Mesolithic, Pre-Kerma, New Kingdom, and Napatan time periods, are poorly represented and, thus, it was not possible to fully investigate respiratory disease in the Middle Nile Valley during these periods. Additionally, cemetery sites within the collection focussed on certain geographical regions of the Middle Nile Valley, limiting the ability to fully investigate differences in prevalence based on variations in precipitation and aridity from regions ranging from the north to the south.

The preservation of the skeletons that were available was also variable. Cemetery sites from certain time periods, such as the Neolithic and Kerma Classique periods, were particularly poorly preserved and fragmented. As a result, the current research included all skeletons with at least one maxillary sinus or one side of the rib cage present with a completeness score of 5-24%. While the inclusion of ribs and sinuses within this completeness category did increase the number of skeletons from the poorly preserved sites that it was possible to analyse, the low level of completeness may have affected the observability of evidence for respiratory disease, resulting in lower crude prevalence rates.

The inclusion criteria for other studies has varied and further disparities between the recording methods used in the current study and those employed by other researchers may also be present. For example, Boocock et al. (1995:485) included individuals with the presence of at least one complete sinus floor. However, the area required to be preserved for an individual to be analysed in the current study was not limited to the floor, because it was observed that bony changes could occur in any region of the sinus. Additionally, while diagnostic criteria for bony changes related to maxillary sinusitis have been employed since the study of Boocock et al. (1995), no published research has attempted to produce criteria for differentiating bony changes on the ribs related to inflammation caused by respiratory disease and changes caused by other factors. Even when similar methods are employed by different studies, small differences may exist in the criteria used by different researchers for analysing respiratory disease. This has been demonstrated in the inter-observer error tests undertaken as part of the current research, which found inconsistences between observers in identifying the types of bone changes occurring in the sinuses and on the ribs. These variables may have affected the comparability of the results of this study with those from other publications.

The lack of current clinical data on respiratory disease specifically within Sudan, and particularly in relation to the arid climate in the country, hinders interpretations of the impact of the desert environment on respiratory disease in the past. Although clinical studies of respiratory disease in other arid regions provide useful evidence of the effect of particulate matter in a desert environment, future clinical studies from Sudan and other Saharan regions may help to elucidate the results from the current research further.

Discussion about the types of lower respiratory tract diseases that may have been present in the Middle Nile Valley in the current study is also fairly limited. Infectious diseases discussed in relation to rib IPR, such as tuberculosis, pneumonia, and actinomycosis, were included because they commonly cause pleural disease and have received the most attention in other bioarchaeological studies. However, a number of rarer respiratory diseases may have caused the inflammation stimulating new bone formation on the ribs, including non-infectious diseases, such as pneumoconiosis and silicosis. Additionally, pleural disease can be caused by a range of other conditions that are not related to the respiratory tract, including heart failure, malignancy, pulmonary embolism, rheumatoid arthritis, and pancreatitis (Rahman et al., 2004:Table 1), but many of these diseases are rarer than infectious respiratory diseases or may cause death before new bone can form. While the presence of rib IPR in individuals in the current study has been used as evidence for inflammatory respiratory diseases, the other possible differential diagnoses should always be taken into consideration.

Very little has been written in clinical texts about bony changes caused by maxillary sinusitis. Until there is further clinical evidence linking certain bone changes to maxillary sinusitis, it should also be considered whether certain bony changes within the sinus are the result of a normal remodelling process. For example, spicule formation in the sinuses, which is an unusual type of bone formation not closely paralleled in any other part of the skeleton, often get dislodged or destroyed in incomplete sinuses. The well-preserved sites in the current study demonstrate that spicules were actually a common occurrence and it should be considered whether they could be a natural process of bony remodelling within the sinus. Certain populations may be more likely to produce this remodelling as a normal part of aging, leading to elevated prevalence rates. While this statement is not intended to disregard the conclusion of previous studies, and that of the current research, that spicules are a product of inflammation caused by sinusitis, it is also worth considering the potential alternative causes of these bony changes when limited clinical evidence is available.

8.10 Future Research

Until now, there has been a predominance of studies of respiratory diseases in skeletons from English sites, which provides a rather narrow understanding of variation in disease frequency according to different environments. The study of respiratory disease in bioarchaeology could be further improved with the investigation of a greater number of populations from different environments, geographical regions, and time periods. The current research identified elevated prevalence rates of respiratory disease in populations from the Middle Nile Valley of Sudan that may be linked to the inhalation of particulates from the desert environment. However, other risk factors present in the fairly limited geographical region may have had an influence. In order to investigate the causal link between the desert environment and the prevalence of respiratory disease, other populations from different arid regions from around the world should be investigated. In addition, it would also be beneficial to have a greater study of populations from different climatic extremes, because the majority of sites already studied (barring in Sudan) originate from fairly temperate environments.

Though substantial, this research was also limited by the number of individuals available from each time period. The study of a wider range of sites from the Middle Nile Valley could also compliment and further contextualise the results of the current research. In particular, the data from R12, the Neolithic site, demonstrate a differing trend in respiratory disease prevalence compared to other sites, which may be due to the more humid conditions during this time period. However, the number of skeletons from R12 which fit the criteria for inclusion in the current study was small, due to poor preservation. An investigation of more Neolithic sites from other Middle Nile Valley regions could provide further evidence that an increasing trend in respiratory disease between the Neolithic and later time periods was present. Additionally, the analysis of a wider range of sites from along the length of the Middle Nile Valley, from north to south, may help to investigate the potential differences in the prevalence of respiratory disease according to variations in aridity and precipitation by latitude.

Dental disease is a common cause of maxillary sinusitis and may have been responsible for more instances of the disease than can be detected by the simple presence of an oroantral fistula. For example, other studies have found a correlation between the presence of other peri-apical lesions, such as abscesses, and maxillary sinusitis (Bernofsky, 2010:171, 251-252; Liebe-Harkort, 2012:392). The same sites included in the current study are also being analysed in a similar doctoral project to investigate changes in oral pathology and dental wear in the Middle Nile Valley through time (R. Whiting, pers. comm., 2018). A combination of the data from both studies may help to elucidate the correlation, if any, between the presence of maxillary sinusitis and different forms of dental disease. This could allow for further discussion of the causative factors involved in maxillary sinusitis in the Middle Nile Valley.

An analysis of samples of dental calculus, taken from skeletons from the sites included in the current study, is also being undertaken as part of a post-doctoral research project (A. Radini and D. Antoine, pers. comm., 2018). Analysis of the molecules and microdebris found within dental calculus can provide a wealth of information. For example, starch granules, plant fibres, and phytoliths can provide evidence of the types of plant material being consumed within the diet, microcharcoal and burnt material can indicate the inhalation of smoke during cooking or other activities, and pollen spores and other microdebris, such as dust or sand, can give an indication of inhaled particles present within the environment (Mackie et al., 2017:78). This approach has been successfully undertaken on the pre-Mesolithic, Neolithic, and Late Meroitic Sudanese site of Al Khiday II, identifying 'char' markers that indicate the inhalation of smoke during all time periods (Buckley et al., 2014). Collaboration is already taking place to use the results from the current study in conjunction with calculus and naturally mummified lung tissue samples taken from individuals from a range of sites in the collection, to identify potential microscopic evidence for the inhalation of smoke, environmental particulates, and other microdebris. This research will be invaluable in providing definitive evidence for the types of molecules that were inhaled, which may have contributed to respiratory disease in the Middle Nile Valley.

Additionally, biomolecular analysis and DNA identification of specific diseases, such as tuberculosis or leprosy, in skeletons from these sites may provide further evidence of the types of pathogens involved in producing bony changes within the respiratory tract. Biomolecular analysis of *M. tuberculosis* complex DNA in association with individuals with rib lesions, both proliferative and destructive, have been successfully undertaken by a number of studies (e.g. Mays et al., 2002; Raff et al., 2006; Nicklish et al., 2012; Cooper et al., 2016). Although the DNA presence of a certain pathogen extracted from the bones of an individual is not definitive evidence that this specific disease was the cause of rib IPR or maxillary sinuistis, identification of these pathogens gives an indication of the type of diseases present within the population, providing further evidence for the possible causes of respiratory disease.

The true prevalence rates systematically recorded within the current research for different sections of the ribs and regions of the ribcage, which allows for a more accurate understanding of the distribution of rib IPR throughout the ribcage, have not been attempted by previous studies. The current study has also produced a flow chart to help in the identification of bony changes on the ribs related to pleural inflammation and to differentiate this from other bony changes. It is hoped that the methods used in the current research will aid in improving consistency between data in future studies. In particular, if the methods for recording the true prevalence of IPR by side, section, and rib cage region are adopted, it will be possible to compare patterns in rib IPR distribution among populations. Together with a thorough analysis of current and future clinical studies relating to the areas of the lungs affected by respiratory diseases, this approach may be able to narrow the scope of differential diagnoses of rib IPR at certain sites.

An omission of the current study was the analysis of non-adult skeletons. While developmental changes in the juvenile skeleton often complicate the observation of bony changes on the ribs and in the sinuses, analysis of rib IPR and maxillary sinusitis in non-adults has been successfully undertaken. Santos & Roberts (2001:Table 2) analysed 66 non-adults from the Coimbra identified human skeletal collection and found a considerably high prevalence of rib IPR in juveniles dying from pulmonary tuberculosis (90.9%, 10/11). Lambert (2002:284) also found a higher prevalence of rib IPR in non-adults (62.5%) compared to adults (17.6%). Maxillary sinusitis in non-adults has also been recorded for a number of sites (e.g. Panhuysen et al., 1997; Merrett & Pfeiffer, 2000; M. E. Lewis, 2002; Bennike et al., 2005; Liebe-Harkort, 2012; Sundman & Kjellström, 2013), although in studies that also include comparative prevalence rates in adults these tend to be higher than in non-adults. There can be a tendency to overlook non-adults in palaeopathological analyses and, despite the difficulties in observing pathological changes on the ribs and sinuses in non-adults, the prevalence of respiratory disease in juveniles can provide a valuable understanding of differences or similarities between age groups. While the time constraints in this study limited the ability to analyse non-adults, further studies of the younger age groups from the same sites would provide a valuable dimension to this research.

Although it is not possible to definitively understand the lived experience of past populations, an appreciation for the effect that these diseases may have had on the lives of people is an important facet of bioarchaeology. A more nuanced understanding of the clinical manifestations and comorbidities related to different respiratory diseases may be helpful for further understanding the impact they had on past populations. It is known that there is a link between inflammation in the upper and lower respiratory tracts and that inflammation of one may stimulate inflammation in the other (Lipworth & White, 2000). For example, there is a strong correlation between sinusitis and asthma (e.g. Steinke, 2006:498; Frieri, 2014:e44). Sinusitis has also been linked to chronic obstructive pulmonary disease (COPD) (Hurst, 2009). COPD, which includes conditions such as bronchitis and emphysema, is caused by a long-term exposure to lung irritants, such as particulate matter from smoke (Rabe & Watz, 2017:1932) and can have co-morbidities with other respiratory diseases, such as tuberculosis (Chakrabarti et al., 2007). COPD has not been discussed in great detail in the current study as it is not commonly associated with pleural disease. Hence, there is as yet little evidence linking the disease to the formation of rib IPR. However, if particulate matter and poor air quality were involved in causing respiratory diseases such as sinusitis, pneumonia, or tuberculosis in past populations, conditions also affected by particulate matter, such as asthma and COPD may also have been present. Additionally, there is a growing body of evidence linking inflammation of the respiratory tract caused by particulate matter, in particular ultrafine PM, to cardiovascular diseases and lung cancer (e.g. van Eeden et al., 2001:826; Hiraiwa & van Eeden, 2013:6; Morales-Bárcenas et al., 2015:172). A more detailed investigation of the clinical evidence for the correlation between exposure to particulate matter and the development of different diseases may help to provide a greater understanding of the potential range of diseases people were exposed to in the past and, in turn, may help to recognise the effects they could have had on past lives.

Chapter 9: Conclusion

9.1 Revisiting the research questions

The data acquired from this research enabled an investigation of the prevalence of respiratory disease in the Middle Nile Valley in relation to the original research questions posed at the beginning of this thesis:

1. How prevalent were bony changes associated with respiratory disease in populations living in the Fourth Cataract region of Sudan?

   The data demonstrates that maxillary sinusitis in people living in the Fourth Cataract region was prevalent across all time periods and displayed very little variation, ranging from between 50% and 60% in all groups. This could suggest that all populations had an equal exposure to risk factors for sinusitis, perhaps due to similarities in the environment, sociocultural activities, and rural agricultural subsistence practices. The prevalence of rib IPR showed greater variation among groups from the Fourth Cataract, possibly reflecting site-specific or temporal differences in risk factors causing lower respiratory tract disease, such as exposure to fine particulate matter or infectious diseases. People living during the Meroitic and Post-Meroitic period in the Fourth Cataract demonstrated the highest prevalence rate for rib IPR recorded in any published bioarchaeological study (47.7%). This suggests that, during this time period, certain risk factors were leading to an elevated susceptibility to lower respiratory tract disease. A similarly elevated IPR prevalence rate was also observed in people buried at Medieval 3-J-23 (43.9%), which was not paralleled at the nearby contemporaneous site of 3-J-18 (24.8%), indicating that temporal trends may also be complicated by population-specific factors, such as socio-economic status.

2. How do observed patterns compare with Middle Nile Valley sites outside the Fourth Cataract with differing practices and environments?

   In comparison to the Fourth Cataract region, people buried at the comparative sites demonstrated a greater range of variation in maxillary sinusitis and rib IPR prevalence. This might be expected in groups from sites chosen to represent people living in different environments, with differing subsistence strategies, and socio-cultural activities. People from the Neolithic site of R12 demonstrated the lowest prevalence of both maxillary sinusitis and rib IPR observed in this study. The prevalence rate of maxillary sinusitis in people from Meroitic, Post-Meroitic, and Medieval Gabati, which potentially represented a rural agricultural population, fell within the range observed in people from the Fourth Cataract. Groups from both P37 (Kerma period) and Gabati also had prevalence rates of rib IPR comparable to the lower end of the range observed in the Fourth Cataract. However, people at P37, also thought to possibly represent a rural agricultural group, demonstrated an extremely high prevalence rate of maxillary sinusitis (76.6%), which did not compare to the other agricultural groups. Individuals from Medieval Soba East, which was the only urban site in this study, demonstrated the highest rate of maxillary sinusitis (82.4%) from all sites analysed in this research and the third highest rate of rib IPR (42.9%).

3. Did the prevalence of bony changes associated with respiratory disease change over time and correlate with differences in climate and environment, as well as changes in social, cultural and occupational practices?

A significant increase in the prevalence of respiratory disease was observed between the population dating to the Neolithic and the later groups from the Kerma periods. This may indicate that the higher humidity during the Neolithic, and therefore the lower levels of ambient particulate matter, may have resulted in a reduced susceptibility to respiratory disease. The transient hunter-gatherer lifestyle and the use of ventilated huts for habitation may also have limited exposure to particulate matter and pathogens. It should be further noted, however, that skeletal remains from the Neolithic site demonstrated the poorest preservation scores of any site and this may have impacted the ability to accurately observe the presence of maxillary sinusitis or rib IPR.

Groups from almost all rural agricultural sites demonstrated a remarkably consistent prevalence rate for maxillary sinusitis, of between 50 to 60%. This could indicate that levels of exposure to particulate matter for people buried at these sites were alike, for example because of similar agricultural and socio-cultural activities and outdoor and indoor living environments. Only at P37 were people observed to have a considerably higher prevalence rate. This may be due to increased levels of particulate matter, due to exposure to the western desert, or to substantially different living conditions or activities related to subsistence, which unfortunately cannot be determined without evidence for an associated settlement.

The prevalence of rib IPR in people buried at different rural agricultural sites demonstrated far greater variation than that for maxillary sinusitis. Rib IPR can be the result of a range of factors that not only includes exposure to particulate matter but is also highly dependent on exposure to infectious diseases of the lower respiratory tract, such as tuberculosis. A differential reliance on animal husbandry at different agricultural sites can result in different levels of exposure to zoonotic pathogens. Additionally, differences in exposure to infectious disease, for example through household crowding, or from fine particulate matter from activities related to occupation, may also be responsible.

Individuals from the only urban site in the study, Soba East, demonstrated among the highest prevalence rates of respiratory disease in all groups. It is likely that factors related to the urban environment led to higher levels of exposure to particulate matter and infectious diseases. For example, industrial pollution from production centres in the city may have affected not only those working within certain trades, but also the whole population, as a result of general air pollution. Increased trade links, social mixing, and crowding within houses may have also led to the introduction and spread of pathogens causing respiratory tract disease. Although the southerly region in which Soba East was located was less arid than in the north, particulates within the general environment may also affected respiratory health.

These results demonstrate that certain differences in environment and lifestyle between populations living in the Middle Nile Valley had an impact on respiratory disease. In particular, increasing aridity in the environment between the Neolithic and Kerma periods and changes in subsistence strategies and socio-cultural activties may have affected prevalence rates.

4. Did evidence for respiratory disease vary according to sex and age?

Very little variation in the prevalence of respiratory disease between different sex or age groups was demonstrated in people from the sites in the Middle Nile Valley. This may indicate that all groups within a population were equally exposed to risk factors that affected the development of respiratory disease, for example through general exposure in the arid environment, or through similar living environments or socio-cultural activities. Only at 3-J-23 and Gabati were significant differences between males and females observed. This suggests that site-specific sex-related activities that exposed a certain group to higher levels of particulate matter or pathogens were taking place. However, the lack of historical and archaeological data on sex-specific activities in the Middle Nile Valley prevents further in-depth interpretation of the causes of the observed differences.

9.2 Significance

The aetiology and pathogenesis of respiratory tract disease is complex and difficult to interpret, particularly considering the numerous risk factors involved. This was further complicated in the current study by the lack of archaeological data for associated settlements, socio-economic status, and activities related to subsistence for the majority of groups analysed. However, this research has demonstrated that past populations in the Middle Nile Valley had relatively high prevalence rates of respiratory disease compared to other regions of the world. In particular, the prevalence rates of rib IPR from the Kerma period onwards are among the highest recorded in any bioarchaeological study. This suggests that certain distinct factors were present within the region that predisposed people to developing respiratory diseases.

A significant rise in the prevalence of respiratory disease is apparent between the Neolithic and later time periods, which parallels a number of environmental and socio-cultural changes in the region, including increasing aridity, a greater reliance on agriculture and cereal production, the use of less ventilated mudbrick housing, and increasing population density. In particular, there is abundant evidence from clinical studies for the negative effect of poor air quality related to arid environments on the respiratory tract, but few populations from arid climates have been investigated in previous bioarchaeological studies of respiratory disease. In the current study, the significant rise in the prevalence of respiratory disease between the Neolithic and Kerma periods, during which time aridity in the region greatly increased, could signify the impact of dust and sand particulates in the air, although the poor preservation of Neolithic skeletal remains should also be considered as a factor in this result. Exposure to high levels of ambient particulate matter in the general environment by all members of the population might also be reflected in the equal prevalence rates for respiratory disease between sex and age groups. However, a number of factors, such as equal exposure in the shared indoor living environment, could also be responsible.

Additionally, the urban site of Soba East demonstrated very high prevalence rates of both maxillary sinusitis and rib IPR, corresponding with the results from a previous study of the urban Middle Nile Valley population from Amara West. This indicates that in the urban environment a complex interplay of factors, including general air pollution from industrial activities, crowding within the home, higher disease load, increased social mixing, and the introduction of diseases via trade routes, in conjunction with poor air quality from the arid climate, resulted in high prevalence rates of respiratory disease.

The data from the current study demonstrate that the climate and environmental air quality, among other factors, may have had a significant impact on the development of respiratory disease in past populations. More studies of populations from a wider range of environments may help to further contextualise these findings. Today, aridity, caused by deforestation, rising global temperatures, and urbanisation, is increasing and at the end of this century arid drylands are predicted to occupy up to 56% of the global land surface (Huang et al., 2016:166, 170). Moreover, by the year 2050, 70% of the world's population is predicted to be living in urban environments (WHO, 2010). The current research has highlighted the impact that these types of environments may have had on respiratory health in past populations, providing a contextually driven and deep time perspective on a problem that is of increasing concern today. This is particularly relevant considering the predicted future rise in aridification and urbanisation in many regions of the world.

References

Acsádi, G. Y. & Nemeskéri, J. (1970). *History of human life span and mortality*. Budapest: Akadémiai Kiadó.

Adams, J. (2002). *Africa during the last 150,000 years*. Retrieved from https://www.esd.ornl.gov/projects/gen/nercAFRICA.html [accessed on 16th May 2018].

Adams, W. Y. (1961). The Christian potteries at Faras. *Kush, 9*, 30-43.

- - - - - (1965). Sudan Antiquities Service excavations at Meinarti, 1963-64. *Kush, 13*, 148-176.

- - - - - (1984a). Meroitic architecture. An analytic survey and bibliography. *Meroitica, 7*, 255-279.

- - - - - (1984b). *Nubia: corridor to Africa.* London & Princeton, New Jersey: Allen Lane & Princeton University Press.

- - - - - (1986). *Ceramic industries of Medieval Nubia: part I.* Lexington, Kentucky: The University Press of Kentucky.

- - - - - (1994a). *Kulubnarti I: the architectural remains.* Lexington, Kentucky: Program for Cultural Resource Assessment, University of Kentucky.

- - - - - (1994b). Castle-houses of late Medieval Nubia. *Archéologie du Nil Moyen, 6*, 11-39.

- - - - - (1996). *Qasr Ibrim: the late Medieval period.* London: Egypt Exploration Society.

- - - - - (1999). *Kulubnarti III: the cemeteries.* Sudan Archaeological Research Society Number 4. British Archaeological Reports International Series 814.

- - - - - (2000). *Meinarti I: the late Meroitic, Ballaña and transitional occupation*. British Archaeological Reports International series 895.

- - - - - (2001). *Meinarti II: the early and classic Christian phases.* London: SARS.

- - - - - (2002). *Meinarti III: the late and terminal Christian phases*. London: SARS.

- - - - - (2010). *Qasr Ibrim: the earlier Medieval period.* London: Egypt Exploration Society.

- - - - - (2011). *Kulubnarti I: the architectural remains.* SARS Publication Number 18. British Archaeological Reports International Series 2241.

Adams, W. Y. & Nordström, H. A. (1963). The archaeological survey on the West Bank of the Nile: third season, 1961-62. *Kush, 11*, 10-46.

Ahmed, S. M. (2014). Kushites at the Fourth Cataract. In J. R. Anderson & D. A. Welsby (Eds.), *The Fourth Cataract and beyond. Proceedings of the 12th International Conference for Nubian Studies* (pp. 111-117). Leuven: Peeters.

Ah-See, K. W. & Evans, A. S. (2007). Sinusitis and its management. *British Medical Journal*, *334*, 358-361.

Aiello, A. E. & Larson, E. L. (2002). What is the evidence for a causal link between hygiene and infections? *The Lancet Infectious Diseases, 2,* 103-110.

Akhlaghi, F., Esmaeelinejad, M., & Safai, P. (2015). Etiologies and treatments of odontogenic maxillary sinusitis: a systematic review. *Iranian Red Crescent Medical Journal, 17*(12), e25536.

Alp, E. & Doganay, M. (2008). Current therapeutic strategy in spinal brucellosis. *International Journal of Infectious Diseases, 12*, 573-577.

Al-Sayyad, M. J. & Abumunaser, L. A. (2011). Tuberculosis arthritis revisited as a forgotten cause of monoarticular arthritis. *Annals of Saudi Medicine, 31*(4), 398-401.

Al-Shahed, M. S., Sharif, H. S., Haddad, M. C., Aabed, M. Y., Sammak., B. M., & Mutairi, M. A. (1994). Imaging features of musculoskeletal brucellosis. *RadioGraphics, 14*(2), 333-348.

Alves Cardoso, M. R., Cousens, S. N., de Góes Sigueira, L. F., Alves, F. M., & D'Angelo, L. A. V (2004). Crowding: risk factor or protective factor for lower respiratory disease in young children? *BMC Public Health, 4,* 19.

Amaral, S. S., de Carvalho, J. A., Jr., Martins Costa, M. A., & Pinheiro, C. (2016). Particulate matter emission factors for biomass combustion. *Atmosphere, 7*, 141.

Amegah, A. K. & Jaakkola, J. J. K. (2016). Household air pollution and the sustainable development goals. *Bulletin of the World Health Organisation, 94*, 215-221.

Anderson, J. R. (1994). House C-One at Hambukol (Upper Nubia). In C. Bonnet (Ed.), *Études Nubiennes. Conférence de Genéve* (Vol. 2, pp. 225-228). Geneva: Société d'études Nubiennes.

- - - - - (1999). Monastic lifestyles of the Nubian desert: seeking the mysterious monks of Makuria. *Sudan and Nubia, 3,* 71-83.

- - - - - (2001). Area C: house C-1. In K. Grzymski & J. R. Anderson, *Hambukol excavations 1986-1989* (pp. 93-118). Mississauga: Benben Publications.

- - - - - (2004). The Medieval kingdoms of Nubia. In D. A. Welsby & J. R. Anderson (Eds.), *Sudan ancient treasures: an exhibition of recent discoveries from the Sudan National Museum* (pp. 202-208). London: The British Museum Press.

Anson, C., Rothschild, B., & Naples, V. (2012). Soft tissue contributions to pseudopathology of ribs. *Advances in Anthropology, 2*(2), 57-63.

Antunes, M. B. & Cohen, N. A. (2007). Mucociliary clearance – a critical upper airway host defense mechanism and methods of assessment. *Current Opinion in Allergy and Clinical Immunology, 7*, 5-10.

Antunes-Ferreira, N., Matos, V. M. J., & Santos, A. L. (2013). Leprosy in individuals unearthed near the Ermida de Santo André and Leprosarium of Beja, Portugal. *Anthropological Science*, *121*(3), 149-159.

Arias-Irimia, O., Barona-Dorado, C., Santos-Marino, J. A., Martínez-Rodríguez, N., & Martínez-González, J. M. (2010). Meta-analysis of the etiology of odontogenic maxillary sinusitis. *Medicina oral Patología oral y Cirugía bucal, 15*(1), e70-3.

Aribandi, M., McCoy, V. A., & Bazan III, C. (2007). Imaging features of invasive and noninvasive fungal sinusitis: a review. *RadioGraphics, 27,* 1283-1296.

Arkell, A. J. (1953). *Shaheinab: an account of the excavation of a Neolithic occupation site carried out for the Sudan Antiquities Service in 1949-50*. London: Oxford University Press.

Arundel, A. V., Sterling, E. M., Biggin, J. H., & Sterling, T. D. (1986). Indirect health effects of relative humidity in indoor environments. *Environmental Health Perspectives, 65*, 351-361.

Asaad, A., Cao, K., & Rumbak, M. (2018). Should hut lung be called domestically acquired particulate lung disease or domestically acquired pneumoconiosis? *Respiratory Medicine Case Reports, 23,* 74-76.

Asano, S. (2012). Granulomatous lymphadenitis. *Journal of Clinical and Experimental Hematopathology, 52*(1), 1-16.

Ashour, M. (1995). The anatomy of left bronchus syndrome. *Clinical Anatomy, 8*, 256-261.

Ashour, M., Pandya, L., Mezraqji, A., Qutashat, W., Desouki, M., Al-Sharif, N., Al-Jaboori, A., & Marie, A. (1990). Unilateral post-tuberculous lung destruction: the left bronchus syndrome. *Thorax, 45*, 210-212.

Asnis, D. S. & Niegowska, A. (1997). Tuberculosis of the rib. *Clinical Infectious Diseases*, *24*, 1018-1019.

Assis, S., Santos, A. L., & Roberts, C. A. (2011). Evidence of hypertrophic osteoarthropathy in individuals from the Coimbra Skeletal assied Collection (Portugal). *International Journal of Paleopathology, 1,* 155-163.

Aufderheide, A. C. & Rodríguez-Martín, C. (1998). *The Cambridge encyclopaedia of human pathology.* Cambridge: Cambridge University Press.

Austrian, R. & Gold, J. (1964). Pneumococcal bacteremia with especial reference to bacteremic pneumococcal pneumonia. *Annals of Internal Medicine, 60*(5), 759-776.

Ayele, W. Y., Neill, S. D., Zinsstag, J., Weiss, M. G., & Pavlik, I. (2004). Bovine tuberculosis: an old disease but a new threat to Africa. *International Journal of Tuberculosis and Lung Disease, 8*(8), 924-937.

Ayers, J. G., Forsberg, B., Annesi-Maesano, I., Dey, R., Ebi, K. L., Helms, P. J., Medina-Ramón, Windt, M., & Forastiere, F. (2009). Climate change and respiratory disease: European Respiratory Society position statement. *European Respiratory Journal*, *34*, 295-302.

Baddock, M. C., Zobeck, T. M., Van Pelt, R. S., & Fredrickson, E. L. (2011). Dust emissions from undisturbed and disturbed, crusted playa surfaces: cattle trampling effects. *Aeolian Research, 3,* 31-41.

Baker, B. J. (1999). Early manifestations of tuberculosis in the skeleton. In G. Pálfi, O. Dutour, J. Deák, & I. Hutás (Eds.), *Tuberculosis: past and present* (pp. 301-307). Szeged, Hungary: Golden Book Publisher Ltd., Tuberculosis Foundation.

Baker, M. G., McDonald, A., Zhang, J., & Howden-Chapman, P. (2013). Infectious diseases attributable to household crowding in New Zealand: a systematic review and burden of disease estimate. Wellington: He Kainga Oranga/Housing and Health Research Programme, University of Otago.

Balcan, B., Akan, S., Ozsancak Ugurlu, A., Ozcelik Handemir, B., Bagci Ceyhan, B., & Ozkaya, S. (2016). *International Journal of COPD, 11*, 1615-1622.

Barton, R. P. E. (1979). Radiological changes in the paranasal sinuses in lepromatous leprosy. *The Journal of Laryngology and Otology, 93*, 597-600.

Bass, W. M. (2005). Human osteology: a laboratory and field manual (5th Ed.). Springfield, MO: Missouri Archaeological Society, Inc.

Bate, D. M. A. (1953). The vertebrate fauna. In A. J. Arkell, *Shaheinab: an account of the excavation of a Neolithic occupation site carried out for the Sudan Antiquities Service in 1949-50* (pp. 11-19). London: Oxford University Press.

Bates, M. N., Chandyo, R. K., Valentiner-Branth, P., Pokhrel, A. K., Mathisen, M., Basnet, S., Shrestha, P. S., Strand, T. A., & Smith, K. R. (2013). Acute lower respiratory infection in childhood and household fuel use in Bhaktapur, Nepal. *Environmental Health Perspectives, 121*, 637-642.

Baud, M. (2008). The Meroitic royal city of Muweis: first steps into an urban settlement of riverine Upper Nubia. *Sudan and Nubia, 12*, 52-63.

Bautista, L. E., Correa, A., Baumgartner, J., Breysse, P., & Matanoski, G. M. (2009). Indoor charcoal smoke and acute respiratory infections in young children in the Dominican Republic. *American Journal of Epidemiology, 169*(5), 572-580.

Becker, S., Soukup, J. M., & Gallagher, J. E. (2002). Differential particulate air pollution induced oxidant stress in human granulocytes, monocytes and alveolar macrophages. *Toxicology in Vitro, 16*(3), 209-218.

Beckett, S. & Lovell, N. C. (1994). Dental disease evidence for agricultural intensification in the Nubian C-Group. *International Journal of Osteoarchaeology, 4*, 223-240.

Beigelman-Aubry, C., Godet, C., & Caumes, E. (2012). Lung infections: the radiologist's perspective. *Diagnostic and Interventional Imaging, 93,* 431-440.

Belcastro, M. G., Bonfiglioli, B., Pedrosi, M. E., Zuppello, M., Tanganelli, V., & Mariotti, V. (2017). The history and composition of the Identified Human Skeletal Collection of the Certosa Cemetery (Bologna, Italy, 19^{th}-20^{th} Century). *International Journal of Osteoarchaeology, 27*(5), 912-925.

Bell, M. L., Levy, J. K., & Lin, Z. (2008). The effect of sandstorms and air pollution on cause-specific hospital admissions in Taipei, Taiwan. *Occupational and Environmental Medicine, 65,* 104-111.

Bennike, P., Lewis, M. E., Schutkowski, H., & Valentin, F. (2005). Comparison of child morbidity in two contrasting Medieval cemeteries from Denmark. *American Journal of Physical Anthropology, 128*(4), 734-746.

Bereza, M. A. (2016). *An investigation into the possible correlation between maxillary sinusitis and the nasal index in five British populations dating to the medieval and post Medieval periods.* Unpublished MSc Dissertation, Durham University.

Berger, H. W. & Granada, M. G. (1974). Lower lung field tuberculosis. *Chest, 65*(5), 522-526.

Berger, H. W. & Mejia, E. (1973). Tuberculous pleurisy. *Chest, 63*(1), 88-92.

Berim, I. & Sethi, S. (2012). Community-acquired pneumonia. In S. G. Spiro, G. A. Silvestri, & A. Agustí (Eds.), *Clinical respiratory medicine* (4th Ed., pp. 296-308). Philadelphia: Elsevier Saunders.

Berking, J., Körper, J., Wagner, S., Cubasch, U., & Schütt (2012). Heavy rainfalls in a desert(ed) city: a climate-archaeological case study from Sudan. In L. Giosan, D. Q Fuller, K. Nicoll, R. K. Flad & P. D. Clift (Eds.), *Climates, landscapes, and civilisations* (pp. 163-168). Geophysical Monograph Series, Vol. 198. Washington, DC: American Geophysical Union.

Bernofsky, K. S. (2006). *The effects of environment on respiratory health in early Medieval northeast England.* Unpublished MSc Dissertation, Durham University.

- - - - - (2010). *Respiratory health in the past: a bioarchaeological study of chronic maxillary sinusitis and rib periostitis from the Iron Age to the post Medieval period in southern England.* Unpublished PhD Thesis, Durham University.

Bernstein, A. S. & Rice, M. B. (2013). Lungs in a warming world: climate change and respiratory health. *Chest, 143*(5), 1455-1459.

Bernstein, J. A., Alexis, N., Bacchus, H., Bernstein, I. L., Fritz, P., Horner, E., Li, N., Mason, S., Nel, A., Oullette, J., Reijula, K., Reponen, T., Seltzer, J., Smith, A., & Tarlo, S. M. (2008). The health effects of nonindustrial indoor air pollution. *Journal of Allergy and Clinical Immunology*, *121*(3), 585-591.

Bhat, R. M. & Prakash, C. (2012). Leprosy: an overview of pathophysiology. *Interdisciplinary Perspectives on Infectious Diseases, 2012,* 181089.

Bhattacharyya, N. (2009). Air quality influences the prevalence of hay fever and sinusitis. *The Laryngoscope, 119*, 429-433.

Binder, M. (2014). *Health and diet in Upper Nubia through climate and political change: a bioarchaeological investigation of health and living conditions at ancient Amara West between 1300 and 800BC.* Unpublished PhD Thesis, Durham University.

Binder, M. & Spencer, N. (2014). The bioarchaeology of Amara West in Nubia: investigating the impacts of political, cultural and environmental change on health and diet. In A. Fletcher, D. Antoine, & J. D. Hill (Eds.), *Regarding the dead* (pp. 123-136). London: British Museum Press.

Birdi, S. M., Singh, S., & Singh, A. (1998). Mucociliary clearance in chronic sinusitis. *Indian Journal of Otolaryngology and Head and Neck Surgery, 50*(1), 15-19.

Bolger, W. E. (2001). Anatomy of the paranasal sinuses. In D. W. Kennedy, W. E. Bolger, & S. J. Zinreich (Eds.), *Diseases of the sinuses: diagnosis and management* (pp. 1-11). London: B. C. Decker Inc.

Boloursaz, M. R., Khalilzadeh, S., Baghaie, N., Khodayari, A. A., & Velayati, A. A. (2010). Radiologic manifestation of pulmonary tuberculosis in children admitted in pediatric Ward-Massih Daneshvari Hospital: a 5-year retrospective study. *Acta Medica Iranica, 48*(4), 244-249.

Bomeli, S. R., Branstetter, B. F., & Ferguson, B. J. (2009). Frequency of a dental source for acute maxillary sinusitis. *The Laryngoscope, 119,* 580-584.

Bonnet, C. (1982). Archaeological excavations at Kerma (Sudan). *Kerma, Soudan: 1981-1982, Geneva, n.s., 30*, 43-53.

- - - - - (1984). Archaeological excavations at Kerma (Sudan). *Kerma, Soudan: 1982-1983 – 1983-1984, Geneva, n.s., 32*, I-VII.

- - - - - (1988). The archaeological excavations at Kerma (Sudan). *Kerma, Soudan: 1986-1987 – 1987-1988, Geneva, n.s., 36*, I-VI.

- - - - - (2003). Kerma: preliminary report on the 2001-2002 and 2002-2003 seasons. *Kerma, Soudan: 2001 – 2002 2002 – 2003, Geneva, n.s., 51*, I-XII.

- - - - - (2004a). The Kerma culture. In D. A. Welsby & J. R. Anderson (Eds.), *Sudan ancient treasures: an exhibition of recent discoveries from the Sudan National Museum* (pp. 69-77). London: The British Museum Press.

- - - - - (2004b). Kerma. In D. A. Welsby & J. R. Anderson (Eds.), *Sudan ancient treasures: an exhibition of recent discoveries from the Sudan National Museum* (pp. 78-89). London: The British Museum Press.

- - - - - (2014a). Forty years research on Kerma cultures. In J. R. Anderson & D. A. Welsby (Eds.), *The Fourth Cataract and beyond. Proceedings of the 12th International Conference for Nubian Studies* (pp. 81-93). Leuven: Peeters.

- - - - - (2014b). *La ville de Kerma: Une capitale nubienne au sud de l'Egypte.* Paris: Éditions Favre SA.

Boocock, P., Roberts, C. A., & Manchester, K. (1995). Maxillary sinusitis in Medieval Chichester, England. *American Journal of Physical Anthropology, 98*, 483-495.

Bourke, S. J. (2007). *Respiratory medicine* (7th Ed.). Blackwell Publishing: Oxford.

Boxall, A. B. A., Hardy, A., Beulke, S., Boucard, T., Burgin, L., Falloon, P. D., . . . & Williams, R. J. (2009). Impacts of climate change on indirect human exposure to pathogens and chemicals from agriculture. *Environmental Health Perspectives, 117*, 508-514.

Boy, E., Bruce, N., & Delgado, H. (2002.) Birth weight and exposure to kitchen wood smoke during pregnancy in rural Guatemala. *Environmental Health Perspectives, 110*(1), 109-114.

Bradley, R. J. (1984). Comments on Meroitic architecture. *Meroitica, 7*, 280-286.

Brass, M. (2015). Interactions and pastoralism along the southern and southeastern frontiers of the Meroitic state, Sudan. *Journal of World Prehistory, 28*, 255-288.

Breysse, P. N., Diette, G. B., Matsui, E. C., Butz, A. M., Hansel, N. N., & McCormack, M. C. (2010). Indoor air pollution and asthma in children. *Proceedings of the American Thoracic Society, 7*, 102-106.

Brook, I. (2006). Sinusitis of odontogenic origin. *Otolaryngology - Head and Neck Surgery, 135*, 349-355.

- - - - - (2009). Sinusitis. *Periodontology 2000*, *49*(1), 126-139.

Brooks, S. T. & Suchey, J. M. (1990). Skeletal age determination based on the os pubis: a comparison of the Acsádi-Nemeskéri and Suchey-Brooks methods. *Human Evolution, 5*, 227-238.

Brothwell, D. R. (1972). *Digging up bones: the excavation, treatment and study of human skeletal remains.* London: The British Museum (Natural History).

Bruce, N., Perez-Padilla, R., & Albalak, R. (2000) Indoor air pollution in developing countries: a major environmental and public health challenge. Bulletin of the World Health Organisation, 78(9), 1078-1092.

- - - - - (2002). *The health effects of indoor air pollution exposure in developing countries.* Geneva: World Health Organisation.

Brunekreef, B. & Holgate, S. T. (2002). Air pollution and health. *The Lancet, 360*(9341), 1233-1242.

Bruzek, J. (2002). A method for visual determination of sex, using the human hip bone. *American Journal of Physical Anthropology, 117*, 157-168.

Buckberry, J. L. & Chamberlain, A. T. (2002). Age estimation from the auricular surface of the ilium: a revised method. *American Journal of Physical Anthropology, 119*, 231-239.

Buckley, S., Usai, D., Jakob, T., Radini, A., & Hardy, K. (2014). Dental calculus reveals unique insights into food items, cooking and plant processing in prehistoric Central Sudan. *PLOS ONE*, *9*(7), e100808.

Buikstra, J. E. & Ubelaker, D. H. (1994). *Standards for data collection from human skeletal remains*. Fayetteville, AL: Arkansas Archaeological Survey.

Buikstra, J. E. & Williams, S. (1991). Tuberculosis in the Americas: current perspectives. In D. J. Ortner & A. C. Aufderheide (Eds.), *Human palaeopathology: current syntheses and future options* (pp. 161-172). London: Smithsonian Institution.

Calvert, G. M., Rice, F. L., Boiano, J. M., Sheehy, J. W., & Sanderson, W. T. (2003). Occupational silica exposure and risk of various diseases: an analysis using death certificates from 27 states of the United States. *Occupational and Environmental Medicine, 60*, 122-129.

Capasso, L. (1999). Brucellosis at Herculaneum (79 AD). *International Journal of Osteoarchaeology, 9,* 277-288.

- - - - - (2000). Indoor pollution and respiratory diseases in Ancient Rome. *The Lancet, 356*, 1774.

Capasso, L. & Di Tota, G. (1999). Tuberculosis in Herculaneum (79 AD). In G. Pálfi, O. Dutour, J. Deák, & I. Hutás (Eds.), *Tuberculosis: past and present* (pp. 463-467). Szeged, Hungary: Golden Book Publisher Ltd., Tuberculosis Foundation.

Capone, R. B., Capone, D., Mafort, T., Mogami, R., de Souza Rodrigues, R., Barreto, M. M., & Rufino, R. (2017). Tomographic aspects of advanced active pulmonary tuberculosis and evaluation of sequelae following treatment. *Pulmonary Medicine, 2017,* 9876768.

Cardoso, H. F. V. (2006). Brief communication: the collection of identified human skeletons housed at the Bocage Museum (National Museum of Natural History), Lisbon, Portugal. *American Journal of Physical Anthropology, 129,* 173-176.

Carpio, G. & Guillen, S. (2005). Excavations at site 3-J-23, et-Tereif. *Sudan and Nubia, 9*, 14-16.

Carter, P. L. & Foley, R. (1980). Appendix B: a report on the fauna from the excavations at Meroe, 1967-1972. In P. L. Shinnie & R. J. Bradley, The capital of Kush I. Meroe Excavations 1965-1972. *Meroitica, 4*, 298-310.

Cartwright, C. (1998). The wood, charcoal, plant remains and other organic material. In D. A. Welsby, *Soba II: renewed excavations within the metropolis of the kingdom of Alwa in Central Sudan* (pp. 255-268). London: British Museum Press.

- - - - - (1999). Reconstructing the woody resources of the Medieval kingdom of Alwa, Sudan. In M. van der Veen (Ed.), *The exploitation of plant resources in ancient Africa* (pp. 241-259). New York: Kluwer Academic/ Plenum Publishers.

- - - - - (2001). The plant remains. In D. A. Welsby, *Life on the desert edge.* (Vol. 2, pp. 556-567). London: SARS.

CDC (2016). *Chronic sinusitis*. Retrieved from http://www.cdc.gov/nchs/fastats/sinuses.html [Accessed on 26th April 2016].

Cenci, L. (2008). Ancient recycling: the animal bone tools. In S. Salvatori & D. Usai (Eds.), *A Neolithic cemetery in the Northern Dongola Reach: excavations at site R12* (pp. 79-81). London: SARS.

Chaix, L. (1998). The fauna. In D. A. Welsby, *Soba II: renewed excavations within the metropolis of the kingdom of Alwa in Central Sudan* (pp. 233-255). London: British Museum Press.

- - - - - (2001). Animals as symbols: the bucrania of the grave KN 24 (Kerma, Northern Sudan). In H. Buitenhuis & W. Prummel (Eds.), *Animals and man in the past* (pp. 364-370). Groningen: ARC-Publicatie.

- - - - - (2006). New data about rural economy in the Kerma culture: the site of Gism el-Arba (Sudan). In K. Kroeper, M. Chłodnicki, & M. Kobusiewicz (Eds.), *Archaeology of early northeastern Africa. Studies in African Archaeology* (Vol. 9, pp. 25-38). Poznań: Poznań Archaeological Museum.

- - - - - (2010). Animal exploitation during Napatan and Meroitic times in the Sudan. In *Between the Cataracts. Proceedings of the 11th Conference of Nubian Studies. Warsaw University, 27 August - 2 September 2006* (Vol. 2.2, pp. 519-525). Warsaw: Polish Centre of Mediterranean Archaeology & Warsaw University Press.

- - - - - (2017). Cattle, a major component of the Kerma Culture (Sudan). In U. Albarella (Ed.), *The Oxford handbook of zooarchaeology* (pp. 414-426). Oxford: Oxford University Press.

Chaix, L. & Grant, A. (1993). Palaeoenvironment and economy at Kerma, Northern Sudan, during the third millennium B.C.: archaeozoological and botanical evidence. In L. Krzyżaniak, M. Kobusiewicz, & J. Alexander (Eds.), *Environmental change and human culture in the Nile Basin and northern Africa until the second millennium B.C.* (pp. 399-404). Poznań: Poznań Archaeological Museum.

Chakrabarti, B., Calverley, P. M. A., & Davies, P. D. O. (2007). Tuberculosis and its incidence, special nature, and relationship with chronic obstructive pulmonary disease. *International Journal of COPD, 2*(3), 263-272.

Chang, C. & Koster, H. A. (1986). Beyond bones: toward an archaeology of pastoralism. *Advances in Archaeological Method and Theory, 9*, 97-148.

Chang, E. H., Stern, D. A., Willis, A. L., Guerra, S., Wright, A L., & Martinez, F. D. (2018). Early life risk factors for chronic sinusitis: a longitudinal birth cohort study. *Journal of Allergy and Clinical Immunology, 141,* 1291-1297.

Chang, S., Lee, P., & Perng, R. (1967). Lower lung field tuberculosis. *Chest, 91*(2), 230-232.

Chang, T., Mou, C., Shen, T., Yang, C., Yang, M., Wu, F., & Sung, F. (2016). Retrospective cohort evaluation on risk of pneumonia in patients with pulmonary tuberculosis. *Medicine, 95,* 26(e4000).

Chernihovski, A., Loberant, M., Cohen, I., Nassar, F., Lemer, J., & Altman, E. (2007). Chest wall actinomycosis. *The Israel Medical Association Journal, 9*, 686-687.

Cho, S. H., Min, H. J., Han, H. X., Paik, S. S., & Kim, K. R. (2006). CT analysis and histopathology of bone remodelling in patients with chronic rhinosinusitis. *Otolaryngology - Head and Neck Surgery*, *135*(3), 404-408.

Cirillo, J. & Henneberg, M. (2012). Sequencing human ribs into anatomical order by quantitative multivariate methods. *HOMO - Journal of Comparative Human Biology*, *63*, 182-201.

Clapham, A. & Edwards, D. N. (1998). Appendix 8: botanical remains. In D. N. Edwards, *Gabati: a Meroitic, Post-Meroitic and Medieval cemetery in Central Sudan* (Vol. 1, pp. 241-243). London: SARS.

Clapham, A. & Rowley-Conwy, P. (2006). Rewriting the history of African agriculture. *Planet Earth*, *2006 Summer*, 24-25.

Clerico, D. M. (2001). Environmental influence on sinus disease: the role of chemical air pollutants. In: D. W. Kennedy, W. E. Bolger, & S. J. Zinreich (Eds.), *Diseases of the sinuses: diagnosis and management* (pp. 107-117). London: B. C. Decker Inc.

Clouet, P. I., Berthezene, Y., Marchand, B., Nesme, P. & Mornex, J. F. (2001). Pneumonias. In M. Sperber (Ed.), *Radiologic diagnosis of chest disease* (2nd Ed., pp. 171-179). London: Springer.

Cohen, A. & Mehta, S. (2007). Pollution and tuberculosis: outdoor sources. *PLoS Medicine*, *4*(3), e142.

Cooper, C., Fellner, R., Heubi, O., Maixner, F., Zink, A., & Lösch, S. (2016). Tuberculosis in early medieval Switzerland – osteological and molecular evidence. *Swiss Medical Weekly, 146,* w14269.

Corbel, M. J. (2006). *Brucellosis in humans and animals.* Geneva: WHO.

Cosivi, O., Grange, J. M., Daborn, C. J., Raviglione, M. C., Fujikura, T., Cousins, D., Robinson, R. A., Huchzermeyer, H. F. A. K., de Kantor, I., & Meslin, F. X. (1998). Zoonotic tuberculosis due to *Mycobacterium bovis* in developing countries. *Emerging Infectious Diseases, 4*(1), 59-70.

Cowie, R. L. (1994). The epidemiology of tuberculosis in gold miners with silicosis. *The American Journal of Respiratory and Critical Care Medicine, 150*, 1460-1462.

Cox, M. (2000). Ageing adults from the skeleton. In M. Cox & S. Mays (Eds.), *Human osteology in archaeology and forensic science* (pp. 61-81). Cambridge: Cambridge University Press.

Crawford, O. G. S. & Addison, F. (1951). *Abu Geili. The Wellcome excavations in the Sudan* (Vol. 3). London: Oxford University Press.

Crowder, C. & Austin, D. (2005). Age ranges of epiphyseal fusion in the distal tibia and fibula of contemporary males and females. *Journal of Forensic Sciences, 50*(5), 1001-1007.

Crowfoot, E. G. (1977). The clothing of a fourteenth-century Nubian bishop. In V. Gervers (Ed.), *Studies in textile history. In memory of Harold B. Burnham* (pp.43-51). Toronto: Royal Ontario Museum.

Culver, B. H. (2012). Respiratory mechanics. In S. G. Spiro, G. A. Silvestri, & A. Agustí (Eds.), *Clinical respiratory medicine* (4th Ed., pp. 19-28). Philadelphia: Elsevier Saunders.

Cunha, E. & Wasterlain, S. (2007). The Coimbra identified skeletal collections. In G. Grupe & J. Peters (Eds.), *Skeletal series and their socioeconomic context* (pp. 23-33). Rahden, Germany: Verlag Marie Leidorf.

Dabernat, H. & Crubézy, É. (2010). Multiple bone tuberculosis in a child from predynastic Upper Egypt (3200 BC). *International Journal of Osteoarchaeology, 20*, 719-730.

Daborn, C. J., Grange, J. M., & Kazwala, R. R. (1996). The bovine tuberculosis cycle – an African perspective. *Journal of Applied Bacteriology Symposium Supplement, 81*, 27S-32S.

Dal Sasso, G., Maritan, L., Salvatori, S., Mazzoli, C., & Artioli, G. (2014). Discriminating pottery production by image analysis: a case study of Mesolithic and Neolithic pottery from Al Khiday (Khartoum, Sudan). *Journal of Archaeological Science, 46*, 125-143.

D'Amato, G., Holgate, S. T., Pawankar, R., Ledford, D. K., Cecchi, L., Al-Ahmad, M., . . . & Annesi-Maesano, I. (2015). Meteorological conditions, climate change, new emerging factors, and asthma and related disorders. A statement of the World Allergy Organisation. *World Allergy Organisation Journal, 8*(1), 25.

D'Ambrosio, L., Spanevello, A., & Centis, R. (2012). Epidemiology of TB. In C. Lange & G. B. Migliori (Eds.), *Tuberculosis. European Respiratory Monograph 58* (pp. 14-24). Sheffield: European Respiratory Society.

Davies, H. E., Davies, R. J. O., & Davies, C. W. H. (2010). Management of pleural infection in adults: British Thoracic Society pleural disease guideline 2010. *Thorax*, *65*(Suppl. 2), ii41-ii53.

de Francisco, A., Morris, J., Hall, J. A., Armstrong Schellenberg, J. R. M., & Greenwood, B. M. (1993). Risk factors for mortality from acute lower respiratory tract infections in young Gambian children. *International Journal of Epidemiology, 22*(6), 1174-1182.

de Longueville, F., Ozer, P., Doumbia, S., & Henry, S. (2013). Desert dust impacts on human health: an alarming worldwide reality and a need for studies in West Africa. *International Journal of Biometeorology, 57*, 1-19.

deShazo, R. D., Chapin, K., & Swain, R. E. (1997). Fungal sinusitis. *The New England Journal of Medicine, 337*(4), 254-259.

Destouet, J. M. & Murphy, W. A. (1983). Acquired acroosteolysis and acronecrosis. *Arthritis and Rheumatism, 26*(9), 1150-1154.

DeWitte, S. N. (2014). Differential survival among individuals with active and healed periosteal new bone formation. *International Journal of Paleopathology, 7,* 38-44.

DeWitte, S. N. & Stojanowski, C. M. (2015). The osteological paradox 20 years later: past perspectives, future directions. *Journal of Archaeological Research, 23,* 397-450.

Dherani, M., Pope, D., Mascarenhas, M., Smith, K. R., Weber, M., & Bruce, N. (2008). Indoor air pollution from unprocessed solid fuel use and pneumonia risk in children aged five years: a systematic review and meta-analysis. *Bulletin of the World Health Organisation, 86*(5), 390-398.

DiGangi, E. A. & Sirianni, J. E. (2017). Maxillary sinus infection in a 19th-century almshouse skeletal sample. *International Journal of Osteoarchaeology, 27,* 155-166.

Dominici, F., Peng, R. D., Bell, M. L., Pham, L., McDermott, A., Zeger, S. L., & Samet, J. M. (2006). Fine particulate air pollution and hospital admission for cardiovascular and respiratory diseases. *The Journal of the Medical Association (JAMA)*, *295*(10), 1127-1134.

Dong, H. & Lanza, D. C. (2001). Fungal Rhinosinusitis. In D. W. Kennedy, W. E. Bolger, & S. J. Zinreich (Eds.), *Diseases of the sinuses: diagnosis and management* (pp. 179-196). London: B. C. Decker Inc.

Drake, R. L., Vogl, W., Mitchell, A. W. M., & Gray, H. (2010). *Gray's anatomy for students.* Philadelphia, PA: Elsevier.

Drzewiecki, M. (2014). Banganarti – fortifications. In J. R. Anderson & D. A. Welsby (Eds.), *The Fourth Cataract and beyond. Proceedings of the 12th International Conference for Nubian Studies* (pp. 901-908). Leuven: Peeters.

Dudar, J. C. (1993). Identification of rib number and assessment of intercostal variation at the sternal rib end. *Journal of Forensic Sciences, 38*(4), 788-797.

Duvall, C. S. (2017). Cannabis and tobacco in precolonial and colonial Africa. *Oxford research encyclopedia of African history.* Retrieved from http://oxfordre.com/africanhistory/view/10.1093/acrefore/9780190277734.001.0001/acrefore-9780190277734-e-44 [accessed on 13th September 2018].

Ebrahimi, S. J. A., Ebrahimzadeh, L., Eslami, A., & Bidarpoor, F. (2014). Effects of dust storm events on emergency admissions for cardiovascular and respiratory diseases in Sanandaj, Iran. *Journal of Environmental Health Science & Engineering, 12*, 110.

Ebrahimpour, S., Bayani, M., Moulana, Z., & Hasanjani Roushan, M. R. (2017). Skeletal complications of brucellosis: a study of 464 cases in Babol, Iran. *Caspian Journal of Internal Medicine, 8*(1), 44-48.

Edwards, D. N. (1989). *Archaeology and settlement in Upper Nubia in the 1st Millennium AD.* British Archaeological Reports international series 537.

- - - - - (1996). *The archaeology of the Meroitic state. New perspectives on its social and political organisation.* British Archaeological Reports International Series 640, Cambridge Monographs in African Archaeology 38. Oxford: Tempvs Reparatvm.

- - - - - (1998a). Meroe and the Sudanic kingdoms. *Journal of African History, 39*, 175-193.

- - - - - (1998b). *Gabati: a Meroitic, Post-Meroitic and Medieval cemetery in Central Sudan* (Vol. 1). London: SARS.

- - - - - (1999). Musawwarat es Sufra III: a Meroitic pottery workshop at Musawwarat es Sufra. *Meroitica, 17*(2).

- - - - - (2004). *The Nubian past: an archaeology of the Sudan.* London: Routledge.

Edwards, D. N. & Fuller, D. Q (2005). Excavations and survey in the central Amri-Kirbekan area, Fourth Cataract, 2003-2004. *Gdańsk Archaeological Museum African Reports, 5*, 21-29.

Edwards, D. N., Osman, A., Tahir, Y. F., Sadig, A. M., & el-Zein, I. S. (2012). On a Nubian frontier – landscapes and settlement on the Third Cataract of the Nile, Sudan. *Azania: Archaeological Research in Africa, 47*(4), 450-487.

Eigner, D. (2002). Bauaufnahme der Räume 507 – 509 ("Heilige Hochzeit") der Grossen Anlage von Musawwarat es Sufra. *Mitteilungen der Sudanarchäologischen Gesellschaft zu Berlin e.V., 13,* 14-21.

ElHassan, A. M., Elamin, W. M., Elhassan, L. A. M., Elkareem, G. D. A., Musa, A. M., Abd Alla, E. A., Ibrahim, M. E., & Khalil, E. A. G. (2015). Oesophageal cancer: pathological subtypes and markers of metastasis. *Journal of Histology and Histopathology, 2*(11).

el-Tayeb, M. (2010). Kirwan memorial lecture. The Post-Meroitic from Kirwan to the present. *Sudan and Nubia, 14,* 2-14.

El-Zein, I. S. (2004). Islamic archaeology in Sudan. In D. A. Welsby & J. R. Anderson (Eds.), *Sudan ancient treasures: an exhibition of recent discoveries from the Sudan National Museum* (pp. 238-242). London: The British Museum Press.

Emberling, G. (2014). Pastoral states: toward a comparative archaeology of Early Kush. *Origini: Prehistory and Protohistory of Ancient Civilisations, 36*, 125-156.

Emberling, G. & Williams, B. (2010). The kingdom of Kush in the 4th Cataract: archaeological salvage of the Oriental Institute Nubian Expedition 2007 season. Part I: preliminary report on the sites of Hosh el-Guruf and el-Widay. *Gdańsk Archaeological Museum African Reports*, *7*, 17-38.

Emberling, G., Williams, B. B., Ingvoldstad, M., & James, T. R. (2014). Peripheral vision: identity at the margins of the early kingdom of Kush. In J. R. Anderson & D. A. Welsby (Eds.), *The Fourth Cataract and beyond. Proceedings of the 12th International Conference for Nubian Studies* (pp. 329-336). Leuven: Peeters.

Emery, W. B. & Kirwan, L. P. (1935). *The excavations and survey between Wadi es-Sebua and Adindan 1929 – 1931* (Vol. 1). Cairo: Government Press, Bulâq.

Enna, C. D., Jacobson, R. R., & Rausch, R. O. (1971). Bone changes in leprosy: a correlation of clinical and radiographic features. *Radiology, 100*, 295-306.

Esmaeil, N., Gharagozloo, M., Rezaei, A., & Grunig, G. (2014). Dust events, pulmonary diseases and immune system. *American Journal of Clinical and Experimental Immunology, 3*(1), 20-29.

Eyler, W. R, Monsein, L. H., Beute, G. H., Tilley, B., Schultz, L. R., & Schmitt, W. G. H. (1996). Rib enlargement in patients with chronic pleural disease. *American Journal of Roentgenology, 167*(4), 921-926.

Ezzati, M. & Kammen, D. M. (2001). Indoor air pollution from biomass combustion and acute respiratory infections in Kenya: an exposure-response study. *The Lancet, 358*, 619-624.

Falys, C. G. & Lewis, M. E. (2011). Proposing a way forward: a review of standardisation in the use of age categories and ageing techniques in osteological analysis (2004-2009). *International Journal of Osteoarchaeology, 21,* 704-716.

Farrokh, D., Rezaitalab, F., & Bakhshoudeh, B. (2014). Pulmonary actinomycosis with endobronchial involvement: a case report and literature review. *Tanaffos, 13*(1), 52-56.

Ferembach, D., Schwidetzky, I. & Stloukal, M. (1980). Recommendations for age and sex diagnoses of skeletons. *Journal of Human Evolution, 9*, 517-549.

Ferkol, T. & Schraufnagel, D. (2014). The global burden of respiratory disease. *Annals of the American Thoracic Society, 11*(3), 404-406.

Ferraro, C. F., Trotter, C. L., Nascimento, M. C., Jusot, J., Omotara, B. A., Hodgson, A., Ali, O., Alavo, S., Sow, S., Moto Daugla, D., & Stuart J. M. (2014). Household crowding, social mixing patterns and respiratory symptoms in seven countries of the African meningitis belt. *PLoS ONE, 9*(7), e101129.

Ferreira, M. T., Vicente, R., Navega, D., Gonçalves, D., Curate, F., & Cunha, E. (2014). A new forensic collection housed at the University of Coimbra, Portugal: the 21st century identified skeletal collection. *Forensic Science International, 245*, 202.e1-202.e5.

Field, J. P., Belnap, J., Breshears, D. D., Neff, J. C., Okin, G. S., Whicker, J. J., Painter, T. H., Ravi, S., Reheis, M. C., & Reynolds, R. L. (2010). The ecology of dust. *Frontiers in Ecology and the Environment, 8*(8), 423-430.

Filer, J. (1998). The skeletal remains. In D. A. Welsby, *Soba II: renewed excavations within the metropolis of the kingdom of Alwa in Central Sudan* (pp. 213-233). London: British Museum Press.

FIRS (2017). *The global impact of respiratory disease* (2nd Ed.). Sheffield: European Respiratory Society.

Flander, L. B. (1978). Univariate and multivariate methods for sexing the sacrum. *American Journal of Physical Anthropology, 49*, 103-110.

Forastiere, F., Goldsmith, D. F., Sperati, A., Rapiti, E., Miceli, M., Cavariani, F., & Perucci, C. A. (2002). Silicosis and lung function decrements among female ceramic workers in Italy. *American Journal of Epidemiology, 156*(9), 851-856.

Frieri, M. (2014). Asthma linked with rhinosinusitis: an extensive review. *Allergy and Rhinology, 5*, e41-e49.

Frost, W. H. (1995). The age selection of mortality from tuberculosis in successive decades. 1939. *American Journal of Epidemiology, 141*(1), 4-9.

Fuller, D. Q (2004). The central Amri to Kirbekan survey: a preliminary report on excavations and survey 2003-04. *Sudan and Nubia, 8,* 5-11.

- - - - - (2014). Agricultural innovation and state collapse in Meroitic Nubia. The impact of the savannah package. In C. J. Stevens, S. Nixon, M. A. Murray, & D.Q Fuller (Eds.), *Archaeology of African plant use* (pp. 165-177). London: Routledge.

Fuller, D. Q & Edwards, D. N. (2001). Medieval plant economy in middle Nubia: preliminary archaeobotanical evidence from Nauri. *Sudan and Nubia, 5*, 95-103.

Fullerton, D. G., Bruce, N., & Gordon, S. B. (2008). Indoor air pollution from biomass fuel smoke is a major health concern in the developing world. *Transactions of the Royal Society of Tropical Medicine and Hygiene, 102*, 843-851.

Gabriel, B. (1997). Zur quartären Landschaftsentwicklung der nördlichen Butana (Sudan). *Mitteilungen der Sudanarchäologischen Gesellschaft zu Berlin e.V.*, *7*, 23-30.

Gad El Rab, M. O., Thatcher, D. R., & Kay, A. B. (1980). Widespread IgE-mediated hypersensitivity in the Sudan to the 'green nimitti' midge, *Cladotanytarsus lewisi* (Diptera: Chironomidae). II. Identification of a major allergen. *Clinical and Experimental Immunology, 41,* 389-396.

Gao, W., Ou, C., Fang, S., Sun, Y., Zhang, H., Cheng, L., . . . & Fu, Q. (2016). Occupational and environmental risk factors for chronic rhinosinusitis in China: a multicentre cross-sectional study. *Respiratory Research, 17*, 54.

Garg, R. K. & Somvanshi, D. S. (2011). Spinal tuberculosis: a review. *The Journal of Spinal Cord Medicine*, *34*(5), 440-454.

Garvin, H. M., Sholts, S. B. & Mosca, L. A. (2014). Sexual dimorphism in human cranial trait scores: effects of population, age, and body size. *American Journal of Physical Anthropology, 154*, 259-269.

Gatto, M. C. & Zerboni, A. (2015). Holocene supre-regional environmental changes as trigger for major socio-cultural processes in northeastern Africa and the Sahara. *The African Archaeological Review, 32*, 301-333.

Gauderman, W. J., Avol, E., Gilliland, F., Vora, H., Thomas, D., Berhane, K., McConnell, R., Kuenzli, N., Lurmann, F., Rappaport, E., Margolis, H., Bates, D., & Peters, J. (2004). The effect of air pollution on lung development from 10 to 18 years of age. *The New England Journal of Medicine, 351*(11), 1057-1067.

Gautier, A. & Van Neer, W. (2011). The fauna of Kadero and the arrival of pastoralism in the Nile Valley of Central Sudan. In M. Chłodnicki, M. Kobusiewicz, & K. Kroeper (Eds.), *Kadero: the Lech Krzyżaniak excavations in the Sudan.* Studies in African Archaeology (Vol. 10, pp. 375-407). Poznań: Poznań Archaeological Museum.

Geus, F. (1986). Editorial forward. *Archeologie du Nil Moyen, 1*, 5-8.

Ginns, A. (2006). Preliminary report on the excavations conducted on Mis Island (AKSC), 2005-2006. *Sudan and Nubia, 10*, 13-19.

- - - - - (2007). Preliminary report on the second season of excavations conducted on Mis Island (AKSC). *Sudan and Nubia, 11*, 20-26.

- - - - - (2010a). *Church 3-J-18.* Sudan Archaeological Research Society (SARS) draft report. Retrieved from http://www.sudarchrs.org.uk/wp-content/uploads/2013/09/SARS_draft_3-J-18_church.pdf [accessed on 29th May 2018].

- - - - - (2010b). *The cemetery associated with the church at 3-J-18.* Sudan Archaeological Research Society (SARS) draft report. Retrieved from http://www.sudarchrs.org.uk/wp-content/uploads/2013/09/SARS_draft_3-J-18_graves.pdf [accessed on 29th May 2018].

- - - - - (2010c). *Medieval settlement 3-J-19.* Sudan Archaeological Research Society (SARS) draft report. Retrieved from http://www.sudarchrs.org.uk/wp-content/uploads/2013/09/SARS_draft_3-J-19_report.pdf [accessed on 29th May 2018].

- - - - - (2010d). *Medieval cemetery 3-J-20.* Sudan Archaeological Research Society (SARS) draft report. Retrieved from http://www.sudarchrs.org.uk/wp-content/uploads/2018/07/SARS_draft_3-J-20.pdf [accessed on 29th May 2018].

- - - - - (2010e). *Medieval cemetery 3-J-10.* Sudan Archaeological Research Society (SARS) draft report. Retrieved from http://www.sudarchrs.org.uk/wp-content/uploads/2018/07/SARS_draft_3-J-10_report.pdf [accessed on 29th May 2018].

- - - - - (2010f). *Medieval cemetery 3-J-11.* Sudan Archaeological Research Society (SARS) draft report. Retrieved from http://www.sudarchrs.org.uk/wp-content/uploads/2018/07/SARS_draft_3-J-11_report.pdf [accessed on 29th May 2018].

Glanville, W. (1993). Livestock development in the Sudan, 1899-1956. D. Lavin (Ed.), *The transformation of the old order in the Sudan. Proceedings of the Durham Sudan Historical Records Conference 1982* (Vol. 2., pp. 57-64). Durham: Centre for Middle Eastern & Islamic Studies, University of Durham.

Glaziou, P., Sismanidis, C., Zignol, M., & Floyd, K. (2018). *Methods used by WHO to estimate the global burden of TB disease.* Geneva: WHO.

Godlewski, W. (1989). The mosque building in Old Dongola. In P. van Moorsel (Ed.), *New discoveries in Nubia. Proceedings of the colloquium on Nubian studies, The Hague, 1979* (pp. 21-28). Leiden: Nederlands Instituut voor het Nabije Oosten.

- - - - - (1990). Old Dongola 1988-1989. House PCH. 1. *Polish Archaeology in the Mediterranean, 1*, 14-16.

- - - - - (1991). Old Dongola 1988-1989, House PCH. 1. *Archéologie du Nil Moyen, 5*, 79-96.

- - - - - (1997). Kom A. *Polish Archaeology in the Mediterranean, 8*, 179-187.

- - - - - (1998). Excavations 1997 – Kom A. *Polish Archaeology in the Mediterranean, 9*, 171-180.

- - - - - (2002). Old Dongola: Kom A, 2001. *Polish Archaeology in the Mediterranean, 13*, 203-216.

- - - - - (2010). Dongola after the 2008-2010 seasons: royalty, saints and blessed bishops. *Sudan and Nubia, 14*, 75-82.

Gold, J. A., Jagirdar, J., Hay, J. G., Addrizzo-Harris, D. J., Naidich, D. P., & Rom, W. N. (2000). Hut lung: a domestically acquired particulate lung disease. *Medicine, 79*(5), 310-317.

Goto, D. M., Lança, M., Obuti, C. A., Galvão Barbosa, C. M., Nascimento Saldiva, P. H., Trevisan Zanetta, D. M., Lorenzi-Filho, G., de Paula Santos, U., & Nakagawa, N. K. (2011). Effects of biomass burning on nasal cavity mucociliary clearance and mucus properties after sugarcane harvesting. *Environmental Research, 111*(5), 664-669.

Goudie, A. S. & Middleton, N. J. (2001). Saharan dust storms: nature and consequences. *Earth-Science Reviews, 56*, 179-204.

Grant, A. (2001). The animal remains. In D. A. Welsby, *Life on the desert edge.* (Vol. 2, pp. 544-555). London: SARS.

Gratien, B. (1986). *Saï I. La nécropole Kerma.* Paris: Centre National de la recherche Scientifique.

- - - - - (1999). Some rural settlements at Gism el-Arba in the Northern Dongola Reach. *Sudan and Nubia*, *3*, 10-12.

Gratien, B., Marchi, S., Thuriot, O., & Willot, J. (2003). Gism el-Arba, habitat 2. Rapport préliminaire sur un centre de stockage Kerma au bord du Nil. *CRIPEL, 23*, 29-43.

Gregg, J. B. & Gregg, P. S. (1987). *Dry bones: Dakota territory reflected*. Sioux Falls, South Dakota: Sioux Printing Press.

Grobbelaar, J. P. & Bateman, E. D. (1991). Hut lung: a domestically acquired pneumoconiosis of mixed aetiology in rural women. *Thorax, 46*, 334-340.

Grzymski, K. (1990). Excavations at Hambukol (Upper Nubia): 1987 and 1988 seasons. *Journal of the American Research Centre in Egypt, 27,* 139-163.

- - - - - (2004). Meroe. In D. A. Welsby & J. R. Anderson (Eds.), *Sudan ancient treasures: an exhibition of recent discoveries from the Sudan National Museum* (pp. 165-173). London: The British Museum Press.

Guirado, E. & Schlesinger, L. S. (2013). Modeling the *Mycobacterium tuberculosis* granuloma - the critical battlefield in host immunity and disease. *Frontiers in Immunology, 4*, 98.

Gupta, P. R. (2004). Difficulties in managing lymph node tuberculosis. *Lung India, 21,* 50-53.

Gurley, E. S., Homaira, N., Salje, H., Ram., P. K., Haque, R., Petri, W., Bresee, J., Moss, W. J., Breysse, P., Luby, S. P., Azziz-Baumgartner, E. (2013). Indoor exposure to particulate matter and the incidence of acute lower respiratory infections among children: a birth cohort study in urban Bangladesh. *Indoor Air, 23*, 379-386.

Guttentag, A. R. & Salwen, J. K. (1999). Keep your eyes on the ribs: the spectrum of normal variants and diseases that involve the ribs. *Radiographics, 19*, 1125-1142.

Haaland, R. (1981). Seasonality and division of labour: a case study from Neolithic sites in the Khartoum Nile environment. *Norwegian Archaeological Review, 14*(1), 44-59.

- - - - - (1987). *Socio-economic differentiation in the Neolithic Sudan.* Cambridge Monographs in African Archaeology 20. Oxford: BAR International series 350.

- - - - - (2012). Changing food ways as indicators of emerging complexity in Sudanese Nubia: from Neolithic agropastoralists to the Meroitic civilisation. *Azania: Archaeological Research in Africa, 47*(3), 327-342.

- - - - - (2014). The Meroitic empire: trade and cultural influences in an Indian Ocean context. *African Archaeological Review, 31*, 649-673.

- - - - - (2017). Kirwan memorial lecture. Nile Valley archaeology and Dafur ethnography: the impact of women on cultural evolution. A personal reflection. *Sudan and Nubia, 21,* 3-14.

Haberlah, D. (2012). Cultural landscape of Dar al-Manasir. In C. Kleinitz & C. Näser (Eds.), "Nihna nâs al-bahar – We are the people of the river." Ethnographic Research in the Fourth Nile Cataract Region, Sudan. *Meroitica, 26*, 49-74.

Hafsaas-Tsakos, H. (2013). Edges of bronze and expressions of masculinity: the emergence of a warrior class at Kerma in Sudan. *Antiquity*, *87*, 79-91.

Hajnóczi, G. (1974). Architectural characteristics of the settlement and buildings. *Acta Archaeologica Academiae Scientiarum Hungaricae*, *26*, 339-368.

Hamilos, D. L. (2000). Chronic sinusitis. *The Journal of Allergy and Clinical Immunology*, *106*(2), 213-227.

Harisinghani, M. G. (2013). *Atlas of lymph node anatomy.* New York: Springer.

Harisinghani, M. G., McLoud, T. C., Shepard, J. O., Ko, J. P., Shroff, M. M., & Mueller, P. R. (2000). Tuberculosis from head to toe. *RadioGraphics, 20,* 449-470.

Harrington, A. D., Schmidt, M. P., Szema, A. M., Galdanes, K., Tsirka, S. E., Gordon, T., & Schoonen, M. A. A. (2017). The role of Iraqi dust in inducing lung injury in United States soldiers – an interdisciplinary study. *GeoHealth, 1,* 237-246.

Hassan, F. A. (1986). Chronology of the Khartoum 'Mesolithic' and 'Neolithic' and related sites in the Sudan: statistical analysis and comparisons with Egypt. *The African Archaeological Review, 4*, 83-102.

Hauhnar, C. Z., Mann, S. B. S., Sharma, V. K., Kaur, S., Mehta, S., & Radotra, B. D. (1992). Maxillary antrum involvement in multibacillary leprosy: a radiologic, sinuscopic, and histologic assessment. *International Journal of Leprosy, 60*(3), 390-395.

Hefflin, B. J., Jalaludin, B., McClure, E., Cobb, N., Johnson, C. A., Jecha, L., & Etzel, R. A. (1994). Surveillance for dust storms and respiratory diseases in Washington State, 1991. *Archives of Environmental Health, 49*(3), 170-174.

Heffron, R. (1939). *Pneumonia: with special reference to pneumococcus lobar pneumonia.* London: Harvard University Press.

Henderson, C. Y., Mariotti, V., Pany-Kucera, D., Villotte, S., & Wilczak, C. (2016). The new 'Coimbra method': a biologically appropriate method for recording specific features of fibrocartilaginous entheseal changes. *International Journal of Osteoarchaeology, 26,* 925-932.

Hillson, S. (2005). *Teeth* (2nd Ed). Cambridge: Cambridge University Press.

Hinkel, F. W. & Sievertsen, U. (2002). Die Royal City von Meroe und die repräsentative profanarchitektur in Kusch. In *The Archaeological Map of the Sudan, Supplement IV.* Berlin: Verlag Monumenta Sudanica.

Hiraiwa, K. & van Eeden, S. F. (2013). Contribution of lung macrophages to the inflammatory responses induced by exposure to air pollutants. *Mediators of Inflammation, 2013*, 619523.

Hirsch, M., Bar-Ziv, J., Lehmann, E., & Goldberg, G. M. (1974). Simple siliceous pneumoconiosis of Bedouin females in the Negev Desert. *Clinical Radiology, 25*, 507-510.

Holt, R. (1996). Effects of air pollution on the upper aerodigestive tract. *Otolaryngology – Head and Neck Surgery*, *114*, 201-204.

Honegger, M. (2001). Evolution de la société dans le bassin de Kerma (Soudan) des derniers chasseurs-cueilleurs au premier royaume de Nubie. *Bulletin de la Société Française D'Égyptologie*, *152*, 12-27.

- - - - - (2004a). Settlement and cemeteries of the Mesolithic and Early Neolithic at el-Barga (Kerma region). *Sudan and Nubia, 8*, 27-32.

- - - - - (2004b). The Pre-Kerma period. In D. A. Welsby & J. R. Anderson (Eds.), *Sudan ancient treasures: an exhibition of recent discoveries from the Sudan National Museum* (pp. 61-63). London: The British Museum Press.

- - - - - (2014). Recent advances in our understanding of prehistory in Northern Sudan. In J. R. Anderson & D. A. Welsby (Eds.), *The Fourth Cataract and beyond. Proceedings of the 12th International Conference for Nubian Studies* (pp. 19-30). Leuven: Peeters.

Honegger, M. & Williams, M. (2015). Human occupations and environmental changes in the Nile Valley during the Holocene: the case of Kerma in Upper Nubia (northern Sudan). *Quaternary Science Reviews, 130*, 141-154.

Hoppa, R. D. (2000). Population variation in osteological aging criteria: an example from the pubic symphysis. *American journal of Physical Anthropology, 111*, 185-191.

Hosseini, S., Li, Q., Cocker, D., Weise, D., Miller, A., Shrivastava, M., Miller, J. W., Mahalingam, S., Princevac, M., & Jung, H. (2010). Particle size distributions from laboratory-scale biomass fires using fast response instruments. *Atmospheric Chemistry and Physics, 10,* 8065-8076.

Houtmeyers, E., Gosselink, R., Gayan-Ramirez, G., & Decramer, M. (1999). Regulation of mucociliary clearance in health and disease. *European Respiratory Journal, 13*, 1177-1188.

Hox, V., Steelant, B., Fokkens, W., Nemery, B., & Hellings, P. W. (2014). Occupational upper airway disease: how work affects the nose. *European Journal of Allergy and Clinical Immunology, 69*, 282-291.

Huang, J., Yu, H., Guan, X., Wang, G., & Guo, R. (2016). Accelerated dryland expansion under climate change. *Nature Climate Change, 6*, 166-171.

Humphris, J. (2014). Post-Meroitic iron production: initial results and interpretations. *Sudan and Nubia, 18*, 121-129.

Hunt, D. R. & Albanese, J. (2005). History and demographic composition of the Robert J. Terry anatomical collection. *American Journal of Physical Anthropology, 127,* 406-417.

Hwang, S., Kang, S., Lee, J., Lee, J. S., Kim, H. J., Han, S. K., & Yim, J. J. (2014). Impact of outdoor air pollution on the incidence of tuberculosis in the Seoul metropolitan area, South Korea. *The Korean Journal of Internal Medicine, 29*, 183-190.

Iacumin, P., Bocherens, H., & Chaix, L. (2001). Keratin C and N stable isotope ratios of fossil cattle horn from Kerma (Sudan): a record of dietary changes. *Italian Journal of Quaternary Sciences, 14*(1), 41-46.

Idso, S. B. (1976). Dust storms. *Scientific American, 235*(4), 108-115.

Ikeda, A., Ikeda, M., & Komatsuzaki, A. (1998). A CT study of the course of growth of the maxillary sinus: normal subjects and subjects with chronic sinusitis. *ORL: Journal for Oto-Rhino-Laryngology and Its Related Specialities, 60*(3), 147-152.

Ingale, L. T., Dube, K., J., Sarode, D. B., Attarde, S. B., & Ingle, S. T. (2011). Monitoring and respiratory health assessment of the population exposed to cooking fuel emissions in a rural area of Jalgoan district, India. *Asia-Pacific Journal of Public Health*, 25(6), 463-475.

Ip, M., Chen, N., So, S., Chiu, S., & Lam, W. (1989). Unusual rib destruction in pleuropulmonary tuberculosis. *Chest, 95*(1), 242-244.

İşcan, M. Y., Loth, S. R., & Wright, R. K. (1984a). Age estimation from the rib by phase analysis: white males. *Journal of Forensic Sciences, 29*(4), 1094-1104.

- - - - - (1984b). Metamorphosis at the sternal rib end: a new method to estimate age at death in white males. *American Journal of Physical Anthropology, 65*, 147-156.

- - - - - (1985). Age estimation from the rib by phase analysis: white females. *Journal of Forensic Sciences, 30*(3), 853-863.

- - - - - (1987). Racial variation in the sternal extremity of the rib and its effect on age determination. *Journal of Forensic Sciences, 32*(2), 452-466.

Iversen, M., Kirychuk, S., Drost, H., & Jacobson, L. (2000). Human health effects of dust exposure in animal confinement buildings. *Journal of Agricultural Safety and Health, 6*(4), 283-288.

Jabbar, A., Hussain, S. F., & Khan, A. A. (2006). Clinical characteristics of pulmonary tuberculosis in adult Pakistani patients with co-existing diabetes mellitus. *La Revue de Santé de la Méditerranée orientale, 12*(5), 522-527.

Jacquet, J. (1971). Remarques sur l'architecture domestique á l'époque méroïtique. Documents recueillis sur les fouilles d'Ash-Shaukan. *Beitråge zur Ägyptischen Bauforschung, 12*, 121-131.

Jakob, B. (2004). *Prevalence and patterns of disease in early medieval populations: a comparison of skeletal samples from fifth to eighth century AD Britain and Southwestern Germany.* Unpublished PhD Thesis, Durham University.

Jakobielski, S. (1991). Old Dongola 1989-1990. *Polish Archaeology in the Mediterranean, 2*, 65-73.

- - - - - (2008). The Holy Trinity Monastery in Old Dongola. In *Between the Cataracts. Proceedings of the 11th Conference of Nubian Studies. Warsaw University, 27 August - 2 September 2006* (Vol. 1, pp. 283-302). Warsaw: Polish Centre of Mediterranean Archaeology & Warsaw University Press.

Jang, A. (2012). Particulate air pollutants and respiratory diseases. In B. Haryanto (Ed.), *Air pollution: a comprehensive perspective* (pp. 153-174). Rijeka: InTech Open.

Jary, H. R., Aston, S., Ho, A., Giorgi, E., Kalata, N., Nyirenda, M., Mallewa, J., Peterson, I., Gordon, S. B., & Mortimer, K. (2017). Household air pollution, chronic respiratory disease and pneumonia in Malawian adults: a case-control study. *Wellcome Open Research, 2,* 103.

Jesse, F. (2004). The Neolithic. In D. A. Welsby & J. R. Anderson (Eds.), *Sudan ancient treasures: an exhibition of recent discoveries from the Sudan National Museum* (pp. 35-41). London: The British Museum Press.

Jeung, M., Gangi, A., Gasser, B., Vasilescu, C., Massard, G., Wihlm, M., & Roy, C. (1999). Imaging of chest wall disorders. *RadioGraphics, 19*(3), 617-637.

Jiang, X., Mei, X., & Feng, D. (2016). Air pollution and chronic airway diseases: what should people know and do? *Journal of Thoracic Disease, 8*(1), E31-E40.

Jindal, S. K. (2014). Relationship of household air pollution from solid fuel combustion with tuberculosis? *The Indian Journal of Medical Research, 140,* 167-170.

Johnson, P., Ramaswamy, P., Santu, G., Preetha, P., Sitalakshmi, R., Kalpana, B., Vijayalakshmi, T., & Subhashini, A. S. (2011). Evaluation of mucociliary clearance among women using biomass and clean fuel in a periurban area of Chennai: a preliminary study. *Lung India, 28*(1), 30-33.

Jones, A. P. (1999). Indoor air quality and health. *Atmospheric Environment, 33*, 4535-4564.

Jones, N. (2001). The nose and paranasal sinuses physiology and anatomy. *Advanced Drug Delivery Reviews*, *51*, 5-19.

Judd, M. (2001). The human remains. In D. A. Welsby, *Life on the desert edge* (Vol. 2, pp. 458-543). London: SARS.

- - - - - (2008). The human skeletal analysis. In S. Salvatori & D. Usai (Eds.), *A Neolithic cemetery in the Northern Dongola Reach: excavations at site R12* (pp. 83-104). London: SARS.

- - - - - (2012). *Gabati: a Meroitic, Post-Meroitic and Medieval cemetery in Central Sudan.* Vol. 2: the physical anthropology. London: SARS.

Judd, M. & Irish, J. (2009). Dying to serve: the mass burials at Kerma. *Antiquity, 83*, 709-722.

Kant, S., Srivastava, R., Verma, A. K., Singh, H. P., Singh, S., Ranganath, T. G., & Anand, S. (2013). Maxillary sinus tuberculosis: various presentations. *The Indian Journal of Chest Diseases and Allied Sciences*, *55*(3),175-177.

Karsten, J. K. (2018). A test of the preauricular sulcus as an indicator of sex. *American Journal of Physical Anthropology, 165,* 604-608.

Kasai, N., Kondo, O., Suzuki, K., Aoki, Y., Ishii, N., & Goto, M. (2018). Quantitative evaluation of maxillary bone deformation by computed tomography in patients with leprosy. *PLoS Neglected Tropical Diseases, 12*(3), e0006341.

Kass, S. M., Williams, P. M., & Reamy, B. V. (2007). Pleurisy. *American Family Physician, 75*(9), 1357-1364.

Katalinić-Janković, V., Furci, L., & Cirillo, D. M. (2012). Microbiology of *Mycobacterium tuberculosis* and a new diagnostic test for TB. In C. Lange & G. B. Migliori (Eds.), *Tuberculosis. European Respiratory Monograph 58* (pp. 1-13). Sheffield: European Respiratory Society.

Katz, D. & Suchey, J. M. (1989). Race differences in pubic symphyseal aging patterns in the male. *American Journal of Physical Anthropology, 80*, 167-172.

Kay, A. B., MacLean, U., Wilkinson, A. H., & Gad El Rab, M. O. (1983). The prevalence of asthma and rhinitis in a Sudanese community seasonally exposed to a potent airborne allergen (the “green nimitti” midge, *Cladotanytarsus lewisi*). *Journal of Allergy and Clinical Immunology, 71*(3), 345-352.

Kay, A. U. & Kaplan, J. O. (2015). Human subsistence and land use in sub-Saharan Africa, 1000 BC to AD 1500: a review, quantification, and classification. *Anthropocene*, *9*, 14-32.

Kelley, M. A. & El-Najjar, M. Y. (1980). Natural variation and differential diagnosis of skeletal changes in tuberculosis. *American Journal of Physical Anthropology, 52,* 153-167.

Kelley, M. A. & Micozzi, M. S. (1984). Rib lesions in chronic pulmonary tuberculosis. *American Journal of Physical Anthropology, 65*(4), 381-386.

Kelley, M. A., Murphy, S. P., Levesque, D. R., & Sledzik, P. S. (1994). Respiratory disease among protohistoric and early historic Plains Indians. In D. W. Owsley & R. L. Jantz (Eds.), *Skeletal biology in the Great Plains: migration, warfare, health, and subsistence* (pp. 123-130). London: Smithsonian Institution Press.

Kelly, M. S., Wirth, K. E., Madrigo, J., Feemster, K. A., Cunningham, C. K., Arscott-Mills, T., Boiditswe, S., Shah, S. S., Finalle, R., & Steenhoff, A. P. (2015). The effect of exposure to wood smoke on outcomes of childhood pneumonia in Botswana. *The International Journal of Tuberculosis and Lung Disease, 19*(3), 349-355.

Kendall, R., Kendall, E. J., Macleod, I., Gowland, R., & Beaumont, J. (2015). An unusual exostotic lesion of the maxillary sinus from Roman Lincoln. *International Journal of Palaeopathology*, *11*, 45-50.

Kennedy, D. W. (2001). Functional endoscopic sinus surgery: concepts, surgical indications, and instrumentation. In D. W. Kennedy, W. E. Bolger, & S. J. Zinreich (Eds.), *Diseases of the sinuses: diagnosis and management* (pp. 197-210). London: B. C. Decker Inc.

Kent, S. & Dunn, D. (1996). Anemia and the transition of nomadic hunter-gatherers to a sedentary life-style: follow-up study of a Kalahari community. *American Journal of Physical Anthropology, 99*, 455-472.

Kim, J., Lee, I. J., & Kim, J. (2017). CT findings of pulmonary tuberculosis and tuberculous pleurisy in diabetes mellitus patients. *Diagnostic and Interventional Radiology, 23,* 112-117.

Kim, K. Y., Bae, J. H., Park, J. S., & Lee, S. (2014). Primary sinonasal tuberculosis confined to the unilateral maxillary sinus. *International Journal of Clinical and Experimental Pathology, 7*(2), 815-818.

Kim, K., Kabir, E., & Kabir, S. (2015). A review on the human health impact of airborne particulate matter. *Environment International, 74*, 136-143.

Kini, U. & Nandeesh, B. N. (2012). Physiology of bone formation, remodelling, and metabolism. In I. Fogelman, G. Gnanasegaran, & H. Van der Wall, (Eds.), *Radionuclide and hybrid bone imaging* (pp. 29-57). Berlin: Springer.

Kiris, A., Karlidag, T., Kocakoc, E., Bozgeyik, Z., & Sarsilmaz, M. (2007). Paranasal sinus computed tomography findings in patients treated for lepromatous leprosy. *The Journal of Laryngology and Otology, 121*, 15-18.

Kirkhorn, S. R. & Garry, V. F. (2000). Agricultural lung diseases. *Environmental Health Perspectives, 108*(4), 705-712.

Kleinitz, C. (2004). Rock art and 'rock gongs' in the Fourth Nile Cataract region: the Ishashi island rock art survey. *Sudan and Nubia, 8*, 12-17.

Klepinger, L. L., Katz, D., Micozzi, M. S., & Carroll, L. (1992). Evaluation of cast methods for estimating age from the os pubis. *Journal of Forensic Sciences, 37*(3), 763-770.

Knüsel, C. J. & Outram, A. K. (2004). Fragmentation: the zonation method applied to fragmented human remains from archaeological forensic contexts. *The Journal of Human Palaeoecology, 9*, 85-98.

Knustad, J. (1966). Serra East and Dorginarti. *Kush*, *14*, 165-186.

Kolappan, C. & Subramani, R. (2009). Association between biomass fuel and pulmonary tuberculosis: a nested case-control study. *Thorax, 64*, 705-708.

Kołosowska, E., el-Tayeb, M., & Paner, H. (2003). Old Kush in the Fourth Cataract region. *Sudan and Nubia, 7*, 21-25.

Koltai, P. J. (1994). Effects of air pollution on the upper respiratory tract of children. *Otolaryngology - Head and Neck Surgery, 111*(1), 9-11.

Korzeniewski, K., Nitsch-Osuch, A., Konior, M., & Lass, A. (2015). Respiratory tract infections in the military environment. *Respiratory Physiology & Neurobiology, 209,* 76-80.

Kourbatova, E. V., Borodulin, B. E., Borodulina, E. A., del Rio, C., Blumberg, H. M., & Leonard, M. K. (2006). Risk factors for mortality among adult patients with newly diagnosed tuberculosis in Samara, Russia. *International Journal of Tuberculosis and Lung Disease, 10*(11), 1224-1230.

Kroegel, C. & Antony, V. B. (1997). Immunobiology of pleural inflammation: potential implications for pathogenesis, diagnosis and therapy. *European Respiratory Journal, 10*, 2411-2418.

Krogman, W. M. & İşcan, M. Y. (1986). *The human skeleton in forensic medicine* (2nd Ed.). Springfield, IL: C. C. Thomas.

Królik, H. & Schild, R. (2001). Site E-75-6: an El Nabta and Al Jerar Village. In F. Wendorf, R. Schild & Associates, *Holocene settlement of the Egyptian Sahara. Vol. 1: the archaeology of Nabta Playa* (pp. 111-146). New York: Kluwer Academic/Plenum Publishers.

Krzyżaniak, A. (2011). Neolithic cemetery. In M. Chłodnicki, M. Kobusiewicz, & K. Kroeper (Eds.), *Kadero: the Lech Krzyżaniak excavations in the Sudan.* Studies in African Archaeology (Vol. 10, pp. 57-197). Poznań: Poznań Archaeological Museum.

Krzyżaniak, L. (1978). New light on early food-production in the Central Sudan. *The Journal of African History, 19*(2), 159-172.

- - - - - (1984). The Neolithic habitation at Kadero (Central Sudan). In L. Krzyżaniak & M. Kobusiewicz (Eds.), *Origin and early development of food-producing cultures in north-eastern Africa* (pp. 309-315). Poznań: Poznań Archaeological Museum.

- - - - - (1991). Early farming in the Middle Nile Basin: recent discoveries at Kadero (Central Sudan). *Antiquity*, *65*, 515-532.

- - - - - (2011). Changes in the natural environment between 8000 and 3000 BC. In M. Chłodnicki, M. Kobusiewicz, & K. Kroeper (Eds.), *Kadero: the Lech Krzyżaniak excavations in the Sudan.* Studies in African Archaeology (Vol. 10, pp. 17-38). Poznań: Poznań Archaeological Museum.

Kuper, R. & Kröpelin, S. (2006). Climate-controlled Holocene occupation in the Sahara: motor of Africa's evolution. *Science, 313*, 803-807.

Lai, L. & Cheng, W. (2008). The impact of air quality on respiratory admissions during Asian dust storm periods. *International Journal of Environmental Health Research, 18*(6), 429-450.

Lakshmi, P. V. M., Virdi, N. K., Thakur, J. S., Smith, K. R., Bates, M. N., & Kumar, R. (2012). Biomass fuel and risk of tuberculosis: a case-control study from northern India. *Journal of Epidemiology and Community Health, 66*(5), 457-461.

Lambert, P. M. (2002). Rib lesions in a prehistoric Puebloan sample from southwestern Colorado. *American Journal of Physical Anthropology, 117*(4), 281-292.

Lange, J. L., Campbell, K. E., & Brundage, J. F. (2003). Respiratory illness in relation to military assignments in the Mojave Desert: retrospective surveillance over a 10-year period. *Military Medicine, 168*(12), 1039-1043.

Lapple, C. E. (1961). Characteristics of particles and particle dispersoids. *Stanford Research Institute Journal, 5,* 95.

Lario, J., Sanchez-Moral, S., Fernandez, V., Jimeno, A., & Menendez, M. (1997). Palaeoenvironmental evolution of the Blue Nile (Central Sudan) during the Early and Mid-Holocene (Mesolithic-Neolithic transition). *Quaternary Science Reviews, 16*, 583-588.

Larsen, C. S. (2015). *Bioarchaeology: interpreting behaviour from the human skeleton* (2nd Ed.). Cambridge: Cambridge University Press.

Lastória, J. C. & de Abreu, M. A. M. M. (2014). Leprosy: a review of the epidemiological, clinical, and etiopathogenic aspects – part 1. *Anais Brasileiros De Dermatologia, 89*(2), 205-218.

Lee, A., Kinney, P., Chillrud, S., & Jack, D. (2015). A systematic review of innate immunomodulatory effects of household air pollution secondary to the burning of biomass fuels. *Annals of Global Health, 81*(3), 368-374.

Lee, K. C. & Lee, S. J. (2010). Clinical features and treatments of odontogenic sinusitis. *Yonsei Medical Journal, 51*(6), 932-937.

Leigh, R. W. (1928). Dental pathology of aboriginal California. *University of California Publications in American Archaeology and Ethnology, 23*(10), 399-440.

Lenoble, P. (1999). The division of the Meroitic empire and the end of pyramid building in the 4th century AD: an introduction to further excavations of imperial mounds in the Sudan. In D. A. Welsby (Ed.), *Recent research in Kushite history and archaeology. Proceedings of the 8th International Conference for Meroitic studies.* British Museum Occasional Papers, 131 (pp. 157-184). London: British Museum Press.

Leopold, P. L., O'Mahony, M. J., Lian, X. J., Tilley, A. E., Harvey, B., & Crystal, R. G. (2009). Smoking is associated with shortened airway cilia. *PLoS ONE, 4*(12), e8157.

Levine, B. D., Motamedi, K., Chow, K., Gold, R. H., & Seeger, L. L. (2009). CT of rib lesions. *American Journal of Roentgenology, 193*(1), 5-13.

Lewis, D. J. (1954). Nimitti and some other small annoying flies in the Sudan. *Sudan Notes and Records, 35*(2), 76-89.

Lewis, M. E. (2002). Impact of industrialization: comparative study of child health in four sites from Medieval and Postmedieval England (A.D. 850-1859). *American Journal of Physical Anthropology*, *119*(3), 211-223.

- - - - - (2007). *The bioarchaeology of children: perspectives from biological and forensic anthropology.* Cambridge: Cambridge University press.

- - - - - (2017). *Paleopathology of children: identification of pathological conditions in the human skeletal remains of non-adults.* London: Academic Press.

Lewis, M. E., Roberts, C. A., & Manchester, K. (1995). Comparative study of the prevalence of maxillary sinusitis in later Medieval urban and rural populations in northern England. *American Journal of Physical anthropology, 98,* 497-506.

Li, N., Sioutas, C., Cho, A., Schmitz, D., Misra, C., Sempf, J., Wang, M., Oberley, T., Froines, J., & Nel, A. (2003). Ultrafine particulate pollutants induce oxidative stress and mitochondrial damage. *Environmental Health Perspectives, 111*(4), 455-460.

Liapikou, A., Cillóniz, C., Gabarrús, A., Amaro, R., De la Bellacasa, J. P., Mensa, J., Sánchez, M., Niederman, M., & Torres, A. (2016). Multilobar bilateral and unilateral chest radiograph involvement: implications for prognosis in hospitalised community-acquired pneumonia. *European Respiratory Journal, 48,* 257-261.

Liebe-Harkort, C. (2012). Cribra orbitalia, sinusitis and linear enamel hypoplasia in Swedish Roman Iron Age adults and subadults. *International Journal of Osteoarchaeology, 22*(4), 387-397.

Light, R. W. (2013). *Pleural diseases* (6th Ed.). Philadelphia: Lippincott Williams & Wilkins.

Lilley, J. M., Stroud, G., Brothwell, D. R., & Williamson, M. H. (1994). *The Jewish burial ground at Jewbury*. York: Council for British Archaeology.

Lin, H., Suk, C., Lo, H., Huang, R., Enarson, D. A., & Chiang, C. (2014). Indoor air pollution from solid fuel and tuberculosis: a systematic review and meta-analysis. *International Journal of Tuberculosis and Lung Disease, 18*(5), 613-621.

Lin, H., Ezzati, M., & Murray, M. (2007). Tobacco smoke, indoor air pollution and tuberculosis: a systematic review and meta-analysis. *PLoS Medicine, 4*(1), e20.

Lin, S., Luo, M., Walker, R. J., Liu, X., Hwang, S., & Chinery, R. (2009). Extreme high temperatures and hospital admissions for respiratory and cardiovascular diseases. *Epidemiology, 20*(5), 238-746.

Lipworth, B. J. & White, P. S. (2000). Allergic inflammation in the unified airway: start with the nose. *Thorax, 55,* 878-881.

Litwic, A., Edwards, M., Dennison, E., & Cooper, C. (2013). Epidemiology and burden of osteoarthritis. *British Medical Bulletin, 105*, 185-199.

Loebinger, M. R. & Wilson, R. (2012). Pneumonia. *Medicine*, *40*(6), 329-334.

Lombardi, E., Stein, R. T., Wright, A. L., Morgan, W. J., & Martinez, F. D. (1996). The relation between physician-diagnosed sinusitis, asthma, and skin test reactivity to allergens in 8-year-old children. *Pediatric Pulmonology, 22*, 141-146.

Longhini, A. B. & Ferguson, B. J. (2011). Clinical aspects of odontogenic maxillary sinusitis: a case series. *International Forum of Allergy and Rhinology, 1,* 409-415.

Lopatin, A. S., Sysolyatin, S. P., Sysolyatin, P. G., & Melnikov, M. N. (2002). Chronic maxillary sinusitis of dental origin: is external surgical approach mandatory? *The Laryngoscope, 112,* 1056-1059.

Loth, S. R. & Henneberg, M. (1996). Mandibular ramus flexure: a new morphological indicator of sexual dimorphism in the human skeleton. *American Journal of Physical Anthropology, 99*, 473-485.

Lovejoy, C. O. (1985). Dental wear in the Libben population: its functional pattern and role in the determination of adult skeletal age at death. *American Journal of Physical Anthropology, 68*, 47-56.

Lovejoy, C. O., Meindl, R. S., Pryzbeck, T. R., & Mensforth, R. P. (1985). Chronological metamorphosis of the auricular surface of the ilium: a new method for the determination of adult skeletal age at death. *American Journal of Physical Anthropology, 68*, 15-28.

Lovell, N. C. (1997). Trauma analysis in paleopathology. *Yearbook of Physical Anthropology, 40,* 139-170.

Mabeza, G. F. & Macfarlane, J. (2003). Pulmonary actinomycosis. *European Respiratory Journal, 21*, 545-551.

Macadam, M. F. L. (1949). *The temples of Kawa. I – the inscriptions.* London: Oxford University Press.

- - - - - (1955). *The temples of Kawa. II – history and archaeology of the site.* London: Oxford University press.

Mackie, M., Radini, A., & Speller, C. (2017). The sustainability of dental calculus for archaeological research. In J. Favreau & R. Patalano (Eds.), *Shallow pasts, endless horizons: sustainability and archaeology. Proceedings of the 48th annual Chacmool archaeology conference* (pp. 74-81). Calgary: The Chacmool Archaeological Association of the University of Calgary.

MacLaughlin, S. M. & Bruce, M. F. (1986). The sciatic notch/acetabular index as a discriminator of sex in European skeletal remains. *Journal of Forensic Sciences, 31*(4), 1380-1390.

Madella, M., García-Granero, J. J., Out, W. A., Ryan, P., & Usai, D. (2014). Microbotanical evidence of domestic cereals in Africa 7000 years ago. *PLOS ONE, 9*(10), e110177.

Madeo, J., Patel, R., Gebre, W., & Ahmed, S. (2013). Tuberculous empyema presenting as a persistent chest wall mass: case report. *GERMS, 3*(1), 21-25.

Mafee, M. F., Tran., B. H., & Chapa, A. R. (2006). Imaging of rhinosinusitis and its complications. *Clinical Reviews in Allergy and Immunology, 30*(3), 165-86.

Mahgoub, El S. (1977). Mycoses of the Sudan. *Transactions of the Royal Society of Tropical Medicine and Hygiene, 71*(3), 184-188.

Mahowald, N., Albani, S., Kok, J. F., Engelstaeder, S., Scanza, R., Ward, D. S., & Flanner, M. G. (2014). The size distribution of desert dust aerosols and its impact on the Earth system. *Aeolian Research, 15,* 53-71.

Maillet, M., Bowles, W. R., McClanahan, S. L., John, M. T., & Ahmad, M. (2011). Cone-beam computed tomography evaluation of maxillary sinusitis. *Journal of Endodontics, 37,* 753-757.

Manchester, K., Ogden, A., & Storm, R. (2016). Nomenclature in Palaeopathology. *Palaeopathology Newsletter, 175.*

Mann, R. W. (1993). A method for siding and sequencing human ribs. *Journal of Forensic Sciences, 38*(1), 151-155.

Marel, M., Zrůstová, M., Štasny, B., & Light, R. W. (1993). The incidence of pleural effusion in a well-defined region. Epidemiologic study in central Bohemia. *Chest*, *104*(5), 1486-1489.

Marieb, E. N. (2012). *Essentials of human anatomy and physiology.* San Francisco: Benjamin Cummings.

Marino, E., Caruso, M., Campagna, D., & Polosa, R. (2015). Impact of air quality on lung health: myth or reality? *Therapeutic Advances in Chronic Disease, 6*(5), 286-298.

Mariotti, V., Zuppello, M., Pedrosi, M. E., Bettuzzi, M., Brancaccio, R., Peccenini, E., Morigi, M. P., & Belcastro, M. G. (2015). Skeletal evidence of tuberculosis in a modern identified human skeletal collection (Certosa Cemetery, Bologna, Italy). *American Journal of Physical Anthropology, 157,* 389-401.

Marks, A. E. & Mohammed-Ali, A. (1991). The place of Shaqadud in the late prehistory of the Central Nile Valley. In A. E. Marks & A. Mohammed-Ali (Eds.), *The late prehistory of the eastern Sahel: the Mesolithic and Neolithic of Shaqadud, Sudan* (pp. 237-282). Dallas: Southern Methodist University Press.

Marks, S. C. & Grossetete, G. (1988). *Facies leprosa*: resorption of maxillary anterior alveolar bone and the anterior nasal spine in patients with lepromatous leprosy in Mali. *International Journal of Leprosy, 56*(1), 21-26.

Marrie, T. J. (1993). Bacteremic pneumococcal pneumonia mortality rate. Is it really different in Sweden? *Chest, 103*(3), 658-660.

Mathur, M. L. & Choudhary, R. C. (1997). Desert lung syndrome in rural dwellers of the Thar Desert, India. *Journal of Arid Environments, 35*, 559-562.

Matos, V. & Santos, A. L. (2006). On the trail of pulmonary tuberculosis based on rib lesions: results from the human identified skeletal collection from the Museu Bocage (Lisbon, Portugal). *American Journal of Physical Anthropology, 130*(2), 190-200.

Matsumoto, Y., Ikeda, T., Yokoi, H., & Kohno, N. (2015). Association between odontogenic infections and unilateral sinus opacification. *Auris Nasus Larynx, 42,* 288-293.

Mays, S. (2012). Nasal septal deviation in a Medieval population. *American Journal of Physical Anthropology, 148*(3), 319-326.

Mays, S. & Cox, M. (2000). Sex determination in skeletal remains. In M. Cox & S. Mays (Eds.), *Human osteology in archaeology and forensic science* (pp. 117-130). Cambridge: Cambridge University Press.

Mays, S., Fysh, E., & Taylor, G. M. (2002). Investigation of the link between visceral surface rib lesions and tuberculosis in a Medieval skeletal series from England using ancient DNA. *American Journal of Physical Anthropology, 119*(1), 27-36.

Mays, S., Vincent, S., Snow, M., & Robson-Brown, M. (2011). Concha bullosa, a neglected condition in palaeopathology. *International Journal of Palaeopathology, 1*(3-4), 184-187.

Mbata, G. C., Ajuonuma, B. C., Ofondu, E. O., Okeke, E. C., Chukwuonye, I. I., & Aguwa, E. N. (2015). Pleural effusion: aetiology, clinical presentation and mortality outcome in a tertiary health institution in eastern Nigeria - a five year retrospective study. *Journal of AIDS and Clinical Research, 6*(2), 426.

McHugh, W. P., Schaber, G. G., Breed, C. S., & McCauley, J. F. (1989). Neolithic adaptation and the Holocene functioning of tertiary palaeodrainages in southern Egypt and northern Sudan. *Antiquity, 63*(239), 320-336.

McKinley, J. I. (2004). Compiling a skeletal inventory: disarticulated and co-mingled remains. In M. Brickley & J. I. McKinley (Eds.), *Guidelines to the standards for recording human remains. IFA Paper No. 7* (pp. 14-17). BABAO: Reading.

Mehra, P. & Jeong, D. (2009). Maxillary sinusitis of odontogenic origin. *Current Allergy and Asthma Reports, 9*, 238-243.

Meindl, R. S. & Lovejoy, C. O. (1985). Ectocranial suture closure: a revised method for the determination of skeletal age at death based on the lateral-anterior sutures. *American Journal of Physical Anthropology, 68*, 57-66.

Meindl, R. S., Lovejoy, C. O., Mensforth, R. P., & Don Carlos, L. (1985). Accuracy and direction of error in the sexing of the skeleton: implications for paleodemography. *American Journal of Physical Anthropologists, 68*, 79-85.

Meng, Z. & Lu, B. (2007). Dust events as a risk factor for daily hospitalization for respiratory and cardiovascular diseases in Minqin, China. *Atmospheric Environment, 41*(33), 7048-7058.

Merrett, D. (2003). Maxillary sinusitis among the Moatfield people. In R. F. Williamson & S. Pfeiffer (Eds.), *Bones of the ancestors: the archaeology and osteobiography of the Moatfield Ossuary. Archaeological survey of Canada, Mercury Series Archaeology Paper 163* (pp. 241-261). Gatinaeu, Quebec: Canadian Museum of Civilisation.

Merrett, D. C. & Pfeiffer, S. (2000). Maxillary sinusitis as an indicator of respiratory health in past populations. *American Journal of Physical Anthropology, 111*(3), 301-318.

Meyer, C. (2010). The kingdom of Kush in the 4th Cataract: archaeological salvage of the Oriental Institute Nubian Expedition 2007 season. Part II. Grinding stones and gold mining at Hosh el-Guruf, Sudan. *Gdańsk Archaeological Museum African Reports*, *7*, 39-52.

Meyer, H., Leifels, L., Bach, A. G., & Surov, A. (2017). Secondary hypertrophic osteoarthropathy caused by non-pleural or pulmonary tumours. *Medicine, 96,* 36(e7985).

Middleton, N. & Kang, U. (2017). Sand and dust storms: impact mitigation. *Sustainability, 9*, 1053.

Miles, A. E. W. (1963). Dentition in the estimation of age. *Journal of Dental Research, 42*, 255-263.

Milgrom, E. C. (2003). Allergic rhinitis. In R. B. Taylor, David, A. K., Fields, S. A., Phillips, D. M., & Scherger, J. E. (Eds.), *Family Medicine* (6th Ed., pp. 318-322). New York: Springer.

Miller, R. (2013). *Respiratory disorders following service in Iraq.* Nashville, TN: Vanderbilt University, Vanderbilt Medical Centre.

Milošev, B., Mahgoub, El S., Abdel Aal, O., & El Hassan, A. M. (1969). Primary aspergilloma of paranasal sinuses in the Sudan: a review of seventeen cases. *British Journal of Surgery, 56*(2), 132-137.

Min, Y., Jung, H., Kim, H. S., Park, S. K., & Yoo, K. Y. (1996). Prevalence and risk factors of chronic sinusitis in Korea: results of a nationwide survey. *European Archives of Oto-Rhino-Layrngology, 253,* 435-439.

Miranker, M. (2016). A comparison of different age estimation methods of the adult pelvis. *Journal of Forensic Sciences, 61*(5), 1173-1179.

Mishra, V. & Retherford, R. D. (2007). Does biofuel smoke contribute to anaemia and stunting in early childhood? *International Journal of Epidemiology, 36,* 117-129.

Molto, J. E. (1990). Differential diagnosis of rib lesions: a case study from middle woodland southern Ontario circa 230 A.D. *American Journal of Physical Anthropology, 83*(4), 439-447.

Morales-Bárcenas, R., Chirino, Y. I., Sánchez-Pérez, Y., Osornio-Vargas, Á. R., Melendez-Zajgla, J., Rosas, I., & García-Cuellar, C. M. (2015). Particulate matter (PM_{10}) induces metalloprotease activity and invasion in airway epithelial cells. *Toxicology Letters, 237*, 167-173

Moreira, J., Belicanta Fochesatto, J., Moreira, A. L., Pereira, M., Porto, N., & Hochhegger, B. (2011). Tuberculous pneumonia: a study of 59 microbiologically confirmed cases. *Jornal Brasileiro de Pneumologia, 37*(2), 232-237.

Morris, M. J., Dodson, D. W., Lucero, P. F., Haislip, G. D., Gallup, R. A., Nicholson, K. L., & Zacher, L. L. (2014). Study of active duty military for pulmonary disease related to environmental deployment exposures (STAMPEDE). *American Journal of Respiratory and Critical Care Medicine, 190*(1), 77-84.

Mossman, B. T. & Churg, A. (1998). Mechanisms in the pathogenesis of asbestosis and silicosis. *American Journal of Respiratory and Critical Care Medicine, 157*, 1666-1680.

Mudway, I. S., Duggan, S.T., Venkataraman, C., Habib, G., Kelly, F. J., & Grigg, J. (2005). Combustion of dried animal dung as biofuel results in the generation of highly redox active fine particulates. *Particle and Fibre Toxicology, 2*, 6.

Munro, R. N., Mohammed Ibrahim, M. A. M., Abuzied, H., & el-Hassan, B. (2012). Aeolian sand landforms in parts of the Sudan and Nubia. Origins and impacts on past and present land use. *Sudan and Nubia, 16*, 140-154.

Murray, K. A. & Murray, T. (1991). A test of the auricular surface aging technique. *Journal of Forensic Sciences, 36*(4), 1162-1169.

Mutolo, M. J., Jenny, L. L., Buszek, A. R., Fenton, T. W., & Foran, D. R. (2012). Osteological and molecular identification of brucellosis in ancient Butrint, Albania. *American Journal of Physical Anthropology, 147*(2), 254-263.

Nabi, G., UlArifeen, M. Z., Khan, A., & Uddin, I. (2015). Wood smoke: still a serious challenge to public health in developing countries. *American-Eurasian Journal of Toxicological Sciences, 7*(3), 140-145.

Nachman, K. E. & Parker, J. D. (2012). Exposures to fine particulate air pollution and respiratory outcomes in adults using two national datasets: a cross-sectional study. *Environmental Health*, *11*(1), 25.

Naclerio, R. M. & Gungor, A. (2001). Etiological factors in inflammatory sinus disease. In D. W. Kennedy, W. E. Bolger, & S. J. Zinreich (Eds.), *Diseases of the sinuses: diagnosis and management* (pp. 47-55). London: B. C. Decker Inc.

Naderi, H., Sheyban, F., Erfani, S. S., Amiri, B., & Nooghabi, M. J. (2017). The mask of acute bacterial pneumonia may disguise the face of tuberculosis. *Electronic Physician, 9*(3), 3943-3949.

Nambu, A., Ozawa, K., Kobayashi, N., & Tago, M. (2014). Imaging of community-acquired pneumonia: roles of imaging examinations, imaging diagnosis of specific pathogens and discrimination from non-infectious diseases. *World Journal of Radiology, 6*(10), 779-793.

Naples, V. L. & Rothschild, B. M. (2011). Do ribs actually have a bare area? A new analysis. *HOMO - Journal of Comparative Human Biology, 62*, 368-373.

Narasimhan, P., Wood, J., MacIntyre, C. R., & Mathai, D. (2013). Risk factors for tuberculosis. *Pulmonary Medicine, 2013,* 828939.

Näser, C. (2005). The island survey of the Humboldt University Nubian Expedition: report of the 2004 survey campaign. *Gdańsk Archaeological Museum African Reports, 4*, 75-88.

Nazaroff, W. W. (2013). Exploring the consequences of climate change for indoor air quality. *Environmental Research Letters, 8*, 015022.

Nerlich, A. G., Haas, C. J., Zink, A., Szeimies, U., & Hagedorn, H. G. (1997). Molecular evidence for tuberculosis in an ancient Egyptian mummy. *The Lancet, 350,* 1404.

Neumann, K. (1989). Vegetation of the eastern Sahara: charcoal from prehistoric sites. *The African Archaeological Review, 7*, 97-116.

NHS (2017). *Peritonitis.* Retrieved from https://www.nhs.uk/conditions/peritonitis/ [accessed on 30th July 2018].

Nicholson, S. E. (2011). *Dryland climatology.* Cambridge: Cambridge University Press.

Nicklisch, N., Maixner, F., Ganslmeier, R., Friederich, S., Dresely, V., Meller, H., Zink, A., & Alt, K. W. (2012). Rib lesions in skeletons from early Neolithic sites in central Germany: on the trail of tuberculosis at the onset of agriculture. *American Journal of Physical Anthropology, 149*(3), 391-404.

Nicoll, K. (2004). Recent environmental change and prehistoric human activity in Egypt and Northern Sudan. *Quaternary Science reviews, 23*, 561-580.

Nkhama, E., Ndhlovu, M., Dvonch, J. T., Lynam, M., Mentz, G., Siziya, S., & Voyi, K. (2017). Effects of airborne particulate matter on respiratory health in a community near a cement factory in Chilanga, Zambia: results from a panel study. *International Journal of Environmental Research and Public Health, 14,* 1351.

Norboo, T., Angchuk, P. T., Yahya, M., Kamat, S. R., Pooley, F. D., Corrin, B., Kerr, I. H., Bruce, N., & Ball, K. P. (1991). Silicosis in a Himalayan village population: role of environmental dust. *Thorax, 46*, 341-343.

Nowotnick, U., Wolf, P., Wöss, F., Büchner, S., & Minow, M. (2014). *Hamadab: urban living at the Nile in Meroitic times.* Information booklet. Berlin: German Archaeological Institute.

Oberdörster, G. (2001). Pulmonary effects of inhaled ultrafine particles. *International Archives of Occupational and Environmental Health, 74*, 1-8.

Obłuski, A. (2018). El-Ghazali – a royal monastery in Northern Sudan? *Sudan and Nubia, 22*, 155-166.

Oettlé, A. C. & Steyn, M. (2000). Age estimation from sternal ends of ribs by phase analysis in South African blacks. *Journal of Forensic Sciences, 45*(5), 1071-1079.

Ogden, A. R. (2008). *Periapical voids in human jaw bones.* In M. Smith & M. Brickley (Eds.), *Proceedings of the eighth annual conference of the British Association for Biological Anthropology and Osteoarchaeology* (pp. 51-56). British Archaeological Reports International Series 1743. Oxford: Archaeopress.

Okuyemi, K. S. & Tsue, T. T. (2002). Radiologic imaging in the management of sinusitis. *American Family Physician, 66*(10), 1882-1886.

Olympus (1997). *News release: series 6 industrial videoimagescopes and camera control unit.* Retrieved from https://www.olympus-global.com/en/news/1997b/nr971111iv6e.html [accessed on 30th January 2017].

- - - - - (n.d). *Industrial remote visual inspection product guide.* Retrieved from http://www.sk-ndt.ru/files/boroscopes.pdf [accessed on 16th May 2017].

O'Rahilly, R., Müller, F., Carpenter, S., & Swenson, R. (2004). *Basic Human Anatomy* (online version). Retrieved from https://www.dartmouth.edu/~humananatomy/index.html [accessed on 24th February 2017].

Ortner, D. J. (2003). *Identification of pathological conditions in human skeletal remains* (2nd Ed.). London: Academic Press.

- - - - - (2008). Differential diagnosis of skeletal lesions in infectious disease. In R. Pinhasi & S. Mays (Eds.), *Advances in human palaeopathology* (pp. 189-214). Chichester, UK: John Wiley & Sons Ltd.

- - - - - (2012). Differential diagnosis and issues in disease classification. In A. L. Grauer (Ed.), *A companion to palaeopathology* (pp. 250-267). Chichester, UK: Blackwell Publishing Ltd.

Osypińska, M. (2014). Animals in the economy of Christian Makuria. In J. R. Anderson & D. A. Welsby (Eds.), *The Fourth Cataract and beyond. Proceedings of the 12th International Conference for Nubian Studies* (pp. 909-916). Leuven: Peeters.

Osypiński, P. (2010). *Lithic assemblage analysis from early-Neolithic sites 3-J-26 and 3-O-3 Fourth Nile Cataract.* Sudan Archaeological Research Society (SARS) Draft Report. Retrieved from http://www.sudarchrs.org.uk/wp-content/uploads/2013/09/SARS_draft_lithics.pdf [accessed on 16th March 2018].

- - - - - (2014). Prehistory of the Fourth Cataract. In J. R. Anderson & D. A. Welsby (Eds.), *The Fourth Cataract and beyond. Proceedings of the 12th International Conference for Nubian Studies* (pp. 9-17). Leuven: Peeters.

Out, W. A., Ryan, P., García-Granero, J. J., Barastegui, J., Maritan, L., Madella, M., & Usai, D. (2016). Plant exploitation in Neolithic Sudan: a review in the light of new data from the cemeteries R12 and Ghaba. *Quaternary International, 412*, 36-53.

Öztürk, A. B., Kiliçaslan, Z., & İşsever, H. (2014). Effects of smoking and indoor air pollution on the risk of tuberculosis: smoking, indoor air pollution and tuberculosis. *Tüberküloz ve Toraks, 62*(1), 1-6.

Ozturk, M. K., Zindanci, I., & Zemheri, E. (2018). Acacia seyal and Terminalia brownii associated airborne contact dermatitis (dukhan dermatitis). *International Journal of Dermatology*, *57*(11), 1382-1386.

Paju, S., Bernstein, J. M., Haase, E. M., & Scannapieco, F. A. (2003). Molecular analysis of bacterial flora associated with chronically inflamed maxillary sinuses. *Journal of Medical Microbiolgy, 52*, 591-597.

Paner, H. (2003a). Archaeological survey on the right bank of the Nile between Kareima and Abu Hamed: a brief overview. *Sudan and Nubia, 7*, 15-20.

- - - - - (2003b). Kerma culture, rock art, dome graves and other discoveries in the Fourth Nile Cataract region. *Gdańsk Archaeological Museum African Reports, 2*, 163-183.

- - - - - (2014). Kerma culture in the Fourth Cataract of the Nile. In J. R. Anderson & D. A. Welsby (Eds.), *The Fourth Cataract and beyond. Proceedings of the 12th International Conference for Nubian Studies* (pp. 53-79). Leuven: Peeters.

Paner, H. & Borcowski, Z. (2005a). Gdańsk Archaeological Museum expedition. A summary of eight seasons' work at the Fourth Cataract. *Gdańsk Archaeological Museum African Reports, 4*, 89-115.

- - - - - (2005b). Gdańsk Archaeological Museum Expedition (GAME) report on the 2002 season. *Gdańsk Archaeological Museum African Reports, 3*, 203-226.

Paner, H. & Pudło, A. (2010). Settlements in the Fourth Cataract GAME concession in the light of radiocarbon analysis. *Gdańsk Archaeological Museum African Reports*, *7*, 131-146.

Panhuysen, R. G. A. M., Coenen, V., & Bruintjes, T. D. (1997). Chronic maxillary sinusitis in Medieval Maastricht, The Netherlands. *International Journal of Osteoarchaeology*, *7*(6), 610-614.

Papapelekanos, A. (2003). *Living in an urban environment: lifestyle implications on a late Medieval population from York with a focus on maxillary sinusitis.* Unpublished MSc Dissertation, Durham University.

Pappas, G., Bosilkoviski, M., Akritidis, N., Mastora, M., Krteva, L., & Tsianos, E. (2003). Brucellosis and the respiratory system. *Clinical Infectious Diseases, 37*, e95-e99.

Park, D., Barabad, M. L., Lee, G., Kwon, S., Cho, Y., Lee, D., Cho, K., & Lee, K. (2013). Emission characteristics of particulate matter and volatile organic compounds in cow dung combustion. *Environmental Science and Technology, 47*, 12952-12957.

Patel, A. M., Ryu, J. H., & Reed, C. E. (2001). Hypersensitivity pneumonitis: current concepts and future questions. *Journal of Allergy and Clinical Immunology, 108*(5), 661-670.

Patel, N. A. & Ferguson, B. J. (2012). Odontogenic sinusitis: an ancient but underappreciated cause of maxillary sinusitis. *Current Opinion in Otolaryngology & Head and Neck Surgery, 20*, 24-28.

Payne, J. (2005). Excavations of the late Kushite and Medieval settlement on Umm Muri. *Sudan and Nubia, 9,* 9-13.

Pelissari, D. M. & Diaz-Quijano, F. A. (2017). Household crowding as a potential mediator of socioeconomic determinants of tuberculosis incidence in Brazil. *PLoS ONE, 12*(4), e0176116.

Perez-Padilla, R., Schilmann, A., & Riojas-Rodriguez, H. (2010). Respiratory health effects of indoor air pollution. *The International Journal of Tuberculosis and Lung Disease, 14*(9), 1079-1086.

Perloff, J. R., Gannon, F. H., Bolger, W. E., Montone, K. T., Orlandi, R., & Kennedy, D. W. (2000). Bone involvement in sinusitis: an apparent pathway for the spread of disease. *The Laryngoscope, 110*, 2095-2099.

Peters, J. (1986). A revision of the faunal remains from two Central Sudanese sites: Khartoum Hospital and Esh Shaheinab. In *Archaeozoologia Mélanges publiés à l'occasion du 5e Congrès International d'Archéozoologie, Bordeaux, Août 1986* (pp.11-33). Grenoble: La Pensée Sauvage Editions.

- - - - - (1991). The faunal remains from Shaqadud. In A. E. Marks & A. Mohammed-Ali (Eds.), *The late prehistory of the eastern Sahel: the Mesolithic and Neolithic of Shaqadud, Sudan* (pp. 197-234). Dallas: Southern Methodist University press.

Pfeiffer, S. (1991). Rib lesions and New World tuberculosis. *International Journal of Osteoarchaeology, 1*(3-4), 191-198.

Pfister, H., Madec, L., Le Cann, P., Costet, N., Chouvet, M., Jouneau, S., & Vernhet, L. (2018). Factors determining the exposure of dairy farmers to thoracic organic dust. *Environmental Research, 165,* 286-293.

Phenice, T. W. (1969). A newly developed visual method of sexing in the os pubis. *American Journal of Physical Anthropology, 30*, 297-301.

Pigrau-Serrallach, C. & Rodríguez-Pardo, D. (2013). Bone and joint tuberculosis. *European Spine Journal, 22*(Suppl. 4), S556-S566.

Pluskota, K. (2001). The kiln sites of Old Dongola. In S. Jakobielski & P. O. Scholz (Eds.), *Dongola-Studien. 35 Jahre polnischer Forschungen im Zentrum des makuritischen Reiches* (pp.357-365). Warsaw: ZAŚ PAN.

Pokhrel, A. K., Bates, M. N., Verma, S. C., Joshi, H. S., Sreeramareddy, C. T., & Smith, K. R. (2010). Tuberculosis and indoor biomass and kerosene use in Nepal: a case-control study. *Environmental Health Perspectives, 118*(4), 558-564.

Pöllath, N. (2008). Tools, ornaments and bucrania: the animal remains. In S. Salvatori & D. Usai (Eds.), *A Neolithic cemetery in the Northern Dongola Reach: excavations at site R12* (pp. 59-77). London: SARS.

Ponce, P. V. (2010). *A comparative study of activity-related skeletal changes in the 3rd-2nd millennium BC coastal fishers and 1st millennium AD inland agriculturalists in Chile, South America*. Unpublished PhD Thesis, Durham University, Durham, UK.

Pope, C. A. 3rd, Dockery, D. W., Spengler, J. D., & Raizenne, M. E. (1991) Respiratory health and PM_{10} pollution: a day time series analysis. *The American Review of Respiratory Disease, 144*, 668-674.

Pope, D., Diaz, E., Smith-Sivertsen, T., Lie, R. T., Bakke, P., Balmes, J. R., Smith, K. R., & Bruce, N. G. (2015). Exposure to household air pollution from wood combustion and association with respiratory symptoms and lung function in nonsmoking women: results from the RESPIRE trial, Guatemala. *Environmental Health Perspectives, 123*(4), 285-292.

Porcel, J. M. (2009). Tuberculous pleural effusion. *Lung, 187*, 263-270.

Porcel, J. M. & Light, R. W. (2006). Diagnostic approach to pleural effusion in adults. *American Family Physician, 73*(7), 1211-1220.

Porres, D. V., Persiva, O., Pallisa, E., & Andreu, J. (2017). Radiological findings of unilateral tuberculous lung destruction. *Insights Imaging, 8*, 271-277.

Prasoon, D. (2003). Tuberculosis of the intercostal lymph nodes. *Acta Cytologica, 47,* 51-55.

Rabe, K. F. & Watz, H. (2017). Chronic obstructive pulmonary disease. *The Lancet, 389,* 1931-1940.

Radomski, K. U. & Neumann, K. (2011). Grasses and grinding stones: inflorescence phytoliths from modern West African poaceae and archaeological stone artefacts. In A. G. Fahmy, S. Kahlheber, & A. C. D'Andrea (Eds.), *Windows on the African past: current approaches to African archaeobotany* (pp. 153-166). Frankfurt am Main: Africa Magna Verlag.

Radon, K., Danuser, B., Iversen, M., Jörres, R., Monso, E., Opravil, U., Weber, C., Donham, K. J., & Nowak, D. (2001). Respiratory symptoms in European animal farmers. *European Respiratory Journal, 17,* 747-754.

Raff, J., Collins Cook, D., & Kaestle, F. (2006). Tuberculosis in the New World: a study of ribs from the Schild Mississippian population, West-Central Illinois. *Memórias do Instituto Oswaldo Cruz, 101*(Suppl. 2), 25-27.

Rahman, N. M., Chapman, S. J., & Davies, R. J. O. (2004). Pleural effusion: a structured approach to care. *British Medical Bulletin, 72*(1), 31-47.

Rajael, E., Hadadi, M., Madadi, M., Aghajani, J., Ahmad, M. M., Farnia, P., Ghanavi, J., Farnia, P., & Valayati, A. A. (2018). Outdoor air pollution affects tuberculosis development based on geographical information system modeling. *Biomedical and Biotechnology Research Journal, 2,* 39-45.

Ramesh Bhat, Y., Manjunath, N., Sanjay, D., & Dhanya, Y. (2012). Association of indoor air pollution with acute lower respiratory tract infections in children under 5 years of age. *Paediatrics and International Child Health,* 32(3), 132-135.

Rana, R. S., Wu, J. S., & Eisenberg, R. L. (2009). Periosteal reaction. *American Journal of Roentgenology, 193*(4): w259-w272.

Ravi, S., D'Odorico, P., Breshears, D. D., Field, J. P., Goudie, A. S., Huxman, T. E., Li, J., Okin, G. S., Swap, R. J., Thomas, A. D., Van Pelt, S., Whicker, J. J., & Zobeck, T. M. (2011). Aeolian processes and the biosphere. *Reviews of Geophysics, 49*, RG3001.

Reed, L. & Nugent, K. (2018). The health effects of dust storms in the southwest United States. *The Southwest Respiratory and Critical Care Chronicles, 6*(22), 42-46.

Rees, D., Cronje, R., & du Toit, R. S. J. (1992). Dust exposure and pneumoconiosis in a South African pottery. 1. Study objectives and dust exposure. *British Journal of Industrial Medicine, 49*, 459-464.

Rehfuess, E. A., Tzala, L., Best, N., Briggs, D. J., & Joffe, M. (2009). Solid fuel use and cooking practices as a major risk factor for ALRI mortality among African children. *Journal of Epidemiology and Community Health, 63,* 887-892.

Rehren, T. (2001). Meroe, iron and Africa. *Mitteilungen der Sudanarchäologischen Gesellschaft zu Berlin e.V., 12*, 102-109.

Reichelmann, H., Rettinger, G., Weschta, M., Keck, T., & Deutschle, T. (2003). Effects of low-toxicity particulate matter on human nasal function. *Journal of Occupational and Environmental Medicine, 45*(1), 54-69.

Reinold, J. (2001). Kadruka and the Neolithic in the Northern Dongola Reach. *Sudan and Nubia, 5*, 2-10.

Reshetnikova, N. (2012). Recent domestic architecture in the area between Dar el Arab and Dar el Waraaq at the Fourth Nile Cataract. In C. Kleinitz & C. Näser (Eds.), "Nihna nâs al-bahar – We are the people of the river." Ethnographic Research in the Fourth Nile Cataract Region, Sudan. *Meroitica, 26*, 89-114.

- - - - - (2014). *Modern vernacular architecture and settlements organisation at the Fourth Nile Cataract between Dar el-Arab and Dar el-Waraaq.* Sudan Archaeological Research Society (SARS) Draft Report. Retrieved from http://www.sudarchrs.org.uk/wp-content/uploads/2014/07/SARS_draft_report_Reshetnikova.pdf [accessed on 30th May 2018].

Resnick. D. (2002). *Diagnosis of bone and joint disorders* (4th Ed.). Philadelphia, PA: Saunders.

Richards, A. L., Hyams, K. C., Watts, D. M., Rozmajzl, P. J., Woody, J. N., & Merrell, B. R. (1993). Respiratory disease among military personnel in Saudi Arabia during operation Desert Shield. *American Journal of Public Health, 83,* 1326-1329.

Rickenbacher, J., Landolt, A. M., & Theiler, K. (1985). *Applied anatomy of the back.* New York: Springer-Verlag Berlin Heidelberg GmbH.

Riley, W. J., McKone, T. E., Lai, A. C. K., & Nazaroff, W. W. (2002). Indoor particulate matter of outdoor origin: importance of size-dependent removal mechanisms. *Environmental Science and Technology, 36*, 200-207.

Robbins, G., Mushrif Tripathy, V., Misra, V. N., Mohanty, R. K., Shinde, V. S., Gray, K. M., & Shug, M. D. (2009). Ancient skeletal evidence for leprosy in India (2000 B. C.). *PLoS ONE, 4*(5), e5669.

Robert, A. C., Cohen, M. D., Patel, A., & Green, F. H. Y. (2008). Lung disease caused by exposure to coal mine and silica dust. *Seminars in Respiratory and Critical Care Medicine, 29*(6), 651-661.

Roberts, C. A. (1999). Rib lesions and tuberculosis: the current state of play. In G. Pálfi, O. Dutour, J. Deák, & I. Hutás (Eds.), *Tuberculosis: past and present* (pp. 311-316). Szeged, Hungary: Golden Book Publisher Ltd., Tuberculosis Foundation.

- - - - - (2007). A bioarchaeological study of maxillary sinusitis. *American Journal of Physical Anthropology, 133*(2), 792-807.

- - - - - (2009). Health and welfare in medieval England: the human remains contextualised. In R. Gilchrist & A. Reynolds (Eds.), *Reflections: 50 years of medieval archaeology 1957-2007. Society of Medieval Archaeology Monograph* (pp. 307-325). Leeds: Maney Publishers.

Roberts, C. A., & Buikstra, J. E. (2003). *The bioarchaeology of tuberculosis: a global perspective on a re-emerging disease.* Gainesville, FL: University Press of Florida.

Roberts, C. A. & Manchester, K. (2010). *The archaeology of disease* (3rd Ed.). Stroud, Gloucestershire: The History Press.

Roberts, C. A., Boylston, A., Buckley. L., Chamberlain, A. C., & Murphy, E. M. (1998). Rib lesions and tuberculosis: the palaeopathological evidence. *Tubercle and Lung Disease, 79*(1), 55-60.

Roberts, C. A., Lewis, M. E., & Boocock, P. (1998). Infectious disease, sex, and gender: the complexity of it all. In A. L. Grauer & P. Stuart-Macadam (Eds.), *Sex and gender in palaeopathological perspective* (pp. 93-113). Cambridge: Cambridge University Press.

Roberts, C. A., Lucy, D., & Manchester, K. (1994). Inflammatory lesions of ribs: an analysis of the Terry collection. *American Journal of Physical Anthropology, 95*(2), 169-182.

Rogers, J., Shepstone, L., & Dieppe, P. (2004). Is osteoarthritis a systemic disorder of bone? *Arthritis & Rheumatism, 50*(2), 452-457.

Rogers, T. & Saunders, S. (1994). Accuracy of sex determination using morphological traits of the human pelvis. *Journal of Forensic Sciences, 39*(4), 1047-1056.

Rom, W. N., Bitterman, P. B., Rennard, S. I., Cantin, A., & Crystal, R. G. (1987). Characterization of the lower respiratory tract inflammation of nonsmoking individuals with interstitial lung disease associated with chronic inhalation of inorganic dusts. *The American Review of Respiratory Disease, 136*, 1429-1434.

Ross, M. H. & Murray, J. (2004). Occupational respiratory disease in mining. *Occupational Medicine, 54*(5), 304-310.

Rowley-Conwy, P. (1989). Nubia AD 0-550 and the "Islamic" agricultural revolution: preliminary botanical evidence from Qasr Ibrim, Egyptian Nubia. *Archéologie du Nil Moyen, 3*, 131-138.

Rozenshtein, A., Hao, F., Starc, M. T., & Pearson, G. D. N. (2015). Radiographic appearance of pulmonary tuberculosis: dogma disproved. *American Journal of Roentgenology, 204,* 974-978.

Rubins, J. B. (2003). Alveolar macrophages: wielding the double-edged sword of inflammation. *American Journal of Respiratory and Critical Care Medicine, 167*, 103-104.

Russell, K. F., Simpson, S. W., Genovese, J., Kinkel, M. D., Meindl, R. S., & Lovejoy, C. O. (1993). Independent test of the fourth rib aging technique. *American Journal of Physical Anthropology, 92*, 53-62.

Rylance, J., Chimpini, C., Semple, S., Russell, D. G., Jackson, M. J., Heyderman, R. S., & Gordon, S. B. (2015). Chronic household air pollution exposure is associated with impaired alveolar macrophage function in Malawian non-smokers. *PLoS* ONE*, 10*(9), e0138762.

Rylance, J., Fullerton, D. G., Scriven, J., Aljurayyan, A. N., Mzinza, D., Barrett, S., Wright, A. K. A., Wootton, D. G., Glennie, S. J., Baple, K., Knott, A., Mortimer, K., Russell, D. G., Heyderman, R. S., & Gordon, S. B. (2015). Household air pollution cases dose-dependent inflammation and altered phagocytosis in human macrophages. *American Journal of Respiratory Cell and Molecular Biology, 52*(5), 584-593.

Sadashivaiah, J. B. & Carr, B. (2009). Severe community-acquired pneumonia. *Continuing Education in Anaesthesia, Critical Care & Pain, 9*(3), 87-91.

Sadig, A. M. (2013). Reconsidering the ‘Mesolithic’ and ‘Neolithic’ in Sudan. In N. Shirai (Ed.), *Neolithisation of northeastern Africa. Studies in early Near Eastern production, subsistence, and environment 16* (pp. 23-42). Berlin: Ex Oriente.

- - - - - (2014). Child burials: a funerary practice in the Middle Nile region. Evidence from the Late Neolithic site of es-Sour. In J. R. Anderson & D. A. Welsby (Eds.), *The Fourth Cataract and beyond. Proceedings of the 12th International Conference for Nubian Studies* (pp. 285-292). Leuven: Peeters.

Saers, J., Ekerljung, L., Forsberg, B., & Janson, C. (2017). Respiratory symptoms among Swedish soldiers after military service abroad: association with time spent in a desert environment. *European Clinical Respiratory Journal, 4,* 1327761.

Sakaue, K. (2006). Application of the Suchey-Brooks system of pubic age estimation to recent Japanese skeletal material. *Anthropological Science, 114*, 59-64.

Salami, M. A., Sanusi, A. A., & Adegboye, V. O. (2018). Current indications and outcome of pulmonary resections for tuberculosis complications in Ibadan, Nigeria. *Medical Principles and Practice, 27,* 80-85.

Salih, A. M. (1999). *The Manasir of northern Sudan: land of people. A riverain society and resource scarcity. Köln: Rüdiger Köppe Verlag.*

Salvatori, S. (2008). Relative and absolute chronology of the R12 cemetery. In: S. Salvatori & D. Usai (Eds.), *A Neolithic cemetery in the Northern Dongola Reach: excavations at site R12* (pp. 139-146). London: SARS.

Salvatori, S. & Usai, D. (2007). The Sudanese Neolithic revisited. *CRIPEL, 26*, 323-333.

- - - - - (2008a). Introduction and description of the site. In S. Salvatori & D. Usai (Eds.), *A Neolithic cemetery in the Northern Dongola Reach: excavations at site R12* (pp. 1-7). London: SARS.

- - - - - (2008b). Bright and colourful: the stone jewels of R12 males and females, adults and young. In S. Salvatori & D. Usai (Eds.), *A Neolithic cemetery in the Northern Dongola Reach: excavations at site R12* (pp. 21-31). London: SARS.

Salvatori, S., Usai, D., & Zerboni, A. (2011). Mesolithic site formation and palaeoenvironment along the White Nile (Central Sudan). *The African Archaeological Review, 28*(3), 177-211.

Salvatori, S., Usai, D., Abdelrahman, M. F., di Matteo, A., Iacumin, P., Linseele, V., & Magzoub, M. K. (2014). Archaeology at El-Khiday: new insight on the prehistory and history of Central Sudan. In J. R. Anderson & D. A. Welsby (Eds.), *The Fourth Cataract and beyond. Proceedings of the 12th International Conference for Nubian Studies* (pp. 243-257). Leuven: Peeters.

Salvatori, S., Usai, D., Cenci, L., Iacumin, P., Irish, J., & Pöllath, N. (2008). Summary and some conclusions. In S. Salvatori & D. Usai (Eds.), *A Neolithic cemetery in the Northern Dongola Reach: excavations at site R12* (pp. 157-159). London: SARS.

Sánchez Fernández, J. M., Anta Escuredo, J. A., Sánchez Del Rey, A., & Santaolalla Montoya, F. (2000). Morphometric study of the paranasal sinuses in normal and pathological conditions. *Acta Oto-Laryngolgica, 120*, 273-278.

Sant’Anna, C. C., Schmidt, C. M., Pombo March, M. F. B., Martins Pereira, S., & Barreto, M. L. (2011). Radiologic findings of pulmonary tuberculosis in adolescents. *Brazilian Journal of Infectious Diseases, 15*(1), 40-44.

Santos, A. L. (1996). How old is this pelvis? A comparison of age-at-death estimation using the auricular surface of the ilium and os pubis. In G. Pwiti & R. A. Soper (Eds.), *Aspects of African archaeology. Proceedings of the 10th Congress of the Pan African Association for Prehistory and Related Studies* (pp. 29-36). Harare, University of Zimbabwe Publications.

Santos, A. L. & Roberts, C. A. (2001). A picture of tuberculosis in young Portuguese people in the early 20th century: a multidisciplinary study of the skeletal and historical evidence. *American Journal of Physical Anthropology, 115*(1), 38-49.

- - - - - (2006). Anatomy of a serial killer: differential diagnosis of tuberculosis based on rib lesions of adult individuals from the Coimbra identified skeletal collection, Portugal. *Journal of Physical Anthropology, 130*(1), 38-49.

Santos, A. L. (1996). How old is this pelvis? A comparison of age-at-death estimation using the auricular surface of the ilium and os pubis. In G. Pwiti & R. A. Soper (Eds.), *Aspects of African archaeology. Proceedings of the 10th Congress of the Pan African Association for Prehistory and Related Studies* (pp. 29-36). Harare, University of Zimbabwe Publications.

Sarajlić, N. & Gradaščević, A. (2012). Morphological characteristics of pubic symphysis for age estimation of exhumed persons. *Bosnian Journal of Basic Medical Sciences, 12*(1), 51-54.

Scanlon, G. T. (1972) Excavations at Kasr el-Wizz: A preliminary report II. *Journal of Egyptian Archaeology,* 58: 7-42

Schaefer, M., Black, S., & Scheuer, L. (2009). *Juvenile osteology: a laboratory and field manual.* London: Academic Press.

Schenker, M. B. (2000). Exposures and health effects from inorganic agricultural dusts. *Environmental Health perspectives, 108*(4), 661-664.

- - - - - (2010). Inorganic agricultural dust exposure causes pneumoconiosis among farmworkers. *Proceedings of the American Thoracic Society, 7,* 107-110.

Schenker, M. B., Pinkerton, K. E., Mitchell, D., Vallyathan, V., Elvine-Kreis, B., & Green, F. H. Y. (2009). Pneumoconiosis from agricultural dust exposure among young California farmworkers. *Environmental Health perspectives, 117*(6), 988-994.

Scheuer, L. & Black, S. (2000). *Developmental juvenile osteology*. London: Academic Press.

Schlesinger, R. B. (1995). Interaction of gaseous and particulate pollutants in the respiratory tract: mechanisms and modulators. *Toxicology, 105*, 315-325.

Schmitt, A. (2004). Age-at-death assessment using the os pubis and the auricular surface of the ilium: a test on an identified Asian sample. *International Journal of Osteoarchaeology, 14*(1), 1-6.

Schultz, M. (2001). Paleohistopathology of bone: a new approach to the study of ancient diseases. *Yearbook of Physical Anthropology, 44*, 106-147.

Scobie, A. (1986). Slums, sanitation, and mortality in the Roman world. *Klio,* 68(2), 399-433.

Scuderi, A. J., Harnsberger, H. R., & Boyer, R. S. (1993). Pneumatization of the paranasal sinuses: normal features of importance to the accurate interpretation of CT scans and MR images. *American Journal of Roentgenology, 160*, 1101-1104.

Seaton, A., MacNee, W., Donaldson, K., & Godden, D. (1995). Particulate air pollution and acute health effects. *The Lancet, 345*, 176-178.

Seiscento, M., Vargas, F. S, Bombarda, S., Sales, R. K. B., Terra, R. M., Uezumi, K., Teixeira, L. R., Antonangelo, L. (2011). Pulmonary involvement in pleural tuberculosis: how often does it mean disease activity? *Respiratory Medicine, 105,* 1079-1083.

Sharma, V. K., Bapural, J. R., Man, S. B. S., Kaur, I., & Kumar, B. (1998). Computed tomographic study of paranasal sinuses in lepromatous leprosy. *International Journal of Leprosy, 66*(2), 201-207.

Shin, H. S. (1986). Clinical significance of unilateral sinusitis. *Journal of Korean Medical Science, 1*(1), 69-74.

Shinnie, P. L. (1961). *Excavations at Soba*. Khartoum: Sudan Antiquities Service.

- - - - - (1967). *Meroe: a civilisation of the Sudan.* London: Thames & Hudson.

Shinnie, P. L. & Anderson, J. R. (2004). The capital of Kush 2: Meroë excavations 1973-1984. *Meroitica, 20*.

Shinnie, P. L. & Bradley, R. J. (1980). The capital of Kush I. Meroe excavations 1965-1972. *Meroitica, 4*.

Shinnie, P. L. & Chittick, H. N. (1961). *Ghazali – a monastery in the northern Sudan.* Sudan Antiquities Service Occasional Papers No. 5.

Shinnie, P. L. & Kense, F. J. (1982). Meroitic iron working. *Meroitica, 6*, 17-28.

Shinnie, P. L. & Shinnie, M. (1978). *Debeira West: a Medieval Nubian town.* Warminster: Aris & Phillips Ltd.

Shitaye, J. E., Tsegaye, W., & Pavlik, I. (2007). Bovine tuberculosis infection in animal and human populations in Ethiopia: a review. *Veterinarni Medicina, 52*(8), 317-332.

Shusterman, D. (2011). The effects of air pollutants and irritants on the upper airway. *Proceedings of the American Thoracic Society, 8*, 101-105.

Simon, G. (1973). *Principles of bone X-Ray diagnosis* (3rd Ed.). London: Butterworth & Co.

Simuntis, R., Kubilius, R., & Vaitkus, S. (2014). Odontogenic maxillary sinusitis: a review. *Stomatologija, Baltic Dental and Maxillofacial Journal, 16*, 39-43.

Singh, L. P., Bhardwaj, A., & Deepak, K. K. (2013). Occupational exposure to respirable suspended particulate matter and lung functions deterioration of steel workers: an exploratory study in India. *ISRN Public Health, Vol. 2013,* 325410.

Singh, S. K., Mokamati, S., Kanzhuly, M. K., & Kumar, N. (2016). Nasal mucosa and mucociliary changes in extreme hot and dry weather in the deserts. *Journal of Evolution of Medical and Dental Sciences, 5*(29), 1483-1487.

Sirajuddin, A. & Kanne, J. P. (2009). Occupational lung disease. *Journal of Thoracic Imaging, 24*(4), 310-320.

Skinsnes, O. K., Sakurai, I., & Aquino, T. I. (1972). Pathogenesis of extremity deformity in leprosy. *International Journal of Leprosy, 40*(4), 375-388.

Slavin, R. G., Spector, S. L., & Bernstein, I. L. (2005). The diagnosis and management of sinusitis: a practice parameter update. *The Journal of Allergy and Clinical Immunology, 116*, S13-S47.

Sledzik, P. S. & Bellantoni, N. (1994). Bioarchaeological and biocultural evidence for the New England vampire folk belief. *American Journal of Physical Anthropology, 94*(2), 269-274.

Smego, R. A. & Foglia, G. (1998). Actinomycosis. *Clinical Infectious Diseases*, *26*(6), 1255-1261.

Smith, K. R., Samet, J. M., Romieu, I., & Bruce, N. (2000). Indoor air pollution in developing countries and acute lower respiratory infections in children. *Thorax, 55*, 518-532.

Soler, A. (2012). *Life and death in a medieval Nubian farming community: the experience at Mis Island.* Unpublished PhD Dissertation, Michigan State University.

Song, J., Park, H. Y., Jeon, K., Um, S., Kwon, O. J., & Koh, W. (2010). Treatment of thoracic actinomycosis: a retrospective analysis of 40 patients. *Annals of Thoracic Medicine, 5*(2), 80-85.

Sood, A. (2012). Indoor fuel exposure and the lung in both developing and developed countries: an update. *Clinics in Chest Medicine, 33*(4), 649-665.

Spencer, N. (2009). Cemeteries and a late Ramesside suburb at Amara West. *Sudan and Nubia, 13,* 47-61.

- - - - - (2015). Creating a neighbourhood within a changing town: household and other agencies at Amara West in Nubia. In M. Müller (Ed.), *Household studies in complex societies: (micro) archaeological and textual approaches. The University of Chicago Oriental Institute Seminars, number 10* (pp. 169-210). Chicago, Illinois: The University of Chicago.

Spencer, N., Macklin, M., & Woodward, J. (2012). Re-assessing the abandonment of Amara West: the impact of a changing Nile? *Sudan and Nubia, 16*, 37-43.

Spigelman, M., Greenblatt, C., Vernon, K., Zylber, M., Sheridan, S., Van Gerven, D., Shaheem, Z., Hansraj, F., & Donoghue, H. (2005). Preliminary findings on the paleomicrobiological study of 400 naturally mummified human remains from Upper Nubia. *Journal of Biological Research, 80,* 91-95.

Spradley, K. M. & Jantz, R. L. (2011). Sex estimation in forensic anthropology: skull versus postcranial elements. *Journal of Forensic Sciences, 56*(2), 289-296.

Steele, R. W. (2005). Chronic sinusitis in children. *Clinical Pediatrics*, *44*, 465-471.

Stefanescu, C., Berger, V. W., & Hershberger, S. (2004). *Yates's continuity correction.* Retrieved from https://pdfs.semanticscholar.org/da9e/c9d0878437f606583634e2ec1be55c5e93ac.pdf?_ga=2.265558927.1215040099.1543758424-1438843130.1537173590 [Accessed on 5th August 2018].

Steinke, J. W. (2006). The relationship between rhinosinusitis and asthma sinusitis. *Current Allergy and Asthma Reports, 6,* 495-501.

Sterling, E. M., Arundel, A., & Sterling, T. D. (1985). Criteria for human exposure to humidity in occupied buildings. *ASHRAE Transactions, 91*(1), 611-622.

Steyn, M., Scholtz, Y., Botha, D., & Pretorius, S. (2013). The changing face of tuberculosis: trends in tuberculosis-associated skeletal changes. *Tuberculosis, 93,* 467-474.

Suki, B., Stamenovic, D., & Hubmayr, R. (2011). Lung parenchymal mechanics. *Comprehensive Physiology, 1*(3), 1317-1351.

Sumpter, C. & Chandramohan, D. (2013). Systematic review and meta-analysis of the association between indoor air pollution and tuberculosis. *Tropical Medicine and International Health, 18*(1), 101-108.

Sundman, E. A. & Kjellström, A. (2013). Chronic maxillary sinusitis in medieval Sigtuna, Sweden: a study of sinus health and effects on bone preservation. *International Journal of Osteoarchaeology, 23*, 447-458.

Sutherland, L. D. & Suchey, J. M. (1991). Use of the ventral arc in pubic sex determination. *Journal of Forensic Sciences, 36*(2), 501-511.

Talbot, J. C., Bismil, Q., Saralaya, D., Newton, D., Frizzel, R. M., & Shaw, D. L. (2007). Musculoskeletal tuberculosis in Bradford - a 6-year review. *Annals of the Royal College of Surgeons of England, 89*, 405-409.

Tam, W. W. S., Wong, T. W., Wong, A. H. S., & Hui, D. S. C. (2011). Effect of dust storm events on daily emergency admissions for respiratory diseases. *Respirology, 17*, 143-148.

Tao, H. E. L. & Peh, W. C. G. (2004). Skeletal tuberculosis in children. *Pediatric Radiology, 34,* 853-860.

Tatem, A. J., Rogers, D. J., & Hay, S. I. (2006). Global transport networks and infectious disease spread. *Advances in Parasitology, 62*, 293-343.

Taylor, C. (2005). The disposal of human waste: a comparison between ancient Rome and medieval London. *Past Imperfect, 11*, 53-72.

Taylor, J. H. & Antoine, D. (2014). *Ancient lives, new discoveries: eight mummies, eight stories.* London: British Museum Press.

Thomas, R. (2008). The origin and use of ceramics on the islands of Mis and Umm Muri, in the late Meroitic to Christian periods. *Sudan and Nubia, 12,* 64-73.

Thompson, A. H., Chaix, L., & Richards, M. P. (2008). Stable isotopes and diet at ancient Kerma, Upper Nubia (Sudan). *Journal of Archaeological Science, 35*, 376-387.

Thompson, A. J. & Carty, H. (1979). Pulmonary actinomycosis in children. *Pediatric Radiology, 8*, 7-9.

Tiemersma, E. W., van der Werf, M. J., Borgdorff, M.W., Williams, B. G., & Nagelkerke, N. J. D. (2011). Natural history of tuberculosis: duration and fatality of untreated pulmonary tuberculosis in HIV negative patients: a systematic review. *PLoS ONE, 6*(4), e17601.

Tilley, A. E., Walters, M. S., Shaykhiev, R., & Crystal, R. G. (2014). Cilia dysfunction in lung disease. *Annual Review of Physiology, 77*, 379-406.

Ting, C. & Humphris, J. (2017). The technology and craft organisation of Kushite technical ceramic production at Meroe and Hamadab, Sudan. *Journal of Archaeological Science: Reports, 16*, 34-43.

Tjoe Nij, E., Burdorf, A., Parker, J., Attfield, M., van Duivenbooden, C., & Heederik, D. (2003). Radiographic abnormalities among construction workers exposed to quartz containing dust. *Occupational and Environmental Medicine, 60*, 410-417.

Todd, T. W. (1920). Age changes in the pubic bone. *American Journal of Physical Anthropology, 4*, 1-70.

Török, L. (1997a). *The kingdom of Kush. Handbook of the Napatan-Meroitic civilization.* Leiden: Koninklijke Brill.

- - - - - (1997b). *Meroe city. An ancient African capital. John Garstang's excavations in the Sudan. Part one: text.* London: Egypt Exploration Society.

- - - - - (2004). The kingdom of Kush: Napatan and Meroitic periods. In D. A. Welsby & J. R. Anderson (Eds.), *Sudan ancient treasures: an exhibition of recent discoveries from the Sudan National Museum* (pp. 132-157). London: The British Museum Press.

Tovi, F., Benharroch, D., Gatot, A., & Hertzanu, Y. (1992). Osteoblastic osteitis of the maxillary sinus. *The Laryngoscope, 102*(4), 426-430.

Trevino, R. J. (1996). Air pollution and its effect on the upper respiratory tract and on allergic rhinosinusitis. *Otolaryngology - Head and Neck Surgery, 114*(2), 239-241.

Trianti, S., Samoli, E., Rodopoulou, S., Katsouyanni, K., Papiris, S. A., & Karakatsani, A. (2017). Desert dust outbreaks and respiratory morbidity in Athens, Greece. *Environmental Health, 16,* 72.

Trigger, B. G. (1967). *The Late Nubian settlement at Arminna West.* New Haven & Philadelphia: The Peabody Museum of Natural History of Yale University & The University Museum of the University of Pennsylvania.

Troeger, C., Forouzanfar, M., Rao, P. C., Khalil, I., Brown, A., Swartz, S., … & Mokdad, A. H. (2017). Estimates of the global, regional, and national morbidity, mortality, and aetiologies of lower respiratory tract infections in 195 countries: a systematic analysis for the Global Burden of Disease Study 2015. *The Lancet Infectious Diseases, 17,* 1133-1161.

Tsao, Y., Liu, S., Tzeng, I., Hsieh, T., Chen, J., & Luo, J. J. (2017). Do sanitary ceramic workers have a worse presentation of chest radiographs or pulmonary function tests than other ceramic workers? *Journal of the Formosan Medical Association, 116,* 139-144.

Turaclar, U. T., Sumer, H., & Akyurek, O. (1999). The effect of biomass fuel combustion on pulmonary function tests in the adult population of Sivas Province. *Indian Journal of Physiology and Pharmacology, 43*(1), 121-124.

Turgut, M. (2001). Spinal tuberculosis (Pott's disease): is clinical presentation, surgical management, and outcome. A survey study on 694 patients. *Neurosurgical Review, 24,* 8-13.

Udumah, A. U. & Jimoh, W. L. O. (2013). High incidence of asthma, bronchitis, pneumonia and sinusitis in Kano State, north west Nigeria during Saharan dust events. *American Journal of Environment, Energy and Power Research, 1*(8), 174-185.

Uluğ, M. & Can-Uluğ, N. (2012). Pulmonary involvement in brucellosis. *Canadian Journal of Infectious Diseases and Medical Microbiology, 23*(1), e13-e15.

Upadhyay, R., Prakash, V., Singh, A. B., & Saheer, S. (2014). Maxillary sinusitis with pulmonary tuberculosis. *BMJ Case Reports, 2014*, bcr2014203952.

Usai, D. (2008). The other stone tools: axes, mace-heads, grinding stone, etc. In S. Salvatori & D. Usai (Eds.), *A Neolithic cemetery in the Northern Dongola Reach: excavations at site R12* (pp. 53-58). London: SARS.

- - - - - (2014). Recent advances in understanding the prehistory of Central Sudan. In J. R. Anderson & D. A. Welsby (Eds.), *The Fourth Cataract and beyond. Proceedings of the 12th International Conference for Nubian Studies* (pp. 31-44). Leuven: Peeters.

- - - - - (2016). *A picture of prehistoric Sudan: the Mesolithic and Neolithic periods*. Oxford Handbooks Online. Oxford University Press.

Usai, D. & Salvatori, S. (2005). The IsIAO archaeological project in the El Salha area (Omdurman South, Sudan): results and perspectives. *Africa, 60*(3/4), 474-493.

Valdés, L., Alvarez, D., Valle, J. M., Pose, A., & San José, E. (1996). The etiology of pleural effusions in an area with high incidence of tuberculosis. *Chest, 109*, 158-162.

van der Does, M., Korte, L. F., Munday, C. I., Brummer, G. A., & Stuut, J. W. (2016). Particle size traces modern Saharan dust transport and deposition across the equatorial north Atlantic. *Atmospheric Chemistry and Physics, 16,* 13697-13710.

Van der Poll, T. & Opal, S. M. (2009). Pathogenesis, treatment, and prevention of pneumococcal pneumonia. *The Lancet, 374*(9700), 1543-1556.

van der Veen, M. (1991). The plant remains. In D. A. Welsby & C. M. Daniels, *Soba: archaeological research at a medieval capital on the Blue Nile* (pp. 264-273). London: The British Institute in Eastern Africa.

van Eeden, S. F., Tan, W. C., Suwa, T., Mukae, H., Terashima, T., Fujii, T., Qui, D., Vincent, R., & Hogg, J. C. (2001). Cytokines involved in the systemic inflammatory response induced by exposure to particulate matter air pollutants (PM_{10}). *American Journal of Respiratory and Critical Care Medicine, 164*, 826-830.

Vincentelli, I. (1993). A discharge of clay sealings from the Natakamani Palace. *Kush, 16*, 116-141.

Vogelsang-Eastwood, G. M. (1991). The textiles. In D. A, Welsby & C. M. Daniels, *Soba: archaeological research at a medieval capital on the Blue Nile* (pp. 300-308). London: The British Institute in Eastern Africa.

Waddy, B. B. (1952). Climate and respiratory infections. *The Lancet, 260*(6736), 674-677.

Wagenmann, M. & Nacleiro, R. M. (1992). Complications of sinusitis. *Journal of Allergy and Clinical Immunology, 90*, 552-554.

Wakely, J., Manchester, K., & Roberts, C. (1991). Scanning electron microscopy of rib lesions. *International Journal of Osteoarchaeology, 1*, 185-189.

Wald, E. R. (1995). Chronic sinusitis in children. *The Journal of Pediatrics, 127*(3), 339-347.

Waldron, T. (2009). *Palaeopathology.* Cambridge: Cambridge University Press.

Walker, D. & Henderson, M. (2010). Smoking and health in London's East End in the first half of the 19th century. *Post-Medieval Archaeology, 44*(1), 209-222.

Walker, P. L. (1995). Problems of preservation and sexism in sexing: some lessons from historical collections for paleodemographers. In S. Saunders & A. Herring (Eds.), *Grave reflections: portraying the past through skeletal studies* (pp. 31-47). Toronto: Canadian Scholars' Press.

- - - - - (2008). Sexing skulls using discriminant function analysis of visually assessed traits. *American Journal of Physical Anthropology*, *136*, 39-50.

Walter, N. & Daley, C. L. (2012). Tuberculosis and nontuberculous mycobacterial infections. In S. G. Spiro, G. A. Silvestri, & A. Agustí (Eds.), *Clinical respiratory medicine* (4th Ed., pp. 383-405). Philadelphia: Elsevier Saunders.

Ward, J. P. T., Ward, J., & Leach, R. M. (2015). *The respiratory system at a glance* (4th Ed.). Chichester: John Wiley & Sons Ltd.

Watts, H. G. & Lifeso, R. M. (1996). Tuberculosis of bones and joints. *The Journal of Bone and Joint Surgery, 78-A*(2), 288-298.

Weeks, K. R. (1967). *The classic Christian townsite at Arminna West.* New Haven & Philadelphia: The Peabody Museum of Natural History of Yale University & The University Museum of the University of Pennsylvania.

Weissberg, D. & Refaely, Y. (1996). Pleural empyema: 24-Year experience. *The Annals of Thoracic Surgery, 62*(4), 1026-1029.

Wells, C. (1964). Chronic sinusitis with alveolar fistulae of mediaeval date. *The Journal of Laryngology & Otology, 78*(3), 320-322.

- - - - - (1977). Disease of the maxillary sinus in antiquity. *Medical and Biological Illustration, 27*, 173-178.

Welsby, D. A. (1995). Survey in the northern Sudan 1993-1995. *Mitteilungen der Sudanarchäologischen Gesellschaft zu Berlin e.V., 3,* 26-31.

- - - - - (1996). *The kingdom of Kush. The Napatan and Meroitic empires.* London: British Museum Press.

- - - - - (1998). *Soba II: renewed excavations within the metropolis of the kingdom of Alwa in Central Sudan.* London: British Museum Press.

- - - - - (2000a). The Kawa excavation project. *Sudan and Nubia, 4*, 5-10.

- - - - - (2000b). The Amri to Kirbekan survey, 1999. *Sudan and Nubia, 7*, 26-32.

- - - - - (2001). *Life on the desert edge*. London: SARS.

- - - - - (2002). *The medieval kingdoms of Nubia. Pagans, Christians and Muslims along the Middle Nile.* London: British Museum Press.

- - - - - (2003a). The kingdom of Kush: Rome's neighbour on the Nile. In M. Liverani (Ed.), *Arid lands in Roman times. Papers from the international conference (Rome, July 9th-10th 2001)* (pp. 65-78). Arid Sone Archaeology Monographs, 4. Florence: All'insegna del giglio.

- - - - - (2003b). The Amri to Kirbekan survey: the 2002-2003 season. *Sudan and Nubia,* 7, 26-32.

- - - - - (2004). The Northern Dongola Reach. In D. A. Welsby & J. R. Anderson (Eds.), *Sudan ancient treasures: an exhibition of recent discoveries from the Sudan National Museum* (pp. 90-91). London: The British Museum Press.

- - - - - (2005). The Merowe dam archaeological salvage project: survey in the vicinity of ed-Doma (AKSA), 2004-2005. *Sudan and Nubia, 9*, 2-8.

- - - - - (2006a). The Merowe dam archaeological salvage project: excavations in the vicinity of ed-Doma (AKSA), 2005-2006. *Sudan and Nubia, 10*, 8-12.

- - - - - (2006b). Settlement in Nubia in the medieval period. In I. Caneva & A. Roccati (Eds.), *Acta Nubica. Proceedings of the X International Conference of Nubian Studies Rome 9-14 September 2002* (pp. 21-43). Rome: Liberia Dello Stato.

- - - - - (2007). The Merowe dam archaeological salvage project. Survey and excavations in the vicinity of ed-Doma (AKSE) and et-Tereif (AKSCW), 2006-2007. *Sudan and Nubia, 11*, 15-19.

- - - - - (2008). The Merowe dam archaeological salvage project 1996-2006. In *Between the Cataracts. Proceedings of the 11th Conference of Nubian Studies. Warsaw University, 27 August - 2 September 2006* (Vol. 1, pp. 33-47). Warsaw: Polish Centre of Mediterranean Archaeology & Warsaw University Press.

- - - - - (2010). *Survey data on all the sites located in grid square 4-L.* Sudan Archaeological Research Society (SARS) draft report. Retrieved from http://www.sudarchrs.org.uk/wp-content/uploads/2013/09/SARS_draft_Gazetteer_4-L.pdf [accessed on 29th May 2018].

- - - - - (2011). Excavations in the Kushite town and cemetery at Kawa, 2010-11. *Sudan and Nubia, 15*, 54-63.

- - - - - (2013). *Excavations in grid square 3-O.* Sudan Archaeological Research Society (SARS) draft report. Retrieved from http://www.sudarchrs.org.uk/wp-content/uploads/2013/09/SARS_draft_3-O_excavations.pdf [accessed on 29th May 2018].

- - - - - (2014a). The kingdom of Alwa. In J. R. Anderson & D. A. Welsby (Eds.), *The Fourth Cataract and beyond. Proceedings of the 12th International Conference for Nubian Studies* (pp. 183-199). Leuven: Peeters.

- - - - - (2014b). *Kawa: the pharaonic and Kushite town of Gematon. History and archaeology of the site.* London: The British Museum.

- - - - - (2015). *Excavations in grid square 4-M.* Sudan Archaeological Research Society (SARS) draft report. Retrieved from http://www.sudarchrs.org.uk/wp-content/uploads/2015/05/SARS_draft_4-M_excavations.pdf [accessed on 29th May 2018].

Welsby, D. A. & Anderson, J. R. (eds.) (2004) *Sudan Ancient Treasures: An exhibition of recent discoveries from the Sudan National Museum.* London: The British Museum Press.

Welsby, D. A. & Daniels, C. M. (1991). *Soba: archaeological research at a medieval capital on the Blue Nile.* London: The British Institute in Eastern Africa.

Welsby, D. A., Macklin, M. G., & Woodward, J. C. (2002). Human responses to Holocene environmental changes in the Northern Dongola Reach of the Nile, Sudan. In R. Friedman (Ed.), *Egypt and Nubia: gifts of the desert* (pp. 28-38). London: The British Museum Press.

Welsby Sjöström, I. (2001). Pottery from the Kerma Moyen graves at site P37. In D. A. Welsby, *Life on the Desert Edge* (Vol. 2, pp. 349-354). London: SARS.

Welsh, F. (2005). Architecture of the modern houses of the Fourth Cataract. *Sudan and Nubia, 9*, 17-22.

- - - - - (2013). *Architecture and life in villages of the Fourth Nile Cataract in the region of et-Tereif.* Sudan Archaeological Research Society (SARS) Draft Report. Retrieved from http://www.sudarchrs.org.uk/wp-content/uploads/2014/07/SARS_draft_report_Welsh.pdf [accessed on 29th May 2018].

Weschenfelder, P. (2012a). Manâsîr women's contributions to economic and social life: a case study from Kirbekân in Dâr al-Manâsir. In C. Kleinitz & C. Näser (Eds.), "Nihna nâs al-bahar – We are the people of the river." Ethnographic Research in the Fourth Nile Cataract Region, Sudan. *Meroitica, 26*, 75-87.

- - - - - (2012b). Life and traditions of Manasir women in Kirbekān. In H. Wotzka (Ed.), *Proceedings of the third international conference on the archaeology of the Fourth Nile Cataract. University of Cologne, 13 – 14 July 2006. Africa Praehistorica, 22* (pp. 249-256). Cologne: Heinrich-Barth-Intitut.

Weston, D. A. (2008). Investigating the specificity of periosteal reactions in pathology museum specimens. *American Journal of Physical Anthropology, 137*, 48-59.

- - - - - (2012). Nonspecific infection in palaeopathology: interpreting periosteal reactions. In A. L. Grauer (Ed.), *A companion to palaeopathology* (pp. 492-512). Chichester, UK: Blackwell Publishing Ltd.

White, C. & Franco-Paredes, C. (2015). Leprosy in the 21st century. *Clinical Microbiology Reviews, 28*(1), 80-94.

White, C. D. & Schwarcz, H. P. (1994). Temporal trends in stable isotopes for Nubian mummy tissues. *American Journal of Physical Anthropology, 93*, 165-187.

White, T. D., Black, M. T., & Folkens, P. A. (2012). *Human osteology* (3rd Ed.). London: Academic Press.

Whittaker, D. (2000). Ageing from the dentition. In M. Cox & S. Mays (Eds.). *Human Osteology in Archaeology and Forensic Science* (pp. 83-99). Cambridge: Cambridge University Press.

WHO (1999). *Hazard prevention and control in the work environment: airborne dust.* Geneva: WHO.

- - - - - (2010). Urbanisation and health. *Bulletin of the World Health Organisation, 88*, 245-246.

- - - - - (2018a). *Household air pollution and health.* Retrieved from http://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health [accessed on 21st June 2018].

- - - - - (2018b) *Global tuberculosis report 2018.* Geneva: WHO.

Wilkinson, M. & Woodhead, M. (2004). Pneumonia. *Medicine, 32*(2), 129-134.

Williams, B. A. & Rogers, T. L. (2006). evaluating the accuracy and precision of cranial morphological traits for sex determination. *Journal of Forensic Sciences, 51*(4), 729-735.

Wiltschke-Schrotta, K. & Berner, M. (1999). Distribution of tuberculosis in the skeletal material of eastern Austrian sites. In G. Pálfi, O. Dutour, J. Deák, & I. Hutás (Eds.), *Tuberculosis: past and present* (pp. 543-548). Szeged, Hungary: Golden Book Publisher Ltd., Tuberculosis Foundation.

Wolf, P. (2015). The Qatar-Sudan archaeological project – the Meroitic town of Hamadab and the palaeo-environment of the Meroe region. *Sudan and Nubia, 19*, 115-131.

Wolf, P. & Nowotnick, U. (2005a). The second season of the SARS Anglo-German expedition to the Fourth Cataract. *Sudan and Nubia, 9*, 23-31.

- - - - - (2005b). First season of the SARS Anglo-German survey at the Fourth Cataract. *Gdańsk Archaeological Museum African Reports, 4*, 181-198.

- - - - - (2006a). Hamadab – a Meroitic urban settlement. Excavations 2001-2003. *Archéologie du Nil Moyen, 10*, 257-272.

- - - - - (2006b). The third season of the SARS Anglo-German expedition to the Fourth Cataract of the Nile. *Sudan and Nubia, 10*, 20-32.

Wolf, P., Nowotnick, U., & Hof, C. (2014). The Meroitic urban town of Hamadab in 2010. In J. R. Anderson & D. A. Welsby (Eds.), *The Fourth Cataract and beyond. Proceedings of the 12th International Conference for Nubian Studies* (pp. 719-737). Leuven: Peeters.

- - - - - (2015). Hamadab – insights into development and lifestyle of a Meroitic urban settlement. In M. H. Zach (Ed.), *The Kushite world. Proceedings of the 11th international conference for Meroitic studies. Vienna, 1-4 September 2008* (pp. 123-139). Vienna: Beiträge zur Sudanforschung. Beiheft 9.

Wolkoff, P. & Kjærgaard, S. K. (2007). The dichotomy of relative humidity on indoor air quality. *Environment International, 33*, 850-857.

Wong, V. K., Turmezei, T. D., & Weston, V. C. (2011). Actinomycosis. *BMJ*, *343*, d6099.

Wood, J. W., Milner, G. R., Harpending, & H. C., Weiss (1992). The osteological paradox: problems of inferring prehistoric health from skeletal samples. *Current Anthropology, 33*(4), 343-370.

Woodward, J., Macklin, M., Fielding, L., Millar, I., Spencer, N., Welsby, D., & Williams, M. (2015). Shifting sediment sources in the world's longest river: a strontium isotope record for the Holocene Nile. *Quaternary Science Reviews, 130*, 124-140.

Woolley, C. L. (1911). *Karanòg: the town* (Vol. 5). Philadelphia: The University Museum of the University of Pennsylvania.

Woolley, C. L. & Randall-MacIver, D. (1910a). *Karanòg: the Romano-Nubian cemetery* (Vol. 3). Philadelphia: The University Museum of the University of Pennsylvania.

- - - - - (1910b). *Karanòg: the Romano-Nubian cemetery* (Vol. 4). Philadelphia: The University Museum of the University of Pennsylvania.

Wright, J. L. & Churg, A. M. (2012). Macro and micro structure of the lung. In S. G. Spiro, G. A. Silvestri, & A. Agustí (Eds.), *Clinical respiratory medicine* (4th Ed. pp. 1-6). Philadelphia: Elsevier Saunders.

Wrightson, J. M., Davies, H. E., & Lee, Y. C. G. (2012). Pleural effusion, empyema, and pneumothorax. In S. G. Spiro, G. A. Silvestri, & A. Agustí (Eds.), *Clinical respiratory medicine* (4th Ed, pp. 818-836.). Philadelphia: Elsevier Saunders.

Yap, F. Y., Skalski, M. R., Patel, D. B., Schein, A. J., White, E. A., Tomasian, A., Masih, S., & Matcuk, G. R., Jr. (2017). Hypertrophic osteoarthropathy: clinical and imaging features. *RadioGraphics, 37,* 157-175.

Yoder, C., Ubelaker, D. H., & Powell, J. F. (2001). Examination of variation in sternal rib end morphology relevant to age assessment. *Journal of Forensic Sciences, 46*(2), 223-227.

Young, E. J. (1995). An overview of human brucellosis. *Clinical infectious diseases, 21*(2), 283-289.

Yue, R. P. H., Lee, H. F., & Wu, C. Y. H. (2017). Trade routes and plague transmissions in pre-industrial Europe. *Scientific Reports, 7*, 12973.

Yusa, A., Berry, P., Cheng, J. J., Ogden, N., Bonsal, B., Stewart, R., & Waldick, R. (2015). Climate change, drought and human health in Canada. *International Journal of Environmental Research and Public Health, 12*(7), 8359-8412.

Yvanez, E. (2016). Spinning in Meroitic Sudan: textile production implements from Abu Geili. *Dotawo, 3*, 153-178.

Zink, A. R., Grabner, W., Reischl, U., Wolf, H., & Nerlich, A. G. (2003). Molecular study on human tuberculosis in three geographically distinct and time delineated populations from ancient Egypt. *Epidemiology and Infection, 130,* 239-249.

Zink, A. R., Sola, C., Reischl, U., Grabner, W., Rastogi, N., Wolf, H., & Nerlich, A. G. (2004). Molecular identification and characterisation of *Mycobacterium tuberculosis* complex in ancient Egyptian mummies. *International Journal of Osteoarchaeology, 14*, 404-413.

Zuckerkandl, E. (1893). *Normale und Pathologische Anatomie der Nasenhöhle und Ihrer Pneumatischen Anhänge* (2nd Ed.). Vienna: Wilhelm Braumüller, K. U. K. Hof- und Universitätsbuchhändler.

Żurawski, B. (1999). The monastery on Kom H in Old Dongola. The monk's graves. A preliminary report. *Nubia et Æthiopica, 4/5*, 201-253.

- - - - - (2014). The Fourth Cataract in the Medieval period. In J. R. Anderson & D. A. Welsby (Eds.), *The Fourth Cataract and beyond. Proceedings of the 12th International Conference for Nubian Studies* (pp. 135-153). Leuven: Peeters.

Zuskin, E., Mustajbegovic, J., Schachter, E. N., & Rienzi, N. (1993). Respiratory symptoms and ventilator capacity in workers in a vegetable pickling and mustard production facility. *International Archives of Occupational and Environmental Health, 64*, 547-461.

Zuskin, E., Mustajbegovic, J., Schachter, E. N., Kanceljak, B., & Godnic-Cvar, J. (1995). Respiratory symptoms and lung function in wool textile workers. *American Journal of Industrial Medicine*, *27*, 845-857.

Zuskin, E., Mustajbegovic, J., Schachter, E. N., Kanceljak, B., Kern, J., Macan, J., & Ebling, Z. (1998). Respiratory function and immunological status in paper-recycling workers. *Journal of Occupational and Environmental Medicine, 40*(11), 986-993.

Zuskin, E., Mustajbegovic, J., Schachter, E. N., Kern, J., Budak, A., & Godnic-Cvar, J. (1998). Respiratory findings in synthetic textile workers. *American Journal of Industrial Medicine, 33*, 263-273.

Zuskin, E., Mustajbegovic, J., Schachter, E. N., Kern, J., Deckovic-Vukres, V., Pucarin-Cvetkovic, J., & Nola-Premec, I. A. (2004). Respiratory findings in pharmaceutical workers. *American Journal of Industrial Medicine, 46,* 472-479.

Zuskin, E., Skuric, Z., Kanceljak, B., Pokrajac, D., Schachter, E. N., & Witek, T. J. (1988). Respiratory symptoms and lung function in furriers. *American Journal of Industrial medicine, 14*, 189-196.

- - - - - (1990). Respiratory symptoms and lung function in hemp workers. *British Journal of Industrial Medicine, 47*, 627-632.

Appendix A: Data from previous bioarchaeological studies

Table A.1 – Data from bioarchaeological studies of maxillary sinusitis, including the geographical region, population, time period, subsistence economy, and prevalence rate and frequency of maxillary sinusitis. Where possible, data has been presented for adults only (* = mixed adult and non-adult populations that could not be separated). To avoid small inconsistencies, all prevalence rates have been recalculated using the available frequency data provided in the studies.

[1]Bernofsky (2006); [2]Bernofsky (2010); [3]Binder (2014); [4]Boocock et al. (1995); [5]DiGangi and Sirianni (2017); [6]Lewis et al. (1995); [7]Liebe-Harkort (2012); [8]Merrett (2003); [9]Merrett and Pfeiffer (2000); [10]Papapelekanos (2003); [11]Panhuysen et al. (1997); [12]Roberts (2007); [13]Roberts, Lewis, & Boocock (1998); [14]Soler (2012); [15]Sundman & Kjellström (2013)

Geographical region	Site	Approximate time period	Subsistence economy	Maxillary sinusitis prevalence	Frequency (n/N)
Sudan	Amara West, 2nd to 3rd Cataracts[3]	1200 – 800 BC	Urban	76.3%	45/59
	Kulubnarti, 2nd to 3rd Cataracts[12]	AD 600 – 1100	Rural agriculture	21.8%	22/101
	Mis Island, 4th Cataract[14]	AD 550 – 1500	Rural agriculture	38.4%	28/73
Mainland Europe	Smörkullen, Östergötland, Sweden[7]	AD 0 – 260	Rural agriculture	88.4%	61/69
	*Boschstraat, Maastricht, Netherlands[11]	AD 600 – 800	Rural agriculture	25.0%	7/28
	*Servaas, Maastricht, Netherlands[11]	AD 450 – 950	Semi-urban	43.3%	29/67
	Nunnery, Maastricht, Netherlands[11]	AD 1250 – 1600	Urban	41.9%	13/31
	*Sigtuna, Sweden[15]	AD 970 – 1530 AD	Urban	94.5%	259/274
North America	Indian Knoll, Kentucky, USA[12]	4570 – 3500 BC	Rural agriculture	38.5%	37/96
	Bluff Mounds, Illinois, USA[12]	AD 800 – 1100	Hunter-gatherer/early agriculture	38.6%	27/70
	*Moatfield Ossuary, Ontario, Canada[8]	AD 1300	Rural agriculture	59.5%	44/74
	Uxbridge Ossuary, Ontario, Canada[9]	AD 1410 – 1483	Rural agriculture	63.2%	72/114
	Aleutian Islanders, Alaska, USA[12]	AD 1500 – 1600	Hunter-gatherer	42.9%	15/35

	South Dakota, USA[12]	AD 1500 – 1800	Hunter-gatherer/early agriculture	17.2%	15/87
	Hardin Village, Kentucky, USA[12]	AD 1550 – 1675	Rural agriculture	51.5%	17/33
	Rochester, New York, USA[5]	AD 1826 – 1863	Urban	54.5%	54/99
England	Iron Age England[2]	500 – 100 BC	Rural agriculture	75.4%	43/57
	Lankhills, Hampshire[2]	AD 300 – 500	Rural agriculture	35.1%	26/74
	Roman London[2]	AD 1 – 400	Semi-urban	31.8%	28/88
	Raunds Furnells, Northamptonshire[13]	AD 700 – 900	Rural agriculture	50.5%	55/109
	Spofforth, Yorkshire[1]	AD 700 – 1200	Rural agriculture	42.9%	15/35
	Bishopsmill School, Durham[1]	AD 900 – 1200	Rural agriculture	80.0%	20/25
	Cannington, Somerset[2]	AD 200 – 700	Rural agriculture	48.1%	63/131
	Early Medieval Southeast England[2]	AD 500 – 1000	Rural agriculture	47.3%	26/55
	Abingdon Vineyard, Oxfordshire[2]	AD 1100 – 1540	Rural agriculture	66.9%	95/142
	Merton Priory, Surrey[2]	AD 1117 – 1538	Rural agriculture	56.3%	58/103
	St Mary Graces, London[2]	AD 1350 – 1540	Urban	59.0%	46/78
	Late Medieval London[2]	AD 1000 – 1550	Urban	50.0%	20/40
	Wharram Percy, Yorkshire[6]	AD 1000 – 1800	Rural agriculture	51.4%	91/177
	St Helen-on-the-Walls, Yorkshire[6]	AD 1100 – 1600	Urban	63.3%	119/188
	Fishergate House, Yorkshire[10]	AD 1100 – 1600	Urban	48.6%	53/109
	Chichester, Sussex[4]	AD 1100 – 1600	Rural agriculture	54.9%	73/133
	Chelsea Old Church, London[2]	AD 1700 – 1900	Semi-urban	42.3%	33/78

St Bride's Crypt, London[2]	AD 1800 – 1854	Urban	30.6%	41/134
St Bride's Lower, London[2]	AD 1770 – 1849	Urban	52.5%	64/122
Christchurch, Spitalfields, London[12]	AD 1700 – 1900	Urban	18.0%	71/394

Table A.2 – Data from bioarchaeological studies of maxillary sinusitis according to sex, including the geographical region, population, and prevalence rates and frequencies of maxillary sinusitis for males and females. To avoid small inconsistencies, all prevalence rates have been recalculated using the available frequency data provided in the studies.

[1]Bernofsky (2010); [2]Binder (2014); [3]Boocock et al. (1995); [4]Lewis et al. (1995); [5]Liebe-Harkort (2012); [6]Merrett and Pfeiffer (2000); [7]Papapelekanos (2003); [8]Panhuysen et al. (1997); [9]Roberts (2007); [10]Roberts, Lewis, & Boocock (1998); [11]Soler (2012); [12]Sundman & Kjellström (2013)

Geographical region	Site	Male		Female	
		Prevalence	Frequency (n/N)	Prevalence	Frequency (n/N)
Sudan	Amara West, 2nd to 3rd Cataracts[2]	76.9%	20/26	88.9%	24/27
	Kulubnarti, 2nd to 3rd Cataracts[9]	17.8%	8/45	25.0%	14/56
	Mis Island, 4th Cataract[11]	32.5%	13/40	45.2%	14/31
England	Iron Age England[1]	84.4%	27/32	66.7%	14/21
	Lankhills, Hampshire[1]	33.3%	15/45	39.3%	11/28
	Roman London[1]	33.3%	21/63	30.4%	7/23
	Raunds Furnells, Northamptonshire[10]	52.9%	36/68	46.3%	19/41
	Cannington, Somerset[1]	54.5%	42/77	44.4%	24/54
	Early Medieval Southeast England[1]	46.9%	15/32	52.4%	11/21

	Abingdon Vineyard, Oxfordshire[1]	65.6%	59/90	64.7%	33/51
	Merton Priory, Surrey[1]	55.2%	53/96	71.4%	5/7
	St Mary Graces, London[1]	66.1%	37/56	40.9%	9/22
	Late Medieval London[1]	48.1%	13/27	63.6%	7/11
	Wharram Percy, Yorkshire[4]	44.3%	43/97	58.3%	42/72
	St-Helen-on-the-Walls, Yorkshire[4]	75.5%	37/49	69.2%	45/65
	Fishergate House, Yorkshire[7]	51.8%	29/56	45.3%	24/53
	Chichester, Sussex[3]	56.0%	47/84	59.6%	31/52
	Chelsea Old Church, London[1]	40.4%	19/47	46.7%	14/30
	St Bride's Crypt, London[1]	31.4%	22/70	29.7%	19/64
	St Bride's Lower, London[1]	48.8%	40/82	60.0%	24/40
	Christchurch, Spitalfields, London[9]	17.7%	34/192	18.3%	37/202
Mainland Europe	Smörkullen, Östergötland, Sweden[5]	88.2%	30/34	85.7%	24/28
	Maastricht, Netherlands[8]	38.5%	15/39	45.2%	28/62
	Sigtuna, Sweden[12]	97.3%	145/149	89.2%	74/83
North America	Indian Knoll, Kentucky, USA[9]	36.7%	18/49	40.4%	19/47
	Bluff Mounds, Illinois, USA[9]	28.6%	12/42	53.6%	15/28
	Uxbridge Ossuary, Southern Ontario, Canada[6]	76.4%	13/17	84.6%	11/13
	Aleutian Islanders, Alaska, USA[9]	30.8%	4/13	50.0%	11/22

	South Dakota, USA[9]	16.7%	8/48	17.9%	7/39
	Hardin Village, Kentucky, USA[9]	25.0%	4/16	76.5%	13/17

Table A.3 – Data from bioarchaeological studies of maxillary sinusitis according to route of infection, including the geographical region, population, and prevalence rates and frequencies of rhinogenic and odontogenic sinusitis (* = only the presence of an oroantral fistula considered to be evidence for odontogenic sinusitis). To avoid small inconsistencies, all prevalence rates have been recalculated using the available frequency data provided in the studies.

[1]Boocock et al. (1995); [2]Liebe-Harkort (2012); [3]Merrett & Pfeiffer (2000); [4]Panhuysen et al. (1997); [5]Roberts (2007); [6]Sundman & Kjellström (2013)

Geographical region	Site	Odontogenic sinusitis		Rhinogenic sinusitis	
		Prevalence	Frequency (n/N)	Prevalence	Frequency (n/N)
Sudan	*Kulubnarti, 2nd to 3rd Cataracts, Sudan[5]	13.6%	3/22	86.4%	19/22
Mainland Europe	*Smörkullen, Östergötland, Sweden[2]	11.5%	7/61	88.5%	54/61
	Maastricht, Netherlands[4]	56.8%	25/44	43.2%	19/44
	*Sigtuna, Sweden[6]	9.7%	15/155	90.3%	140/155
North America	*Indian Knoll, Kentucky, USA[5]	43.2%	16/37	56.8%	21/37
	*Bluff Mounds, Illinois, USA[5]	7.4%	2/27	92.6%	25/27
	Uxbridge Ossuary, Ontario, Canada[3]	45.6%	47/103	54.4%	56/103
	*Aleutian Islanders, Alaska, USA[5]	0%	0/15	100%	15/15
	*South Dakota, USA[5]	13.3%	2/15	86.7%	13/15
	*Hardin Village, Kentucky, USA[5]	11.8%	2/17	88.2%	15/17

England	*Chichester, Sussex[1]	9.6%	7/73	90.4%	66/73
	*Christchurch, Spitalfields, London[5]	9.9%	7/71	90.1%	64/71

Table A.4 – Data from bioarchaeological studies of rib IPR, including the geographical region, population, time period, subsistence economy (when provided), and prevalence rate and frequency of rib IPR. Where possible, data has been presented for adults only (* = mixed adult and non-adult populations that could not be separated). To avoid small inconsistencies, all prevalence rates have been recalculated using the frequency data provided in the studies, when available.

[1]Bernofsky (2010); [2]Binder (2014); [3]Boulter et al. (1998); [4]Boylston (1991); [5]Boylston & Roberts (1996); [6]Buikstra & Williams (1991); [7]Capasso (2000); [8]Chundun (1992); [9]Cooper et al. (2016); [10]Kelley et al. (1994); [11]Lambert (2002); [12]Nicklisch et al. (2012); [13]Roberts (1989); [14]Roberts, Lewis, & Boocock (1998); [15]Walker & Henderson (2010); [16]Wiggins et al. (1993)

Geographical Region	Site	Approximate time period	Subsistence economy	Prevalence	Frequency (n/N)
Sudan	Amara West, 2nd to 3rd Cataracts, Sudan[2]	1200 – 800 BC	Urban	46.7%	49/105
The Americas	*South Dakota, USA[10]	AD 1600 – 1832	-	6.2%	46/740
	*Ute Mountain, Colorado, USA[11]	AD 1075 – 1280	-	28.1%	9/32
	*Pueblo Bonito, New Mexico, USA[11]	AD 900 – 1150	-	6.7%	3/45
	*Eldon Pueblo, Arizona, USA[11]	AD 1100 – 1300	-	10.0%	2/20
	Estuquina, Peru[6]	AD 1350	-	7.4%	15/204
Mainland Europe	Saxony-Anhalt, Germany[12]	5450 – 4780 BC	Hunter-gatherer/Early agriculture	21.1%	12/57
	*Herculaneum, Italy[7]	AD 79	Urban	11.6%	-
	*Courroux, Switzerland[9]	Early Medieval	-	9.1%	3/33
England	Iron Age England[1]	500 – 100 BC	Rural agriculture	1.6%	1/63

*Kempston, Bedfordshire[5]	AD 300 – 400	-	4.6%	4/87
*Kingsholm, Gloucestershire[13]	AD 300 – 400	-	19.4%	7/36
Lankhills, Hampshire[1]	AD 300 – 500	Rural agriculture	13.1%	8/61
Roman London[1]	AD 1 – 400	Semi-urban	17.3%	14/81
Raunds Furnells, Northamptonshire[14]	AD 700 – 900	Rural agriculture	4.4%	5/113
Cannington, Somerset[1]	AD 200 – 700	Rural agriculture	4.1%	4/97
Early Medieval Southeast England[1]	AD 500 – 1000	Rural agriculture	2.9%	2/69
*Addingham, West Yorkshire[4]	AD 700 – 1000	-	8.3%	2/24
*Castledyke, Lincolnshire[16]	AD 700 – 1000	-	1.4%	3/209
*St. Giles Hospital, North Yorkshire[8]	AD 1100 – 1600	-	22.9%	8/35
Chichester, Sussex[14]	AD 1100 – 1600	Rural agriculture	20.0%	38/190
Abingdon Vineyard, Oxfordshire[1]	AD 1100 – 1540	Rural agriculture	27.0%	33/122
Merton Priory, Surrey[1]	AD 1117 – 1538	Rural agriculture	15.7%	16/102
St Mary Graces, London[1]	AD 1350 – 1540	Urban	10.5%	8/76
Late Medieval London[1]	AD 1000 – 1550	Urban	13.2%	5/38
*The Newcastle Infirmary, Newcastle[3]	AD 1700 – 1900	-	4.3%	9/210
Chelsea Old Church, London[1]	AD 1700 – 1900	Semi-urban	26.5%	22/83
St Bride's Crypt, London[1]	AD 1800 – 1854	Urban	17.5%	22/126
St Bride's Lower, London[1]	AD 1770 – 1849	Urban	29.8%	36/121
St Mary & St Michael, London[15]	AD 1843 – 1854	Urban	26.5%	71/268

Table A.5 – Data from bioarchaeological studies of rib IPR according to sex, including the geographical region, population, and prevalence rates and frequencies of rib IPR for males and females. To avoid small inconsistencies, all prevalence rates have been recalculated using the frequency data provided in the studies, when available.

[1]Bernofsky (2010); [2]Binder (2014); [3]Lambert (2002); [4]Nicklish et al. (2012); [5]Roberts, Lewis, & Boocock (1998)

Geographical region	Site	Male		Female	
		Prevalence	Frequency (n/N)	Prevalence	Frequency (n/N)
Sudan	Amara West, 2nd to 3rd Cataracts[2]	71.0%	22/31	72.2%	26/36
Germany	Saxony-Anhalt[4]	29.2%	7/24	16.1%	5/31
England	Iron Age England[1]	0%	0/38	5.9%	1/17
	Lankhills, Hampshire[1]	15.8%	6/38	8.7%	2/23
	Roman London[1]	15.5%	9/58	25.0%	5/20
	Cannington, Somerset[1]	3.6%	2/55	4.9%	2/41
	Early Medieval Southeast England[1]	2.6%	1/39	3.8%	1/26
	Abingdon Vineyard, Oxfordshire[1]	26.7%	20/75	27.3%	12/44
	Merton Priory, Surrey[1]	16.7%	16/96	0%	0/6
	St. Mary Graces, London[1]	9.6%	7/73	5.3%	1/19
	Late Medieval London[1]	12.0%	3/25	18.2%	2/11
	Chichester, Sussex[5]	23.0%	-	7.0%	-
	Chelsea Old Church, London[1]	37.5%	18/48	17.6%	6/34
	St Bride's Crypt, London[1]	19.1%	13/68	15.5%	9/58
	St Bride's Lower, London[1]	28.9%	24/83	31.6%	12/38
USA	Ute Mountain, Colorado[3]	12.5%	1/8	41.7%	5/12

Table A.6 – Prevalence rates of rib IPR from human identified skeletal collections, categorised according to cause of death. Frequency data is presented in brackets below.

[1]Kelley & Micozzi (1984); [2]Roberts et al. (1994); [3]Santos & Roberts (2001); [4]Santos & Roberts (2006); [5]Matos & Santos (2006); [6]Mariotti et al. (2015)

Human identified skeletal collection	Cause of death					Total
	Pulmonary tuberculosis	Non-pulmonary tuberculosis	Tuberculosis (all forms)	Pulmonary disease (non-TB)	Non-pulmonary disease	
Hamann-Todd Collection[1]	-	-	8.8% (39/445)	-	-	-
Robert J. Terry Collection[2]	61.6% (157/255)	-	-	22.2% (51/230)	15.2% (165/1086)	24.0% (413/1718)
Coimbra Collection (non-adults)[3]	90.9% (10/11)	14.3% (1/7)	61.1% (11/18)	14.3% (1/7)	2.4% (1/41)	19.7% (13/66)
Coimbra Collection (adults)[4]	85.7% (54/63)	83.3% (15/18)	85.2% (69/81)	15.4% (4/26)	18.8% (12/64)	49.7% (85/171)
Luís Lopes (Lisbon) Collection[5]	90.5% (76/84)	-	-	36.7% (18/49)	25.0% (16/64)	55.8% (110/197)
Certosa Cemetery Collection[6]	58.8% (30/51)	-	54.2% (32/59)	7.4% (2/27)	8.2% (11/134)	-

Appendix B: Recording form

SUMMARY

Burial context

Skeleton no.:

Site: **Period:**

Grave no: **Comingling/other:**

Burial type: **Other context details:**

Overall condition

Cortical surface preservation score[1]: 0 1 2 3 4 5 5+

Fragmentation grade[2]: None (0) Minor (1) Moderate (2) Severe (3)

Completeness score[3]: <5% 5-24% 25-49% 50-74% 75-100%

Soft tissue preservation: Present / Absent **Regions:**

Sex: M M? ?? F? F Unknown

Age group: 16-19 (Adolescent) 20-34 (Young adult) 35-49 (Middle adult) 50+ (Old adult) Adult (19+)

Pathological changes:

Maxillary sinusitis: Present / Absent Bilateral / Unilateral Left / Right Unobservable

Endoscope used: No / Yes Left / Right / Both

Periapical lesions: Granuloma Abscess Sinus Oro-Antral Fistula None Unobservable

Rib IPR: Present / Absent Bilateral / Unilateral Left / Right Upper / Middle / lower Unobservable

Other:

Comments:

Images:

RECORDING FORM – INVENTORY & RIB IPR	Site:	Grave no.:	Skeleton no.:	Date:

Right Ribs			Complete-ness[3]			Rib IPR (P/A)			No. frag
			N	A	S	N	A	S	
Upper		1st							
		2nd							
		3rd							
Middle	UM	4th							
		5th							
		6th							
	LM	7th							
		8th							
		9th							
Lower		10th							
		11th							
		12th							
Other/13th									

No. of rib sections (#)	N	A	S	N	A	S
Upper						
Upper-middle						
Middle						
Lower-middle						
Lower						

Left Ribs			Complete-ness[3]			Rib IPR (P/A)			No. frag
			H	N	T	H	N	T	
Upper		1st							
		2nd							
		3rd							
Middle	UM	4th							
		5th							
		6th							
	LM	7th							
		8th							
		9th							
Lower		10th							
		11th							
		12th							
Other/13th									

No. of rib sections (#)	N	A	S	N	A	S
Upper						
Upper-middle						
Middle						
Lower-middle						
Lower						

Vert.	Completeness[3]		No. frag.	Unidentified
	Body	Neural arch		
C1				
C2				
T1				
T12				
L5				
Other				

Vertebrae		
Fragment. grade[2]	Cort. preserv.[1]	Overall completeness[3]

Ribs				
Fragment. grade[2]	Cort. preserv.[1]	Overall ribcage completeness[3]	Right	Left
Surface observability*	Right		Left	

*
1. Surface completely observable
2. Minor patches of soft tissue or dirt, minor lesions may be obscured
3. Large areas of soft tissue or dirt, large lesions may still be apparent
4. Completely unobservable

RECORDING FORM – INVENTORY & AGE & SEX	Site:	Grave no.:	Skeleton no.:	Date:

Skull	Completeness[3] R	Completeness[3] L
Frontal		
Parietal		
Occipital		
Temporal		
Zygomatic		
Maxilla		
Sphenoid		
Ethmoid		
Nasal		
Vomer		
N. conchae		
Cranium Intact?		
Mandible		

Element	Completeness[3] R	Completeness[3] L
Scapula		
Long Bones		
Clavicle		
Humerus		
Radius		
Ulna		
Femur		
Tibia		
Fibula		
Os Coxa		
Ilium		
Ischium		
Pubis		
Patella		

Sternum comleteness[3]	
Manubrium	
Sternal body	
Sacrum completeness[3]	
S1	
S2	
S3	
S4	
S5	
Coccyx	

Joint Surfaces		Completeness[3] R	Completeness[3] L
Mandibular fossa			
Mandibular condyle			
Clavicle	Medial		
	Lateral		
Scapula	Acromion		
	Glenoid		
Humerus	Proximal		
	Distal		
Radius	Proximal		
	Distal		
Ulna	Proximal		
	Distal		
Os Coxa	Acetabulum		
	Auric. surf.		
	Pubic symph.		
Sacrum	Auric. surf.		
Femur	Proximal		
	Distal		
Tibia	Proximal		
	Distal		
Fibula	Proximal		
	Distal		

Sex estimation: skull	
Morphology	**Score£**
Overall morphology	
Glabellar profile	
Supraorbital ridges	
Orbital outline	
Suprameatal crest extension	
Mastoid processes	
Nuchal area and crest	
Mandibular morphology	
Mental protuberance/chin shape	
Gonial angle	
Gonial flare	
Mandibular ramus flexure	
Sex estimation	

Skull: Ferembach et al., 1980; Krogman & Işcan 1986; Schwartz, 1995; Loth & Henneberg, 1996
Pelvis: Phenice, 1969; Ferembach et al., 1980; Krogman & Işcan, 1986; Schwartz, 1995

Sex estimation: pelvis	
Morphology	**Score£**
Overall structure	
Pelvic inlet	
Greater sciatic notch	
Composite arc	
Auricular surface	
Preauricular sulcus	
Acetabulum	
Subpubic angle	
Subpubic concavity	
Ventral arc	
Medial ischio-pubic ridge	
Inferior pubic ramus	
Width of sacral alae	
Sex estimation	

£ / = Not present or not observable
M = Male
M? = possible male
?? = Indeterminate
F? = Possible female
F = Female

Age estimation			
Final epiphyseal fusion (Schaefer et al., 2009)			
Epiphysis		**Age (years)**	**Fusion (F/U/P)**
Iliac crest		18-23	
Rib heads		17-25	
Complete fusion of all scapular elements		By 23	
Sacral bodies		Puberty – 25+	
Medial clavicle		21-30	
Pubic symphyseal degeneration (Brooks & Suchey, 1990)			
Right		**Left**	
Phase	**Age**	**Phase**	**Age**
Auricular surface degeneration (Lovejoy et al., 1985)			
Right		**Left**	
Phase	**Age**	**Phase**	**Age**
Sternal rib end (Işcan et al., 1984)			
Phase		**Age**	
Other methods/comments			**Age estimation**

	Hands (#)					Feet (#)				
Side	Carpals	Metacarpals	Prox. phalan	Int. phalan	Dist. phalan	Tarsals	Metatarsals	Prox. phalan	Int. phalan	Dist. phalan
Left										
Right										

RECORDING FORM – PATHOLOGICAL CHANGES	Site:	Grave no.:	Skeleton no.:	Date:

Maxillary sinuses (Boocock et al., 1995)											
Right						Left					
Complete-ness score[3]		Observability (Y/N/E)		Pathological changes (P/A)		Complete-ness score[3]		Observability (Y/N/E)		Pathological changes (P/A)	
Type of bone changes	Spicules	Remodelled spicules	Pitting	Porous new bone	Other	Type of bone changes	Spicules	Remodelled spicules	Pitting	Porous new bone	Other
Comments						Comments					
Surf. obvs.*:						Surf. obvs.*:					

Maxillary dental/alveolar changes																	
Right	8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8	Left
Periapical lesions																	Periapical lesions

--- Alveolar socket absent
U Intact alveolar bone, lesion unobservable
X Broken alveolar bone or visible socket, absence of lesion
R Bone remodelled after antemortem tooth loss
G Granuloma/cyst

A Abscess
IS Internal sinus
ES External sinus
OAF Oroantral fistula

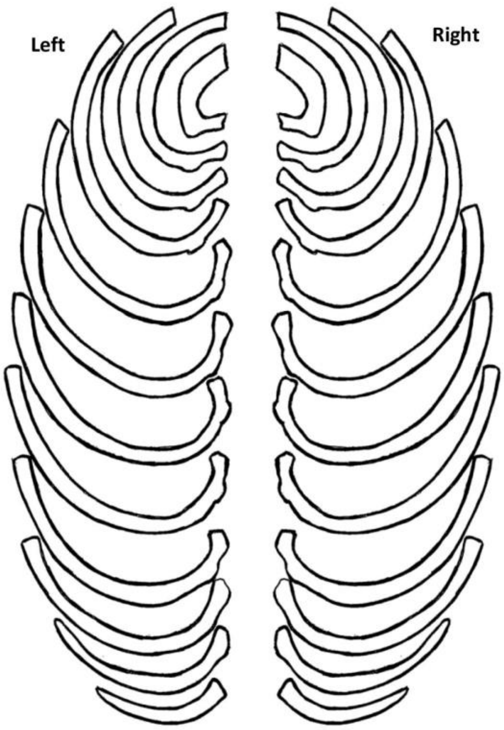
Description of pathological changes on the ribs					
Rib	Side	Surface (V/E)	Region (H/N/T/A/S/E)	Bone changes+	Comments

+ 1. Destructive a. Woven F Fracture
2. Proliferative b. Lamellar DJD Degenerative Joint Disease
3. Mixed c. Mixed

RECORDING FORM – PATHOLOGICAL CHANGES & RIB DIAGRAM	Site:	Grave no.:	Skeleton no.:	Date:

Other notable pathological changes of the skeleton				
Element	Side	Location	Bone changes[&]	Comments

& 1. Destructive a. Woven i. Discrete
2. Proliferative b. Lamellar ii. Multifocal
3. Mixed c. Mixed iii. Diffuse



IPR distribution diagram

- ☐ Absent
- ☐ Woven bone
- ☐ Lamellar bone
- ☐ Mixed bone
- ☐ Destructive lesion
- ☐ Fracture

Appendix C: Intra-observer error results

Skeleton	Completeness score 1st	Completeness score 2nd	Sinusitis 1st	Sinusitis 2nd	Type of bony change 1st	Type of bony change 2nd
3-J-23, Sk92	75-100%	75-100%	A	A	-	-
3-J-23, Sk57	50-74%	25-49%	P	P	Porous new bone	Porous new bone
3-J-23, Sk136	50-74%	50-74%	P	P	Spicules, porous new bone	Spicules, porous new bone
3-Q-33, Gr30, Sk80	50-74%	50-74%	P	A	Spicules, remodelled spicules, pitting	-
4-L-2, sk1049	5-24%	5-24%	P	P	Porous new bone	Porous new bone
4-L-2, sk1060	5-24%	5-24%	A	A	-	-
3-J-18, Sk2002	50-74%	75-100%	P	P	Spicules	Spicules
3-J-18, Sk1101	5-24%	25-49%	P	P	Porous new bone	Porous new bone

Right maxillary sinus

Table C.1 – Results of the test of intra-observer error for the recording of sinusitis in the right maxillary sinus. Corresponding results are highlighted in green, while results highlighted in orange indicate discrepancies between the recorded datasets (A = Absent, P = present).

Skeleton	Left maxillary sinus					
	Completeness score		Sinusitis		Type of bony change	
	1	2	1	2	1	2
3-J-23, Sk92	75-100%	75-100%	A	A	-	-
3-J-23, Sk57	25-49%	25-49%	P	P	Porous new bone	Porous new bone
3-J-23, Sk136	50-74%	50-74%	P	P	Spicules, porous new bone	Spicules, porous new bone
3-Q-33, Gr30, Sk80	50-74%	25-49%	P	P	Spicules, pitting	Spicules, pitting
4-L-2, sk1049	5-24%	5-24%	P	P	Porous new bone	Porous new bone
4-L-2, sk1060	5-24%	5-24%	P	P	Remodelled spicules	Remodelled spicules, porous new bone
3-J-18, Sk2002	50-74%	50-74%	P	P	Spicules	Spicules
3-J-18, Sk1101	50-74%	50-74%	A	A	-	-

Table C.2 – Results of the test of intra-observer error for the recording of sinusitis in the left maxillary sinus. Corresponding results are highlighted in green, while results highlighted in orange indicate discrepancies between the recorded datasets (A = Absent, P = present).

Skeleton	Completeness score		Rib IPR		Type of bone formation		Rib no. affected	
	1	**2**	**1**	**2**	**1**	**2**	**1**	**2**
3-J-23, Sk92	75-100%	75-100%	A	A	-	-	-	-
3-J-23, Sk57	75-100%	75-100%	A	A	-	-	-	-
3-J-23, Sk136	75-100%	75-100%	A	A		-		-
3-Q-33, Gr30, Sk80	25-49%	25-49%	P	P	Woven	Woven, remodelling	9^{th}, 11^{th}	9^{th}, 11^{th}
4-L-2, sk1049	5-24%	<5%	A	-	-	-	-	-
4-L-2, sk1060	25-49%	25-49%	A	A	-	-	-	-
3-J-18, Sk2002	75-100%	75-100%	A	A	-	-	-	-
3-J-18, Sk1101	50-74%	75-100%	A	A	-	-	-	-

Right rib cage

Table C.3 – Results of the test of intra-observer error for the recording of rib IPR in the right side of the rib cage. Corresponding results are highlighted in green, while results highlighted in orange indicate discrepancies between the recorded datasets (A = Absent, P = present).

Left rib cage								
Skeleton	Completeness score		Rib IPR		Type of bone formation		Rib no. affected	
	1	2	1	2	1	2	1	2
3-J-23, Sk92	75-100%	75-100%	P	P	Lamellar, woven	Lamellar, remodelling	2^{nd} – 6^{th}	2^{nd} – 6^{th}
3-J-23, Sk57	75-100%	75-100%	A	A	-	-	-	-
3-J-23, Sk136	75-100%	75-100%	A	A	-	-	-	-
3-Q-33, Gr30, Sk80	25-49%	25-49%	P	P	Woven	Woven	Middle rib	Upper-middle rib
4-L-2, sk1049	5-24%	5-24%	A	A	-	-	-	-
4-L-2, sk1060	5-24%	25-49%	A	A	-	-	-	-
3-J-18, Sk2002	75-100%	75-100%	A	A	-	-	-	-
3-J-18, Sk1101	75-100%	50-74%	A	A	-	-	-	-

Table C.4 – Results of the test of intra-observer error for the recording of rib IPR in the left side of the rib cage. Corresponding results are highlighted in green, while results highlighted in orange indicate discrepancies between the recorded datasets (A = Absent, P = present).

Appendix D: Inter-observer error results

Order recorded	Skeleton	Completeness score			Sinusitis			Type of bony change		
		ADB	RW	TVM	ADB	RW	TVM	ADB	RW	TVM
1st	3-J-23, Sk26	<5%	5-24%	<5%	-	A	-	-	-	-
2nd	3-J-23, Sk21	50-74%	50-74%	50-74%	P	P	P	Spicules, other	Spicules	Spicules, pitting
3rd	3-Q-33, Gr22, Sk72	5-24%	5-24%	5-24%	P	P	P	Spicules, porous new bone	Remodelled spicules, pitting	Spicules, pitting, porous new bone
4th	3-J-18, Sk4178	25-50%	25-49%	5-24%	A	A	A	-	-	-
5th	3-J-23, Sk110	50-74%	50-74%	50-74%	A	A	A	-	-	-
6th	3-J-23, Sk83	5-24%	25-49%	25-49%	P	A	P	Pitting	-	Porous new bone
7th	3-J-23, Sk33	50-74%	50-74%	50-74%	A	A	A	-	-	-
8th	3-J-23, Sk92	75-100%	75-100%	75-100%	A	A	A	-	-	-

Right maxillary sinus

Table D.1 – Results of the test of inter-observer error for the recording of maxillary sinusitis in the right sinus. Corresponding results are highlighted in green, while results highlighted in orange indicate discrepancies between the recorded datasets (A = Absent, P = present).

Left maxillary sinus										
Order recorded	**Skeleton**	**Completeness**			**Sinusitis**			**Type of bony change**		
		ADB	**RW**	**TVM**	**ADB**	**RW**	**TVM**	**ADB**	**RW**	**TVM**
1st	3-J-23, Sk26	25-49%	25-49%	50-74%	A	A	A	-	-	-
2nd	3-J-23, Sk21	50-74%	50-74%	50-74%	P	P	P	Spicules, porous new bone	Spicules	Spicules, pitting
3rd	3-Q-33, Gr22, Sk72	50-74%	50-74%	50-74%	P	P	P	Porous new bone, other	Remodelled spicules	Remodelled spicules, pitting, other
4th	3-J-18, Sk4178	50-74%	50-74%	50-74%	A	A	A	-	-	-
5th	3-J-23, Sk110	25-49%	50-74%	50-74%	A	A	A	-	-	-
6th	3-J-23, Sk83	50-74%	50-74%	50-74%	P	A	P	Spicules, porous new bone	-	Porous new bone
7th	3-J-23, Sk33	50-74%	50-74%	50-74%	A	A	A	-	-	-
8th	3-J-23, Sk92	75-100%	75-100%	75-100%	A	A	A	-	-	-

Table D.2 – Results of the test of inter-observer error for the recording of maxillary sinusitis in the left sinus. Corresponding results are highlighted in green, while results highlighted in orange indicate discrepancies between the recorded datasets (A = Absent, P = present).

Table D.3 – Results of the test of inter-observer error for the recording of rib IPR in the right side of the rib cage. Corresponding results are highlighted in green, while results highlighted in orange indicate discrepancies between the recorded datasets (A = Absent, P = present).

Right rib cage													
Order recorded	Skeleton	Completeness			Rib IPR			Type of bone formation			Rib no. affected		
		ADB	RW	TVM	ADB	RW	TVM	ADB	RW	TVM	ADB	RW	TVM
1st	3-J-23, Sk26	75-100%	75-100%	75-100%	A	P	A	-	Lamellar, remodelling	-	-	2nd, 7th	-
2nd	3-J-23, Sk21	75-100%	75-100%	75-100%	A	A	P	-	-	Lamellar	-	-	8th, 10th, 12th
3rd	3-Q-33, Gr22, Sk72	50-74%	75-100%	50-74%	P	P	P	Lamellar, woven	Lamellar, woven	Lamellar, woven, remodelling	10th, 11th	10th, 11th	10th, 11th
4th	3-J-18, Sk4178	25-49%	25-49%	50-74%	A	A	A	-	-	-	-	-	-
5th	3-J-23, Sk110	75-100%	75-100%	75-100%	P	P	P	Lamellar	Lamellar	Lamellar	5th, 7th, 9th, 10th	4th, 7th, 9th	1st, 5th to 11th
6th	3-J-23, Sk83	75-100%	75-100%	75-100%	A	A	A	-	-	-	-	-	-
7th	3-J-23, Sk33	75-100%	75-100%	75-100%	P	P	P	Woven, Lamellar	Woven, lamellar, remodelling	Remodelling	2nd to 10th	4th to 9th	4th to 9th
8th	3-J-23, Sk92	75-100%	75-100%	75-100%	A	A	A	-	-	-	-	-	-

Table D.4 – Results of the test of inter-observer error for the recording of rib IPR in the left side of the rib cage. Corresponding results are highlighted in green, while results highlighted in orange indicate discrepancies between the recorded datasets (A = Absent, P = present).

Left rib cage													
Order recorded	Skeleton	Completeness			Rib IPR			Type of bone formation			Rib no. affected		
		ADB	RW	TVM	ADB	RW	TVM	ADB	RW	TVM	ADB	RW	TVM
1st	3-J-23, Sk26	75-100%	75-100%	75-100%	A	A	P	-	-	Lamellar	-	-	10th
2nd	3-J-23, Sk21	75-100%	75-100%	75-100%	P	P	P	Woven, remodelling	Lamellar	Lamellar	6th, 8th, 10th	8th, 9th, 10th	5th, 6th, 8th, 10th, 12th
3rd	3-Q-33, Gr22, Sk72	50-74%	75-100%	50-74%	P	A	P	remodelling	-	Lamellar	9th	-	9th
4th	3-J-18, Sk4178	25-49%	25-49%	25-49%	A	A	P	-	-	Lamellar	-	-	7th
5th	3-J-23, Sk110	50-74%	75-100%	75-100%	A	A	A	-	-	-	-	-	-
6th	3-J-23, Sk83	75-100%	75-100%	75-100%	A	A	A	-	-	-	-	-	-
7th	3-J-23, Sk33	75-100%	75-100%	75-100%	P	P	P	Woven, lamellar, remodelling	Woven, lamellar, remodelling	Remodelling	2nd to 7th	2nd to 7th	2nd to 7th
8th	3-J-23, Sk92	75-100%	75-100%	75-100%	P	P	P	Woven, lamellar	Woven	Remodelling	2nd to 6th	5th, 6th	5th, 6th

Appendix E: True prevalence rates of maxillary sinusitis

Table E.1 – 4-L-2 (Fourth Cataract) maxillary sinusitis true prevalence rates (percentage of sinuses affected), according to sex, age, and within the total group. Frequencies are presented in brackets below.

Category		Sinus		Total
		Right	Left	
Sex	Male	30.8% (4/13)	30.8% (4/13)	30.8% (8/26)
	Female	66.7% (4/6)	66.7% (4/6)	66.7% (8/12)
Age	Young adult	40.0% (2/5)	14.3% (1/7)	25.0% (3/12)
	Middle adult	42.9% (6/14)	46.2% (6/13)	44.4% (12/27)
Total		46.2% (12/26)	44.4% (12/27)	45.3% (24/53)

Table E.2 – 4-L-88 (Fourth Cataract) maxillary sinusitis true prevalence rates (percentage of sinuses affected), according to sex, age, and within the total group. Frequencies are presented in brackets below.

Category		Sinus		Total
		Right	Left	
Sex	Male	100% (1/1)	50.0% (1/2)	33.3% (1/3)
	Female	0% (0/1)	0% (0/1)	0% (0/2)
Age	Young Aault	- (0/0)	- (0/0)	- (0/0)
	Middle adult	50.0% (1/2)	33.3% (1/3)	40.0% (2/5)
Total		25.0% (1/4)	60.0% (3/5)	44.4% (4/9)

Table E.3 – 4-L-100 (Fourth Cataract) maxillary sinusitis true prevalence rates (percentage of sinuses affected), according to sex, age, and within the total group. Frequencies are presented in brackets below.

Category		Sinus		Total
		Right	Left	
Sex	Male	0% (0/1)	- (0/0)	0% (0/1)
	Female	- (0/0)	- (0/0)	- (0/0)
Age	Young adult	0% (0/1)	- (0/0)	- (0/0)
	Middle adult	- (0/0)	- (0/0)	0% (0/0)
Total		20.0% (1/5)	0% (0/3)	12.5% (1/8)

Table E.4 – 3-Q-33 (Fourth Cataract) maxillary sinusitis true prevalence rates (percentage of sinuses affected), according to sex, age, time period, and within the total group. Frequencies are presented in brackets below.

Category		Sinus		Total
		Right	Left	
Sex	Male	40.0% (4/6)	50.0% (5/10)	56.3% (9/16)
	Female	60.0% (3/5)	100% (5/5)	80.0% (8/10)
Age	Young adult	50.0% (3/6)	57.1% (4/7)	53.8% (7/13)
	Middle adult	44.4% (4/9)	62.5% (5/8)	52.9% (9/17)
Time period	Meroitic	36.4% (4/11)	63.6% (7/11)	50.0% (11/22)
	Post-Meroitic	60.0% (3/5)	60.0% (3/5)	60.0% (6/10)
Total		43.8% (7/16)	62.5% (10/16)	53.1% (17/32)

Table E.5 – 3-O-1 (Fourth Cataract) maxillary sinusitis true prevalence rates (percentage of sinuses affected), according to sex, age, and within the total group. Frequencies are presented in brackets below.

Category		Sinus		Total
		Right	Left	
Sex	Male	62.5% (5/8)	33.3% (3/9)	47.1% (8/17)
	Female	0.0% (0/2)	50.0% (1/1)	33.3% (1/3)
Age	Young adult	50.0% (4/8)	44.4% (4/9)	47.1% (8/17)
	Middle adult	60.0% (3/5)	40.0% (2/5)	50.0% (5/10)
Total		53.8% (7/13)	42.9% (6/14)	48.1% (13/27)

Table E.6 – 4-M-53 (Fourth Cataract) maxillary sinusitis true prevalence rates (percentage of sinuses affected), according to sex, age, and within the total group. Frequencies are presented in brackets below.

Category		Sinus		Total
		Right	Left	
Sex	Male	0% (0/4)	0% (0/4)	0% (0/8)
	Female	50% (1/2)	50.0% (1/2)	50.0% (2/4)
Age	Young adult	0% (0/4)	0% (0/4)	0% (0/8)
	Middle adult	50.0% (1/2)	50.0% (1/2)	50.0% (2/4)
Total		28.6% (2/7)	16.7% (1/6)	23.1% (3/13)

Table E.7 – 3-J-23 (Fourth Cataract) maxillary sinusitis true prevalence rates (percentage of sinuses affected), according to sex, age, and within the total group. Frequencies are presented in brackets below.

Category		Sinus		Total
		Right	Left	
Sex	Male	57.7% (15/26)	56.0% (14/25)	56.9% (29/51)
	Female	33.3% (8/24)	29.2% (7/24)	31.3% (15/48)
Age	Young adult	42.3% (11/26)	37.0% (10/27)	40.0% (21/53)
	Middle adult	43.5% (10/23)	50.0% (11/22)	46.7% (21/45)
Total		44.2% (23/52)	40.4% (21/52)	42.3% (44/104)

Table E.8 – 3-J-18 (Fourth Cataract) maxillary sinusitis true prevalence rates (percentage of sinuses affected), according to sex, age, and within the total group. Frequencies are presented in brackets below.

Category		Sinus		Total
		Right	Left	
Sex	Male	42.4% (14/33)	45.2% (19/42)	44.0% (33/75)
	Female	67.9% (19/28)	53.6% (15/28)	60.7% (34/56)
Age	Young adult	56.5% (13/23)	53.8% (14/26)	55.1% (27/49)
	Middle adult	50.0% (18/36)	46.5% (20/43)	48.1% (38/79)
Total		51.6% (33/64)	48.6% (35/72)	50.0% (68/136)

Table E.9 – R12 (comparative) maxillary sinusitis true prevalence rates (percentage of sinuses affected), according to sex, age, and within the total group. Frequencies are presented in brackets below.

Category		Sinus		Total
		Right	Left	
Sex	Male	25.0% (2/8)	9.1% (1/11)	15.8% (3/19)
	Female	33.3% (1/3)	25.0% (1/4)	28.6% (2/7)
Age	Young adult	33.3% (1/3)	0% (0/6)	11.1% (1/9)
	Middle adult	25.0% (1/4)	0% (0/5)	11.1% (1/9)
Total		25.8% (8/31)	23.5% (8/34)	24.6% (16/65)

Table E.10 – P37 (comparative) maxillary sinusitis true prevalence rates (percentage of sinuses affected), according to sex, age, time period, and within the total group. Frequencies are presented in brackets below.

Category		Sinus		Total
		Right	Left	
Sex	Male	53.3% (8/15)	66.7% (10/15)	60.0% (18/30)
	Female	85.7% (6/7)	83.3% (5/6)	84.6% (11/13)
Age	Young adult	54.5% (6/11)	70.0% (7/10)	61.9% (13/21)
	Middle adult	70.0% (7/10)	55.6% (5/9)	63.2% (12/19)
Time period	Kerma Ancien	60.0% (12/20)	70.0% (14/20)	65.0% (26/40)
	Kerma Moyen	66.7% (6/9)	50.0% (3/6)	60.0% (9/15)
Total		62.1% (18/29)	65.4% (17/26)	63.6% (35/55)

Table E.11 – Gabati (comparative) maxillary sinusitis true prevalence rates (percentage of sinuses affected), according to sex, age, time period, and within the total group. Frequencies are presented in brackets below.

Category		Sinus		Total
		Right	Left	
Sex	Male	27.8% (10/36)	30.6% (11/36)	29.2% (21/72)
	Female	47.2% (17/36)	50.0% (15/30)	48.5% (32/66)
Age	Young adult	40.0% (16/40)	31.4% (11/35)	36.0% (27/75)
	Middle adult	43.8% (14/32)	53.1% (17/32)	48.4% (31/64)
Time period	Meroitic	39.1% (27/69)	50.0% (31/62)	44.3% (58/131)
	Post-Meroitic	40.0% (6/15)	38.5% (5/13)	39.3% (11/28)
	Medieval	60.0% (6/10)	10.0% (1/10)	35.0% (7/20)
Total		41.5% (39/94)	43.5% (37/85)	42.5% (76/179)

Table E.12 – Soba East (comparative) maxillary sinusitis true prevalence rates (percentage of sinuses affected), according to sex, age, and within the total group. Frequencies are presented in brackets below.

Category		Sinus		Total
		Right	Left	
Sex	Male	81.3% (13/16)	68.8% (11/16)	75.0% (24/32)
	Female	66.7% (4/6)	66.7% (4/6)	66.7% (8/12)
Age	Young adult	84.6% (11/13)	69.2% (9/13)	76.9% (20/26)
	Middle adult	72.7% (8/11)	70.0% (7/10)	71.4% (15/21)
Total		76.5% (26/34)	68.8% (22/32)	72.7% (48/66)

Table E.13 – Kerma Classique (Fourth Cataract) maxillary sinusitis true prevalence rates (percentage of sinuses affected), according to sex, age, and within the total group. Frequencies are presented in brackets below.

Category		Sinus		Total
		Right	Left	
Sex	Male	33.3% (5/15)	33.3% (5/15)	33.3% (10/30)
	Female	57.1% (4/7)	57.1% (4/7)	57.1% (8/14)
Age	Young adult	33.3% (2/6)	14.3% (1/7)	23.1% (3/13)
	Middle adult	43.8% (7/16)	43.8% (7/16)	43.8% (14/32)
Total		40.0% (14/35)	42.9% (15/35)	41.4% (29/70)

Table E.14 – Post-/Meroitic (Fourth Cataract) maxillary sinusitis true prevalence rates (percentage of sinuses affected), according to sex, age, and within the total group. Frequencies are presented in brackets below.

Category		Sinus		Total
		Right	Left	
Sex	Male	40.9% (9/22)	34.8% (8/23)	37.8% (17/45)
	Female	44.4% (4/9)	77.8% (7/9)	61.1% (11/18)
Age	Young adult	38.9% (7/18)	40.0% (8/20)	39.5% (15/38)
	Middle adult	50.0% (8/16)	53.3% (8/15)	51.6% (16/31)
Total		44.4% (16/36)	47.2% (17/36)	45.8% (33/72)

Table E.15 – Medieval (Fourth Cataract) maxillary sinusitis true prevalence rates (percentage of sinuses affected), according to sex, age, and within the total group. Frequencies are presented in brackets below.

Category		Sinus: Right	Sinus: Left	Total
Sex	Male	49.2% (29/59)	49.3% (33/67)	49.2% (62/126)
	Female	51.9% (27/52)	42.3% (22/52)	47.1% (49/104)
Age	Young adult	49.0% (24/49)	45.3% (24/53)	47.1% (48/102)
	Middle adult	47.5% (28/59)	47.7% (31/65)	47.6% (59/124)
Total		48.3% (56/116)	45.2% (56/124)	46.7% (112/240)

Table E.16 – Post-/Meroitic (comparative) maxillary sinusitis true prevalence rates (percentage of sinuses affected), according to sex, age, and within the total group. Frequencies are presented in brackets below.

Category		Sinus: Right	Sinus: Left	Total
Sex	Male	25.0% (8/32)	34.4% (11/32)	29.7% (19/64)
	Female	45.2% (14/31)	56.0% (14/25)	50.0% (28/56)
Age	Young adult	36.4% (12/33)	34.5% (10/29)	35.5% (22/62)
	Middle adult	41.4% (12/29)	60.7% (17/28)	50.9% (29/57)
Total		39.3% (33/84)	48.0% (36/75)	43.4% (69/159)

Table E.17 – Medieval (comparative) maxillary sinusitis true prevalence rates (percentage of sinuses affected), according to sex, age, and within the total group. Frequencies are presented in brackets below.

Category		Sinus		Total
		Right	Left	
Sex	Male	75.0% (15/20)	55.0% (11/20)	65.0% (26/40)
	Female	63.6% (7/11)	45.5% (5/11)	54.5% (12/22)
Age	Young adult	75.0% (15/20)	52.6% (10/19)	64.1% (25/39)
	Middle adult	71.4% (10/14)	50.0% (7/14)	60.7% (17/28)
Total		72.7% (32/44)	54.8% (23/42)	64.0% (55/86)

Appendix F: True prevalence rates of rib IPR presented by rib number

F.1 Rib IPR by site

Table F.1 – 4-L-2 (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib number. Frequencies are presented in brackets below.

Side	Section	Prevalence by rib number												Total prevalence		
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Section**	**Side**	**Ribcage**
Right	**Neck**	0% (0/10)	0% (0/16)	0% (0/14)	0% (0/7)	12.5% (1/8)	0% (0/7)	0% (0/8)	16.7% (1/6)	12.5% (1/8)	23.1% (3/13)	0% (0/18)	0% (0/17)	4.5% (6/132)	6.5% (21/325)	4.2% (27/647)
	Angle	7.1% (1/14)	7.1% (1/14)	8.3% (1/12)	10.0% (1/10)	0% (0/9)	0% (0/7)	0% (0/8)	14.3% (1/7)	0% (0/7)	7.7% (1/13)	7.1% (1/14)	7.1% (1/14)	6.2% (8/129)		
	Shaft	0% (0/10)	0% (0/5)	20.0% (1/5)	28.6% (2/7)	0% (0/4)	33.3% (1/3)	25.0% (1/4)	0% (0/4)	0% (0/3)	16.7% (1/6)	0% (0/6)	14.3% (1/7)	10.9% (7/64)		
Left	**Neck**	0% (0/8)	0% (0/16)	0% (0/15)	0% (0/9)	0% (0/7)	0% (0/5)	16.7% (1/6)	0% (0/6)	0% (0/6)	10.5% (2/19)	5.3% (1/19)	0% (0/15)	3.1% (4/131)	1.9% (6/322)	
	Angle	0% (0/14)	0% (0/13)	0% (0/15)	0% (0/9)	0% (0/7)	0% (0/5)	0% (0/6)	0% (0/5)	0% (0/6)	5.9% (1/17)	0% (0/15)	6.7% (1/15)	1.6% (2/127)		
	Shaft	0% (0/12)	0% (0/4)	0% (0/4)	0% (0/5)	0% (0/4)	0% (0/2)	0% (0/3)	0% (0/3)	0% (0/3)	0% (0/5)	0% (0/8)	0% (0/15)	0% (0/64)		

Table F.2 – 4-L-88 (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib number. Frequencies are presented in brackets below.

Side	Section	Prevalence by rib number												Total prevalence		
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Section**	**Side**	**Ribcage**
Right	**Neck**	0% (0/5)	0% (0/4)	0% (0/2)	0% (0/1)	0% (0/1)	0% (0/2)	0% (0/1)	0% (0/1)	0% (0/2)	0% (0/4)	0% (0/3)	0% (0/5)	0% (0/31)	9.0% (9/100)	6.6% (13/197)
	Angle	0% (0/4)	0% (0/4)	0% (0/3)	0% (0/1)	0% (0/1)	50.0% (1/2)	0% (0/1)	0% (0/1)	33.3% (1/3)	25.0% (1/4)	25.0% (1/4)	0% (0/5)	12.1% (4/33)		
	Shaft	0% (0/4)	0% (0/4)	0% (0/2)	0% (0/2)	50.0% (1/2)	50.0% (1/2)	0% (0/2)	0% (0/2)	0% (0/3)	25.0% (1/4)	25.0% (1/4)	20.0% (1/5)	13.9% (5/36)		
Left	**Neck**	0% (0/5)	0% (0/4)	0% (0/3)	0% (0/2)	0% (0/2)	0% (0/2)	0% (0/2)	0% (0/2)	0% (0/2)	0% (0/3)	0% (0/3)	0% (0/4)	0% (0/34)	4.1% (4/97)	
	Angle	0% (0/5)	0% (0/5)	0% (0/3)	0% (0/1)	50.0% (1/2)	0% (0/1)	0% (0/2)	0% (0/2)	0% (0/3)	50.0% (1/2)	20.0% (1/5)	0% (0/5)	8.1% (3/37)		
	Shaft	0% (0/3)	0% (0/4)	- (0/0)	0% (0/2)	0% (0/2)	0% (0/1)	0% (0/1)	50.0% (1/2)	0% (0/3)	0% (0/2)	0% (0/3)	0% (0/4)	3.8% (1/26)		

Table F.3 – 4-L-100 (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib number. Frequencies are presented in brackets below.

Side	Section	Prevalence by rib number												Total prevalence		
		1	2	3	4	5	6	7	8	9	10	11	12	Section	Side	Ribcage
Right	Neck	0% (0/2)	- (0/0)	0% (0/1)	0% (0/1)	0% (0/1)	0% (0/1)	0% (0/1)	0% (0/1)	0% (0/1)	0% (0/1)	0% (0/1)	0% (0/1)	0% (0/12)	0% (0/19)	0% (0/40)
	Angle	0% (0/1)	- (0/0)	0% (0/2)	- (0/0)	- (0/0)	- (0/0)	0% (0/1)	- (0/0)	- (0/0)	- (0/0)	- (0/0)	0% (0/1)	0% (0/5)		
	Shaft	- (0/0)	- (0/0)	0% (0/1)	- (0/0)	- (0/0)	- (0/0)	- (0/0)	- (0/0)	- (0/0)	- (0/0)	- (0/0)	0% (0/1)	0% (0/2)		
Left	Neck	0% (0/2)	- (0/0)	0% (0/1)	0% (0/1)	0% (0/1)	- (0/0)	- (0/0)	- (0/0)	- (0/0)	0% (0/1)	0% (0/2)	- (0/0)	0% (0/8)	0% (0/21)	
	Angle	0% (0/2)	0% (0/1)	0% (0/2)	0% (0/1)	0% (0/1)	- (0/0)	- (0/0)	- (0/0)	- (0/0)	- (0/0)	0% (0/1)	0% (0/1)	0% (0/9)		
	Shaft	0% (0/1)	- (0/0)	0% (0/1)	0% (0/1)	- (0/0)	- (0/0)	- (0/0)	- (0/0)	- (0/0)	- (0/0)	- (0/0)	0% (0/1)	0% (0/4)		

Table F.4 – 3-Q-33 (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib number. Frequencies are presented in brackets below.

Side	Section	Prevalence by rib number												Total prevalence		
		1	2	3	4	5	6	7	8	9	10	11	12	Section	Side	Ribcage
Right	Neck	0% (0/18)	5.9% (1/17)	5.3% (1/19)	5.9% (1/17)	5.6% (1/18)	11.1% (2/18)	11.1% (2/18)	11.8% (2/17)	11.8% (2/17)	11.8% (2/17)	5.9% (1/17)	5.9% (1/17)	7.6% (16/210)	3.0% (19/626)	4.4% (55/1245)
	Angle	0% (0/17)	0% (0/19)	0% (0/20)	0% (0/18)	0% (0/19)	0% (0/17)	0% (0/18)	0% (0/19)	5.6% (1/18)	0% (0/19)	0% (0/19)	0% (0/16)	0.5% (1/219)		
	Shaft	0% (0/15)	0% (0/17)	0% (0/14)	0% (0/18)	0% (0/17)	0% (0/14)	0% (0/18)	0% (0/16)	5.9% (1/17)	0% (0/17)	5.3% (1/19)	0% (0/15)	1.0% (2/197)		
Left	Neck	12.5% (2/16)	0% (0/18)	7.7% (1/13)	0% (0/17)	5.9% (1/17)	5.6% (1/18)	15.8% (3/19)	16.7% (3/18)	21.1% (4/19)	23.5% (4/17)	12.5% (2/16)	6.7% (1/15)	10.8% (22/203)	5.8% (36/619)	
	Angle	5.3% (1/19)	5.0% (1/20)	0% (0/20)	5.3% (1/19)	5.9% (1/17)	0% (0/19)	5.3% (1/19)	0% (0/18)	5.6% (1/18)	0% (0/18)	0% (0/19)	0% (0/17)	2.7% (6/223)		
	Shaft	5.6% (1/18)	0% (0/14)	13.3% (2/15)	5.9% (1/17)	0% (0/13)	5.6% (1/18)	6.7% (1/15)	0% (0/17)	0% (0/17)	5.6% (1/18)	6.3% (1/16)	0% (0/15)	4.1% (8/193)		

Table F.5 – 3-O-1 (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib number. Frequencies are presented in brackets below.

Side	Section	Prevalence by rib number												Total prevalence		
		1	2	3	4	5	6	7	8	9	10	11	12	Section	Side	Ribcage
Right	Neck	0% (0/13)	13.3% (2/15)	18.2% (2/11)	22.2% (2/9)	14.3% (1/7)	22.2% (2/9)	37.5% (3/8)	33.3% (2/6)	12.5% (1/8)	11.1% (1/9)	15.4% (2/13)	15.4% (2/13)	16.5% (20/121)		
	Angle	0% (0/14)	13.3% (2/15)	0% (0/11)	11.1% (1/9)	11.1% (1/9)	11.1% (1/9)	12.5% (1/8)	12.5% (1/8)	12.5% (1/8)	10.0% (1/10)	14.3% (2/14)	8.3% (1/12)	9.4% (12/127)	11.9% (42/352)	
	Shaft	0% (0/11)	0% (0/9)	11.1% (1/9)	16.7% (1/6)	11.1% (1/9)	12.5% (1/8)	12.5% (1/8)	12.5% (1/8)	14.3% (1/7)	11.1% (1/9)	10.0% (1/10)	10.0% (1/10)	9.6% (10/104)		7.0% (50/715)
Left	Neck	0% (0/9)	7.1% (1/14)	0% (0/11)	10.0% (1/10)	11.1% (1/9)	0% (0/9)	0% (0/9)	0% (0/9)	0% (0/8)	0% (0/10)	0% (0/12)	0% (0/10)	2.5% (3/120)		
	Angle	0% (0/13)	0% (0/14)	0% (0/14)	0% (0/9)	0% (0/9)	22.2% (2/9)	11.1% (1/9)	11.1% (1/9)	0% (0/9)	8.3% (1/12)	0% (0/13)	0% (0/10)	3.8% (5/130)	2.2% (8/363)	
	Shaft	0% (0/11)	0% (0/10)	0% (0/10)	0% (0/10)	0% (0/8)	0% (0/8)	0% (0/9)	0% (0/9)	0% (0/8)	0% (0/11)	0% (0/9)	0% (0/10)	0% (0/113)		

Table F.6 – 4-M-53 (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib number. Frequencies are presented in brackets below.

Side	Section	Prevalence by rib number												Total prevalence		
		1	2	3	4	5	6	7	8	9	10	11	12	Section	Side	Ribcage
Right	Neck	0% (0/5)	0% (0/6)	0% (0/6)	0% (0/6)	0% (0/5)	0% (0/6)	0% (0/7)	0% (0/6)	0% (0/6)	0% (0/6)	14.3% (1/7)	0% (0/6)	1.4% (1/70)		
	Angle	0% (0/6)	0% (0/7)	0% (0/6)	0% (0/6)	0% (0/6)	0% (0/6)	0% (0/6)	0% (0/6)	0% (0/5)	0% (0/6)	0% (0/7)	16.7% (1/6)	1.4% (1/73)	1.0% (2/210)	
	Shaft	0% (0/5)	0% (0/6)	0% (0/5)	0% (0/6)	0% (0/5)	0% (0/6)	0% (0/6)	0% (0/6)	0% (0/6)	0% (0/5)	0% (0/6)	0% (0/5)	0% (0/67)		1.0% (4/411)
Left	Neck	0% (0/5)	0% (0/6)	0% (0/5)	0% (0/5)	0% (0/5)	0% (0/6)	0% (0/6)	16.7% (1/6)	0% (0/6)	0% (0/6)	14.3% (1/7)	0% (0/6)	2.9% (2/69)		
	Angle	0% (0/5)	0% (0/5)	0% (0/5)	0% (0/6)	0% (0/6)	0% (0/6)	0% (0/6)	0% (0/6)	0% (0/6)	0% (0/6)	0% (0/7)	0% (0/6)	0% (0/70)	1.0% (2/201)	
	Shaft	0% (0/5)	0% (0/5)	0% (0/5)	0% (0/6)	0% (0/6)	0% (0/6)	0% (0/5)	0% (0/4)	0% (0/5)	0% (0/5)	0% (0/6)	0% (0/4)	0% (0/62)		

Table F.7 – 3-J-23 (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib number. Frequencies are presented in brackets below.

Side	Section	Prevalence by rib number												Total prevalence		
		1	2	3	4	5	6	7	8	9	10	11	12	Section	Side	Ribcage
Right	Neck	3.2% (6/62)	11.1% (7/63)	15.6% (10/64)	14.5% (9/62)	16.1% (10/62)	12.9% (8/62)	16.1% (10/62)	12.9% (8/62)	11.3% (7/62)	11.1% (7/63)	6.3% (4/64)	3.4% (2/58)	11.3% (84/746)	8.4% (186/2227)	8.5% (381/4502)
	Angle	3.1% (2/64)	9.4% (6/64)	12.5% (8/64)	12.9% (8/62)	12.9% (8/62)	9.7% (6/62)	6.5% (4/62)	9.7% (6/62)	8.1% (5/62)	6.3% (4/64)	4.6% (3/65)	1.8% (1/56)	8.1% (61/749)		
	Shaft	4.7% (3/64)	8.2% (5/61)	11.5% (7/61)	8.2% (5/61)	6.5% (4/62)	8.3% (5/60)	4.8% (3/62)	6.7% (4/60)	3.3% (2/60)	1.6% (1/62)	1.6% (1/63)	1.8% (1/56)	5.6% (41/732)		
Left	Neck	0% (0/65)	9.2% (6/65)	15.9% (10/63)	19.4% (12/62)	17.5% (11/63)	14.3% (9/63)	14.5% (9/62)	11.1% (7/63)	9.5% (6/63)	6.1% (4/66)	3.1% (2/65)	1.7% (1/59)	10.1% (77/759)	8.6% (195/2275)	
	Angle	0% (0/65)	4.6% (3/65)	10.8% (7/65)	12.7% (8/63)	15.9% (10/63)	12.7% (8/63)	14.3% (9/63)	14.3% (9/63)	9.5% (6/63)	9.1% (6/66)	4.5% (3/66)	1.7% (1/59)	9.2% (70/764)		
	Shaft	0% (0/65)	4.8% (3/62)	9.5% (6/63)	11.3% (7/62)	6.3% (4/63)	7.9% (5/63)	6.6% (4/61)	6.5% (4/62)	6.3% (4/63)	7.8% (5/64)	7.6% (5/66)	1.7% (1/58)	6.4% (48/752)		

Table F.8 – 3-J-18 (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib number. Frequencies are presented in brackets below.

Side	Section	Prevalence by rib number												Total prevalence		
		1	2	3	4	5	6	7	8	9	10	11	12	Section	Side	Ribcage
Right	Neck	0% (0/110)	5.5% (6/110)	4.6% (5/109)	6.7% (7/105)	6.0% (6/100)	8.1% (8/99)	8.1% (8/99)	6.9% (7/101)	6.9% (7/102)	2.8% (3/107)	2.8% (3/108)	2.0% (2/101)	5.0% (62/1251)	2.9% (110/3748)	3.1% (227/7404)
	Angle	0% (0/110)	0% (0/110)	0.9% (1/110)	2.9% (3/105)	2.0% (2/100)	2.0% (2/100)	6.0% (6/100)	2.0% (2/101)	2.9% (3/102)	1.8% (2/109)	1.8% (2/109)	1.9% (2/103)	2.0% (25/1259)		
	Shaft	0% (0/107)	0.9% (1/107)	1.0% (1/102)	1.9% (2/104)	2.0% (2/101)	2.0% (2/100)	2.0% (2/99)	2.0% (2/101)	2.0% (2/102)	3.7% (4/108)	2.8% (3/107)	2.0% (2/100)	1.9% (23/1238)		
Left	Neck	0.9% (1/108)	3.8% (4/105)	5.7% (6/105)	7.0% (7/100)	5.1% (5/99)	4.2% (4/96)	4.1% (4/98)	4.0% (4/99)	4.1% (4/98)	2.8% (3/109)	1.9% (2/106)	2.2% (2/92)	3.8% (46/1215)	3.2% (117/3656)	
	Angle	1.9% (2/108)	2.8% (3/109)	4.6% (5/108)	4.0% (4/101)	2.0% (2/99)	4.1% (4/98)	6.1% (6/98)	4.0% (4/99)	6.1% (6/99)	3.7% (4/108)	1.9% (2/107)	2.1% (2/96)	3.6% (44/1230)		
	Shaft	0.9% (1/107)	0.9% (1/106)	3.9% (4/102)	2.0% (2/100)	3.0% (3/99)	3.1% (3/98)	2.0% (2/98)	3.1% (3/98)	3.0% (3/99)	2.8% (3/107)	1.0% (1/103)	1.1% (1/94)	2.2% (27/1211)		

Table F.9 – R12 (comparative) rib IPR true prevalence by side, rib section, and rib number. Frequencies are presented in brackets below.

Side	Section	Prevalence by rib number												Total prevalence		
		1	2	3	4	5	6	7	8	9	10	11	12	Section	Side	Ribcage
Right	Neck	0% (0/5)	0% (0/5)	0% (0/3)	0% (0/3)	0% (0/4)	0% (0/1)	0% (0/1)	0% (0/1)	0% (0/1)	0% (0/3)	0% (0/1)	0% (0/2)	0% (0/30)	0% (0/104)	0% (0/178)
	Angle	0% (0/7)	0% (0/7)	0% (0/7)	0% (0/4)	0% (0/4)	0% (0/3)	0% (0/1)	0% (0/1)	0% (0/1)	0% (0/3)	0% (0/3)	0% (0/2)	0% (0/43)		
	Shaft	0% (0/7)	0% (0/2)	0% (0/6)	0% (0/3)	0% (0/3)	0% (0/3)	0% (0/1)	0% (0/1)	- (0/0)	0% (0/2)	0% (0/2)	0% (0/1)	0% (0/31)		
Left	Neck	0% (0/6)	0% (0/6)	0% (0/5)	0% (0/2)	0% (0/2)	- (0/0)	- (0/0)	- (0/0)	0% (0/1)	0% (0/2)	0% (0/2)	- (0/0)	0% (0/26)	0% (0/74)	
	Angle	0% (0/7)	0% (0/9)	0% (0/4)	0% (0/2)	0% (0/2)	- (0/0)	- (0/0)	- (0/0)	0% (0/1)	0% (0/2)	0% (0/2)	0% (0/1)	0% (0/30)		
	Shaft	0% (0/7)	0% (0/2)	0% (0/1)	0% (0/2)	0% (0/2)	- (0/0)	- (0/0)	- (0/0)	0% (0/1)	0% (0/1)	0% (0/1)	0% (0/1)	0% (0/18)		

Table F.10 – P37 (comparative) rib IPR true prevalence by side, rib section, and rib number. Frequencies are presented in brackets below.

Side	Section	Prevalence by rib number												Total prevalence		
		1	2	3	4	5	6	7	8	9	10	11	12	Section	Side	Ribcage
Right	Neck	5.3% (1/19)	3.8% (1/26)	3.6% (1/28)	3.8% (1/26)	8.3% (2/24)	4.5% (1/22)	5.3% (1/19)	4.5% (1/22)	4.3% (1/23)	4.0% (1/25)	4.2% (1/24)	3.8% (1/26)	4.6% (13/284)	4.2% (33/792)	4.1% (66/1592)
	Angle	0% (0/20)	5.0% (1/20)	4.0% (1/25)	8.3% (2/24)	4.5% (1/22)	4.3% (1/23)	0% (0/2)	4.3% (1/23)	0% (0/25)	3.8% (1/26)	4.2% (1/24)	3.7% (1/27)	3.8% (10/261)		
	Shaft	5.0% (1/20)	5.9% (1/17)	5.6% (1/18)	9.1% (2/22)	4.8% (1/21)	5.3% (1/19)	5.3% (1/19)	4.8% (1/21)	4.3% (1/23)	0% (0/23)	0% (0/20)	0% (0/24)	4.0% (10/247)		
Left	Neck	0% (0/21)	4.5% (1/22)	4.5% (1/22)	4.5% (1/22)	4.8% (1/21)	4.8% (1/21)	5.3% (1/19)	5.0% (1/20)	4.5% (1/22)	4.3% (1/23)	4.0% (1/25)	4.5% (1/22)	4.2% (12/292)	4.1% (33/800)	
	Angle	0% (0/23)	0% (0/24)	4.3% (1/23)	4.5% (1/22)	4.5% (1/22)	9.1% (2/22)	4.8% (1/21)	9.5% (2/21)	4.5% (1/22)	3.8% (1/26)	3.8% (1/26)	4.0% (1/25)	4.3% (12/311)		
	Shaft	0% (0/23)	5.0% (1/20)	4.5% (1/22)	5.0% (1/20)	4.5% (1/22)	5.0% (1/20)	5.0% (1/20)	5.0% (1/20)	4.8% (1/21)	4.0% (1/25)	3.8% (1/26)	0% (0/24)	3.8% (10/285)		

Table F.11 – Gabati (comparative) rib IPR true prevalence by side, rib section, and rib number. Frequencies are presented in brackets below.

Side	Section	Prevalence by rib number												Total prevalence		
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Section**	**Side**	**Ribcage**
Right	**Neck**	0% (0/52)	0% (0/60)	1.9% (1/53)	2.5% (1/40)	0% (0/36)	0% (0/36)	0% (0/36)	5.9% (2/34)	0% (0/35)	0% (0/49)	2.0% (1/49)	0% (0/63)	0.9% (5/543)	1.2% (20/1648)	2.1% (69/3337)
	Angle	1.6% (1/63)	0% (0/71)	1.7% (1/59)	0% (0/40)	2.6% (1/38)	2.6% (1/38)	5.6% (2/36)	2.8% (1/36)	0% (0/36)	0% (0/56)	1.6% (1/61)	1.6% (1/63)	1.5% (9/597)		
	Shaft	1.8% (1/57)	0% (0/46)	0% (0/45)	0% (0/37)	0% (0/36)	0% (0/37)	2.9% (1/34)	6.1% (2/33)	0% (0/36)	0% (0/47)	4.3% (2/46)	0% (0/54)	1.2% (6/508)		
Left	**Neck**	1.7% (1/60)	5.8% (3/52)	5.7% (3/53)	2.6% (1/39)	4.8% (2/42)	5.1% (2/39)	7.9% (3/38)	0% (0/36)	2.6% (1/39)	2.0% (1/49)	1.8% (1/55)	1.8% (1/56)	3.4% (19/558)	2.9% (49/1689)	
	Angle	1.5% (1/66)	1.6% (1/63)	1.6% (1/62)	0% (0/42)	2.3% (1/44)	2.3% (1/43)	2.6% (1/39)	5.1% (2/39)	5.0% (2/40)	3.5% (2/57)	1.7% (1/58)	1.8% (1/56)	2.3% (14/609)		
	Shaft	0% (0/62)	4.3% (2/47)	6.3% (3/48)	8.1% (3/37)	0% (0/41)	2.4% (1/41)	2.9% (1/35)	2.9% (1/34)	5.1% (2/39)	3.8% (2/52)	2.2% (1/45)	0% (0/41)	3.1% (16/522)		

Table F.12 – Soba East (comparative) rib IPR true prevalence by side, rib section, and rib number. Frequencies are presented in brackets below.

Side	Section	Prevalence by rib number												Total prevalence		
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Section**	**Side**	**Ribcage**
Right	**Neck**	5.3% (1/19)	10.0% (2/20)	11.1% (2/18)	16.7% (3/18)	17.6% (3/17)	16.7% (3/18)	15.4% (2/13)	18.2% (2/11)	15.4% (2/13)	5.3% (1/19)	13.6% (3/22)	11.1% (2/18)	12.6% (26/206)	9.4% (53/566)	8.9% (104/1169)
	Angle	5.0% (1/20)	0% (0/21)	4.8% (1/21)	5.9% (1/17)	16.7% (3/18)	23.5% (4/17)	15.4% (2/13)	18.2% (2/11)	8.3% (1/12)	4.5% (1/22)	9.5% (2/21)	0% (0/16)	8.6% (18/209)		
	Shaft	5.3% (1/19)	0% (0/15)	0% (0/13)	7.7% (1/13)	18.8% (3/16)	15.4% (2/13)	12.5% (1/8)	0% (0/7)	0% (0/10)	0% (0/15)	8.3% (1/12)	0% (0/10)	6.0% (9/151)		
Left	**Neck**	0% (0/20)	8.3% (2/24)	9.5% (2/21)	17.6% (3/17)	17.6% (3/17)	18.8% (3/16)	15.4% (2/13)	20.0% (3/15)	7.7% (1/13)	10.5% (2/19)	5.6% (1/18)	0% (0/22)	10.2% (22/215)	8.5% (51/603)	
	Angle	0% (0/22)	4.3% (1/23)	0% (0/18)	5.9% (1/17)	6.3% (1/16)	18.8% (3/16)	14.3% (2/14)	7.1% (1/14)	0% (0/16)	0% (0/22)	9.5% (2/21)	0% (0/19)	5.0% (11/218)		
	Shaft	0% (0/18)	7.7% (1/13)	7.7% (1/13)	9.1% (1/11)	18.2% (2/11)	14.3% (2/14)	16.7% (2/12)	9.1% (1/11)	6.7% (1/15)	11.1% (2/18)	16.7% (3/18)	12.5% (2/16)	10.6% (18/170)		

F.2 Rib IPR by time period

Table F.13 – Kerma Classique (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib number. Frequencies are presented in brackets below.

Side	Section	Prevalence by rib number												Total prevalence		
		1	2	3	4	5	6	7	8	9	10	11	12	Section	Side	Ribcage
Right	Neck	0% (0/17)	0% (0/20)	0% (0/17)	0% (0/9)	10.0% (1/10)	0% (0/10)	0% (0/10)	12.5% (1/8)	9.1% (1/11)	16.7% (3/18)	0% (0/22)	0% (0/24)	3.4% (6/176)		
	Angle	5.0% (1/20)	5.6% (1/18)	5.9% (1/17)	9.1% (1/11)	0% (0/10)	11.1% (1/9)	0% (0/10)	12.5% (1/8)	10.0% (1/10)	11.8% (2/17)	11.1% (2/18)	4.8% (1/21)	7.1% (12/169)	6.7% (30/448)	
	Shaft	0% (0/14)	0% (0/9)	12.5% (1/8)	22.2% (2/9)	16.7% (1/6)	40.0% (2/5)	16.7% (1/6)	0% (0/6)	0% (0/6)	20.0% (2/10)	10.0% (1/10)	14.3% (2/14)	11.7% (12/103)		4.5% (40/889)
Left	Neck	0% (0/15)	0% (0/20)	0% (0/19)	0% (0/12)	0% (0/10)	0% (0/7)	12.5% (1/8)	0% (0/8)	0% (0/8)	8.7% (2/23)	4.2% (1/24)	0% (0/20)	2.3% (4/174)		
	Angle	0% (0/21)	0% (0/19)	0% (0/20)	0% (0/12)	10.0% (1/10)	0% (0/6)	0% (0/8)	0% (0/7)	0% (0/9)	10.5% (2/19)	4.8% (1/21)	4.8% (1/21)	2.9% (5/173)	2.3% (10/441)	
	Shaft	0% (0/16)	0% (0/8)	0% (0/5)	0% (0/7)	0% (0/6)	0% (0/3)	0% (0/4)	20.0% (1/5)	0% (0/6)	0% (0/7)	0% (0/11)	0% (0/16)	1.1% (1/94)		

Table F.14 – Post-/Meroitic (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib number. Frequencies are presented in brackets below.

Side	Section	Prevalence by rib number												Total prevalence		
		1	2	3	4	5	6	7	8	9	10	11	12	Section	Side	Ribcage
Right	Neck	0% (0/36)	7.9% (3/38)	8.3% (3/36)	9.4% (3/32)	6.7% (2/30)	12.1% (4/33)	16.1% (5/31)	13.8% (4/29)	9.7% (3/31)	9.4% (3/32)	10.8% (4/37)	8.3% (3/36)	9.2% (37/401)		
	Angle	0% (0/37)	4.9% (2/41)	0% (0/37)	3.0% (1/33)	2.9% (1/34)	3.1% (1/32)	3.1% (1/32)	3.0% (1/33)	6.5% (2/31)	2.9% (1/35)	5.0% (2/40)	5.9% (2/34)	3.3% (14/419)	5.3% (63/1188)	
	Shaft	0% (0/31)	0% (0/32)	3.6% (1/28)	3.3% (1/30)	3.2% (1/31)	3.6% (1/28)	3.1% (1/32)	3.3% (1/30)	6.7% (2/30)	3.2% (1/31)	5.7% (2/35)	3.3% (1/30)	3.3% (12/368)		4.6% (109/2371)
Left	Neck	6.7% (2/30)	2.6% (1/38)	3.4% (1/29)	3.1% (1/32)	6.5% (2/31)	3.0% (1/33)	8.8% (3/34)	12.1% (4/33)	12.1% (4/33)	12.1% (4/33)	8.6% (3/35)	3.2% (1/31)	6.9% (27/392)		
	Angle	2.7% (1/37)	2.6% (1/39)	0% (0/39)	2.9% (1/34)	3.1% (1/32)	5.9% (2/34)	5.9% (2/34)	3.0% (1/33)	3.0% (1/33)	2.8% (1/36)	0% (0/39)	0% (0/33)	2.6% (11/423)	3.9% (46/1183)	
	Shaft	2.9% (1/34)	0% (0/29)	6.7% (2/30)	3.0% (1/33)	0% (0/27)	3.1% (1/32)	3.4% (1/29)	0% (0/30)	0% (0/30)	2.9% (1/34)	3.2% (1/31)	0% (0/29)	2.2% (8/368)		

Table F.15 – Medieval (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib number. Frequencies are presented in brackets below.

Side	Section	Prevalence by rib number												Total prevalence		
		1	2	3	4	5	6	7	8	9	10	11	12	Section	Side	Ribcage
Right	Neck	1.2% (2/173)	7.5% (13/174)	8.6% (15/174)	9.5% (16/168)	9.8% (16/163)	9.9% (16/162)	11.1% (18/162)	9.1% (15/164)	8.5% (14/165)	5.8% (10/171)	4.0% (7/173)	2.5% (4/160)	7.3% (146/2009)	4.9% (296/5999)	5.1% (608/11957)
	Angle	1.1% (2/175)	3.4% (6/175)	5.1% (9/175)	6.5% (11/168)	6.1% (10/163)	4.9% (8/163)	6.1% (10/163)	4.9% (8/164)	4.8% (8/165)	3.4% (6/174)	2.9% (5/175)	1.9% (3/160)	4.3% (86/2020)		
	Shaft	1.8% (3/171)	3.6% (6/168)	4.9% (8/163)	4.2% (7/165)	3.7% (6/163)	4.4% (7/160)	3.1% (5/161)	3.7% (6/161)	2.5% (4/162)	2.9% (5/170)	2.4% (4/170)	1.9% (3/156)	3.2% (64/1970)		
Left	Neck	0.6% (1/174)	5.8% (10/172)	9.5% (16/169)	11.7% (19/163)	9.8% (16/163)	8.1% (13/160)	8.1% (13/161)	6.7% (11/163)	6.2% (10/162)	4.0% (7/176)	2.3% (4/172)	2.0% (3/152)	6.2% (123/1987)	5.2% (312/5958)	
	Angle	1.1% (2/174)	3.4% (6/176)	6.9% (12/174)	7.3% (12/165)	7.4% (12/163)	7.4% (12/162)	9.3% (15/162)	8.0% (13/163)	7.4% (12/163)	5.7% (10/175)	2.9% (5/174)	1.9% (3/156)	5.7% (114/2007)		
	Shaft	0.6% (1/172)	2.4% (4/169)	6.1% (10/165)	5.6% (9/162)	4.3% (7/162)	5.0% (8/161)	3.8% (6/159)	4.4% (7/160)	4.3% (7/162)	4.7% (8/171)	3.6% (6/169)	1.3% (2/152)	3.8% (75/1964)		

Table F.16 – Post-/Meroitic (comparative) rib IPR true prevalence by side, rib section, and rib number. Frequencies are presented in brackets below.

Side	Section	Prevalence by rib number												Total prevalence		
		1	2	3	4	5	6	7	8	9	10	11	12	Section	Side	Ribcage
Right	Neck	0% (0/42)	0% (0/49)	2.4% (1/42)	3.3% (1/30)	0% (0/26)	0% (0/26)	0% (0/27)	8.3% (2/24)	0% (0/26)	0% (0/37)	0% (0/39)	0% (0/51)	1.0% (4/419)	1.2% (15/1282)	2.0% (51/2614)
	Angle	1.9% (1/52)	0% (0/60)	2.1% (1/48)	0% (0/30)	3.6% (1/28)	3.6% (1/28)	3.7% (1/27)	3.8% (1/26)	0% (0/26)	0% (0/44)	2.0% (1/49)	1.9% (1/52)	1.7% (8/470)		
	Shaft	2.1% (1/48)	0% (0/37)	0% (0/35)	0% (0/28)	0% (0/27)	0% (0/28)	0% (0/26)	4.2% (1/24)	0% (0/26)	0% (0/35)	2.7% (1/37)	0% (0/42)	0.8% (3/393)		
Left	Neck	2.0% (1/51)	4.9% (2/41)	4.8% (2/42)	3.4% (1/29)	6.3% (2/32)	6.7% (2/30)	7.1% (2/28)	0% (0/28)	0% (0/29)	0% (0/39)	0% (0/44)	0% (0/45)	2.7% (12/438)	2.7% (36/1332)	
	Angle	1.8% (1/55)	0% (0/52)	1.9% (1/52)	0% (0/32)	2.9% (1/34)	3.0% (1/33)	3.4% (1/29)	6.9% (2/29)	6.7% (2/30)	2.2% (1/45)	0% (0/47)	2.2% (1/46)	2.3% (11/484)		
	Shaft	0% (0/51)	5.4% (2/37)	5.3% (2/38)	6.9% (2/29)	0% (0/32)	0% (0/32)	3.8% (1/26)	4.2% (1/24)	6.7% (2/30)	4.9% (2/41)	2.8% (1/36)	0% (0/34)	3.2% (13/410)		

Table F.17 – Medieval (comparative) rib IPR true prevalence by side, rib section, and rib number. Frequencies are presented in brackets below.

Side	Section	Prevalence by rib number												Total prevalence		
		1	2	3	4	5	6	7	8	9	10	11	12	Section	Side	Ribcage
Right	Neck	3.4% (1/29)	6.5% (2/31)	6.9% (2/29)	10.7% (3/28)	11.1% (3/27)	10.7% (3/28)	9.1% (2/22)	9.5% (2/21)	9.1% (2/22)	3.2% (1/31)	12.5% (4/32)	6.7% (2/30)	8.2% (27/330)		
Right	Angle	3.2% (1/31)	0% (0/32)	3.1% (1/32)	3.7% (1/27)	10.7% (3/28)	14.8% (4/27)	13.6% (3/22)	9.5% (2/21)	4.5% (1/22)	2.9% (1/34)	6.1% (2/33)	0% (0/27)	5.7% (19/336)	6.2% (58/932)	
Right	Shaft	3.6% (1/28)	0% (0/24)	0% (0/23)	4.5% (1/22)	12.0% (3/25)	9.1% (2/22)	12.5% (2/16)	6.3% (1/16)	0% (0/20)	0% (0/27)	9.5% (2/21)	0% (0/22)	4.5% (12/266)		6.4% (121/1892)
Left	Neck	0% (0/29)	8.6% (3/35)	9.4% (3/32)	11.1% (2/27)	11.1% (3/27)	12.0% (3/25)	13.0% (3/23)	13.0% (3/23)	8.7% (2/23)	10.3% (3/29)	6.9% (2/29)	3.0% (1/33)	8.4% (28/335)		
Left	Angle	0% (0/33)	5.9% (2/34)	0% (0/28)	3.7% (1/27)	3.8% (1/26)	11.5% (3/26)	8.3% (2/24)	4.2% (1/24)	0% (0/26)	2.9% (1/34)	9.4% (3/32)	0% (0/29)	4.1% (14/343)	6.6% (63/960)	
Left	Shaft	0% (0/29)	4.3% (1/23)	8.7% (2/23)	10.5% (2/19)	10.0% (2/20)	13.0% (3/23)	9.5% (2/21)	4.8% (1/21)	4.2% (1/24)	6.9% (2/29)	11.1% (3/27)	8.7% (2/23)	7.4% (21/282)		

Appendix G: Prevalence data for the Meroitic period

G.1 Maxillary sinusitis

Table G.1 – Meroitic (Fourth Cataract) maxillary sinusitis prevalence rates, according to sex, age, and within the total group. Prevalence rates are presented separately for individuals with evidence for sinusitis who have two sinuses preserved (2SP) or have one or both sinuses preserved (1+SP). Frequencies are presented in brackets below.

Category		2SP	1+SP
Sex	Male	57.1% (4/7)	55.6% (5/9)
	Female	100% (1/1)	66.7% (2/3)
Age	Young Adult	50.0% (2/4)	57.1% (4/7)
	Middle Adult	60.0% (3/5)	50.0% (3/6)
Total		55.6% (5/9)	53.8% (7/13)

Table G.2 – Meroitic (Fourth Cataract) maxillary sinusitis true prevalence rates (percentage of sinuses affected), according to sex, age, and within the total group. Frequencies are presented in brackets below.

Category		Sinus		Total
		Right	Left	
Sex	Male	37.5% (3/8)	62.5% (5/8)	50.0% (8/16)
	Female	50.0% (1/2)	100% (2/2)	75.0% (3/4)
Age	Young adult	40.0% (2/5)	66.7% (4/6)	54.5% (6/11)
	Middle adult	33.3% (2/6)	60.0% (3/5)	45.5% (5/11)
Total		36.4% (4/11)	63.6% (7/11)	50.0% (11/22)

Table G.3 – Meroitic (comparative) maxillary sinusitis prevalence rates, according to sex, age, and within the total group. Prevalence rates are presented separately for individuals with evidence for sinusitis who have two sinuses preserved (2SP) or have one or both sinuses preserved (1+SP). Frequencies are presented in brackets below.

Category		2SP	1+SP
Sex	Male	41.7% (10/24)	40.7% (11/27)
	Female	72.2% (13/18)	69.6% (16/23)
Age	Young Adult	47.6% (10/21)	45.8% (11/24)
	Middle Adult	77.3% (17/22)	75.0% (18/24)
Total		58.3% (35/60)	56.3% (40/71)

Table G.4 – Meroitic (comparative) maxillary sinusitis true prevalence rates (percentage of sinuses affected), according to sex, age, and within the total group. Frequencies are presented in brackets below.

Category		Sinus		Total
		Right	Left	
Sex	Male	24.0% (6/25)	34.6% (9/26)	29.4% (15/51)
	Female	43.5% (10/23)	61.1% (11/18)	51.2% (21/41)
Age	Young adult	34.8% (8/23)	31.8% (7/22)	33.3% (15/45)
	Middle adult	41.7% (10/24)	68.2% (15/22)	54.3% (25/46)
Total		39.1% (27/69)	50.0% (31/62)	44.3% (58/131)

G.2 Rib IPR

Table G.5 – Meroitic (Fourth Cataract) rib IPR crude prevalence, according to sex and age categories and within the total group. Frequencies are presented in brackets below.

Category		Crude prevalence
Sex	Male	55.6% (5/9)
	Female	50.0% (2/4)
Age	Young Adult	50.0% (4/8)
	Middle Adult	50.0% (3/6)
Total		50.0% (7/14)

Table G.6 – Meroitic (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib cage region. Frequencies are presented in brackets below.

Side	Section	Prevalence by ribcage region					Total prevalence		
		Upper	Upper-Middle	Middle	Lower-Middle	Lower	Section	Side	Ribcage
Right	Neck	5.3% (2/38)	7.5% (3/40)	6.3% (5/79)	5.3% (2/38)	8.3% (3/36)	6.5% (10/153)	2.4% (11/458)	4.5% (41/917)
	Angle	0% (0/39)	0% (0/40)	0% (0/81)	0% (0/40)	0% (0/38)	0% (0/158)		
	Shaft	0% (0/36)	0% (0/38)	0% (0/76)	0% (0/38)	2.9% (1/35)	0.7% (1/147)		
Left	Neck	7.9% (3/38)	5.3% (2/38)	11.4% (9/79)	17.1% (7/41)	10.5% (4/38)	10.3% (16/155)	6.5% (30/459)	
	Angle	4.8% (2/42)	4.9% (2/41)	4.9% (4/81)	5.0% (2/40)	0% (0/39)	3.7% (6/162)		
	Shaft	8.6% (3/35)	5.6% (2/36)	4.2% (3/72)	2.8% (1/36)	5.7% (2/35)	5.6% (8/142)		

Table G.7 – Meroitic (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib number. Frequencies are presented in brackets below.

Side	Section	Prevalence by rib number												Total prevalence		
		1	2	3	4	5	6	7	8	9	10	11	12	Section	Side	Ribcage
Right	Neck	0% (0/13)	8.3% (1/12)	7.7% (1/13)	7.7% (1/13)	7.1% (1/14)	7.7% (1/13)	7.7% (1/13)	8.3% (1/12)	0% (0/12)	8.3% (1/12)	8.3% (1/12)	8.3% (1/12)	6.6% (10/151)	2.4% (11/455)	4.5% (41/913)
	Angle	0% (0/12)	0% (0/13)	0% (0/14)	0% (0/13)	0% (0/14)	0% (0/13)	0% (0/13)	0% (0/14)	0% (0/13)	0% (0/13)	0% (0/13)	0% (0/12)	0% (0/157)		
	Shaft	0% (0/11)	0% (0/13)	0% (0/12)	0% (0/14)	0% (0/13)	0% (0/11)	0% (0/13)	0% (0/13)	0% (0/12)	0% (0/11)	7.7% (1/13)	0% (0/11)	0.7% (1/147)		
Left	Neck	14.3% (2/14)	0% (0/14)	10.0% (1/10)	0% (0/13)	8.3% (1/12)	7.7% (1/13)	14.3% (2/14)	15.4% (2/13)	21.4% (3/14)	23.1% (3/13)	7.7% (1/13)	0% (0/11)	10.4% (16/154)	6.6% (30/458)	
	Angle	7.1% (1/14)	7.1% (1/14)	0% (0/14)	7.1% (1/14)	7.7% (1/13)	0% (0/14)	7.1% (1/14)	0% (0/13)	7.7% (1/13)	0% (0/14)	0% (0/14)	0% (0/11)	3.7% (6/162)		
	Shaft	7.7% (1/13)	0% (0/11)	18.2% (2/11)	7.7% (1/13)	0% (0/9)	7.1% (1/14)	9.1% (1/11)	0% (0/12)	0% (0/13)	7.1% (1/14)	9.1% (1/11)	0% (0/10)	5.6% (8/142)		

Table G.8 – Meroitic (comparative) rib IPR crude prevalence, according to sex and age categories and within the total group. Frequencies are presented in brackets below.

Category		Crude prevalence
Sex	Male	22.7% (5/22)
	Female	35.3% (6/17)
Age	Young Adult	25.0% (4/16)
	Middle Adult	31.8% (7/22)
Total		28.9% (13/45)

Table G.9 – Meroitic (comparative) rib IPR true prevalence by side, rib section, and rib cage region. Frequencies are presented in brackets below.

Side	Section	Prevalence by ribcage region					Total prevalence		
		Upper	Upper-Middle	Middle	Lower-Middle	Lower	Section	Side	Ribcage
Right	Neck	2.5% (2/81)	2.9% (2/69)	2.8% (6/211)	1.4% (1/73)	0% (0/98)	2.1% (8/390)		3.0% (67/2247)
	Angle	2.0% (2/100)	1.1% (1/88)	2.7% (7/264)	1.2% (1/85)	2.4% (3/123)	2.5% (12/487)	2.1% (24/1148)	
	Shaft	0% (0/58)	0% (0/46)	2.1% (3/142)	0% (0/49)	1.4% (1/71)	1.5% (4/271)		
Left	Neck	4.2% (3/72)	4.2% (3/72)	7.1% (13/184)	3.0% (2/66)	1.1% (1/94)	4.9% (17/350)		
	Angle	2.0% (2/98)	4.0% (4/99)	5.8% (15/259)	3.7% (3/82)	1.9% (2/108)	4.1% (19/465)	3.9% (43/1099)	
	Shaft	1.5% (1/65)	3.5% (2/57)	3.9% (6/155)	3.3% (2/60)	0% (0/64)	2.5% (7/284)		

Table G.10 – Meroitic (comparative) rib IPR true prevalence by side, rib section, and rib number. Frequencies are presented in brackets below.

Side	Section	Prevalence by rib number												Total prevalence		
		1	2	3	4	5	6	7	8	9	10	11	12	Section	Side	Ribcage
Right	Neck	0% (0/23)	0% (0/29)	4.5% (1/22)	9.1% (1/11)	0% (0/6)	0% (0/6)	0% (0/7)	25.0% (1/4)	0% (0/6)	0% (0/18)	0% (0/19)	0% (0/32)	1.6% (3/183)		1.8% (21/1190)
	Angle	3.1% (1/32)	0% (0/40)	3.6% (1/28)	0% (0/10)	0% (0/8)	0% (0/8)	0% (0/7)	0% (0/6)	0% (0/6)	0% (0/24)	3.4% (1/29)	3.0% (1/33)	1.7% (4/231)	1.6% (9/568)	
	Shaft	3.6% (1/28)	0% (0/17)	0% (0/15)	0% (0/8)	0% (0/7)	0% (0/8)	0% (0/6)	0% (0/4)	0% (0/6)	0% (0/15)	5.9% (1/17)	0% (0/23)	1.3% (2/154)		
Left	Neck	3.2% (1/31)	4.5% (1/22)	4.5% (1/22)	0% (0/9)	8.3% (1/12)	10.0% (1/10)	12.5% (1/8)	0% (0/8)	0% (0/9)	0% (0/20)	0% (0/24)	0% (0/26)	3.0% (6/201)		
	Angle	2.9% (1/35)	0% (0/32)	3.1% (1/32)	0% (0/12)	0% (0/14)	0% (0/13)	0% (0/9)	0% (0/9)	10.0% (1/10)	4.0% (1/25)	0% (0/27)	3.7% (1/27)	2.0% (5/245)	1.9% (12/622)	
	Shaft	0% (0/31)	0% (0/17)	5.3% (1/19)	0% (0/9)	0% (0/12)	0% (0/12)	0% (0/6)	0% (0/6)	0% (0/10)	0% (0/22)	0% (0/16)	0% (0/16)	0.6% (1/176)		

Appendix H: Prevalence data for the Post-Meroitic period

H.1 Maxillary sinusitis

Table H.1 – Post-Meroitic (Fourth Cataract) maxillary sinusitis prevalence rates, according to sex, age, and within the total group. Prevalence rates are presented separately for individuals with evidence for sinusitis who have two sinuses preserved (2SP) or have one or both sinuses preserved (1+SP). Frequencies are presented in brackets below.

Category		2SP	1+SP
Sex	Male	42.9% (6/14)	40.0% (6/15)
	Female	71.4% (5/7)	71.4% (5/7)
Age	Young Adult	46.2% (6/13)	42.9% (6/14)
	Middle Adult	60.0% (6/10)	60.0% (6/10)
Total		54.2% (13/24)	53.8% (14/26)

Table H.2 – Post-Meroitic (Fourth Cataract) maxillary sinusitis true prevalence rates (percentage of sinuses affected), according to sex, age, and within the total group. Frequencies are presented in brackets below.

Category		Sinus		Total
		Right	Left	
Sex	Male	42.9% (6/14)	20.0% (3/15)	31.0% (9/29)
	Female	42.9% (3/7)	71.4% (5/7)	57.1% (8/14)
Age	Young adult	38.5% (5/13)	28.6% (4/14)	33.3% (9/27)
	Middle adult	60.0% (6/10)	50.0% (5/10)	55.0% (11/20)
Total		48.0% (12/25)	40.0% (10/25)	44.0% (22/50)

Table H.3 – Post-Meroitic (comparative) maxillary sinusitis prevalence rates, according to sex, age, and within the total group. Prevalence rates are presented separately for individuals with evidence for sinusitis who have two sinuses preserved (2SP) or have one or both sinuses preserved (1+SP). Frequencies are presented in brackets below.

Category		2SP	1+SP
Sex	Male	40.0% (2/5)	37.5% (3/8)
	Female	80.0% (4/5)	60.0% (6/10)
Age	Young Adult	66.7% (4/6)	54.5% (6/11)
	Middle Adult	50.0% (2/4)	42.9% (3/7)
Total		60.0% (6/10)	50.0% (9/18)

Table H.4 – Post-Meroitic (comparative) maxillary sinusitis true prevalence rates (percentage of sinuses affected), according to sex, age, and within the total group. Frequencies are presented in brackets below.

Category		Sinus		Total
		Right	Left	
Sex	Male	28.6% (2/7)	33.3% (2/6)	30.8% (4/13)
	Female	50.0% (4/8)	42.9% (3/7)	46.7% (7/15)
Age	Young adult	40.0% (4/10)	42.9% (3/7)	41.2% (7/17)
	Middle adult	40.0% (2/5)	33.3% (2/6)	36.4% (4/11)
Total		40.0% (6/15)	38.5% (5/13)	39.3% (11/28)

H.2 Rib IPR

Table H.5 – Post-Meroitic (Fourth Cataract) rib IPR crude prevalence, according to sex and age categories and within the total group. Frequencies are presented in brackets below.

Category		Crude prevalence
Sex	Male	37.5% (6/16)
	Female	62.5% (5/8)
Age	Young Adult	43.8% (7/16)
	Middle Adult	50.0% (6/12)
Total		46.7% (14/30)

Table H.6 – Post-Meroitic (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib cage region. Frequencies are presented in brackets below.

Side	Section	Prevalence by ribcage region					Total prevalence		
		Upper	Upper-Middle	Middle	Lower-Middle	Lower	Section	Side	Ribcage
Right	Neck	5.6% (4/72)	11.8% (8/68)	13.7% (19/139)	16.2% (11/68)	9.7% (7/72)	10.6% (30/283)	7.2% (60/828)	4.8% (78/1638)
	Angle	2.6% (2/76)	7.8% (6/77)	7.6% (12/157)	8.1% (6/74)	6.7% (5/75)	6.2% (19/308)		
	Shaft	1.8% (1/55)	5.4% (3/56)	5.9% (7/119)	6.5% (4/62)	4.8% (3/63)	4.6% (11/237)		
Left	Neck	1.7% (1/59)	4.4% (3/68)	5.0% (7/140)	5.5% (4/73)	6.3% (4/63)	4.6% (12/262)	2.2% (18/810)	
	Angle	0% (0/73)	2.8% (2/72)	2.6% (4/155)	2.7% (2/74)	1.4% (1/71)	1.7% (5/299)		
	Shaft	0% (0/58)	0% (0/64)	0.8% (1/129)	0% (0/60)	0% (0/62)	0.4% (1/249)		

Table H.7 – Post-Meroitic (Fourth Cataract) rib IPR true prevalence by side, rib section, and rib number. Frequencies are presented in brackets below.

Side	Section	Prevalence by rib number												Total prevalence		
		1	2	3	4	5	6	7	8	9	10	11	12	Section	Side	Ribcage
Right	Neck	0% (0/23)	7.7% (2/26)	8.7% (2/23)	10.5% (2/19)	6.3% (1/16)	15.0% (3/20)	22.2% (4/18)	17.6% (3/17)	15.8% (3/19)	10.0% (2/20)	12.0% (3/25)	8.3% (2/24)	10.8% (27/250)	7.1% (52/733)	4.7% (68/1458)
	Angle	0% (0/25)	7.1% (2/28)	0% (0/23)	5.0% (1/20)	5.0% (1/20)	5.3% (1/19)	5.3% (1/19)	5.3% (1/19)	11.1% (2/18)	4.5% (1/22)	7.4% (2/27)	9.1% (2/22)	5.3% (14/262)		
	Shaft	0% (0/20)	0% (0/19)	6.3% (1/16)	6.3% (1/16)	5.6% (1/18)	5.9% (1/17)	5.3% (1/19)	5.9% (1/17)	11.1% (2/18)	5.0% (1/20)	4.5% (1/22)	5.3% (1/19)	5.0% (11/221)		
Left	Neck	0% (0/16)	4.2% (1/24)	0% (0/19)	5.3% (1/19)	5.3% (1/19)	0% (0/20)	5.0% (1/20)	10.0% (2/20)	5.3% (1/19)	5.0% (1/20)	9.1% (2/22)	5.0% (1/20)	4.6% (11/238)	2.2% (16/725)	
	Angle	0% (0/23)	0% (0/25)	0% (0/25)	0% (0/20)	0% (0/19)	10.0% (2/20)	5.0% (1/20)	5.0% (1/20)	0% (0/20)	4.5% (1/22)	0% (0/25)	0% (0/22)	1.9% (5/261)		
	Shaft	0% (0/21)	0% (0/18)	0% (0/19)	0% (0/20)	0% (0/18)	0% (0/18)	0% (0/18)	0% (0/18)	0% (0/17)	0% (0/20)	0% (0/20)	0% (0/19)	0% (0/226)		

Table H.8 – Post-Meroitic (comparative) rib IPR crude prevalence, according to sex and age categories and within the total group. Frequencies are presented in brackets below.

Category		Crude prevalence
Sex	Male	22.2% (2/9)
	Female	18.2% (2/11)
Age	Young Adult	23.1% (3/13)
	Middle Adult	14.3% (1/7)
Total		20.0% (4/20)

Table H.9 – Post-Meroitic (comparative) rib IPR true prevalence by side, rib section, and rib cage region. Frequencies are presented in brackets below.

Side	Section	Prevalence by ribcage region					Total prevalence		
		Upper	Upper-Middle	Middle	Lower-Middle	Lower	Section	Side	Ribcage
Right	Neck	0% (0/60)	0% (0/60)	0.8% (1/120)	1.7% (1/60)	0% (0/58)	0.4% (1/238)	0.8% (6/715)	2.1% (30/1425)
	Angle	0% (0/60)	3.3% (2/60)	3.3% (4/120)	3.3% (2/60)	0% (0/59)	1.7% (4/239)		
	Shaft	0% (0/59)	0% (0/60)	0.8% (1/120)	1.7% (1/60)	0% (0/59)	0.4% (1/238)		
Left	Neck	3.4% (2/59)	5.0% (3/60)	3.3% (4/120)	1.7% (1/60)	0% (0/58)	3.4% (6/237)	3.4% (24/710)	
	Angle	0% (0/60)	3.3% (2/60)	5.0% (6/120)	6.7% (4/60)	0% (0/59)	2.5% (6/239)		
	Shaft	5.1% (3/59)	3.3% (2/60)	5.1% (6/118)	6.9% (4/58)	5.3% (3/57)	5.1% (12/234)		

Table H.10 – Post-Meroitic (comparative) rib IPR true prevalence by side, rib section, and rib number. Frequencies are presented in brackets below.

Side	Section	Prevalence by rib number												Total prevalence		
		1	2	3	4	5	6	7	8	9	10	11	12	Section	Side	Ribcage
Right	Neck	0% (0/19)	0% (0/20)	0% (0/20)	0% (0/19)	0% (0/20)	0% (0/20)	0% (0/20)	5.0% (1/20)	0% (0/20)	0% (0/19)	0% (0/20)	0% (0/19)	0.4% (1/236)	0.8% (6/714)	2.1% (30/1424)
	Angle	0% (0/20)	0% (0/20)	0% (0/20)	0% (0/20)	5.0% (1/20)	5.0% (1/20)	5.0% (1/20)	5.0% (1/20)	0% (0/20)	0% (0/20)	0% (0/20)	0% (0/19)	1.7% (4/239)		
	Shaft	0% (0/20)	0% (0/20)	0% (0/20)	0% (0/20)	0% (0/20)	0% (0/20)	0% (0/20)	5.0% (1/20)	0% (0/20)	0% (0/20)	0% (0/20)	0% (0/19)	0.4% (1/239)		
Left	Neck	0% (0/20)	5.3% (1/19)	5.0% (1/20)	5.0% (1/20)	5.0% (1/20)	5.0% (1/20)	5.0% (1/20)	0% (0/20)	0% (0/20)	0% (0/19)	0% (0/20)	0% (0/19)	2.5% (6/237)	3.1% (24/710)	
	Angle	0% (0/20)	0% (0/20)	0% (0/20)	0% (0/20)	5.0% (1/20)	5.0% (1/20)	5.0% (1/20)	10.0% (2/20)	5.0% (1/20)	0% (0/20)	0% (0/20)	0% (0/19)	1.7% (6/239)		
	Shaft	0% (0/20)	10.0% (2/20)	5.3% (1/19)	10.0% (2/20)	0% (0/20)	0% (0/20)	5.0% (1/20)	5.6% (1/18)	10.0% (2/20)	10.5% (2/19)	5.0% (1/20)	0% (0/18)	5.1% (12/234)		

Appendix I: Other pathological changes possibly related to respiratory disease

Table I.1 – Descriptions of other pathological changes observed in skeletons in the current study that may be related to respiratory disease.

Site	Time period	Sk/Gr No.	Sex	Age	Maxillary sinusitis	Rib IPR	Description of pathological changes
3-Q-33	Meroitic	Sk67, Gr17	Female?	Adult	Present	Absent	**Unsided hand phalanges, proximal (x4), intermediate (x3) & distal (x1):** almost complete resorption of the distal heads of the proximal phalanges and the proximal bases of the intermediate phalanges. The distal base of one distal phalanx also displays resorption. Some localised mixed new bone formation around the areas of resorption. **Left radius:** remodelling lamellar bone formation on the postero-medial aspect of the distal quarter of the shaft.
		Sk71, Gr21	Female	Middle adult	Present	Present	**Thoracic vertebrae 9-12:** destructive lesions on the anterior, superior, and inferior surfaces of the vertebral bodies. Destruction of the surfaces with associated prolific diffuse mixed new bone formation. New bone has an irregular porous 'honeycomb' texture. Extreme destruction of the inferior surfaces of thoracic vertebrae 9 and 11. Vertebral lesions correspond in location to new bone formation on the visceral surfaces of the ribs. **Left ulna:** some porosity/pitting and lamellar bone formation at the medial margin of the articular surface of the trochlear notch (not on the joint surface itself).
4-M-53	Post-Meroitic	Sk52, Gr9	?	Adult	Present	Present	**Lower lumbar vertebra (possibly L4):** a large rounded destructive lesion on the superior end plate of the vertebral body. Some remodelling of the margins. Lamellar bone formation on the right lateral aspect of the body, near the destructive lesion.
3-O-1	Post-Meroitic	Sk60	Male	Young adult	Absent	Absent	**Vertebrae T12, L1 & L2:** a giant destructive lesion between the bodies of L1 and L2, causing complete excavation of the inferior end plate and internal trabeculae of the body of L1 and partial excavation of the superior end plate and trabeculae of L2. The lesion is rounded and smooth-walled, but the floor consists of trabecular bone. The

							cortical walls of the vertebral bodies of L1 and L2 remain intact. Prolific wax-like osteophytes on the anterior bodies of L1, L2, and T12, causing fusion between all three vertebrae. Some spiculated new bone formation on the vertebral bodies. **Vertebra T5:** small, smooth-walled destructive lesion, revealing trabecular bone on the superior end plate. Cyst-like shape (circular and regular in shape, with sharp margins, dense walls and no new bone formation) with rounded margins. **Right clavicle:** destruction on the posterior aspect of the lateral facet, with destruction of the cortical surface and deep excavation of the facet. Slightly rounded remodelled margins and remodelling of the floor of the lesion, with partial trabeculae exposure.
3-J-23	Medieval	Gr22A	Male	Adolescent	Present	Present	**Left & right calcanei, left & right metatarsals, left & right femora, left humerus, left & right tibiae, left & right fibulae, left & right ulnae, left & right radii, left metacarpals:** diffuse and prolific woven bone formation on the shafts of these elements.
		Sk59	Male	Middle adult	Present	Present	**Lumbar vertebrae 1 & 2:** scalloped destructive lesions on the inferior surfaces of the end plates of the vertebral bodies of L1 and L2. Minimal new bone formation around the margins. Interpretation of these lesions is masked by severe intervertebral disk disease on the lumbar vertebrae, making differentiation from other pathological changes difficult.
		Sk75	Female	Young adult	Absent	Present	**Vertebrae T5 – L1:** large destructive lesions on the vertebral bodies. Rounded 'cyst-like' lesions with smooth, remodelled margins. Complete destruction of the bodies of T10 to T12, resulting in collapse and kyphosis of the spine (Pott's disease), fusion between the neural arches, and a compression fracture on L1. Shallow destructive lesions are also present on the transverse processes of T9 to T11. Minimal new bone formation. Vertebral lesions correspond to destructive lesions on the ribs. **Left Humerus:** small region of bone destruction on the medial margin of the olecranon fossa. No new bone formation.
3-J-18	Medieval	Sk2002	Female	Adolescent	Present	Absent	**1st thoracic vertebra:** possible destructive lesion on the right aspect of the vertebral body and on the right transverse process.

					Vertebrae L4 & L5: Destructive lesions on the right aspect of both vertebral bodies. Margins of the lesions are remodelled and rounded, and are accompanied by some lamellar bone formation. Complete destruction of the spinous process of L5 and lamellar bone formation surrounding the margins of this lesion.
Sk2097	Male	Middle adult	Present	Absent	**Nasal cavity:** complete resorption of the nasal conchae, vomer, and the inferior surface of the ethmoid. Medial walls of the maxillary sinuses are also completely resorbed. Nasal aperture and the anterior alveolar bone of the maxilla are beginning to recede (rhinomaxillary syndrome). **Right proximal phalanx of 2nd digit of hand:** thinning and resorption of bone around the distal neck. **Left distal phalanx of the 5th digit of hand:** resorption of the distal head. **Right and left fibulae and tibiae:** thick diffuse lamellar bone formation on the distal surfaces of the shafts.
Sk2106	Female?	?	Absent	Unobservable	**Maxilla & Vomer:** resorption of the anterior base of the nasal spine and vomer. **Distal phalanges of the right and left hands:** slight resorption of the distal heads of the phalanges.
Sk2139	Male?	Middle adult	Present	Present	**Nasal cavity:** resorption of the base of the vomer, the nasal conchae, and the anterior spine of the maxilla. **Right metatarsals 1, 2, & 3 and one proximal foot phalanx:** resorption of the distal heads, leading to 'pencilling'. In Metatarsals 1 and 2 the heads are completely resorbed and the shafts are receding. **Right tibia:** diffuse lamellar bone formation on the lateral surface of the distal third of the shaft.
Sk2224	Female?	Yound adult	Present	Absent	**Maxilla:** some pitting and resorption around the nasal aperture and the anterior nasal spine.

					Left and right phalanges of the foot: resorption of the distal ends of the phalanges on the right foot and resorption of the cortical surfaces of the shafts of the phalanges on the left foot. **Left and right phalanges of the hands:** resorption of the distal heads and of the cortical bone on the shafts. Pitting and cyst-like lesions or cloaca present. **Left 5th metatarsal and right Metatarsals 1, 3, & 5:** diffuse woven bone on the shafts. **Left and right tibiae and fibulae:** diffuse mixed new bone formation across the majority of the surfaces of the shafts. **Left and right scapulae:** posterior surfaces of the scapular spines are extremely pitted and porous, with loss of the cortical bone.
Sk2248	Male	Young adult	Present	Present	**Vertebrae T3 – L3:** extensive destruction of the cortical bone of the vertebral bodies and scalloped lesions within the trabecular bone. Extreme destruction of the rib heads corresponding to the vertebral lesions.
Sk2273	Male	Young adult	Unobservable	Absent	**Vertebra T12:** scalloped destructive lesion, with undercutting of the cortical surface, on the inferior end plate of the vertebral body. No new bone formation. **Vertebra L2:** shallow destructive lesion on the superior end plate of the vertebral body, with irregular margins and scalloped edges. No new bone formation.
Sk4019	Male?	Young adult	Present	Present	**Vertebrae T1-T8:** various destructive lesions on the vertebral bodies and neural arches. Lesions on the vertebral bodies have scalloped margins and floors. In T4, half the neural arch has been destroyed. The corresponding right rib heads have also been destroyed. No new bone formation.
Sk4235	Male	Young adult	Unobservable	Absent	**Nasal cavity:** resorption of the anterior base of the vomer. Possible resorption of the alveolar bone of the maxilla, although taphonomic damage makes it difficult to determine. **Right 5th metatarsal, 2 proximal phalanges of the right foot, 1 proximal phalanx of the left foot, & the left distal phalanx of the 1st digit:** Resorption of the distal heads,

							thinning of the proximal phalanx shafts and flaring of the bases. The head of the distal phalanx is completely resorbed. **Right fibula:** remodelling diffuse woven bone on the lateral surface of the shaft. **Right & left tibiae:** lamellar bone formation on the lateral surfaces of the shafts.
		Sk4284	Male	Middle adult	Absent	Absent	**Vertebrae T1 & T5:** small destructive lesions on the inferior aspects of the anterior surfacees of the vertebral bodies, surrounded by a margin of lamellar bone formation. **Vertebra L1:** Small destructive lesion on the postero-inferior surface of the vertebral body, at the midline, with minimal lamellar bone formation around the margins.
		Sk4348	Male	Middle adult	Present	Absent	**Vertebra L2:** destructive lesion on the inferior end plate of the vertebral body, exposing the trabeculae. Slight undercutting. Many other vertebrae display cyst-like lesions on the neural arches. **Right 2nd metacarpal:** Erosion around the margins of the distal facet and a cyst-like lesion on the dorsal surface of the shaft. **Right distal foot phalanx of the 1st digit:** destruction of the proximal base of the phalanx and a cyst-like lesion on the lateral surface of the shaft. No new bone formation. **Left distal foot phalanx of the 1st digit:** almost complete destruction of the phalanx, leaving only the proximal base present. No new bone formation. **4th Left rib:** Small destructive lesion on the superior margin of the shaft of the rib. Some dense new bone formation around the margin of the lesion.
P37	Kerma Ancien	Sk43-50, GrK3	Male	Adult	Present	Present	**Vertebra L5/S1(?):** almost all of the anterior vertebral body is destroyed, with the body appearing as 'wedge-like' in shape. Prolific lamellar bone formation on the

							lateral aspects of the body. Another possible destructive lesion on the inferior surface of the body. **Sacrum:** prolific, irregular, spiculated lamellar bone formation on the anterior surfaces of the sacral bodies.
Gabati	Post-Meroitic	Sk37-1061	?	Young adult	Present	Unobservable	**1st sacral vertebra:** two shallow circular lytic lesions on the superior end plate of the sacral body. No new bone formation. Lesions appear to have slightly scalloped edges. **Unidentified lumbar vertebra:** possible shallow lytic lesions on the superior surface of the vertebral body. No new bone formation.
		Sk94-156	Male	Young adult	Absent	Unobservable	**Vertebrae L3 & L4:** extreme destruction on the anterior portion of the superior surface of the vertebral bodies, revealing trabecular bone. Some lamellar bone formation around the margins. Extreme vascularity and widening of the foramina on the other lumbar vertebrae.
	Medieval	Sk20-20	Male	Young adult	Present	Present	**Vertebra L4:** Destructive scalloped lesion with minimal new bone formation around the margins on the superior aspect of the anterior surface of the vertebral body. **Vertebra L3:** Porosity and irregular lamellar bone formation on the anterior surface of the vertebral body.
		Sk61-67	Female?	Middle adult	Absent	Present	**Vertebra C4:** Destructive lesions on the inferior end plate of the vertebral body and nodular woven bone formation on the anterior surface of the body. **Vertebra C5:** destructive scalloped lesions on the entire superior surface of the vertebral body. No new bone formation.