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Childhood Health and Diet in Roman London: The Palaeodemographic, Palaeopathological and Isotopic Evidence

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Abstract

Roman London has been extensively excavated, particularly over the last two decades, and substantial cemetery sites have been uncovered within and around the City. This study represents the first to undertake an integrated analysis of the palaeodemographic, palaeopathological, isotopic and funerary evidence from Roman London. This thesis seeks to identify social age transitions and the impact of these on the growing body. The specific aim of the research was to examine the perceptions of childhood and childcare in Roman London, utilising skeletal and funerary indicators of diet, health and social status. A total sample of 967 individuals formed the sample for analysis. The osteological data was obtained via the WORD database and the funerary data from archives and available publications. A further 120 number of individuals were sampled for carbon and nitrogen isotope analysis of diet. The results yielded a number of interesting patterns regarding age, sex and social status, and the impact of these identities on diet and well-being.

Overall, subadults at Roman London were found to have experienced higher rates of health stress than their adult counterparts, with subadults exhibiting higher prevalence rates for four of the six stress indicators examined. Causative stressors identified within the population included poor living conditions and population mobility. Within the subadult age group, differences in the level of health stress were experienced during the life course, with weaning and the introduction of occupationally related activities being pivotal points of increased health stress. An infant feeding pattern specific to Roman Britain and distinctive from Roman Italy was identified and further evidence for a special breastfeeding diet for women implicated. Distinctions in diets between males and females were identified, with females yielding greater variation, potentially linked to social stratification. Shifting dietary isotope signatures and indicators of health stress throughout the growth period were linked to social age transitions. Temporal trends within Roman London were also identified, with health in the early Roman period being worse than the preceding Iron Age period, but declining further during the later period of Roman occupation. In times of economic uncertainty the exploitation of local freshwater fish also occurred, but these supplemented the diet of children alone. No statistically significant difference between diet, health and social status were observed, which suggests that status was not simply a linear, ranked, hierarchy, but cross-cut by other aspects of the social personae such as gender and age. This integrated approach is the first of its kind to be undertaken in order to examine the Roman perceptions of childhood. It makes a number of important contributions regarding the experience of infancy and childhood in Roman Britain and the Roman life course more generally.

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Chapter 1: Introduction

1.1 Roman Childhood

Within preindustrial societies, children would have constituted a third or more of the population (Chamberlain 2006: 178), yet until the last two decades they have been largely invisible within archaeology. Gender and feminist perspectives that emerged within post-processual archaeology in the 1980's were the first to seek out those individuals previously marginalised within archaeological discourse (Hodder 1985; Moore and Scott 1997; Meskell 2001; Diaz-Andreu 2005). However, these initial studies focused primarily on the role of women, with children only considered in relation to how they affected the lives of women (Lillehammer 1989; Scott 1997: 6-7; Baxter 2005a: 17; Halcrow and Tayles 2008: 199). As such, children were still viewed as peripheral and passive beings. It was not until the 1990's, when increasing attention was given to the socially constructed nature of identity, that children came to be viewed as active participants in the past and worthy of study in their own right (Sofaer Derevenski 1994a; 1994b; 1997; Baker 1997; Kamp 2001; Baxter 2005a; 2005b; Gowland 2006; Halcrow and Tayles 2008; 2011).

In parallel with these developments, the variable constructions of childhood in the past had become an increasingly popular focus of historical study following the works of Ariès (1962). It was out of this tradition that Roman studies of childhood and the family emerged, through the work of scholars, such as Rawson (1986a; 1986b; 1991; 2003; 2011), who utilised classical texts and iconography to examine the nature of ancient childhood. Increasing numbers of publications have since emerged on childhood in the Roman Empire, focusing on the roles of children within society through the study of their representation within Roman culture (Huskinson 1996; Dixon 2001; Uzzi 2005; Laes 2011; Mander 2012). In addition, recent work utilising a life course approach has led to the identification of how Romans themselves may have perceived their life stages (Gowland 2002; Harlow and Laurence 2002). An important consideration within these works is the recognition that age is not just the passing of years, but rather is a series of culturally constructed identities strongly linked to other aspects of identity such as gender and status (Gowland 2002; Harlow and Laurence 2002; Baxter 2005a).

While these studies provide a strong foundation for future research, many rely on traditional sources such as literature, epigraphy, law codes and sculpture, which are often heavily weighted towards the elite sections of Mediterranean communities. Though this bias is largely due to the paucity of available evidence elsewhere, it is problematic for those seeking to study childhood in the wider Empire. It is only more recently that studies of Roman childhood have started to move away from Rome and Italy to encompass the wider reaches of the Empire (Scott 1999; Callow and Harlow 2012; Derks 2014; Southwell-Wright 2014). The lack of historical data for provinces such as Roman Britain forces a greater reliance on archaeological data-sets. These have started to yield some useful information concerning the perceptions of infancy and childhood in Roman Britain (e.g. Scott 1999; Gowland 2001; 2002; Redfern 2007), though to date there have been overwhelming dominant discussions of infanticide (Mays 1993; 1995; 2000; Mays and Eyers 2011).

One commonly overlooked and underrepresented source in traditional studies of childhood are the physical remains of the children themselves. The study of human remains has undergone significant developments over the last four decades (Klaus 2014: 294). Traditionally, palaeopathological studies tended to focus on descriptive analyses of pathological conditions and the consideration of interesting individual casestudies, largely driven by the biomedical origins of the discipline (Buzan 2012: 59). However, in the late 1970's and 1980's, American researchers began to criticise the ability of these descriptive accounts to answer meaningful questions about the lives of people in the past (Buikstra 1977; Armelagos *et al.* 1982; Zuckerman *et al.* 2012: 41). From these criticisms emerged the discipline of bioarchaeology, which began to undertake question driven population-based analyses (for further information regarding the establishment of the discipline see Buikstra 2006; Roberts 2006; Buzan 2012; Buikstra and Roberts 2012). A central tenet of bioarchaeology is the recognition that biological skeletal data must be interpreted within its wider archaeological context to be properly understood (Buikstra 1977; Buzan 2012: 59-60). Bioarchaeological investigations have also benefited from adopting an interdisciplinary approach, utilising methods and comparative data from a broad range of other disciplines, such as anthropology, medical science, history and geography (Martin *et al.* 2013: 1; Zuckerman *et al.* 2012:35). More recently, new scientific methods, such as stable isotope analyses and aDNA studies, have also further improved our understanding of life in the past (Ambrose and Krigbaum 2003; Larsen 2006; Katzenberg 2008; Brown and Brown 2010; Gosman 2012). Whilst surveys of published bioarchaeological studies have demonstrated the uptake of large population-based analyses has occurred at a slower pace amongst British researchers than their American counterparts (Mays 1997; 2010; Park *et al.* 2009), the implementation of such bioarchaeological investigations is increasingly being realised (Roberts 2006).

Within bioarchaeology over the last two decades there has also been an increasing awareness of the significance of subadult remains not only to the study of past health, but also in the identification of care and the lived experiences of children directly reflected within them (e.g.

Saunders 2000; Lewis 2007; Halcrow and Tayles 2008). Bones and teeth are particularly susceptible to environmental onslaughts, such as poor nutrition and exposure to pathogens, during the growth period, making the skeletal remains of children a sensitive barometer of overall population health (Lewis 2007:20). Despite this, there have been few studies of child health in Roman Britain. Those that have been undertaken have demonstrated the potential of these kinds of investigations for understanding perceptions of childhood and child care in areas of the Empire lacking more traditionally exploited historical sources (e.g. Redfern 2007; Lewis 2010; 2011; Gowland and Redfern 2010; Redfern *et al.* 2012).

1.2 Research Context: Roman London

Within the province of *Britannia*, Roman London was one of the largest and most important urban centres, being a key hub of communications and head of the provincial administration. London was unique in Roman Britain, in that is did not resemble any other town, with its status over the course of the occupation being the focus of much debate (Merrifield 1965: 32-35; Marsden 1980: 17; Millett 1996; Perring 1991: 16-21; 2011; Wallace 2011). Extensive excavation over the last two decades has uncovered substantial settlement and cemetery sites within and around the City. Yet, little is known about the lives of the town's inhabitants and interpretations of the living environment, population composition and health within Roman London (and the *coloniae* of Roman Britain more generally) are scarce. The historical and monumental evidence that is available tends to be biased towards adults, in particular males, while little is known of the children who lived and died in this urban centre.

Children would have formed a significant component of the Roman London population and this is attested to by the wealth of skeletal remains uncovered. Yet, children have so far remained invisible in archaeological narratives of the town, which tend to focus on aspects such as the legal status of the town, public buildings, ritual, religion, and the potential influence of the military (Marsden 1980; Brigham 1993; Milne 1995; Bird *et al.* 1996; Watson 1998; Bateman *et al.* 2008; Clark *et al.* 2008). Children as active agents within past societies have been largely overlooked and this is particularly true of Roman Britain. While much has been written in classical sources about childhood, the relevance of these historical texts to peripheral provinces are now being increasingly questioned. More recent studies have suggested that Roman family life was subject to considerable regional variability across the Empire (e.g. Woolf 2005). Therefore, the ability of these sources to inform about life in Roman London, along with perceptions of childhood and childcare, are in question and require further investigation.

Roman London is unique in Roman Britain in that it has substantial inhumation evidence that spans the entirety of the Roman occupation. Elsewhere in the province, cremation tended to be the predominant burial rite in the first and second centuries AD and the vast majority of studies of inhumation burials are therefore heavily biased towards the third and fourth centuries AD (Philpott 1991), making it difficult to assess what kind of impact the invasion initially had on the health and diet of the indigenous population, making meaningful analysis of diachronic trends problematic. Yet, Roman London did not remain static over the course of its four hundred year habitation, either in terms of its wealth, status, or the composition of its population (Perring 1991). Undoubtedly, the Roman conquest and the subsequent occupation of Britain would have had substantial social and economic impacts on the lives of the native population. The introduction of urbanisation would also have certainly had environmental consequences for the living conditions of the inhabitants of the new towns. Previous palaeopathological investigations have identified significant increases in the level of stress indicators between the Iron Age and Roman period, suggesting the overall effect of the Roman conquest was deleterious to health (Roberts and Cox 2003; Peck 2009; Redfern 2007; Redfern *et al.* 2010; Redfern and DeWitte 2011a; Redfern *et al.* 2012). Stable isotope analyses have also detected changes in dietary intake following the Roman conquest (Richards *et al.* 1998; Müldner 2013). Therefore, the presence of burials dating from the early period of Roman London provides a unique opportunity to discuss questions regarding the nature of health and diet in post-conquest Roman Britain. Further to this, the occurrence of inhumation burials dating to both the early and late period of Roman London means it is also possible to determine if, and how, health, living conditions and dietary intake changed over the course of the Romano-British period.

Classical sources have revealed the hierarchical nature of Roman society, yet determining status or identity from burial remains is complicated by the lack of obvious status-based differentiation in funerary practice in Roman London, as well as Roman Britain generally (Hall 1996; Pearce 2000). Despite the wealth of cemetery data from Roman London, numbering greater than 10,000 burials, only one study has attempted to provide a detailed analysis of the Roman funerary data (Hall 1996). To date, there has been no large-scale, synthetic and integrated analysis of the skeletal remains, the evidence for which resides within descriptive sections of individual cemetery reports. The skeletal remains provide an important avenue for the investigation of the identities of Roman London's inhabitants through the analysis of demography, health and diet. This evidence has yet to be contextualised within an understanding of both the life course and funerary practices for Roman Britain and the Empire.

1.3 Research Aims

This research aims to develop an in-depth understanding of childhood health, diet and status in Roman London through the isotopic and osteological analysis of the children who lived there. In order to arrive at a better understanding of childhood and child care in Roman London it is important to consider the scientific data in relation to the archaeological context in terms of the impact of the Roman conquest on the local living environment and diet and the changing fortunes of Roman London over the centuries of Roman occupation.

1.4 Research Objectives

In order to achieve this aim, the project has six principal objectives:

1) Utilise and synthesise data already produced by Museum of London anthropologists regarding the age-at-death distribution and skeletal evidence for physiological indicators of poor health from subadult skeletal remains buried within the cemeteries of Roman London
2) Undertake a desk-based assessment of the funerary practices undertaken in Roman London and integrate this evidence with the skeletal data.
3) Undertake carbon and nitrogen isotopic analysis of a minimum sample of 120 individuals of different ages throughout childhood and 50 animals in order to elucidate diet
4) Integrate the results from the isotopic and osteological analysis to examine potential relationships between diet and skeletal indicators of health stress and mortality.
5) Examine these results in relation to the funerary indicators of status differences as denoted by burial containers and temporal trends
6) Compile a database of published data concerning health stress and isotopic evidence for weaning, diet and health from sites elsewhere in Roman Britain and the Roman Empire.

1.5 Research Questions

1) What is the age distribution of the subadult skeletal remains recovered from cemeteries in Roman London?

2) What skeletal indicators of poor nutrition and living environment are evident in the skeletal remains of these children and how do these compare to the adults?
3) Are there age-related patterns in terms of the prevalence of skeletal indicators of poor health amongst subadults?
4) What is the diet, as indicated by isotopic evidence, of subadults in Roman London and how does this compare to adult diet?
5) What were the infant feeding practices evident in Roman London and how do they compare to elsewhere in Roman Britain and the wider Empire?
6) Were there health consequences of the particular infant feeding regime in Roman London as assessed through skeletal indicators?
7) What is the relationship between skeletal indicators of poor health and isotopic evidence for diet throughout childhood?
8) What was the initial impact of the Roman conquest on childhood health and diet?
9) Did childhood health and diet in Roman London mirror the fluctuating fortunes of the city throughout its four hundred year history?
10) Can we access perceptions of childhood through status-related burial practices and what role, if any, does status play in the health and diet of children?
11) How does the evidence for childhood in Roman London compare to published data from contemporary sites from Roman Britain and the Roman Empire?

1.6 Thesis Outline

In order to address the research aims and objectives outline above, the structure of the thesis is as follows:

- Chapter 2 provides a literature of the archaeology of childhood in order to contextualise the current study which focuses on Roman London. Childhood has become a burgeoning field of study over the last couple of decades and within archaeology there have been a number of theoretical and methodological developments which will be explored. Within this chapter, the bioarchaeology will be addressed, with special attention being paid to the stress indicators that were utilised within the study to examine poor health in childhood. The final part of the chapter will look specifically at the historical and bioarchaeological studies of childhood within the context of the Roman period.
- Chapter 3 is a literature review of stable isotope research on dietary intake undertaken within archaeology, with a specific focus on the isotopes of carbon and nitrogen. Basic

principles of the technique will be considered, alongside the potential and limitations of these kinds of analyses.

- Chapter 4 provides a review of the current understanding of Roman London that has been gained from extensive recent excavations over the last thirty years. This chapter discusses the nature of the economy and living conditions of the town, alongside the diet and population composition. The limited evidence for childhood in Roman London is also examined.
- Chapter 5 outlines the materials and methods utilised in this study, including the databases interrogated, the sample selection, and the isotopic protocols employed.
- Chapter 6 provides the results of the osteological and palaeopathological assessment. The results are presented in three sections: firstly, the nature of childhood in Roman London; secondly, temporal trends in childhood health; and finally, status-based differences in the skeletal material.
- Chapter 7 gives the isotopic results for subadult diet, including an in-depth analysis of weaning timetables and the changing composition of dietary intake over the life course
- Chapter 8 draws together the results of the thesis and discusses them in relation to the research questions outline above. The results are also compared to other contemporaneous population both within Roman Britain and the wider empire
- Chapter 9 summarises and concludes the thesis by addressing the research questions directly and outlining potential future directions for the study of childhood in Roman London and in archaeology more generally.

Chapter 2: The Archaeology of Childhood

This chapter provides an overview of studies of childhood within archaeology. It will begin with a discussion of the theoretical background and the development of the study of childhood in the past within sociology, history and archaeological discourse. A discussion of a bioarchaeological approach to childhood will follow, including information on the non-specific indicators of physiological poor health that occur during the growth period. These are known as skeletal indicators of "stress" and will be utilised in this study to gauge age and status-related patterns in the health of children in relation to isotopic and funerary evidence. The chapter will conclude with an outline of the study of childhood in the Roman world, including the previous contributions of bioarchaeology to the study of childhood in Roman Britain.

2.1 Theoretical Discussions

2.1.1 "Discovering" Children and Childhood

The impetus behind the study of childhood in the past is generally attributed to the historical study by Philip Ariès (1962). Focusing on family life under the *ancien régime* in France, Ariès (1962) declared the concept of childhood to be a relatively modern notion that post-dated the seventeenth century. Ariès (1962) argued that prior to this time children were offered no differential treatment to adults and there existed a lack of sentimentality towards children by their parents. While many since have criticised his pessimism and choice of source material (amongst others DeMause 1976; Pollock 1983; Shahar 1990; James and Prout 1997a; Jenks 2005), Ariès (1962) seminal book 'Centuries of Childhood' was instrumental in highlighting the idea that childhood is not a biologically universal concept and was instead subject to cultural interpretation. Furthermore, his work established childhood as an important area of research in its own right.

While historical studies that followed Ariès continued to debate the nature of parental concern in the past (DeMause 1976; Stone 1977; Shorter 1976; Pollock 1983; Hanawalt 1993), the discourse that emerged in the disciplines of sociology and anthropology recognised the need to break down modern perceptions of children and childhood (e.g. James and Prout 1997a; 1997b; James *et al.* 1998; Prout 2000; 2005; Jenks 2005). These studies benefited greatly from the rise of feminist theory, which sought to challenge the nature of identities previously considered biologically universal (e.g. Baker 1997; Meskell 2001; Diaz-Andreu 2005). This notion of age as a biological determinant led to the unquestioned application of vague terminology, such as infant, child or adolescent, to children in the past without appropriate consideration of the modern western social connotations with which they are imbued (James *et al.* 1998: 71-80; Kamp 2001:4; Gowland 2002: 10; 2006: 144; Baxter 2005a: 20; Jenks 2005: 7; Perry 2006: 89; Sofaer 2006: 119-128; Halcrow and Tayles 2008: 193-194; Lally and Arden 2008). Indeed, just as with gender, the interplay of age with other aspects of identity such as gender, status, and ethnicity tended to be overlooked (Sofaer Deverenski 1997; Lucy 2005: 58-59; Gowland 2006: 144).

Children, along with women, were often tied to the 'semantics of biology' (Hastrup 1978: 49), with the progression from birth to adulthood viewed as biologically determined (James and Prout 1997b: 14). Early studies of childhood recognised that it was the same andocentric biases that had previously rendered women invisible in the past that were responsible for the marginalisation of children (Baker 1997; Sofaer Derevenski 1997; Gowland 2002: 8). By viewing the child in binary opposition to the adult, such biases served to strengthen the powerful position of adults while reducing the child to the realm of "other" (Rothschild 2002: 1; Wyness 2006: 34-35). This "othering" was further entrenched by the use of terminologies, such as "sub-adult", that assign children an inferior hierarchical position as lesser, incomplete versions of adults (Rothschild 2002: 1-4; Jenks 2005: 3; Prout 2005: 10, 33; Sofaer 2006: 121; Halcrow and Tayles 2008: 193). While the use of "non-adult" as a more favourable alternative has been proposed by some (e.g. Bennike *et al.* 2005; Lewis 2007: 2), the negative binary opposition of children to adults still reduces their perceived importance and marks them out as "other" (Halcrow and Tayles 2008: 193). As such, the term fails to provide a truly valid alternative and, in the absence of better terminology, the traditional "subadult" is favoured in this thesis. Children and childhood have been further trivialised by western perceptions that sentimentalise childhood as a time of frivolity, innocence and dependence, viewing children as empty vessels" or "tabula rasa" on which the socialisation and civilisation by adults could be inscribed (James and Prout 1997b; James *et al.*1998: 9ff; Baxter 2005a: 2; Jenks 2005: 35).

In order to counteract these views, the central tenet of the new childhood studies was the recognition that childhood is a social construction rather than a biological one (social constructionism), with each culture having its own definition of what constitutes a child (Qvortrup 1990; 1994; James and Prout 1997b; James *et al.* 1998; Prout 2000; 2005; Jenks 2005; Wyness 2006). While all societies recognise an extended period of biologically immaturity (Bogin 1998; 1999), the ways in which societies construct and negotiate this stage are numerous (Qvortrup 1990; 1994; James and Prout 1997b; James *et al.* 1998; Prout 2000; 2005; Baxter 2005a; Jenks 2005; Gowland 2006; Wyness 2006; Halcrow and Tayles 2008). Indeed, the meaning given to this period of immaturity and the way in which it is understood within a community is socially determined (La Fontaine 1986; Baxter 2005a). However, while childhood is a social construction, social dimensions of age cannot be separated from biological aspects of ageing (James and Prout 1997b; James *et al.* 1998; Prout 2000; Jenks 2005; Gowland 2006: 144; Sofaer 2006: 111-124).

Ginn and Arber (1995: 5) recognised three distinct types of age:

1) 'biological age' defined by physical biological maturation, and one viewed,
2) 'chronological age', defined as the amount of time passed from birth, and
3) 'social age', defined by the socially constructed transitions prescribed within a society

As Gowland (2006: 143-146) discusses, these different types of age are used interchangeably within archaeological studies of cemetery evidence. As a consequence, it has led to the identification of "anomalies" within the archaeological record. For example Crawford (1991; 1999) has discussed the phenomenon of "child weapon burials" from Anglo-Saxon England. She has demonstrated that in actual fact the individuals buried with these weapons were considered to be "adults" when viewed in relation to the social age norms for this period, as indicated by Saxon law codes (Crawford 1999: 157-160). Anthropological studies have demonstrated that different societies construct and conceive of the life course in various ways, imbuing each different life course stage with particular social behavioural norms and expected behaviours (Fortes 1984; Lucy 2005: 55). Within Western societies age is largely based on chronological norms due to bureaucratic and legal structures which govern human behaviour and participation in roles and activities (James *et al.* 1998; Prout 2000). However, these three categories are not discrete and exclusive; for example, biological development is influenced by social perceptions of the life course (Gowland 2006: 143-147). Factors such as living environment or social status can also influence physical changes to the body which may be culturally significant for the life course (e.g. menarche in females) (Levine 1998; Shilling 2003; Sofaer 2011: 297). Discussions of age therefore need to focus on the interaction of all three types of age. Based on these principles, childhood as a social construction is a separate entity to that of biological immaturity, and while biological milestones may influence notions of social identity, social and biological transitions do not always align – bodily maturity may not be needed to achieve an adult status (Myerhoff 1984; La Fontaine 1986; Moore 1994; Sofaer Deverenski 1997; Sofaer 2006).

The notions of childhood within populations may also differ because of the intersection of other aspects of identity. For example, age categories may vary according to gender or status (Lucy 2005: 58). It is frequently observed within different societies that males and females experience different age trajectories (for Roman examples see: Laurence 2000; Harlow and Laurence 2002). Therefore, when considering age, it is important to think of childhood, and all aspects of identity, as multivalent.

Within the modern Western world children are perceived to be both passive and dependent due to their lack of contribution to economic roles (James *et al.* 1998: 101-122; Prout 2000; Jenks 2005). This characterisation of passivity has created an identity which denies children agency in the present, but has also contributed towards our neglect of them in the past (Sofaer Deverenski 1994). However, this notion of a lack of economic contribution contrasts what we know of recent history within Britain and current practice in many developing countries, where children regularly take part in economic roles, from assisting in care giving and domestic chores to full employment (James *et al.* 1998: 101-122; Panter-Brick 1998a; 1998b; Wyness 2006; Hindman 2009). Indeed, even in the Western world in which children are largely dependent on adults, children exert a great deal of agency in terms of creating their own environment, material culture and social networks (Sofaer Deverenski 2000a; 2000b; Jenks 2005; Wyness 2006). Children are also very adept at influencing the people around them, affecting adult decision making and day-to-day activities (Bogin 1998). We also must be careful when discussing ideas of children’s needs in terms of care, as our own views are largely governed by our own particular perceptions of these needs during this phase of the life course (Wyness 2006).

The study of childhood cannot simply focus on immaturity as an isolated stage of the life course. Childhood also needs to be considered as a “training ground”, revealing information about concepts of early life and broader societal understanding of the life course (Prout 2000; 2005). It is a period during which individuals are taught how to become members of the society in which they live and thus provides us with the fundamentals of the way community perceives itself (James *et al.* 1998; Sofaer Deverenski 2000a). Therefore a study of childhood must be contextualised within a broader understanding of the way in which identities are played out over the entirety of the life course (Gilchrist 2000).

2.1.2. Children and Childhood in Archaeological Discourse

While sociology and anthropology were quick to realise the potential of the study of childhood, archaeology was much slower to investigate such ideas. Despite the potential of archaeology to provide primary evidence for children and childhood, their presence was often neglected (Kamp 2001). Indeed, prior to the incorporation of child social theory, children were only incidentally considered when direct traces of their existence, such as finger prints, tooth impressions, or mortuary remains, were present (Lillehammer 1989; 2000; Sofaer Deverenski 2000a). Such studies were often specific in nature and tended to focus on children in reference to mortality or sensationalist aspects such as infanticide (Sofaer Derevenski 1994: 8). This lack of focus on children was often attributed to their apparent absence from the archaeological record, as evidenced by their underrepresentation in the skeletal record and their supposed lack of contribution to observable material culture, making them "unknowable" (Baxter 2005a: 20). This perceived "absence" of the child in the archaeological record served to further entrench western notions of children as passive social beings and the period of childhood as nothing other than biological fact (Sofaer Deverenski 2000a). This exclusion of children and childhood created a past peopled by adults, reinforcing the hegemony of the gatekeepers of archaeological research (Gowland 2006: 145).

As within sociology and anthropology, feminist theory began to stimulate discourse on the invisibility of children in archaeology from the 1990s (Sofaer Deverenski 1994a; 1994b; 1997; Baker 1997; Meskell 2001). The parallel emergence of post-processual discourse at this time was also instrumental. Post-processual discourse sought to move away from the population-based scientific evolutionary models of processual archaeology, choosing to focus instead on the individual agency and marginalised aspects of identity, such as status, gender, ethnicity and religious belief (see Hodder 1985; Johnston 1999 for further discussion). However, of all the identities considered, age identity has been one of the least explored in the past (Lucy 2005). Consequently, this has led to the projection of western contemporary age paradigms onto the past and the interchangeable use of inappropriate and culturally loaded terminology, such as "child", "adolescent", and "teenager", without any standard definition (Gowland 2006).

While initial archaeological discussions of children fell under the purview of gender and family studies, often under the guise of a mother's burden, by the end of the decade, children and childhood was being to emerge as a topic of study in its own right. Lillehammer's (1989) seminal work, '*A child is born. The child's world in an archaeological perspective*', is regarded as the birth of the archaeological investigation of childhood. Through an investigation of children's material culture in eighteenth century Icelandic societies, Lillehammer (1989) demonstrated what could be achieved by focusing on the interaction of children with their environment and the adult world. In addition, she admonished the lack of attention given to children and childhood in archaeological discourse and encouraged others to seek out children in the past. While more recent scholars have pointed out various short comings with her approach, namely that of her modern perception of "toys" and her advocacy that children need to be found despite being obviously ubiquitous (amongst others Rothschild 2002; Baxter 2005a; 2005b), the article proved the impetus for future research into the area.

While the subsequent studies of the 1990s lamented the invisibility of the child in the archaeological record (Sofaer Derevenski 1997), it was not until the 2000s that archaeological analyses began to start systematically reconstructing aspects of age identity, such as childhood, in the past (e.g. papers within Sofaer Deverenski 2000b; Gowland 2001). As a result, over the last 10 years increasing numbers of books, theses, conferences, journals and societies dedicated to the study of children and childhood have emerged (Halcrow and Tayles 2008: 191). Despite this increasing interest in children and childhood in archaeology, most studies continue to include justifications for the study of childhood in the past and argue for the need for further studies in the area, suggesting this area of age identity has yet to become part of mainstream archaeological discourse (Kamp 2001; Baxter 2005a; Halcrow and Tayles 2008; 2011).

2.1.3 Children in Bioarchaeology

While the recognition of children and childhood as a social construction has enabled scholars to move past the biases of modern perceptions and facilitate a greater understanding of life in the past, it has also served to marginalise the importance of the biological body/skeletal remains themselves (Shilling 2003: 22, 105; Prout 2005: 57). With the movement away from the scientific approaches of processual archaeology, skeletal remains became increasingly perceived as biological organisms from which empirical facts, such as age and sex, could be drawn to generate theory regarding social age (Sofaer 2006: 1-3). By seemingly placing greater value on material culture, post-processual archaeology rendered skeletal remains as “empty shells” or “clothes horses” on which theory could be draped (Sofaer 2006: 2; Gowland and Knüsel 2006: xiiii; Insoll 2007a: 4; Sofaer 2011: 285). Bioarchaeologists themselves have added to this growing separation by aligning themselves solely with the scientific aspects of the discipline, and failing to engage with appropriate contextual theory by preferentially focusing on the biological and chronological aspects of age (Gowland and Knüsel 2006: ix). The result of this paradigm shift was an increasing division between social theory (nurture) and the scientific study of skeletal remains (nature), dubbed the science-theory divide (Sofaer 2006: xiiii; Gowland and Knüsel 2006: ix; Buikstra and Scott 2009).

The lack of integration between archaeology and bioarchaeology has also led to the insinuation that biological and cognitive development from birth to skeletal maturity occurs in a fixed and universal manner (Gowland and Knüsel 2006: ix-x; Sofaer 2006: 4-5; 2011).

However, within bioarchaeology, the growth process has long been recognised as notoriously variable, with intrinsic factors, such as genetics and biological sex, and extrinsic social and environmental factors, such as poor health and malnutrition, all profoundly affecting the process (Saunders and Hoppa 1993; Bogin 1999: 228-239; Hoppa and Fitzgerald 1999; Saunders 2000; Perry 2006: 92; Sofaer 2011). Cultural practices can also affect the age at which "biological milestones" are attained, especially when particular abilities are preferentially favoured or required (Gowland 2002: 12). For example, the economic pressure on mothers to return to work as soon as possible in some African communities has encouraged families to ensure the attainment of walking occurs much earlier than would be deemed normal in the west (Levine 1998). These variations have implications for the prized chronological age-at-death estimations utilised in many social constructions of identity in the past (Gowland 2006: 144).

Studies of age identity within bioarchaeology are relatively recent (Gowland 2002; Sofaer 2006; 2011; Perry 2006; Insoll 2007a, b; Halcrow and Tayles 2008; 2010; 2011; Buikstra and Scott 2009). The medico-historical perspective of much of the initial work in the field tended to focus on individual case-study diagnoses, methodological techniques or epidemiological trends of particular diseases (Mays 1997; 2010a; Park *et al.* 2010). However, the growing recognition of the need to understand disease processes in their social context led to the adoption of biocultural theory (Buikstra 1977; 2006; Roberts 2006; papers within Insoll 2007b; Buzan 2012). Biocultural approaches recognise the inter-related nature of both biological and social systems and stress the need to combine osteological, historical and archaeological evidence in order to understand patterns of health in the past (Goodman *et al.* 1988; Buikstra 2006; Roberts 2006; Buzan 2012: 59-60; Klaus 2014; Temple and Goodman 2014). As such they seek to identify how socio-cultural, physical and economic aspects may selectively impact populations, and vice versa. Another more recent approach adopted within the discipline is that of the life course. Rather than viewing skeletons as individuals of a fixed age, life course theory seeks to identify the whole process of development throughout the life experience (Gilchrist 2000; Sofaer 2011). Under this framework, childhood is not perceived as a static period of time, rather it is viewed as part of the overall progression of birth to death, allowing greater consideration of the transitions between phases such as childhood and adulthood (Gowland 2002: 27; Baxter 2005a: 3-4). Over recent years there has been a greater integration of social theory within bioarchaeology and an increasing emphasis on accessing aspects of past social identities from skeletal remains (e.g. Sofaer 2006; Gowland and Knüsel 2006; Perry 2006; Insoll 2007a,b; Agarwal and Glencross 2011).

One of the outcomes of the life course approach has been the production of "osteobiographies". Instead of looking at population-level trends, osteobiographies recognise the temporal quality of the skeleton, combining biological evidence from their skeletal remains with known cultural aspects of the life course (e.g. Robb 2002; Mayes and Barber 2008; Boutin 2012). Though incipient these theoretical progressions within bioarchaeology place the discipline in a unique position to allow proper integration of both biological and social aspects of childhood in the past.

(i) Limitations of Bioarchaeological Research

Bioarchaeological research has allowed us to develop a greater understanding of a number of aspects of life in the past. However, the analysis of skeletal remains is limited by a number of methodological and interpretational difficulties. Acknowledgement of these limitations is essential in all studies that utilise human skeletal remains and a summary of some of the key issues in relation to subadult remains are given below (also see Section 2.2.2 for discussion of the osteological paradox). A more detailed discussion of these limitations may also be obtained from: Waldron (1994; 2007); Haglund and Sorg (2002); Chamberlain (2006); Lewis (2007); Stodder (2008); and Roberts (2009).

(a) Sample Completeness

The skeletal population excavated from an archaeological cemetery represents just a subset of the once living population. Unlike modern epidemiological studies, the skeletal populations available for bioarchaeological investigations cannot be regarded as true random samples, with their overall composition being the result of numerous biases (Waldron 2007: 26). Firstly, in order for a skeleton to be recovered from a cemetery, it must first be buried within it. If and where a person is buried is largely culturally determined, with inclusion being governed by a number of factors including: religious belief, age, gender, and status (Parker Pearson 2003). Forms of preferential age-based exclusion from formal cemeteries, particularly regarding infants, have been identified in many archaeological periods, including the Roman period (Scott 1999; Pearce 2001; Lewis 2007: 31 Moore 2009; Carroll 2011; 2012; Craig-Atkins 2014; Lancy 2015: 51-53). The mode of disposal adopted by a community, i.e. inhumation, cremation, or excarnation, may also affect inclusion within the archaeological record (Henderson 1987: 49; Stodder 2008: 72; Roberts 2009: 60-61). For example, excarnation and cremation may reduce the amount of an individual's remains available for burial, if they are buried at all. As a result of these factors, the cemetery population may not be an accurate reflection of the living population from which they were drawn (Dutour *et al.* 2003: 154; Waldron 2007: 26; Jackes 2011).

Once buried within the ground, taphonomic processes will affect the preservation of skeletal remains and the overall proportion of skeletons that ultimately survive. Factors that have been identified as being influential to bone preservation include: depth of burial, water movement, soil type, pH level, temperature, bioturbation, bacterial and fungal activity, and animal scavenging (Gordon and Buikstra 1981; Henderson 1987; Garland and Janaway 1989; Rodriguez 1997; Millard 2001; Trueman and Martill 2002; Denys 2002; Nielsen-Marsh *et al.* 2007; Pijoan *et al.* 2007; Smith *et al.* 2007; Pokines and Baker 2013). The presence and type of burial container utilised may also be a determining factor, with some containers preferentially buffering the skeleton from the burial environment and potential scavenging (Duday 2009: 150-151; Nord *et al.* 2005: 82; Stodder 2008: 74; Damann and Carter 2013: 43). The effect of these extrinsic burial conditions will not affect all bones in the same way, with intrinsic aspects such as bone size, shape, surface area, density and composition all affecting their survival (Von Endt and Ortner 1984; Willey *et al.* 1997; Stodder 2008: 81-85). In general, small bones with a greater surface area by volume and those with a higher proportion of cancellous bone, such as phalanges, carpals, vertebrae, and patellae, are often underrepresented in skeletal assemblages (Bello and Andrews 2006; Mays 2010b: 29-31). Studies of bone diagenesis have also identified age-related differences in bone preservation, with subadult bones being particularly susceptible to diagenetic changes due to their small size, greater porosity, high collagen content and lower mineral density (Gordon and Buikstra 1981; Walker *et al.* 1988; Buckberry 2000; Lewis 2007: 23-26; Manifold 2010; Djurić *et al.* 2011). Bone preservation appears to positively correlate with increasing age, with the poorest levels of preservation being observed before the age two to four years (Guy *et al.* 1997; Bello *et al.* 2006; Stodder 2008: 84). This preservation bias is often cited as a leading cause of the underrepresentation of infants within cemetery assemblages. However, poor preservation of infant remains is not universally observed, and under conditions of good bone preservation may be similar to that seen in the adult population (Saunders *et al.* 1995; Buckberry 2000; Lewis 2007: 20; Saunders 2008: 119-121; Mays 2010b: 28-29).

The final factor that may introduce bias is the nature of archaeological recovery. Due to financial constraints and the presence of existing buildings and infrastructure, modern excavations rarely uncover the full extent of a cemetery. Therefore, all elements of the buried population may not be equally represented in the proportion uncovered, particularly if cultural burial conventions marginalise or partition particular social groups (Dutour *et al.* 2003: 154; Parker Pearson 2003: 11-17; Waldron 2007: 30-31). The techniques used to recover skeletal remains may also result in increased loss. The small size and greater frequency of subadult bones makes them harder to identify and vulnerable to being missed during excavation, particularly if the excavator has no osteological training or is subject to significant time pressures (Buckberry 2000; Roberts 2009: 73-80). The practice of soil sampling and the sieving of grave contents may mitigate this loss, though it may not always be possible despite its recommendation within standard guidelines (Keily *et al.*1994; Stodder 2008: 77; Roberts 2009: 59). A further consideration that should be made is that the skeletons recovered from a cemetery may represent hundreds of years of burial deposits. While careful excavation may uncover datable grave goods and evidence of phasing, it is often difficult to date burials more accurately than in hundred year date ranges (Waldron 2007: 33). As a result, it is not possible to examine short term trends in palaeodemography or palaeopathology, with prevalence rates representing “smoothed out” long term averages (Dutour *et al.* 2003: 154).

(b) Methods of Analysis – Sex and Age Determination

The inability to determine the biological sex of subadults is perhaps one of the greatest limitations to current osteological investigations. When skeletal preservation is good, the assessment of biological sex in adults based on sexually dimorphic traits of the skull and pelvic regions can yield accuracies of up to 95% (Mays and Cox 2000: 119-120). However, the traits scored in these methods only start to become apparent after the onset of puberty, making them inappropriate for subadult analyses. Indeed, Walker (1995) discovered that even young adults can present with ambiguous sexually dimorphic traits. A number of methods for sex estimation of subadults have been proposed, focusing on either pelvic and/or craniofacial morphology (Schutkowski 1993, Molleson *et al.* 1998; Loth and Henneberg 2001), or dental measurements (Black 1978; De Vito and Saunders 1990). However, when these methods have been subject to retesting, accuracy rates have proved to be poor (Weaver 1980; Hunt 1990; Mittler and Sheridan 1992; Holcomb and Konisberg 1995; Mays and Cox 2000; Sutter 2003; Vlak *et al.* 2008). Ancient DNA studies offer an alternative method for the determination of sex in subadults (e.g. Faerman *et al.* 1998), although the cost is often prohibitive and beyond the reach of most researchers. Furthermore, aDNA analyses are not without their own problems and limitations (see Cooper and Poinar 2000; Stone 2008; Brown and Brown 2010). This inability to determine biological sex in subadults not only makes it impossible to determine differences in childhood mortality rates by sex, but also introduces error in age-at-death estimates due to the different maturation rates between the sexes (see below).

Subadult age estimations are usually based on macroscopic, microscopic and radiographic techniques that assess dental development and eruption (e.g. Moorrees *et al.* 1963a; 1963b;

Ubelaker 1989), growth (diaphyseal bone length e.g. Maresh 1955) and skeletal maturation (appearance and fusion of ossification centres e.g. Scheuer and Black 2000). In all of these techniques, the main aim is to equate biological age with chronological age, using skeletal development data from documented modern and archaeological known-age samples. Age estimates based on tooth formation and eruption timetables are considered the most accurate technique as they tend to produce smaller age ranges and are least affected by environmental factors (Saunders 2008: 126; Cardoso 2007; Scheuer and Black 2000: 12-13). As tooth formation begins *in utero* and continues into late adolescence and early adulthood, it provides a useful indicator of age throughout the growth period (Whittaker 2000: 83-87).

Diaphyseal bone length is particularly useful for foetal-infant age estimations as rapid growth during this developmental stage more closely parallels chronological age (Fazekas and Kosa 1978; Scheuer *et al.* 1980). However, it becomes less useful after the first year of life due to increased intra-individual variability and greater susceptibility to environmental stresses. Comparisons of age estimations within populations often show ages generated by diaphyseal bone lengths being much younger than those determined from dental methods (e.g. Lampl and Johnston 1996). Presumably this is because long bone growth standards derived from modern data are inappropriate for past populations who may have experienced less than adequate nutrition (Cardoso 2007). It may also be because children buried within cemeteries represent “non-survivors”, and prolonged poor health prior to death in some instances may have resulted in growth stunting (Saunders and Hoppa 1993; Bogin 1999: 228-239). Maturation estimates based on observations of the appearance and fusion of secondary ossification centres, or epiphyses, are another useful means of estimating chronological age as these occur in a recognised sequence. Maturation age indicators are most useful for estimating age in older subadults, where diaphyseal lengths and dental estimates are less indicative (Scheuer and Black 2000: 11-12). However, maturation estimates are also sensitive to environmental stresses.

Using a combination of the above techniques, bioarchaeologists can generate average age ranges for individual subadults, which tend to be more accurate and more precise than those derived for adult skeletal remains. However, the ability to assign an individual to a particular age category is affected by a number of issues. Firstly, skeletal preservation within a population is important for age determination, as adequate preservation of the regions scored for the different ageing methods is required in order for them to be scored. While teeth are quite robust and often survive well in the burial environment, small epiphyses that have yet to fuse tend to be more poorly preserved and/or missed during archaeological excavation (Bello *et al* 2006; Manifold 2010). If skeletal preservation is particularly poor, an investigator may only be able to assign an individual to a generic 'subadult' age category (<18 years), making nuanced age-related observations difficult. A further source of potential error in subadult age estimations is introduced by our inability to sex subadult skeletons, making it difficult to account for male and female variations in maturation and growth rates (Lewis 2007: 58). Intra-observer and inter-observer error must also be acknowledged in the both application, and selection, of the ageing methods applied (Wittwer-Backofen *et al.* 2008; Falys and Lewis 2011).

Many of the methods utilised to convert biological age to chronological age in osteological investigations are based on modern samples and archaeological populations of known age (e.g. Moorees *et al.* 1963a; 1963b; Maresh 1955; Fazekas and Kosa 1978; Scheuer and Black 2000). As such, these methods are based on the assumption that people from the past followed a similar course of development as those today. However, growth is known to be a highly variable process that is subject to a great difference between populations and is susceptible to environmental stress (Hoppa and Fitzgerald 1999). Consequently, using modern data to determine age, often obtained from children with good nutrition and health, is less advantageous for past populations and may introduce wide discrepancies that result in under-ageing. For example, Lampl and Johnston (1996) found ages determined for living Mexican children based on dental and skeletal maturation tables derived from white American children could result in under-ageing by as much as 18 months. Therefore, it is important to ensure that the most appropriate methods are utilised for each archaeological population. However, this may render comparisons between populations incompatible.

(c) Terminology and Age Categories

One of the biggest tensions between discussions of social identity and skeletal analyses is the different and conflicting terminologies and age categories used by both disciplines. For example, within bioarchaeology, the term "subadult" is used when referring to those individuals who have yet to reach skeletal maturity, with the age of eighteen years often being regarded as the point when adulthood commences (Gowland 2002: 10-20; 2006; Sofaer 2011; Halcrow and Tayles 2008: 348-350). However, it is acknowledged here that this imposed "cut-off" point does not equate with complete maturation, as some of the late-fusing bones, such as the clavicle, do not fuse in some individuals until their late twenties (Scheuer and Black 2000: 252). As such, the use of eighteen years as a marker of adulthood is more a reflection of modern chronological age perceptions (Sofaer 2006). Regardless of this, it is likely that skeletal maturation may fail to converge with social transitions from childhood to adulthood, making the use of the term "subadult" completely inappropriate to discussions of social identity where adulthood is achieved much earlier (Gowland 2006). This situation is further compounded by the use of terms that mirror western notions of the life course, such as “early childhood”, “late childhood”, and “adolescent”, which are often attached to biological age categories without consideration of social age in the archaeological population under investigation (Sofaer Deverenski 1997; Gowland 2002: 10-20; 2006; Sofaer 2006: 24; 2011). However, this situation is difficult to resolve as the use of consistent age categories across archaeological populations, as recommended by recognised standard guidelines (e.g. Buikstra and Ubelaker 1994; Brickley and McKinley 2004), is essential for comparability between populations (Halcrow and Tayles 2010: 334-336).

2.2 Bioarchaeological Investigations of Subadult Health

The study of health and nutritional status in the past is now widely recognised as crucial to our understanding of how populations functioned and sustained themselves in the past. As well as influencing important demographic aspects, such as fertility, mortality and morbidity, the health status of a population can also have important secondary socio-political and economic effects that can in turn force changes in cultural and environmental systems (Goodman *et al.* 1984a; 1988; Bush 1991; Steckel and Rose 2002). Subadults are particular useful for studies of health and disease in the past, as their immature immune system and rapid growth makes them vulnerable to adverse health and nutritional influences (Goodman and Armelagos 1989: 239; Perry 2006; Halcrow and Tayles 2008: 336). As poor health and nutrition in the prenatal period and/or early childhood has been shown to have broader health implications in later life, such as compromised immunity, the study of childhood health provides a “sensitive barometer” for overall population health (Lewis 2007: 20). This section will focus on some of the more commonly recorded skeletal indicators or poor health observed in children, with a focus on those utilised in this study of childhood in Roman London.

2.2.1 Concepts of Health Stress in Bioarchaeology

Today, the World Health Organisation defines health as ‘a state of complete physical, mental and social well-being and not merely the absence of disease of infirmity’ (http://www.who.int/about/definition/en/print.html). However, health is a holistic concept that encompasses many aspects including not only factors such as disease and nutrition, but also how a person is able to function daily, their overall quality of life and even their own self perception of health (Noack 1987; Freund *et al.*2003; Duncan 2007; Huber *et al.* 2011; Brüssow 2013; Reitsema and McIlvaine 2014: 181). Therefore, rather than being considered in static binary opposition to disease, “health” reflects a changing continuum (Goodman *et al.* 1988:

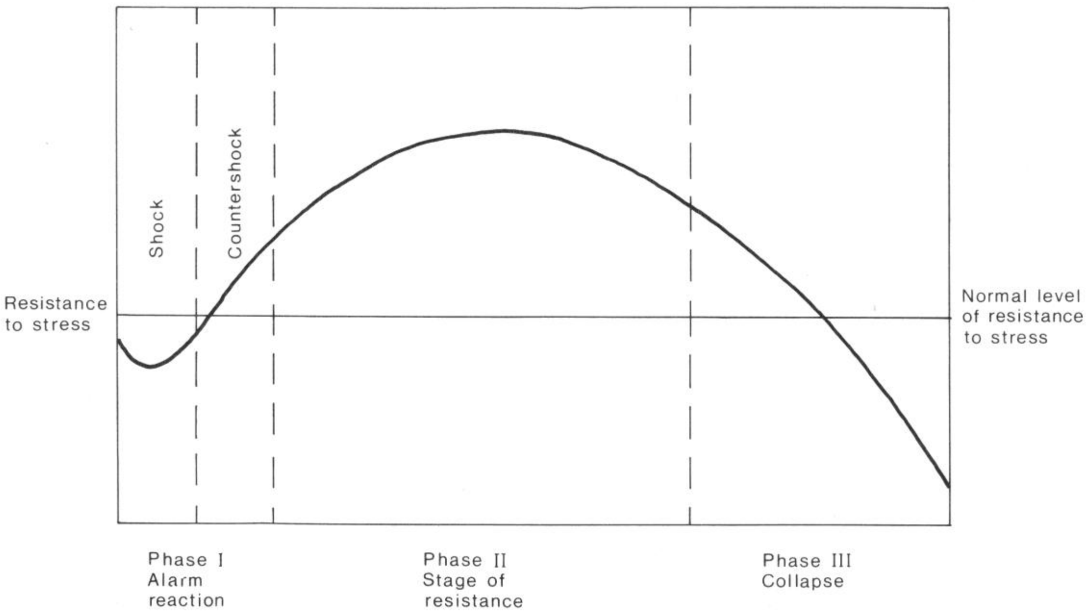

Figure 2.1: Seyle's (1973) general adaptation model (Bush 1991: 21)

195; Bush 1991: 11; Larsen 2015: 9). Furthermore, how "health" is perceived within a population is subject to cultural and temporal change, with past perceptions of what is considered "healthy" potentially diverging from our own (Goodman *et al.* 1988; Freund *et al.* 2003: 4-6; King 2005; Roberts 2009: 154; papers within Agarwal and Glencross 2011; Temple and Goodman 2014). While the multifaceted and complex nature of health can be examined in living populations through a multitude of clinical data, biocultural investigations of health are limited to the data that can be obtained from skeletal remains (DeWitte and Stojanowski 2015).

A key concept within biocultural studies of health in the past is the identification of stress. Within physical anthropology, stress is defined as 'a physiological changed caused by strain on an organism from environmental, nutritional and other pressures' (Reitsema and McIlvaine 2014: 181). One of the most influential concepts of stress within biocultural studies is Seyle's (1973) general-adaptation-syndrome (GAS) model (Figure 2.1). Within it, stress is considered as 'the non-specific response of the body to any demand upon it' (Seyle 1973: 692). The GAS model identifies three key stages of response in the body (Figure 2.1). In the first stage, or 'alarm response', initial exposure to a stressor leads to an excessive response due to an individual's low resistance (Seyle 1973: 694). If this initial exposure is severe enough, it may overwhelm the individual and lead to death (Seyle 1973: 694). With repeated exposure the 'resistance stage' is reached, where an individual's resistance to a particular stressor increases as the body adapts to accommodate it (Seyle 1973: 695). However, if the individual is subject

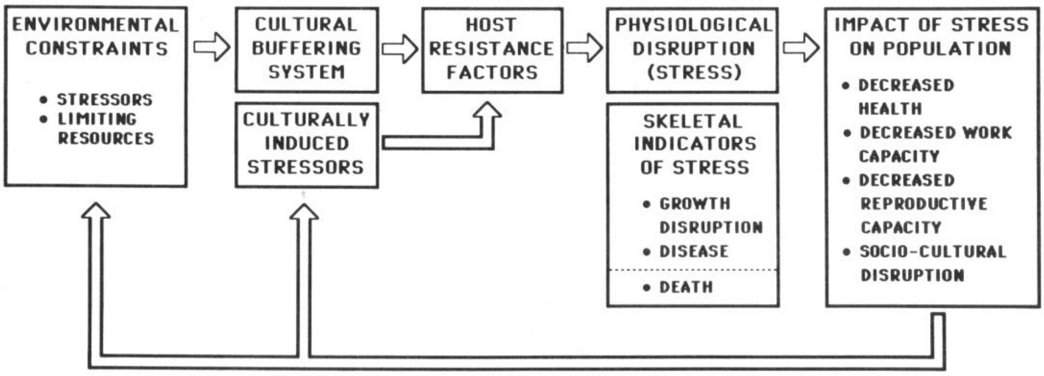

Figure 2.2: Goodman and Armelagos (1989: 226) stress adaptation model (revised from Goodman *et al.* 1984a)

to long-term, continued exposure to the stressor, it will reach a point of exhaustion, or ‘collapse’, where it is no longer able to adapt, rendering it more susceptible to other stressors and eventually leading to death (Seyle 1973: 696). Ultimately, it is the ability of the body to recover, adapt and maintain homeostasis that determines the health of the individual, and the population overall (Seyle 1973). This Seylean notion of stress has been criticised for its explicit focus on physiological aspects of stress and its failure to consider psychological stress (Goodman *et al.* 1988: 174-175; Armelagos and Goodman 1991; Bush 1991; Weston 2012: 504-505). Bush (1991: 15) in particular argues that the way a person perceives social and environmental constraints will also influence the way in which they experience stress. Therefore, she argues that there is no “universal stressor” as individuals will experience and respond to stress differently, something she terms the ‘individuality of response’ (Bush 1991: 17).

The level of stress a population is exposed to and its ability to adapt is highly dependent on the complex interaction of environmental, cultural, and biological constraints and adaptations. Goodman *et al.*’s (1984; 1988) model for the interpretation of stress in skeletal populations, which has become the primary reference of biocultural stress studies, identifies the potential of the environment to both buffer and create stress (Figure 2.2).While cultural adaptations can be made to mitigate these stresses, for example through technological advancements or through the organisation of social systems, these changes can also be a source of additional stressors (Goodman *et al.* 1984a). For instance, a population may choose to preferentially protect or expose different sections of its society to stress. If cultural adaptations fail to buffer these stresses, an individual’s host response, affected by factors such as their genetic, developmental and physiological status, becomes important (Goodman *et al.* 1984a). For example, the youngest and oldest members of a society are often the most vulnerable to stress (Goodman and Armelagos 1989; Overfield 1995; Rogers 1997; Lewis 2002: 38; Last and McGinnis 2003: 47; WHO 2008: 8-10; Lupien *et al.* 2009), and studies have shown females tend to be more physiologically buffered from stress than males (Stinson 1985; Overfield 1995: 170-182; Ortner 1998; Last and McGinnis 2003: 47; Lee and Owens 2007: 133). If a population's cultural and individual adaptation to stress ultimately fails, physiological disruption, poor health and eventually death may occur (Temple and Goodman 2014: 188).

In living populations, the identification of stress and physiological disruption can be achieved through the physical examination of a living patient's symptoms and hormone levels. However, within palaeopathology, evidence for stress must be derived indirectly from a series of recognised diagnostic dental and skeletal lesions, commonly referred to as "stress markers" or "stress indicators" (Goodman *et al.* 1984a; 1988; Lewis and Roberts 1997; Goodman and Martin 2002; Reitsema and McIlvaine 2014; Larsen 2015: 8-58). These stress markers either represent physiological growth disruptions (e.g. enamel hypoplasia, Harris lines, growth and stature), metabolic disturbances (i.e. *cribra orbitalia*, porotic hyperostosis, and vitamin C and vitamin D deficiency), infection or trauma. Understanding the specific cause of an individual stress indicator is often not possible, due to its non-specific nature and the wide range of stressors that have been implicated in their aetiology (Cutress and Suckling 1982; Goodman *et al.* 1984a; 1988; Lewis and Roberts 1997; Temple and Goodman 2014; Vercellotti *et al.* 2014).

They include, amongst others: nutritional deficiency, disease, parasitic infection, poor living conditions, and psychological disturbance (Goodman *et al.* 1984a; 1988; Martin *et al.* 1985; Stuart-Macadam 1985; 1991; Bush 1991; Lewis and Roberts 1997; Klaus 2014; Tanner and TAPS Bolivia Study Team 2014). This situation is further exacerbated by the potential co-existence of multiple stressors (Goodman *et al.* 1988: 187). For example, malnutrition often increases an individual's susceptibility to infection, as well as producing metabolic disturbances implicated in anaemia and vitamin C deficiency (Scrimshaw and SanGiovanni 1997; Buckley 2000: 499; Jacob and Sotoudeh 2002; Scrimshaw 2003). Stress markers are then best considered as non-specific indicators of stress (Goodman 1993; Lewis and Roberts 1997; Goodman and Martin 2002).

An important consideration that must be made is that the identification of stress indicators within a population cannot be directly linked to health status. While the physiological disruptions responsible for the manifestation of stress indicators are "unhealthy", stress indicators represent a physiological disruption at a specific point in time (Reitsema and McIlvaine 2014: 155). Therefore, they cannot be considered as a direct measure of overall health outcomes or broader perceptions of well being (Temple and Goodman 2014: 189-190).

Instead, they should be used to evaluate stress and adaptation within a population in light of environmental, sociocultural and biological constraints within the community. Goodman *et al* (1988) emphasise the importance of following a holistic approach that utilises multiple stress indicators to understand the total stress load at the population level.

Following this approach, distributions of stress indicators amongst different societies have been used to assess the effect of cultural and environmental factors. Two examples of areas where this has been successfully applied is the study of health implications of the transition to agriculture (Cohen and Armelagos 1984; Kent 1987; Armelagos 1990; Larsen 1997; Starling and Stock 2007; Eshed *et al.* 2010), and the impact of urbanisation (Brothwell 1994; Lewis 2002; Sullivan 2005; Brickley *et al.* 2007; Redfern 2007; Redfern and DeWitte 2011a). Intra-population studies of the differential health experiences of different social identities, such as age, gender and status have also been undertaken (Šlaus 2000; Robb *et al.* 2001; Redfern 2005; Gowland and Redfern 2010; DeWitte 2014).

2.2.2 Selective Mortality and Frailty in the Archaeological Record - The Osteological Paradox

Traditional interpretations of health in the past were based on the assumption that high levels of stress indicators within a population were representative of the most disadvantaged and unhealthy, while low levels were thought to represent more advantageously healthy individuals (Cohen 1989; Armelagos 1990; Allison 1984; Cohen and Armelagos 1984; Goodman *et al.* 1984a; 1988; Armelagos *et al.* 1999). However, Wood *et al.*'s (1992) influential work challenged this conventional wisdom. They highlighted that in order for a stress marker to be observed, an individual must be able to adapt and live for a sufficient amount of time for osseous changes to manifest within bones or teeth (Wood *et al.* 1992; also Harpending 1990; Ortner 1991; 1992; 2003: 113). Therefore, those individuals with stress indicators may represent individuals with "healthier" immune systems, with those least able to adapt, dying before skeletal changes could occur (Wood *et al.* 1992: 345). This hypothesis, referred to as the "osteological paradox", suggests that rather than being viewed as indicators of poor health, skeletal stress indicators should be seen as indicative of a good adaptive immune response (Ortner 1991: 10). Wood *et al.* (1992: 345) stress that as a result of this, there is a possibility that those individuals who died before skeletal lesions could develop could be conflated with those individuals who show no skeletal lesions due to advantageous buffering. Remodelling of skeletal lesions over time may also remove traces of stress indicators, further obscuring patterns of stress within a population. A notable exception to this is enamel hypoplasia, as the enamel in which it is formed does not remodel (Goodman and Rose 1990; Aufderheide and Rodríguez-Martín 1998: 406; Armelagos *et al.* 2009).

Furthermore, when attempting to understand past subadult health, it is important to consider that the skeletal assemblages available for analysis represent a biased cross-sectional sample of those individuals who failed to attain adulthood – the “non-survivors” (Wood *et al.* 1992: 349; Saunders and Hoppa 1993: 128; Lewis 2007: 103). Within a population, not all individuals within an age cohort will be exposed to the same risk of death (frailty), due to inherent differences of biology and differential exposure to environmental and cultural risks. As a result of this difference in frailty, those subadults less adapted to these constraints and most at risk of stress at a particular age are more likely to enter the skeletal record than their less frail counterparts (Bolsden and Milner 2012: 121-122; DeWitte and Stojanowski 2015: 11). This selective mortality means the morbidity and mortality risks observed amongst these “non-survivors” may be unrepresentative of the once-living subadult population and may even lead to an overestimation of the prevalence rates of skeletal lesions in the past (Wood *et al.* 1992: 349; Saunders and Hoppa 1993; Lewis 2002: 2; DeWitte and Stojanowski 2015: 11). Identifying the level of frailty within a skeletal population is near impossible (“hidden heterogeneity”), making it difficult to infer patterns of mortality, morbidity and stress indicator prevalence in the general population (Wood *et al.* 1992).

While responses to the “osteological paradox” acknowledge the issue of selective mortality and frailty, the wholesale reinterpretation of stress indicators as evidence of better health has been challenged (Lukacs 1992; Wilkinson 1992; Goodman 1993; Jackes 1993; Cohen 1994). For example, Cohen (1994) argues an overall decline in health is a more probable interpretation of the increased stress indicator prevalence rate observed with the movement to sedentism in American prehistoric populations. Cohen (1994: 631) also challenged the idea that the patterns of stress indicators within a population are unrepresentative of the lived population as many deaths may be accorded to random events. However, this has been subsequently refuted (Wood and Milner 1994: 634). Goodman (1993) also maintains that the osteological paradox overstates the importance of hidden frailty and selective mortality due to a failure to consider cultural and biological processes. For example, by considering age and mortality when interpreting stress indicator prevalence, Goodman (1993: 283) shows it is possible to separate those individuals without lesions due to increased frailty from those without lesions due to better health. Furthermore, Goodman (1993) stressed the importance of interpreting multiple stress indicators to properly understand patterns of health. In response to these criticisms, Wood and Milner (1994) identify their observation that stress indicators may indicate better health is not necessarily more correct than traditional interpretations. Instead, they state that both outcomes are equally plausible, with the original article drawing attention to potential problems that were previously overlooked (Wood and Milner 1994: 636). The osteological paradox continues to be a subject of discussion within bioarchaeological literature and many of the problems it highlights still remaining unresolved (Wright and Yodder 2003; Bolsden and Milner 2012; DeWitte and Stonjanowski 2015). However, the best approach to meeting these concerns is considered to be a holistic approach that analyses multiple stress indicators within its archaeological context (Goodman and Martin 2002: 13).

DeWitte and Stojanowski (2015) also suggest that one way of identifying frailty within a subadult population is to compare stress indicator prevalence rates among subadults. For, if stress prevalence rates are higher in early childhood than late childhood, the pattern would conform to the conventional wisdom, whilst higher prevalence rates would indicate lower frailty with increased age in accordance with the osteological paradox (DeWitte and Stojanowski 2015: 21-23). Such studies within the bioarchaeological literature have found both patterns (Wright and Chew 1998; Bennike 2005; Perry 2014) as well as no connection between age and stress indicators (Saunders and Hoppa 1993; Cucina *et al.* 2011), indicating the importance of understanding the archaeological context within which the stress indicator prevalence rates must be interpreted (DeWitte and Stojanowski 2015).

2.2.3 Measures of Childhood Health – Skeletal Stress Indicators

Within bioarchaeology, a suite of non-specific indicators of stress are employed to identify childhood health in the past. These include, amongst others: mortality rates, linear and appositional bone growth, enamel hypoplasia, dental enamel defects, *cribra orbitalia*, non-specific infection, specific infection, and metabolic disease. As some of these indicators, such as enamel hypoplasia, may survive to be identified into adulthood, their identification in adults may also shed light on childhood health.

Below is a summary of the stress indicators analysed within this thesis, including typical skeletal manifestations. For further information regarding other non-specific stress indicators, please see: Goodman *et al.* (1988); Lewis and Roberts (1997); Aufderheide and Rodríguez-Martín (1998); Goodman and Martin (2002); Ortner (2003); Lewis (2007); Larsen (2015: 7-64).

(i) *Cribra orbitalia* and Porotic Hyperostosis

Cribra orbitalia is a term used to describe the appearance of porosity within the orbits of the skull (Figure 2.3). Usually occurring bilaterally, *cribra orbitalia* can range in appearance from

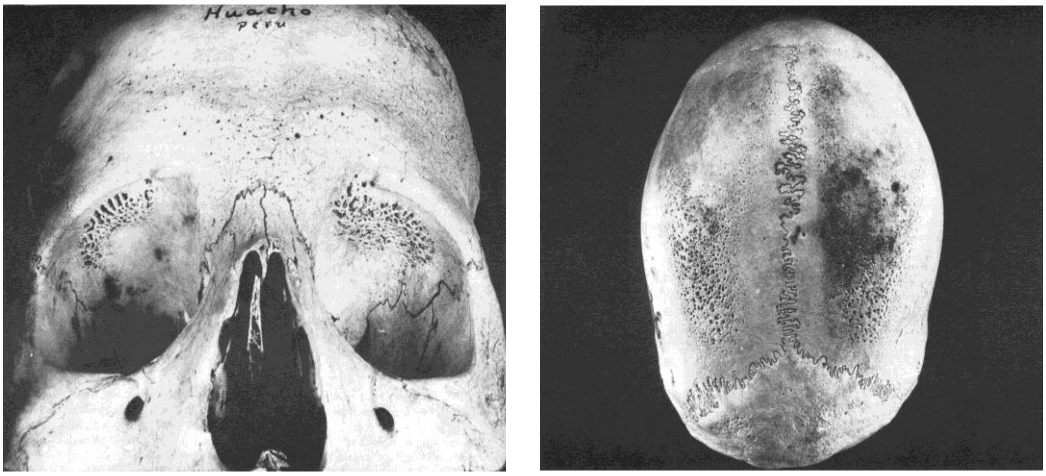

Figure 2.3: Examples of *cribra orbitalia*, affecting both orbital roofs (left), and porotic hyperostosis (right) (taken from Stuart-Macadam 1991: 108)

small pin prick holes to large coalescing foramina that expose the underlying trabeculae (Stuart-Macadam 1991: 109; Aufderheide and Rodríguez-Martín 1998: 349; Wapler *et al.* 2004; Walker *et al.* 2009: 109). Porotic hyperostosis is the term applied to lesions of a similar macroscopic appearance observed on the outer table of the cranial vault, with the frontal and parietal bones being the most commonly affected areas (Angel 1966; Stuart-Macadam 1992; Aufderheide and Rodríguez-Martín 1998: 348; Ortner 2003: 102-103) (Figure 2.3). Both of these lesions are caused by an expansion of the diploic space (marrow hypertrophy) to facilitate increased red blood cell production, resulting in the subsequent thinning of the outer cortex (Ortner 2003: 102; Hughes-Jones *et al.* 2009: 24-26; Walker *et al.* 2009: 111; Kawthalkar 2013: 150). It is this marrow expansion that causes the parallel rearrangement of the trabecular structure, termed "hair-on-end", that is considered diagnostic of porotic hyperostosis (Stuart-Macadam 1987; Aufderheide and Rodríguez-Martín 1998: 348; Schultz 2001: 131-137; Ortner 2003: 103). In severe cases of porotic hyperostosis, expansion of the diploe can increase beyond the original ectocranial surface and create palpable bossing (Ortner 2003: 103; Walker *et al.* 2009: 111).

While both of these lesions are commonly recorded in the palaeopathological literature, their aetiology is still a cause of much debate. Anaemia was first initially identified as the aetiology of these lesions, due to their identification in cases of genetic anaemia, such as sickle cell and thalassemia, and iron deficient patients (Sheldon 1936; Mosely 1974; Stuart-Macadam 1985; 1987; Hershkovitz *et al.* 1997; Lagia *et al.* 2006; Walker *et al.* 2009: 109). However, the frequency of *cribra orbitalia* and porotic hyperostosis in archaeological populations is considered too high to be attributed to genetic anaemia alone (Stuart-Macadam 1989a: 218; 1998: 47; Sullivan 2005: 252; Walker *et al.* 2009: 110). This led researchers to identify acquired anaemia as a more likely explanation, with iron deficiency anaemia being considered the most likely candidate due to its epidemiological parallels with these skeletal lesions (Stuart-Macadam and Kent 1992; Kent *et al.* 1994; Stuart-Macadam 1998: 47; Miller 2013). Consequently, *cribra orbitalia* and porotic hyperostosis have become synonymous with iron deficiency anaemia within palaeopathology (Stuart-Macadam 1989a; 1989b; Grauer 1993; Sullivan 2005; Šlaus 2008). While at first dietary deficiency was considered the main cause of iron deficiency anaemia, Stuart-Macadam (1992; 1998) highlighted the complexity of iron metabolism, with blood loss, gastrointestinal malabsorption diseases, parasitism and exposure to a high pathological load also being implicated (Ramakrishnan and Semba 2008: 486-487). Stuart-Macadam (1991) also suggested that a state of mild iron deficiency, or hypoferremia, may in fact be an adapted defensive mechanism against disease, as bacteria require a supply of iron within the blood to thrive (also Weinberg 1992). Consequently, interpretations of *cribra orbitalia* and porotic hyperostosis tend to examine the synergistic combination of all these causal factors (e.g. Grauer 1993; Sullivan 2005; Šlaus 2008).

More recently, Walker *et al.* (2009) have challenged this widely accepted link between iron deficiency anaemia and porotic hyperostosis, suggesting iron deficiency anaemia could not cause the marrow hypertrophy responsible for these lesions. Instead, they suggest megaloblastic anaemia, caused by deficiencies of vitamin B9 and B12 are a more likely aetiological factor (Walker *et al.* 2009). This theory has been summarily challenged by Oxeham and Cavill (2010), who argue that the required erythropoietic response can occur with iron deficiency anaemia. Despite these differences in aetiologies, the same risk factors (i.e. dietary deficiency and malabsorption due to gastrointestinal disease or parasitic load) are cited in the development of both conditions, with B9, B12 and iron deficiency often co-occurring (Stabler and Allen 2004). However, McIlvaine (2013) has suggested the co-occurrence of both conditions may be problematic if iron-deficiency does inhibit marrow hypertrophy, as it may result in the underrepresentation of megaloblastic anaemia. The role of malaria in the production of these lesions has also been recently addressed (Gowland and Garnsey 2010; Gowland and Western 2012).

Another area of contention previously under debate is the association between the lesions. Previously, *cribra orbitalia* and porotic hyperostosis were both considered to be the result of the same pathophysiological process (Stuart-Macadam 1989b, Salvadei *et al.* 2001). However, Walker *et al.* (2009) have questioned the strength of the link between these lesions, citing a lack of clinical data and the poor correlation of lesions. Wapler *et al.* (2004) have also questioned the link between *cribra orbitalia* and anaemia, identifying that only 43.5% of lesions previously identified as *cribra orbitalia* macroscopically were found to be the result of marrow expansion when examined histologically. In 25.8% of the cases, Wapler *et al.* (2004) identified scurvy as the aetiology, with porous new bone formation caused by subperiosteal haematomas being mistaken form *cribra orbitalia* on gross examination. Pseudopathologies were also responsible for 20% of lesions identified as *cribra orbitalia* macroscopically (Wapler *et al.* 2004). Wapler *et al.'s* (2004) findings highlight the difficulties in identifying pathological processes from skeletal lesions and demonstrate the importance of differential diagnosis through careful examination of lesions and their skeletal distribution. The consideration of differential diagnoses for porotic hyperostosis is also essential, as scalp infections, and vitamin C and vitamin D deficiencies are also known to produce similar lesions (Schulz 2001: 131-137; Ortner 2003: 102-105).

Despite these issues and the lack of consensus regarding the exact aetiology of *cribra orbitalia* and porotic hyperostosis, they are still considered robust indicators of non-specific health stress within palaeopathological analyses.

(ii) Dental Enamel Hypoplasia

Dental enamel hypoplasias (DEH) are deficiencies in enamel thickness that occur due to a physiological disturbance of ameloblastic activity during the development of deciduous (second trimester- 1yr) and permanent tooth crowns (1-13yr) (Goodman and Rose 1990: 60-67; Aufderheide and Rodríguez-Martín 1998: 406; Hillson 2005: 168-170; Guatelli-Steinberg 2008: 71). As such, they represent time specific growth disturbances caused by acute periods of stress during childhood (Goodman and Rose 1990; Regezi *et al.* 2000: 151; Goodman and Martin 2002: 27; Ortner 2003: 595; Kessler 2013: 571). Macroscopically, they are observed as disruptions in the contours of the crown surface that vary in appearance from single or multiple small pits to areas of complete absence of tooth enamel, with horizontal linear grooves or furrows (linear enamel hypoplasias) being the most commonly recorded form (Hillson and Bond 1997: 90-100; Goodman 2000: 210; Hillson 2005: 170; Ogden *et al.* 2007; Kessler 2013: 571-572) (Figure 2.4). Microscopically, DEHs are recognised as exaggerated Striae of Retzius or Wilson bands (FitzGerald and Rose 2008; Ritzman *et al.* 2008; Hillson 2014: 174). DEHs are one of the most commonly utilised stress indicators in palaeopathology as, due to their robust structure, teeth are often preserved in even the most adverse burial conditions (Hillson 2005: 206; Turner-Walker 2008; Manifold 2010; 2013). In addition, the inability of tooth enamel to remodel and repair itself ensures DEHs are retained into adulthood, providing a permanent record of childhood stress (Lewis and Roberts 1997: 581; Aufderheide and Rodríguez-Martín 1998: 406; Roberts and Manchester 2005: 75; King *et al.* 2005; Armelagos *et al.* 2009).

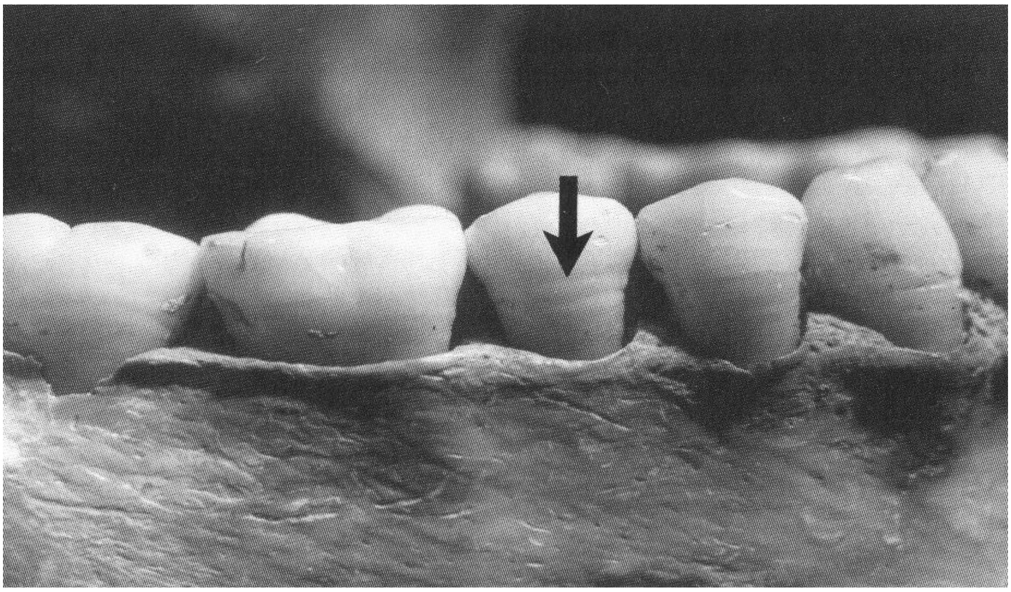

Figure 2.4: Linear enamel hypoplasia (taken from Roberts and Manchester 2005: 75)

Goodman and Rose's (1990) "threshold model" recognises the role of host resistance, nutritional inadequacies, and disease as concomitant causal factors in the production of DEHs. However, the sensitivity of amelogenesis to multiple physiological and metabolic perturbations means it is often not possible to identify a specific causal factor(s) (Goodman and Rose 1990; Goodman and Martin 2002: 24; Hillson 2005: 175). Clinical and palaeopathological studies have identified a wide range of aetiologies for DEH, including: premature birth, low birth weight, dietary deficiencies in vitamin A, C, and D, fever, specific infections, such as TB, poor living conditions, and parasitic infections (Noren *et al.* 1978; Cutress and Suckling 1982; Dobney and Goodman 1991; Seow 1992; Aufderheide and Rodríguez-Martín 1998: 405-407; King *et al.* 2005; Roberts and Manchester 2005: 75-77; Brickley and Ives 2008: 110, 249; Ogden *et al.* 2007; Šlaus 2008; Hillson 2014: 184-191). In total, Cutress and Suckling (1982) have linked DEH to nearly 100 possible causal stress conditions. Therefore, DEH's are best thought of as non-specific indicators of periods of stress within childhood.

As DEHs are localised to the part of the enamel under formation, the location of linear DEHs has been utilised as a chronological indicator of the age-at- defect formation (Goodman *et al.* 1984b; Goodman and Rose 1990: 96-98; Buikstra and Ubelaker 1994: 56-57; Ensor and Irish 1995; Taji *et al.* 2000). This is most often achieved macroscopically by measuring the location of the DEH from the cemento-enamel junction and converting it into chronological years using standard enamel formation charts (e.g. Goodman *et al.* 1980). Using these measurements, several studies have identified a peak in DEH's between the ages of two and four years (e.g. Goodman *et al.* 1984b; Corruccini 1985; Wright 1990; Moggi-Cecchi *et al.* 1994; Bermúdez de

Castro and Perez 1995; Ensor and Irish 1995; Taji *et al.* 2000). As this age band correlates with weaning age in many traditional and developing countries, the peak in DEHs at this time has been linked to weaning stress caused by the introduction of supplementary foods, increased exposure to pathogens, and the reduction of passive immunity from breast milk (Katzenberg *et al.* 1996; Herring *et al.* 1998; McDade and Worthman 1998; Lewis 2007: 100-103; WHO 2008). However, the validity of this weaning hypopthesis was challenged by Blakey *et al.* (1994) who identified a lack of corroboration between the peak age of DEH formation and weaning age in a population where weaning age was known. Since then, the greater susceptibility of enamel to stress in the second to fourth year and the possible masking of earlier defects by the appositional layering of enamel in the occlusal area of the tooth have been offered as possible alternative suggestions (Goodman and Rose 1990; Hodges and Wilkinson 1990; Hillson and Bond 1997; Goodman and Song 1999; Reid and Dean 2000; Fitzgerald and Saunders 2005; King *et al.* 2005; FitzGerald and Rose 2008; Martin *et al.* 2008; Hillson 2014: 179-181). Ritzman *et al.* (2008) also found that the macroscopic methods employed by these studies tended to produce ages-at-defect formation significantly lower than those using more recent histological methods. Based on these findings, they suggest that re-evaluation of these techniques are needed due to the ability to produce divergent interpretations in skeletal populations.

(iii) Non-Specific Infection

Infectious disease processes are one of the most commonly encountered pathological conditions found within the skeletal record (Ortner 2003: 206; Weston 2012: 492). Despite this, the level of infectious disease observed within a skeletal population will be an underrepresentation of true prevalence rates in the past. This is because a large proportion of infectious diseases, including plague, cholera, typhus, small pox and rubella, predominantly affect the soft tissues and only rarely result in skeletal manifestations (Aufderheide and Rodríguez-Martín 1998: 191-212). Furthermore, some infections may be overcome or conversely overwhelm an individual before skeletal involvement occurs (Roberts 2000: 145; Ortner 2008: 191-192). The majority of infections that affect bone tend to have a bacterial aetiology, although viral, fungal, and parasitic causative organisms may also be implicated (Resnick 2002: 2377; Rosenberg *et al.* 2010: 344). The routes of transmission to the bone can either be due to: direct implantation of the infectious organism through an open fracture or penetrating wound; haematogenous dissemination via the bloodstream; or indirect transmission from a contiguous extra-skeletal focus, such as the surrounding soft tissue structures (Aufderheide and Rodríguez-Martín 1998: 172; Resnick 2002: 2379; Rosenberg *et al.* 2010: 341-344).

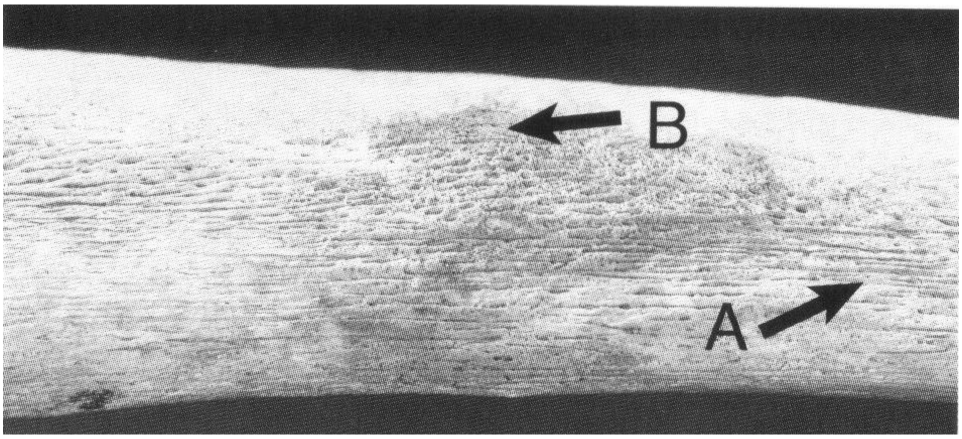

Figure 2.5: Non-Specific Infection on a long bone. A= New bone formation, B = area of porous new bone formation (taken from Roberts and Manchester 2005: 172)

The patterns of pathological changes that occur within the skeleton as a result of infectious processes vary significantly, depending on a variety of factors including: age, sex, route of transmission, and infecting organism (Roberts 2000: 146; Resnick 2002: 2380; Rosenberg *et al.* 2010: 341). They can consist of either new bone formation, bone destruction, or a combination of the two, and may affect different aspects of the bone structure (Ortner 2008: 192-193). "Periostitis" is the term used to describe inflammation of the periosteum, caused either due to direct infection or infection of the surrounding soft tissues (Resnick 2002: 2378; Buck and Bohndorf 2013: 137). This inflammation can be identified skeletally as resorptive pitting and/or the subperiosteal deposition of new bone on the original bone surface (Ortner 2003: 206). As the term periostitis refers to a process that occurs within the absent soft tissue, other terms such as "periostosis" and "periosteal new bone formation" are preferred (Ragsdale 1993: 465; Ortner 2008: 196; Weston 2012: 493). In the initial active phase of infection, the rapidly deposited new bone is disorganised and porous (woven bone) (Ortner 2003: 206). However, once healing begins, the bone will be subsequently remodelled into smooth, more organised bone (lamellar bone), which will eventually be incorporated into the original parent bone (Ortner 2008: 198; Larsen 2015: 87). Therefore, by examining the type of new bone deposits, it is possible to determine whether the infection was active, healing, or healed at the time of the individual's death (Mays 2010: 179-182). While periosteal new bone formation may occur on any bone surface, affecting either single or multiple elements, palaeopathological studies have identified a predilection for its occurrence on the anterior tibia, due to its close proximity to the skin, cooler surface temperature and greater vascularity (Roberts and Manchester 2005: 173).

While a clear link between infectious processes and periostosis has been demonstrated, periosteal new bone formation can occur in the absence of infective organisms. For example, an inflammatory response to trauma, seronegative spondyloarthropathies, rheumatoid arthritis, or haemorrhagic conditions, such as those observed with scurvy, will also stimulate new bone formation (Aufderheide and Rodríguez-Martín 1998: 179; Ortner 2003: 84, 563; Burgener 2006: 131; Brickley and Ives 2008: 56f; Schultz 2012: 261-262). Differential diagnoses should also consider other conditions that result in the deposition of new bone; such as: neoplastic disease (e.g. Ewing's sarcoma, osteosarcoma, osteoid osteoma, fibrous cortical defect, benign bone cysts, and leukaemia) and granulomas (Aufderheide and Rodríguez-Martín 1998: 179; Resnick 2002: 2418; Vigorita 2008: 298). Morphological variations of the different periosteal lesions associated with these various aetiologies, described by Ragsdale *et al.* (1981) and Resnick and Niwayama (1995: 4435) amongst others, will allow for some differentiation (Ortner 2003: 206; Ortner 2008: 192-193). However, Weston (2008; 2009) found the uniform way in which the periosteum responds to multiple pathological processes meant it was not possible to differentiate between specific aetiologies responsible for periosteal new bone formation through macroscopic, histological, or radiographic investigation. As a result, Weston (2008; 2009) argues the interpretation of periosteal new bone formation solely as evidence of infection within archaeological collections may lead to a false impression of the level of infectious disease in the past.

Interpretations of periosteal new bone formation may also be complicated in subadults by the presence of woven bone deposited during normal apposition growth, particularly during periods of rapid growth (Vigorita 2008: 296). Consequently, several bioarchaeologists have concluded it may not be possible to differentiate between pathological and normal growth-related new bone formation in infants (Shopfner 1966; Mann and Murphy 1990; Ribot and Roberts 1996; Lewis 2004; Weston 2012). Lewis (2007: 135) has suggested that new bone formation with an infectious aetiology in subadults is most likely to be recorded as localised and unilateral, with new bone formation due to growth being instead characterised by circumferential thick single layered deposits occurring bilaterally (Shopfner 1966; Lewis 2007: 135; Weston 2012: 497). However, if an infection is systemic and leads to periosteal new bone formation throughout the skeleton, it may be impossible to differentiate this pathological process in subadults from normal growth. This is particularly problematic as the periosteum is less securely attached in subadults, making it more likely to rupture and allow extensive new bone formation (Resnick 2002: 2397; Lewis 2007: 135; Vigorita 2008: 298; Tadros *et al.* 2012: 973).

Another criticism Weston (2012: 506) has discussed regarding the interpretation of periosteal new bone formation is its use as a stress indicator. She states that as new bone formation is inhibited under conditions of physiological stress, due to the concomitant increase in glucocorticoid secretion, periosteal lesions cannot be viewed as stress indicators (Weston 2012: 506). However, Klaus (2014) has recently challenged this notion. Firstly, although he acknowledges that stress will inhibit bone formation, Klaus (2014: 295-299) argues the effect of stress on bone production is much more complex than a simple on/off causal relationship, with bone formation and remodelling both being possible under stress conditions. Secondly, he suggests that as pathological new bone formation tends to occur in the later stages of infection/inflammation once subsequent recovery has begun, periosteal lesions may be considered analogous with the stress indicator dental enamel hypoplasia (Klaus 2014: 298). Larsen (2015: 88) also argues periosteal lesions should still be considered an important stress indicator despite issues regarding their aetiology, due to the association of their increased prevalence with sedentism, population aggregation and poor living conditions in many archaeological populations. Further to this, Larsen (2015: 88) suggests the conduciveness of these aforementioned conditions to the transmission of infectious diseases, makes this aetiology a more likely cause of periosteal lesions in the prehistoric populations he discusses.

"Osteitis" is the term used to describe infection that occurs within the inner structures of the bone cortex itself (Resnick 2002: 2378; Buck and Bohndorf 2013: 137). The diagnosis of osteitis may be difficult without radiological investigation, and macroscopic identification usually requires the examination of the cortex in cross section. However, an expansion in the width of "bulging" of the affected area may be observed. Radiographically osteitis may be observed as a thickening of the bone cortex and narrowing of the medullary cavity (Resnick 2002: 2377). An infection that occurs within the medullary cavity is termed "osteomyelitis" (Resnick 2002: 2378). Osteomyelitis most often occurs due to haematogenous spread of bacteria from elsewhere in the body, but will also occur from other microorganisms and through direct implantation into the bone (Rosenberg *et al.* 2010: 341-344; McCarthy and Frassica 2015: 147). *Staphylococcus aureus* is the most common cause of osteomyelitis (90%), though other bacteria, such as *Streptococci*, and *Haemophylus Influenzae,* may also be responsible (Adler 2000: 129; Resnick 2002: 2380; Ortner 2003: 181). In infants, group B *Streptococci, Streptococcus Pyogenes*, and *Escherichia Coli* are also more frequently encountered (McCarthy and Frassica 2015: 147-148; Sukhtankar *et al.* 2015: 207-212). Initially, the infection within the medullary cavity may be limited to the formation of pyogenic abscesses ("Brodie's abcess"), which are observed as sharply delineated radiolucent cavities radiographically (Chew 2010: 299-300). As the infection spreads throughout the bone, the internal pressure will gradually result in progressive penetration of the outer cortex of the bone, resulting in the creation of small holes or *cloacae* to allow discharge of the pus (Ortner 2003: 183-184; Lito *et al.* 2015: 259-260). The periosteum may also be affected and new bone formation may be observed on the outer cortex, and if extensive, may form a new sheath of bone (“involucrum”) that enlarges the diameter of the bone shaft (Ortner 2008: 196; McCarthy and Frassica 2015: 147-148). Another feature of osteomyelitis is necrosis of the original bone cortex, which when separated from the living bone is called the “sequestrum” (Aufderheide and Rodríguez-Martín 1998: 175; Resnick 2002: 2379). Osteomyelitis is most commonly observed in subadults between the ages of 3-15 years, with males being more frequently affected than females (Resnick 2002: 2380; Roberts and Manchester 2005: 172). In subadults, the metaphyseal region of the long bones is most commonly affected, though in infants the infection may extend into the epiphyseal region (Adler 2000: 132-133; Rosenberg *et al.*2010: 341-344). In adults, the short bones and particularly the vertebrae are the most commonly affected regions (Adler 2000: 129; Zimmerli 2015: 221).

Evidence of infection within the skeleton may include one or all of these aspects of bone, and an examination of the types of lesions and their distribution may allow the identification of a specific causative organism (Lovell 2000; Ortner 2008: 194). The best studied of these are tuberculosis, leprosy, and the treponemal diseases, due to the characteristic nature of the suite of pathological changes observed across the skeleton with these diseases (Hackett 1976; Anderson and Manchester 1992; Anderson *et al.* 1994; Lewis *et al.* 1995; Rothschild and Rothschild 1995; Roberts 2000; Roberts *et al.* 2002; Roberts and Buikstra 2003; Ortner 2003: 227-318; 2008; Cook and Powell 2012). However, due to the limited ability of bone to respond to a wide range of infectious processes, it is often not possible to identify a particular aetiology, with most instances being designated as non-specific infection (Roberts and Manchester 2005: 168; Ortner 2008: 192; Ragsdale and Lehmar 2012: 228). Despite this further attention has been given to the presence of non-specific infection in specific skeletal elements, namely the ribs, maxillary sinuses and the endocranium, due to a greater ability to determine potential aetiology in these regions (Roberts and Manchester 2005: 174-179). Periosteal lesions on the visceral rib surfaces and within the maxillary sinuses have been linked to respiratory infections caused by indoor and outdoor air pollution (Boocock *et al.* 1995; Capasso 2000; Roberts 2007; Bernofsky 2010). Periosteal rib lesions have also been associated with tuberculosis, although they are not considered pathognomonic of the disease and can occur with pneumonia and other pulmonary infections (Pfeiffer 1991; Roberts *et al.* 1994; Roberts 1999; Mays *et al.* 2002; Buikstra and Roberts 2003: 105-107). Endocranial new bone formation is caused by inflammation of the meninges, with potential aetiologies including:

meningitis, epidural haematomas, birth trauma, anaemia, neoplasia, scurvy, rickets, tuberculosis, and other venous drainage disorders (Lewis 2004).

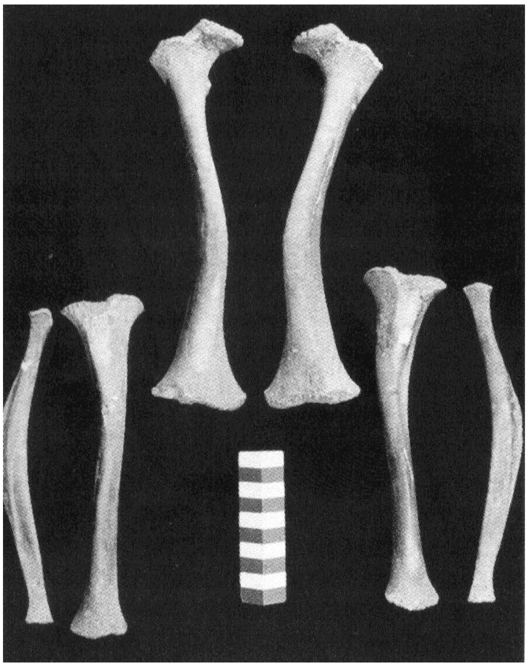

Figure 2.6: Bowing of the long bones of the leg associated with rickets (taken from Roberts and Manchester 2005: 238)

(iv) Vitamin D Deficiency

One of the primary functions of vitamin D within the body is to facilitate the absorption of calcium and phosphorous, two of the principle components of the mineral portion of bone (hydroxyapatite), into the bloodstream (Holick 2003; DeLuca 2004). A deficiency in the supply of vitamin D will therefore result in insufficient levels of these elements for the adequate mineralisation of the protein precursor of bone (osteoid) (Holick 2005: 2741S-2742S). The vast majority of vitamin D is synthesised within the body through a process initiated by exposure of the skin to ultraviolet light, although small amounts can be obtained from diet (Holick 2003; Holick 2007:266-267). As such, the most common cause of vitamin D deficiency is a reduction of sunlight exposure (Holick 2007; Huotari and Herzig 2008). Other causes include congenital malabsorption syndromes, acquired gastrointestinal diseases that inhibit absorption (e.g. Crohn’s disease, persistent diarrhoeal diseases), or dietary deficiencies related to malnutrition (Holick 2007; Bikle 2007; Pappa *et al.* 2008; Ulitsky *et al.* 2011). Within archaeological populations, vitamin D deficiencies have been attributed to poor working and/or living conditions that restrict sunlight, cultural practices, and increased air pollution (Brickley *et al.* 2005*;* 2007; Mays *et al.* 2006).

While vitamin D deficiency can affect both subadults and adults, the expression of the disease within the skeleton differs between these two age groups (Ortner and Mays 1998; Brickley *et al.* 2005*;* 2007; Mays *et al.* 2006; Brickley and Ives 2008: 75-150). Changes that occur in the growing skeleton, referred to as rickets, tend to be more dramatic than those seen in adults, referred to as osteomalacia (Ortner 2003: 393-399; Chew 2010: 284; Root and Diamond 2008: 723; Kozlowski and Witas 2012: 406)

As vitamin D deficiency in the growing skeleton prevents the deposition of mineralised bone in developing cartilage, deformation of the cartilaginous growth plate between the metaphyses and epiphyses occurs under mechanical force, expanding the size of the growth plate (Chew 2010: 284; Pettifor 2012: 641-2). These changes will be most pronounced at prominent areas of endochrondral growth, such as the ends of long bones and the costochondral junction of the ribs (Francis and Selby 1997: 148; Ortner and Mays 1998: 46; Pettifor 2008: 444; Root and Diamond 2008: 723). These changes are observed osteologically as "swellings" of the metaphyses and cupping deformities of the growth plate (Ortner 2003: 393-4; Mays *et al.* 2006: 365-7; Brickley and Ives 2008: 90-91; Pettifor 2008: 444-445; Chew 2010: 284). The bone surface of the affected regions will also take on a frayed appearance, observed radiographically as a "brush-like" appearance, while greater porosity of the growth plate will be observed (Mays *et al.* 2006: 364-367; Root and Diamond 2008: 723; Chew 2010: 284; Manchanda and Gupta 2012: 179; Pettifor 2012: 642). Osteopenia may also occur, resulting in further decreases in mechanical strength (Silverman and Kuhn 1993: 1747-1751; Ortner 2003: 396; Mays *et al.* 2006: 366; Plotkin and Lifshitz 2007: 533-534).

In severe cases, the accumulation of unmineralised osteoid results in mechanical weakening of the bone and subsequent bending deformities in weight-bearing long bones (Ortner and Mays 1998: 46; Schamall *et al.* 2003; Plotkin and Lifshitz 2007: 533-4; Kozlowski and Witas 2012: 405; Manchanda and Gupta 2012: 180) (Figure 2.6). These bowing deformities are the most recognisable and synonymous features of rickets and, prior to the identification of the more subtle changes outlined above, would have previously been the main diagnostic criteria (Mays *et al.* 2006: 363-4). The extent and location of bowing reflects behaviour, with forearm bowing occurring due to crawling and lower leg bowing during walking (Ortner and Mays 1998: 51-2; Ortner 2003: 396; Roberts and Manchester 2005: 237; Pettifor 2008: 444; Kozlowski and Witas 2012: 405). Reduced angulation of the femoral head (*coxa vara*) may also occur due to weight bearing on weakened bone (Ortner 2003: 401; Mays *et al.* 2006: 367; Joshi and Kotwal 2008: 343; Soloman 2010: 136). Pressure exerted through swaddling infants may also cause bowing independent of mechanic weight bearing (Pettifor 2008: 444). Within the chest, cupping deformities and flaring of the costochondral rib ends, referred to as rachitic rosary, may result in the protrusion of the sternum and increased rib angulation (pigeon-chest appearance) (Mays *et al.* 2006: 365; Brickley and Ives 2008: 104; Manchanda and Gupta 2012: 180; Pettifor 2012: 642-3).

Porous lesions on the cranial vault and within the orbits may also be observed (Ortner and Mays 1998: 46; Ortner 2003: 394). Though these lesions may be difficult to differentiate from those attributed to porotic hyperostosis and *cribra orbitalia*, a lack of marrow expansion in association with the lesions is observed (Schulz 2001: 131-137; Ortner 2003: 102-105). In young infants, delayed closure of the fontanelles may occur as well as craniotables (flattening of the bone due to softening of the bone in the occipital region) (Francis and Selby 1997: 148; Root and Diamond 2008: 723; Brickley and Ives 2008: 103; Pettifor 2012: 635-636). Dental abnormalities and/or delayed eruption of the dentition have also been identified in association with rickets (Plotkin and Lifshitz 2007: 533-534; Hillson 2014: 189-191). Due to the decrease in mechanical strength, fractures and Looser's zones (pseudofractures) may also be observed (Pettifor 2008: 445; Chew 2010: 284; Adams 2011: 865).

While the age of onset of rickets may vary considerably, the peak in incidence rates occurs between three and twenty-four months (Ortner and Mays 1998; Ortner 2003: 393; Brickley and Ives 2008: 91; Pettifor 2012: 628). In a clinical context, rachitic changes are rarely seen in subadults prior to this, due to the presence of foetal stores and vitamin D in breast milk (Jelliffe and Jelliffe 1978; Ortner 2003: 393; Pettifor 2012: 628). Therefore, maternal malnutrition during pregnancy and breastfeeding has been implicated in early infantile onset (Rothberg *et al.* 1982; Park *et al.* 1987; Salle *et al.* 2000; Roberts and Manchester 2005: 238). The introduction of cereals containing phytates as part of the weaning diet may also exacerbate vitamin D deficiency (Pettifor and Daniels 1997: 665; Pettifor 2004: 1726S-1727S; Harinarayan *et al.* 2007). If the vitamin D deficiency is overcome, remodelling may resolve some of these pathological changes, although severe bowing may be retained into adulthood (residual rickets) (Ortner 2003: 396; Brickley *et al.* 2010; Pettifor 2012: 643).

As vitamin D deficiency in adults (osteomalacia) only affects bone remodelling, the changes observed are much less severe than those associated with rickets (Ortner 2003: 398-399; Pettifor 2003: 541; Brickley *et al.* 2005*;* 2007; Chew 2010: 284). The main manifestation in adults tends to be osteopenia and the appearance of pseudofractures (linear fractures within the external bone cortex) (Parfitt 1986; Parfitt 1998: 342-343; Burgener 2008a: 73-74; 2008b: 3-4; Chew 2010: 284). These pseudofractures tend to occur bilaterally, showing a predilection for the base of the scapular spinous process, pubic rami and the ribs (Brickley *et al.* 2005: 391-392; Burgener 2008b: 3-4; Manchanda and Gupta 2012: 185). These pseudofractures may eventually become complete fractures. Over time, increased softening of the bone may result in bending deformities, particularly in bones with high proportions of trabecular bone, such as the pelvis, ribs and scapula, due their increased bone turnover rate (Brickley *et al.* 2005: 390-397; Kormano and Pudas 2008a: 320-321; Manchanda and Gupta 2012: 186). Biconcave compression fractures of the vertebral bodies may also occur, leading to scoliosis or kyphosis (Pitt 1988: 2098; Francis and Selby 1997: 148; Brickley *et al.* 2005: 393-394; Kormano and Pudas 2008b: 260; Guglielmi *et al.* 2013: 71). In severe cases, buckling deformities of the ilia and pubic rami that reduce the pelvic dimensions have been observed (Brickley *et al.* 2005: 397-8; Manchanda and Gupta 2012: 186).

An important consideration in the diagnosis of vitamin D deficiency is the presence of co-morbidities (Ortner and Mays 1998: 45; Rivlin 2007: 178-179). Vitamin D deficiency has been identified to co-occur with vitamin C deficiency (Barlow 1883; Follis *et al.* 1940; Ortner and Mays 1998: 45; Ortner *et al.* 2001: 349; Weinstein *et al.* 2001: 4; Pimentel 2003; Ortner 2003: 385; Brickley and Ives 2008: 61). Both diseases have lesions of similar appearance, such as the swelling and cupping deformities of ribs and cranial lesions (Ortner and Mays 1998: 45; Ortner 2003: 82; Brickley and Ives 2008: 69-71; Lewis 2010: 408; Kozlowski and Witas 2012: 406). Therefore, a close examination of the skeletal distribution of manifestations is needed (also see Section 2.2.3 (v))

(v) Vitamin C Deficiency – Scurvy

Vitamin C is essential in humans for the proper synthesis and maintenance of collagen, the main structural protein found in bone, blood vessels and connective tissues (Gropper and Smith 2013: 312-316). As one of the few animals unable to synthesise vitamin C, humans must obtain it directly from their diet (Levine *et al.* 2006: 507). Fresh fruit and vegetables provide the main source of vitamin C, though small amounts can be found in dairy products and fish (Gropper and Smith 2013: 311). Consequently, a deficiency of vitamin C reflects inadequate provisions of these food items within the diet. Alternatively, prolonged food storage and cooking methods (i.e. boiling) may also be responsible (Fafunso and Bassier 1976; Riemer and Karel 1977). In order for vitamin C deficiency, or scurvy, to occur prolonged absence of vitamin C in the diet is required, with skeletal manifestations only appearing after several months (Fain 2005: 126; Polat *et al.* 2015: 1). As such, vitamin C deficiency is rarely seen in neonates and very young infants due to the presence of foetal stores and vitamin C in breast milk (Jelliffe and Jelliffe 1978; WHO 1999: 4-6; Ahmed *et al.* 2004). Even if a mother is deficient in vitamin C, scurvy will still rarely be seen prior to the age of four months, with eight to ten months being the most prevalent age of onset in infants (Jelliffe 1970; Ortner 2003: 384; Fain 2005: 126; Brickley and Ives 2006: 162).

The most characteristic skeletal manifestations observed with scurvy occur as a result of haemorrhages created by damage to blood vessels with weakened collagen structures (Maat 1982; Tamura *et al.* 2000; Ortner 2003: 384; Ratanachu-Ek *et al.* 2003). The damage required to cause these haemorrhages is often minimal, with bleeding occurring as a result of limited normal tissue movement, such as chewing (Ortner and Ericksen 1997: 218; Aufderheide and Rodríguez-Martín 1998: 311). When these haemorrhages occur beneath the periosteum or near to a bone surface, the localised inflammatory response will result in increased bone porosity and/or new bone formation (Tamura *et al.* 2000; Ortner 2003: 384; Ratanachu-Ek *et al.* 2003; Fain 2005; Brickley and Ives 2008: 48). However, these new bone formations will only be observed if vitamin C is reincorporated into the diet, although only small amounts are required to ensure this (Noordin *et al.* 2012: 4). As scurvy also depresses osteoid production, osteopenia (decreased mineral density) may also be observed radiographically as radiolucent areas within the bone (Weinstein *et al.* 2001: 1, 5; Akikusa *et al.* 2003; Burk and Molodow 2007: 105-106; Brickley and Ives 2008:48). The resultant weakness created within the bone structure may also lead to fractures through the affected areas (Aufderheide and Rodríguez-Martín 1998: 312; Paterson 2010).

Skeletal changes associated with scurvy tend to be most prominent in infants and young subadults undergoing rapid growth (Ortner 2003: 384; Fain 2005: 126; Brickley and Ives 2006; Lewis 2007: 131). While haemorrhages may occur anywhere within the body, typical locations for associated porosity and/or new bone formation in subadults are: the external surface of the cranial vault (parrot swellings), the greater wing of the sphenoid, the palatal bones, the orbital roof, mandibular rami, the metaphyses of long bones, and the supraspinous and infraspinous regions of the scapulae (see Ortner and Ericksen 1997; Aufderheide and Rodríguez-Martín 1998: 311-312; Ortner *et al.*1999; Sloan *et al.* 1999; Ortner 2003: 385-387; Brickley and Ives 2006; 2008: 56-65; Brown and Ortner 2011) (Figure 2.7). Identification of the aforementioned cranial manifestations is considered particularly important for diagnosis (Ortner and Ericksen 1997; Ortner *et al.* 2001: 346; Ortner 2003: 390; Brown and Ortner 2011: 203-204). As the periosteum is less firmly attached to the bone in subadults, the extent of haemorrhage, and therefore porosity and/or new bone formation, tends to be much greater than that observed in adults (Jaffe 1972: 455; Ortner 2003: 89; Lewis 2007: 131; Brickley and Ives 2006). In addition to haemorrhagic manifestations, a depression in osteoid production may result in growth retardation in the growing skeleton, with increased mineralisation occurring at the ends of the metaphyses, observed radiographically as a white radio-opaque band, although these are quickly remodelled with the reintroduction of vitamin C (Weinstein *et al.* 2001: 5; Burk and Molodow 2007: 105-106; Noordin *et al.* 2012: 3-4; Polat *et al.* 2015: 2). Microfractures, or Pelkan spurs, may also be apparent at the lateral edge of metaphyses, appearing as spurs of radio-opaque bone, as well as more substantial metaphyseal fractures through osteopenic bone (Tamura *et al.* 2000; Kuhn 2014: 946-8). Enlargement of the ribs at the costochondral junction, referred to as scorbutic rosary, may also be observed (Aufderheide and Rodríguez-Martín 1998: 311; Ortner 2003: 386; Fain 2005: 126; Brickley and Ives 2008: 57; Noordin *et al.* 2012: 4).

In adults, scorbutic lesions tend to be more subtle and non-specific in nature as they only affect bone remodelling (Weinstein 2001: 4; Brickley and Ives 2008: 61-62; Van de Merwe *et al.* 2010). Therefore, the identification of scurvy in adult skeletons is often difficult and probably underreported. New bone formation will tend to be less extensive in adults and is most commonly seen within the orbits (Stuart-Macadam 1989a: 203; Hirschmann and Raugi 1999: 902; Ortner 2003: 387). The often mentioned and synonymous swollen “bleeding gums” associated with scurvy may also result in porosity and/or new bone formation in the mandible and maxillae, as well as potential antemortem tooth loss, caused by the degeneration of connective tissues that hold the teeth in place (Hillson 1996: 165-166; Maat 2004; Brickley and Ives 2008: 49). Bleeding into the joint spaces may also occur resulting in haemarthrosis, with the hip, knee and ankle being the most commonly affected joints (Joffe 1961; Hirschmann and Raugi 1999: 902; Fain 2005: 125). Decreased osteoid production will also result in osteopenia in adults, possibly leading to secondary fractures in severe cases (Fain 2005: 126; Brickley and Ives 2008: 63-64; Baltazar *et al.* 2015: 900e17).

When attempting a diagnosis of vitamin C deficiency in skeletal remains it is important to consider potential differential diagnoses of other disease processes. Many of the aforementioned scorbutic lesions are in themselves non-specific, particularly in adults, making it necessary to identify a pattern of co-occurrence of these lesions throughout the skeleton (Ortner 2003: 385; Brickley and Ives 2008: 61). Therefore, good skeletal preservation is essential to ensure correct diagnosis, which may be problematic in fragmentary archaeological collections. Diagnosis is also further confounded by the presence of co-morbidities, particularly as deficiencies in macronutrients tend to frequently co-occur (Rivlin 2007: 178-179). Anaemia, due to the involvement of vitamin C in the metabolism of iron and folate, and vitamin D deficiency have both been shown to co-occur with scurvy, making careful examination of individual lesions and the skeletal distribution of changes essential (Barlow 1883; Follis *et al.* 1940; Ortner and Mays 1998: 45; Ortner *et al.* 2001: 349; Weinstein *et al.* 2001: 4; Pimentel 2003; Ortner 2003: 385; Brickley and Ives 2008: 61). For example, cranial vault changes have been observed in connection with anaemia and vitamin C and D deficiencies, although those observed with anaemia (see Section 2.2.3 (i)) may be differentiated by its associated marrow hypertrophy that is not present with vitamin C and D deficiencies (Ortner and Ericksen 1997; Schulz 2001: 131-137; Ortner 2003: 102-105).

2.3 Roman Children and Childhood

There is a strong tradition of studies of children and the family within classics and ancient history (Rawson 2011). However, early studies were dominated by the more sensationalist aspects such as infanticide or lack of care/parental indifference (e.g. DeMause 1976). Emerging from this in the 1980s was Rawson's research which focused on all aspects of the Roman family, including the role of children within the household and parent/child relations (1986a; 1986b; 1991). This work provided an important foundation and stimulus for other scholars to explore in detail aspects of childhood and the life course, and by drawing on developments in child social theory led to an evolution in discussions of childhood as a distinctive stage of the life course linked to other identities such as status and gender (Huskinson 1996; Laurence 2000; Dixon 2001; Harlow and Laurence 2002; 2010; Rawson 2003; 2011; Uzzi 2005; Laes 2011; Krause 2011).

While informative, many of these studies were biased towards Mediterranean sources of elite communities due a paucity of historical evidence from elsewhere in the Roman Empire (Huskinson 1996; Laurence 2000; Harlow and Laurence 2002; 2010; Rawson 2003; 2011; Uzzi 2005; Laes 2011). This bias has been problematic for those seeking to study perceptions of childhood outside of the core of the Empire. Studies of family life in the western provinces show that it is subject to considerable regional and temporal variation (Woolf 2005). Archaeological evidence is beginning to be exploited in the study of childhood in Roman Britain, but there is still much more work to be done. Likewise, skeletal data is still a comparatively untapped resource that remains peripheral to mainstream Roman studies (Reece 1982: 347). To date, most studies have utilised settlement evidence and material culture, in particular funerary evidence, with a focus on grave furnishings, etc., rather than utilising the actual remains of the people themselves. This type of funerary analyses is particularly problematic for the Roman period in Britain for which inhumations are restricted to the later period of occupation and burial practices tend to be homogenous (Philpott 1991). Many of the Roman burials tend to be unfurnished and relatively uniform in term of coffin type, body position and grave orientation (Philpott 1991). More recently scholars have attempted a more integrated approach, discussing the skeletal evidence for demography, health and status, in relation to the funerary evidence. Examples of these will be discussed below, but first it is worthwhile exploring Roman definitions of childhood as gleaned from historical sources.

2.3.1 Defining the Roman Child

Studies of the life course in the Roman world have identified a series of demarcated stages that marked the progression from child to adult (Harlow and Laurence 2002; Rawson 2003; Laes 2011). During these transitions the infant gradually attained personhood and the child was “socialised” and prepared for adult life (McWilliam 2013: 264ff). Tables 2.1-2.5 outlines a number of formalised age stages that have relevance to Roman perceptions of the life course and the relationship between chronological age and social age-related behavioural norms.

Starting with the point of birth, the conferment of personhood was not immediate, but a more gradual transition (Dasen 2013: 17-20). According to Soranus, once the midwife had inspected the child for any physical deformities, it was the *Paterfamilias* who decided whether to expose or keep the child (Dixon 1992: 101; Krause 2011: 627, contra Shaw 2001). This decision was one that was made very soon after birth and prior to the baby’s first bath, which was regarded as one of the first acts of acceptance (Dasen 2011: 295-297). Following this, the infant was not socially recognised by the community until their naming day (*dies lustricus*), which took place on the 8th or 9th day after birth, depending on sex (Harlow and Laurence 2002: 39; Rawson 2003: 111).

While many different subdivisions of the life course in life tables from the period are known (see Tables 2.1-2.5), all of them recognise this early period as a particularly vulnerable stage in the life course. The term “*Infans”* (which literally means “not speaking”), could be ascribed up until the age of approximately seven years (Harlow and Laurence 2002: 37). This specially denoted period of vulnerability is perhaps not surprising considering the dangers of childbirth and high infant and child mortality rates of the Roman period, with approximately 30% of all infants dying within their first year (see Parkin 2013 for discussion). Recognition of the dangers of this age is evident in large numbers of votives and gods assigned to the protection of the mother and child (Garnsey 1991: 53-4; Turcan 2001: 18-21; Ammerman 2007; Dasen 2009: 213). Evidence from historical documents also indicates a recognition of the different psychological and physical needs of the child, with specific prescriptions for diet and treatment that differed from adults (Baker 2010: 162-7; Laes 2011: 22-50, 83). For example, the medical writer Celsus noted that diarrhoeal diseases were a common cause of death in those under the

Age	Stage	Physical Manifestations
0-7yrs	Small child	Teething
7-14yrs	Child	First facial hair
14-21yrs	Teenager	Full beard
21-28yrs	Young Man	Fully grown body
28-49yrs	Adult man	-
49-56yrs	Older man	-
56-?	Old Man	-

Table 2.1: Ages of Man according to pseudo-Hippocrates (Laes 2011: 89)

Age	Stage	Celestial Body	Descriptions
0-4yrs	Baby	Selene = Luna	Only negative terms, moon moves fastest, unstable, body of the infant is soft and humid, grows rapidly and requires moist nourishment, mentally incompetent and not disciplined
5-14yrs	Child	Hermes = Mercury	(only ½ of 20yr cycle), education is paramount, children begin to learn and talents/character form
15-22yrs	Teenager	Aphrodite = Venus	Dominated by budding sexuality and passion, lack of restraint and reckless behaviour
23-41yrs	Adult Age	Helios = Sun	Recklessness and playfulness make way for sobriety and more orderly conduct, desires distinction & glory
42-56yrs	Manhood	Ares = Mars	Bringer of calamity, phase marked by physical and mental worries, vexation and trouble, aware best years behind
57-68yrs	Old Age	Zeus = Jupiter	More mature, exhibits foresight, prudence and sagacity and able to console others, strives for honour, respect and privilege but conducts himself with restraint and respectable composure
69-?	Very Old Age	Chronos = Saturn	Dark& slow planet, body and soul chill and grow weak, despondency & dissatisfaction, life becomes dull

Table 2.2: Life division according to Ptolemy (Laes 2011: 90)

Age	Stage
0-15yrs	*Puer*
15-30yrs	*Adulescens*
30-45yrs	*Iuvenis*
45-60yrs	*Senior*
60+yrs	*Senex*

Table 2.3: Varro's life table (Laes 2011: 93)

Age	Stage	Characteristics
0-7yrs	*Infantia*	Simple life
7-14yrs	*Pueritia*	Simple life, not suited for procreation, pure age
14-28yrs	*Adolescentia*	Intellect and vigour, mature enough to procreate
28-49yrs	*Iuventus*	Intellect, vigour and physical strength, strongest of all ages
49-77yrs	*Senectus*	Intellect, vigour and maturity of mind and body, not old nor youth
77-?yrs	*Senium*	No specified age limit

Table 2.4: Division of the life course according to Isidore of Seville (after Laes 2011: 95)

Life Stage	Basic Qualities	Temperament	Season
Child (up to 20 or 25yrs)	Warm and moist	Sanguine	Spring
Youth (25-40yrs)	Warm and dry	Choleric	Summer
Maturity (up to 60yrs)	Cold and moist	Phlegmatic	Autumn
Old Age (from 60yrs)	Cold and dry	Melancholic	Winter

Table 2.5: Division of the life course according to Humeral theory (after Laes 2011: 87)

age of ten (*De Med* 2.8.30), while Galen advised against the drinking of wine for children due to their already hot disposition (Dalby 2003: 84; Baker 2010: 162). Despite the use of 0-7 years as denoting a single category of "*infans*", it is clear from iconographic and historical evidence that further sub-divisions were recognised (e.g. Huskinson 1996; Larsson Lovén 2013: 302ff; McWilliam 2013). For example, teething and learning to walk were also viewed as significant for the conferment of personhood, possibly denoted by a distinction between intra-mural and extra-mural burial (Pearce 2001).

Engendered identities are first observed from the age of seven years, indicated by the application of gendered terminology that separated the sexes such as *puer* and *puella* (Harlow and Laurence 2002: 37). It is also the time that that sexuality and virginity is first attributed to children (Fraschetti 1997). From this age onwards, males and females would then have experienced different life course trajectories and social age milestones. The life course of females would have been more closely tied to the rite of marriage (Alberiei and Harlow 2007:203). While documentary evidence suggests that this may have occurred as early as twelve years in elite families (Hopkins 1965; Laurence 2000), it is likely to have occurred later for the majority of the population, probably in their late teenage years or early twenties (Shaw 1987; Saller 1994: 36). Between the ages of 14-17 years of age boys would then remove their *bulla* (a protective amulet bestowed on citizen children) and replace the *toga praetexta*, with the *toga virilis* as a sign of manhood (Harlow and Laurence 2002: 67; Rawson 2003: 323; Krause 2011: 629). Their transition to adulthood, however, was not fully complete at this age and they remained in a liminal, adolescent status until the age of 25 years. Until that time they were still considered to be prone to fickleness, irrationality and could not yet be trusted to hold office (Eyben 1993; Laurence 2000: 446). Males tended not to marry until the age of thirty years, and usually to women who were approximately ten years their junior (Parkin 1992; Saller 1994: 36).

It should be noted, however, that the age divisions given by these life tables tend to favour notions of Roman numbering systems and connections to larger systems such as astrology that may have had no bearing on the everyday perceptions of the life course (Rawson 2003: 136; Laes 2011: 88-95). Though it is noted that Galen's prescriptions for diet and exercise in the *hygiene* also follow a similar numbering system, favouring the division of life into periods of seven years. Perhaps more important sources of key transitions of the Roman subadult life course are observed in the iconographic record, in particular depictions of the life course on the sarcophagi of Roman children (Huskinson 1996; Larsson Lovén 2013: 302ff). Common important moments recorded are the first bath, marking the official acceptance of the child into the family, first steps and scenes of play (Huskinson 1996: 11). Education also seems to have been important, with depictions of lessons also commonly seen (Huskinson 1996: 11; Harlow and Laurence: 50). That the subadults buried within these coffins are sometimes younger than the depictions on them further supports these key transitions, marking the life stages denied to the family (Carroll 2006). The historical, epigraphic and iconographic evidence, although illuminating to a degree, tends to be biased towards an elite male perspective (Prowse 2011: 411). The extent to which these clearly delineated life course stages were adhered to is unknown and this is particularly so when one attempts to understand perceptions of childhood beyond Italy to which much of this evidence pertains.

2.3.2 Subadult Age in Roman Britain

How closely the inhabitants of Roman Britain subscribed to the above Roman Italian notions of the life course and childhood is unknown. The applicability of these age categories and associated social expectations to areas outside of the elite Roman Mediterranean is in doubt, given the fact that the life course is known to be culturally constructed and therefore subject to temporal and spatial differences (Gilchrist 2000:326). A few studies have begun to address other avenues of investigation for studying the socially constructed nature of childhood in Roman Britain. One of the first studies of childhood in Roman Britain based on funerary evidence was undertaken by Gowland (2001) on the Roman cemetery of Lankhills, Winchester. Overall she found that children had a higher overall proportion of grave goods and that four to seven years was a period in which children appeared to undergo an age transition, being buried with an increase in the number and quality of the grave goods (Gowland 2001: 158-160). This age also coincided with a more strongly signified gender identity (Gowland 2001: 161). This shift in burial practice to some extent mirrored that discussed in the historical sources, where a transition at 7 years towards a more strongly expressed gender identity is noted (Fraschetti 1997; Harlow and Laurence 2002: 36). A more recent study by Jenny (2011) on the Roman site of Butt Road, Colchester, noted a similar pattern in terms of the material culture. For example hairpins were only worn by children from the age of seven years onwards (Jenny 2011: 109).

Other studies, while not specifically focused on the life course in a detailed way, have noted differences between subadults and adults. For example, Quensel-Von-Kalben (2000) examined ten cemeteries from Roman Britain and found that a distinction always seemed to be maintained between subadults and adults in burial practice, but the nature of that difference was not always consistent between cemeteries. At some cemeteries children had greater numbers of grave goods than adults, while at other sites the reverse was true (Quensel-Von-Kalben 2000: 220). Occasionally the differences between adults and subadults was more subtle in terms of the treatment of the corpse and general layout of the grave, or location of child graves with respect to other graves and prominent features of the landscape (Quensel-Von-Kalben 2000: 220).

Hamlin (2007) again noted subadult/adult differences in burial treatment in Roman Dorset that were not present during the late Iron Age in this region. The age of the deceased played a role in the distribution of grave goods and, in particular, personal ornaments were buried with subadults while utilitarian items were buried with adults. Puttock's (2002) research on the deposition of personal ornaments in Romano-British contexts noted that the great majority of "wealthy" graves in terms of the deposition of personal ornaments were those of children and young women under the age of 22 years. While these studies of the funerary evidence had been fruitful in terms of identifying distinctions between adults and subadults, as well as more subtle shifts in identity throughout childhood, the skeletal remains themselves have started to play an increasingly important role in the study of Roman children.

2.3.3 Bioarchaeology of Roman Childhood in Britain

Bioarchaeological studies of Roman childhood in Britain are scare. In an examination of the bioarchaeological data produced for the Romano-British period, Bonsall (2013: 38-40) found most of the data was contained within cemetery reports, often being confined to small descriptive accounts in special appendices rather than in-depth interpretations (e.g. McWhirr *et al.* 1982; Crummy *et al.* 1993; Barber and Bowsher 2000; Mackinder 2000; Watson 2003). Indeed, within these volumes, it is common to find more space given over to the discussion of cemetery organisation and material finds than skeletal analyses. Within these restricted summaries, little consideration is often given to the patterns of demography and pathology observed within subadults buried within the cemetery beyond the noting of their underrepresentation, potential evidence for infanticide and weaning stress.

The early compilation dates of many of the large Romano-British cemetery reports pose methodological issues for comparative analyses between populations, particularly due to differences in the osteological methods and subsequent advances made in terms of palaeodemographic and diagnostic techniques. As a result, few attempts to provide a synthesis of this data have been made, a notable exception being Roberts and Cox's (2003: 107-163) *Health and Disease in Britain*. Due to the increasing recognition of the need for population-level analyses, a recent movement towards research on subadult skeletal remains from Roman

Britain has been seen, led by Lewis (2010; 2011; 2012), Gowland (2001; 2002; and Chamberlain 2002); Redfern (2007; *et al.* 2010; 2012; 2014), and Redfern and DeWitte (2011a; 2011b).

Most of this work is confined to a small number of large cemeteries, most notably, Poundbury, Lankhills and Roman Dorset, resulting in a distinct south-eastern bias. However, this appears mostly due to availability of large numbers of subadult skeletons available from these cemeteries. A brief consideration of some of the main findings of this research will be outlined below.

(i) Infanticide

Some of the earliest work on skeletal remains from Roman Britain sought to examine the demographic profile of the large numbers of infants recovered from settlement sites. Mays (1993) identified a strong peak in deaths at 38-41 gestational weeks in infants at Romano-British sites. He argued that this pattern was not comparable to natural attritional mortality and therefore was a consequence of infanticide. Mays (1995, 2000, 2003, Mays and Eyers 2011) has continued to argue this viewpoint in further investigations of perinatal and neonatal mortality in Roman Britain. He also suggests that the underrepresentation of females within Roman cemeteries lends further support to the practice of female infanticide (Mays 1995:8-9). However, none of the DNA analyses conducted on large perinatal and neonatal samples from the Roman period have found evidence for preferential female infanticide, often identifying higher proportions of males than females (Waldron *et al.* 1999; Mays and Faerman 2001; Hassan *et al.* 2014).

The notion that these collections of infant remains from Romano-British contexts represent evidence for infanticide has been challenged by Gowland and Chamberlain (2002). They argue that the peak in infant remains aged between 38-41 gestational weeks observed by Mays (1993) was, in part, an artefact of the ageing method used. Utilising a Bayesian approach, they demonstrated the age distribution of these samples are not incompatible with that expected from natural perinatal mortality (Gowland and Chamberlain 2002). Instead, they suggest that these clusters of burials within settlements are more likely to be a reflection of a specific funerary ritual associated with this age group. A more recent study by Moore (2009) also upholds these findings. Furthermore, discussions of historical evidence have highlighted the illegality of infanticide in the Roman period, stressing accounts within the literature refer not to direct killing, but the “putting out” or abandonment of infants (Gowland *et al.* 2014; Southwell-Wright 2014). Further to this, they stress that abandonment is conceptually very different from infanticide and would have left very different archaeological traces (Gowland *et al.* 2014).

(ii) The Impact of the Roman Conquest

The impact of the Roman conquest and the process of urbanisation that followed is often a key theme in the interpretation of subadult health in Romano-British populations. Early studies by archaeologists and historians tended to highlight the beneficial aspects of urbanisation, pointing towards the positive effects of town planning, effective supplies of water and sewage disposal, and the introduction of a bathing culture on living conditions (Haverfield 1923; Collingwood 1936). However, increasingly archaeological investigations and environmental analyses have been uncovering a different perspective, identifying overcrowding, poor living conditions, increased social inequalities, and a greater susceptibility to malnutrition due to dependency on external food sources as being potentially detrimental to the urban dweller's health (Scobie 1986; Jackson 1988; Addyman 1989; Dobney *et al.* 1999; Garnsey 1999; Wacher 2000; Williams 2003; Morley 2005). Additionally, post-colonial and creolisation theoretical frameworks have begun to focus attention on the negative impacts of the Roman conquest, including the psychological impact of the conquest on indigenous populations (Webster 2001; Hingley 2005; Mattingly 2006; 2011; Rogers 2014: 58-62)

Available bioarchaeological evidence from Roman Britain seemingly supports a decline in overall health. In their synthesis of health and disease in Britain, Roberts and Cox (2003: 163) identified a rise in a number of disease categories following the Roman conquest, including, amongst others: dental disease, anaemia, congenital, neoplastic, metabolic and infectious disease. In a study of temporal trends in Iron Age and Roman Yorkshire, Peck (2009) also identified a negative trend in health between time periods, reporting higher prevalence rates of trauma, non-specific infection, and dental and metabolic disease in the Roman period. Peck (2009) attributed this decline in health to the socio-cultural and economic changes associated with the Roman conquest.

A number of studies specifically examine the impact of Roman occupation on children. These include Redfern *et al.*'s (2010) study of subadult dental health in Roman Dorset. A key finding of the study was the identification of age-related changes in the dietary intake of Romano-British children, which were not present in the late Iron Age. During the Romano-British period, they found a general increase in the overall prevalence rate of caries, as well as a higher prevalence rate of caries within the deciduous dentition (Redfern *et al.* 2010). A further change in dietary intake was also indicated by a slight increase in the prevalence of metabolic disease in subadults from the Roman period (Redfern *et al.* 2010). Overall, this research demonstrates that, following the Roman conquest, cultural and settlement changes resulted in greater susceptibility of subadults to metabolic disease and caries. A further in depth study of overall subadult health in the same population by Redfern (2007), and a study of subadult health across a number of Romano-British sites (Redfern and Roberts 2005), have also confirmed the deleterious effect of the Roman conquest, as evidenced by an increase in stress indicator prevalence.

Redfern and DeWitte's (2011a) study of the impact of the Roman conquest again adopted a regional perspective of cultural change in late Iron Age and Roman Dorset. Using statistical mortality models they were able to demonstrate increasing frailty with Roman occupation, as assessed using a range of non-specific skeletal stress indicators. They found post-conquest mortality risks increased for children and the consequences of urbanism, changes in diet and increased population heterogeneity negatively impacted health.

(iii) Social Status

Few studies have examined the impact of status on subadult health and mortality risks in Roman Britain. One of the most notable is that by Redfern and Dewitte (2011b) which examined the effect of status on child health/mortality. The study included 291 individuals from sites dating from the first to fifth centuries AD in Dorset, integrating the health data with wealth determined by burial status. They found that high status children had lower mortality risk than low status children, with burial type being significantly correlated with mortality for infants and children. The reverse was found for adults. High status in Dorset likely exerted strong protective effects on children, such that high status children had lower frailty than their lower status peers (Redfern and De Witte 2011b). Buffers afforded to high status children potentially included factors such as exposure to less pollution, better drainage, and access to better foods.

Griffin *et al.* (2011) attempted to integrate skeletal health data with information from grave furnishings, in order to examine potential relationships with social inequality at the Roman small town of Baldock, Hertfordshire. They found that aspects of childhood health correlated with grave furnishings, with individuals from graves with furnishings appearing to have greater childhood stress and poorer health. However, the osteological paradox is not considered within their interpretations and, further, the choice of grave furnishings as indicators of status included modest (and possibly intrusive) items such as animal bones. Jenny's (2011) study of health and status at Roman Colchester also found that children with grave goods had higher prevalence rates of stress indicators such as *cribra orbitalia* than those without. She therefore concludes that grave goods were not indicative of socioeconomic status at Colchester. However, Jenny (2011) also failed to consider the osteological paradox, which suggests stress indicators are indicative of an individual's ability to recover and adapt to stress rather than poor health (see Section 2.2.2). Furthermore, she fails to consider that wealth, as defined by grave goods, does not always equate with health.

(iv) Population migration

Two studies of skeletal remains from Roman Britain have attempted to address the question of population mobility on the basis of health stress indicators. Gowland and Redfern (2010) compared prevalence rates of *cribra orbitalia* and enamel hypoplasia from Roman London with that from Rome and Italy. They found that prevalence rates for Roman London were anomalously high when compared to other Romano-British sites, but comparable to those observed in Rome. By contrast, the rates from Rome were similar to those from other Italian urban centres. As these particular skeletal indicators are a reflection of childhood health stress, they argued that one explanation for the high prevalence rates at Roman London could be that they reflected a childhood spent outside of Roman Britain, possibly in the Mediterranean (Gowland and Redfern 2010). However, they suggested further isotopic work is required in order to verify this.

In a re-analysis of subadult remains from the Roman cemetery at Poundbury, Lewis (2010) identified three individuals with skeletal lesions consistent with thalassaemia. As thalassaemia is a genetic anaemia rarely found within northern Europe, Lewis (2010) suggests these individuals represent migrants from areas of the Empire where the condition was endemic, such as the Mediterranean region. Further to this, over the last five years there has been an increasing interest in Roman diasporas and the use of isotopic evidence for identifying population mobility (Chenery *et al* 2010; Eckardt *et al.* 2010; 2014). A number of these studies have demonstrated that it was not only adults that were moving at this time, but that children were also mobile across the Empire (e.g. Eckardt *et al.* 2010)

(v) Infant feeding practices

The type of breastfeeding and weaning timetables adopted by a community can have a profound effect on the infant health and mortality rates (Knodel and Kinter 1977; Stuart-Macadam 1995: 7; Katzenberg *et al.* 1996: 177-8), making it an important area of investigation. New approaches to the study of breastfeeding have been found in the use of stable isotope analysis, which allow the recognition of breastfeeding through a rise in $\delta^{15}N$ values (see Section 3.3.4 (i)). Despite the successful application of this technique, only two studies of breastfeeding practices for Roman Britain have been published prior to this thesis (Fuller *et al.*2006a; Redfern *et al.* 2012). The larger of these studies, focused on the small rural settlement of Queensford Farm, Oxfordshire (Fuller *et al.*2006a), identified breastfeeding was undertaken in Roman Britain, with the process of weaning occurring gradually and being completed by the age of three to four years. Though much smaller, the study of subadults from Roman Dorset upheld these findings (Redfern *et al.* 2012).

Based on these findings, Fuller *et al.* (2006a: 49) concluded the infant feeding practices observed in Roman Britain were comparable with the weaning timetable put forward in the literary record, suggesting the same infant feeding timetables were utilised across the Empire. In particular, Fuller *et al.* (2006a: 49) cite the influence of the treatise of Soranus as being particularly responsible for the weaning timetable observed. Allason Jones (2005: 19, 28) also cites Soranus as being influential on the care practices utilised within the province of *Britannia*. However, in their study of infant feeding practices at the Roman Italian site of Isola Sacra, Prowse *et al.* (2008: 297-8) questioned the use of the weaning timetables derived from the available documentary evidence and sought to emphases their limitations.

The main source of documentary evidence for infant feeding practices used in the Roman world comes from the medical treatises of the *Gynaecology* by Soranus of Ephesus and the *Hygiene* by Galen of Pergamon, both dating to the second century AD (see Sparreboom 2014 for further available evidence). Within the modern secondary literature, it is commonly held that that both Galen and Soranus advised a weaning timetable that commenced at six months and was completed by the age of two to three years, and it is this timetable that was used by Fuller *et al.* (2006a: 49) to confirm the influence of these medical texts on infant feeding practices in Britain. However, Prowse *et al.* (2008: 297-8) have questioned such a simplistic interpretation of the primary documents. They observed that no specific age for the introduction of supplementary foods was favoured by either Soranus or Galen. Instead, the attainment of developmental milestones were favoured by both physicians; for Galen (*Hygiene* 1.10) the appropriate time for the introduction of solid foods was marked by the eruption of the first teeth, while Soranus (*Gynaecology* 2.46.115) required a bodily firmness that he believed could scarcely be achieved before the age of six months (not at six months as is commonly quoted). Within bioarchaeology, it is recognised that growth is subject to individual variation and can be delayed by external factors, such as poor health and malnutrition, resulting in considerable difference in the age at which supplementary food could have been introduced (Saunders and Hoppa 1993).

In addition, Prowse *et al.* (2008: 297-8) found that the evidence for complete cessation of breastfeeding proved to be equally ambiguous and subject to common misinterpretation. Rather than requiring the complete cessation of breastfeeding at two years, Soranus identifies this age as the time when gradual substitution of breast milk with supplementary foods should commence, giving no definitive end date (*Gynaecology* 2.47). The overall picture given by Prowse *et al.*'s (2008: 297-8) reappraisal is one of a more flexible weaning timetable than is commonly considered. Indeed, it is clear that neither of the physicians advocated a strict adherence to a common weaning timetable, acknowledging the need to take into account issues such as the health of the infant (Galen *Hygiene* 1.10) and the time of year in which weaning should commence (Soranus *Gynaecology* 2.48.117). Prowse *et al.* (2008: 297) also called attention to the biased nature of these ancient sources, which were aimed at elite audiences from the Mediterranean rather than the general population of the empire. Furthermore, they stress that the texts themselves are proscriptive rather than descriptive in nature, with the medical advice contained within them representing what their authors believed to be best practice, which would not necessarily be the actual practises that were adopted (Prowse *et al.* 2008: 297).

With such uncertainty regarding the extent to which the practices put forward by Galen and Soranus were adopted throughout the empire, caution should be exercised when attempting to use these treatises to infer aspects of care practices within the Empire as a whole. The breastfeeding and weaning timetable at Isola Sacra identified by Prowse *et al.* (2008) could be considered as complementary to the Roman literary timetables, yet it is markedly different from that at Queensford Farm, with the process of weaning occurring rapidly, with complete cessation by the age of two years. Therefore, unlike Fuller *et al.* (2006a), Prowse *et al.* (2008) conclude that infant feeding practices would have varied widely across the Empire.

(vi) Subadult diet

Garnsey (1999: 43-61) identified that subadult malnutrition during the Roman period was probably endemic. However, the diet of children from the point of post-weaning until adulthood has received far less attention than infant feeding practices. Where discussion of subadult diet in historical studies takes place, the focus tends to be on the social conventions of Roman dining, i.e. the age at which one is permitted to recline, and the presence of children at the *cena*, the main meal of the day (Booth 1991; Bradley 1998; Sigismund Nelson 1998; Dunbabin and Slater 2011). The consistent finding of these studies is the physical accentuation of the socially inferior position of the child by Roman dining practices, which excluded them from full participation and relegated them to an inferior seated position either below or behind their father's couch (Sigismund Nelson 1998: 58). It was not until a boy assumed the toga virilis and entered adulthood that he would be admitted as an equal member at the *cena* (Bradley 1998: 46). While boys could eventually gain full admittance, women often remained excluded from full participation, holding a similar inferior seated position to that of the children (though not always, see Bradley 1998: 47f). Although these studies shed light on the social position of the child in the Roman family, almost all of the evidence discussed focuses on elite and/or imperial males of Rome, making them inapplicable to the wider population and Empire as a whole. Little reference is made to the actual food that would have been consumed by children, though it is believed that their diet would have been more frugal (Bradley 1998: 46; Sigismund Nelson 1998: 64-66).

Within Roman and Greek literature, ancient physicians and moralists recognised, that just as different prescriptions were required to treat the same ailments in children and adults, different dietary proscriptions were also required. Most of these differences were based on the fundamental notion that children were constitutionally "hot" and therefore would require foods regarded as "cold" (Dalby 2003: 84). It is for this reason that Galen forbade the consumption of wine by children, as it was thought to heat the body of the drinker (*Hygiene* XI). The role of diet in repressing this constitutional heat became particularly important for young girls entering puberty, with the exclusion of certain food groups and overall intake deemed necessary to control sexuality prior to marriage (Harlow and Laurence 2002:57, Dalby 2003: 84). Other references within the literature concern the amount of food the growing body required. For example, while Hippocrates considered the innate heat of children meant they would require the most food (Dalby 2003: 84-5), Varro found 'that if immature children eat a great deal and sleep too much, they become so sluggish as to have the dullness of a sufferer of insomnia or lethargy; and their bodies are stunted and underdeveloped' (Aulus Gellius *Noctes Atticae* 4.19). Galen also considered it proper that diet should differ according to age, with the diet of children only being significantly altered in their third seven years (i.e. 14-21yrs) (*Hygiene XI*). However, it is recognised here that the literature considered above were proscriptions and notions of best practice, and the extent to which they were applied, even amongst the literary elite to whom they were addressed, is unknown (Prowse *et al.* 2008: 297-8). Nevertheless, it is important to note that the types of food available to children may not have only been affected by the status of their family and their position within it, but also because they were deemed to be "different" to adults.

To date, only two isotopic studies that have focused on subadult and adult differences in dietary intake in the Roman Empire have been published. In their study of subadult dietary patterns in Dorset from the Iron Age to the Roman period, Redfern *et al.* (2012) found that while the diet of Romano-British subadults was more significantly enriched in $\delta^{13}C$ than their Iron Age counterparts, no age-related variation in diet was observed within the Roman diet post-weaning. The reverse was observed in the remaining study at Isola Sacra, Italy, where Prowse *et al.* (2005) note both a tight clustering of $\delta^{13}C_{ap}$ values and lower $\delta^{15}N$ amongst subadults that, together, indicated a more restricted and herbivorous diet than their adult counterparts. Despite these findings, no mention is made by Prowse *et al.* (2005) of when the adoption of the "adult diet" may have occurred, with large age bands (5-15yrs and 15-30yrs) obscuring potential relationships. Instead much of the focus is placed on age-related variation in those individuals for whom biological sex can be assigned (15yrs+).

2.4 Conclusion

This chapter has provided an overview of the theoretical developments leading to the study of childhood within archaeological and Roman discourse. It has also summarised much of the bioarchaeological evidence and skeletal indicators used in the study of childhood health and well-being in the past. Many of these skeletal indicators will be employed in this study of children from Roman London. Finally, the current historical, archaeological and bioarchaeological evidence for subadult health in Roman Britain has been outlined. The next chapter will provide a literature review of the isotopic methods for examining diet and weaning in the past.

Chapter 3: Stable Isotope Analysis

The study of palaeodiets has long been an area of archaeological interest, due to its ability to provide information regarding subsistence strategies, socio-economic organisation and nutritional regimes. Conventional methods have focused on the examination of floral and faunal assemblages alongside artefact-based evidence, yet none of these investigations provide a direct record of what has actually been consumed, i.e. the different components of any one diet (Price 1989). However, the discovery that stable isotopic signatures detected in archaeologically preserved tissues reflect dietary input has allowed the refinement of palaeodietary studies, providing a direct method for the assessment of consumption (DeNiro and Epstein 1978; 1981). In addition, stable isotope analysis is a method that can be utilised for the identification of differential access to food associated with sex, age and social status.

This chapter will introduce the principles of stable isotope analysis and provide an overview of how it may be applied in palaeodietary studies.

3.1 Principles of Stable Isotope Analysis

3.1.1. Isotopes and isotopic fractionation

Isotopes are atoms of the same element that have the same number of protons and electrons, but differ in the number of their neutrons, creating a difference in atomic mass. This variance in atomic mass alters the physicochemical properties of the different isotope species, giving lighter and heavier isotopes different kinetic properties and bond energies (White 2005). These “isotope effects” are most pronounced in the light elements, such as hydrogen, carbon, nitrogen, and oxygen, where the relative difference in atomic mass is large (Schoeller 1999).

During chemical and physical reactions, these differences can lead to isotopic fractionation, where active discrimination alters the proportions of the isotopes found in the product from the starting substrate (Dawson *et al.* 2002). This discrimination usually favours the lighter isotope, as the additional neutron(s) in the heavier species increases its dissociation energy, allowing it to create stronger bonds that depress its reaction rate relative to that of the lighter isotope (Hoefs 2009). As stable isotopes do not decay, these variations in their relative abundance in materials do not change over time, making it possible to detect these fractionations in archaeological human tissues.

3.1.2. Notation of Results

As the fractional differences in isotopic abundance observed between substrate and product are very small, instead of recording deviations in absolute abundance, data are presented as a relative change (δ), on the scale of parts per thousand (‰), in the ratio of the heavy to light isotopes compared to a recognised standard (Ambrose 1993), using the formula:

$$\delta(‰) = \left(\frac{R_{sample}}{R_{standard}} - 1\right) \times 1000$$

Where R = ratio of heavy to light isotope

The standard used for comparison is an arbitrary zero point, with a δ value of 0‰, and therefore the isotope ratios produced are interval scale data and can give positive or negative values (Ambrose 1993). A positive δ value is observed when the sample contains a higher proportion of the heavier isotope than the standard, and is said to be isotopically heavier or more enriched. A negative δ value represents a sample isotopically lighter or more depleted than the standard (Lajtha and Marshall 1994).

An alternative notation of isotopic results, Δ, denotes the difference between the isotopic delta ratio of a sample (δ) and that of a stated baseline (Coplen 2011).

$$\Delta = \delta\left(\frac{{}^{i}E}{{}^{j}E}\right)_{sample} - \delta\left(\frac{{}^{i}E}{{}^{j}E}\right)_{reference}$$

Where $\delta({}^{i}E/{}^{j}E)_{sample}$ = the delta value (δ) of the isotopes ${}^{i}E$ and ${}^{j}E$ of element E in the sample, likewise for the stated reference.

It is therefore a measurement of the enrichment or depletion of a sample over the stated baseline (Coplen 2011). This notation is useful to compare samples that have different stated baselines. For example, direct comparisons of differences in the weaning process between populations cannot be done using the $\delta^{13}C$ and $\delta^{15}N$ values of infants, as the infants from each population will have different $\delta^{13}C$ and $\delta^{15}N$ baselines, i.e. the $\delta^{13}C$ and $\delta^{15}N$ values of the mothers/adult females. Therefore, by comparing the results by the difference between the delta values of the child and the mother (e.g. $\Delta^{13C} = \delta^{13}C_{infant} - \delta^{13}C_{mother/adult\ female\ mean}$), direct comparisons can be made.

3.1.3 Isotopes and Palaeodietary Analysis

Almost all elements of biological importance exist in the form of two or more stable isotope species, with the relative abundance of each isotope species remaining relatively constant. Amongst the light elements, it is the lighter isotope that is found in the greatest abundance, with other isotope species existing in trace amounts (Ambrose 1993). Within the biosphere, the relative distribution of the different isotope species is not proportionate, as fractionation occurs at the initial incorporation of the element into the food web, with subsequent fractionations occurring at each trophic level, creating stepwise differences in isotopic composition (Lajtha and Marshall 1994). These fractionations occur in predictable patterns and are fundamental to the use of stable isotope analysis in palaeodietary studies as they serve as tracers of dietary inputs, resulting in a consumer being isotopically distinguishable from their food (Lajtha and Marshall 1994).

Whilst hydrogen, oxygen and sulphur have all been used, carbon and nitrogen are by far the most commonly utilised stable isotopes in palaeodietary studies. It is these isotopes that are utilised in this thesis and information regarding their abundance, and the standards used for comparison are given in Table 3.1.

Element	Stable Isotopes	Abundance (%)	Standard	Formula
Carbon	^{12}C	98.89	V-PDB	$\delta 13\text{C}\ (‰) = \left(\frac{\text{13C/12C sample}}{\text{13C/12C vPDB}} - 1\right) \times 1000$
	^{13}C	1.11		
Nitrogen	^{14}N	99.633	AIR	$\delta 15\text{N}\ (‰) = \left(\frac{\text{15N/14N sample}}{\text{15N/14N AIR}} - 1\right) \times 1000$
	^{15}N	0.366		

Table 3.1: Stable isotopes utilised in this thesis

3.2 Dietary Variation in the Abundance of Carbon

The incorporation of carbon within a food chain is predominantly determined by the process of photosynthesis, with associated fractionations responsible for the majority of systematic variations in the isotopic composition of the carbon geochemical cycle (Tieszen 1991). The photosynthetic pathway adopted by a plant and its carbon source will ultimately determine its isotopic composition. Archaeologically, these variations in the distribution of carbon within the biosphere have been utilised to identify the consumption of different terrestrial plant species and the exploitation of marine resources for diet.

3.2.1 Identification of Terrestrial Plant Consumption - C_3 and C_4 plants

During photosynthesis, fractionations that actively discriminate against the heavier ^{13}C isotope occur at both the diffusion of atmospheric CO_2 into the leaf and during subsequent chemical enzymatic reactions, resulting in the plant being isotopically depleted in its $^{13}C/^{12}C$ ratio (O'Leary 1981). The extent of isotopic fractionation varies depending on the photosynthetic pathway utilised by the plant (O'Leary 1981).

The majority of plants, including all trees, shrubs and those native to temperate climates, follow the C_3 (Calvin-Benson) pathway, which heavily discriminates against the ^{13}C isotope, resulting in a depleted mean $\delta^{13}C$ of -26‰ (range -22 to -38‰) (O'Leary 1988). In contrast, some grasses adapted to xeric and tropical environments use the C_4 (Hatch-Slack) pathway, which discriminates against ^{13}C to a lesser extent (Smith and Epstein 1971). As a result, C_4 plant species are less depleted than C_3 plants, with an average $\delta^{13}C$ of -12.5‰ (range -9 to -16‰) (O'Leary 1988). Laboratory (DeNiro and Epstein 1978; Teeri and Schoeller 1979) and field analysis (Vogel and van der Merwe 1977) has demonstrated these consistent and non-overlapping differences in the $\delta^{13}C$ of C_3 and C_4 plants are retained throughout the food web, with the isotopic composition of an animal's tissues reflecting the mean dietary $\delta^{13}C$ ingested in life, thereby allowing the assessment of their relative importance in a consumer's diet.

This method has been used archaeologically to identify the incorporation of C_4 cultigens, such as maize, millet, sugar cane and sorghum, into previously C_3 dominated food chains. This analysis has been successfully applied to the identification of changes in subsistence strategies in North America attributed to the introduction of maize horticulture (for review see Larsen, 1997). As C_4 plant species are confined to tropical and arid regions, the application of this method in temperate Europe is limited. The only C_4 plant found in Europe in the Roman period is millet, noted in Northern Europe from 3000BCE (Zvelebil and Dolukhanov 1991). The importance of this crop within the Roman Empire appears limited and within Roman-Britain is considered negligible (Cummings 2008). However, a previous isotopic study of the Roman population of London has identified some individuals exhibiting a C_4 signal (Redfern 2011 pers comm.). As this study was limited to only a few individuals, the importance of C_4 plants in Roman London requires further investigation.

(i) Non-Dietary Variations in δ^{13}C Values of Terrestrial Plants

Although, photosynthesis is the main determinant in the variation of the natural abundance of carbon ratios within the biosphere, deviations in source carbon alongside climatic, environmental and genetic factors can influence the extent of fractionation at any stage of the process (Chisholm 1989). These factors introduce non-dietary variations in the endpoint values detected in tissues (see below). While it is possible to correct for some of these factors, a culmination of several may be impossible to distinguish (Chisholm 1989). These non-dietary variations highlight the importance of the utilisation of local fauna and flora in the reconstruction of palaeodietary food webs to avoid introducing errors into analyses.

(a) Variations in Source Carbon

The δ^{13}C value of terrestrial plants is ultimately derived from its carbon source. Therefore, if fluctuations in the isotopic composition of a carbon reservoir occur, they will be incorporated into primary producers and passed through the food chain. The global average δ^{13}C for atmospheric CO_2 is approximately -8.0‰, but, slight deviations associated with anthropogenic factors have been noted (Friedli *et al.* 1986; Marino and McElroy 1991). Since the industrial revolution, the burning of ^{13}C-depleted fossil fuels (with an average δ^{13}C value of -27.28‰) has led to the depletion of atmospheric CO_2, making it approximately 1.5‰ more negative than pre-1800 averages (Leavitt and Long 1986). Whilst studies conducted on populations prior to the burning of fossil fuels will not be affected by these shifts in δ^{13}C, any food web reconstructions that utilise modern samples of possible food sources must correct for this offset to avoid introducing errors into analyses (van Klinken *et al.* 2000).

Spatial variations in atmospheric CO_2 have also been identified in connection with forest ecosystems. In dense closed canopy forest environments, where the free-mixing of atmospheric CO_2 is restricted, a vertical cline of 2-5‰ in the δ^{13}C of forest vegetation is observed, with δ^{13}C values increasing with height. This phenomenon, termed the “canopy effect”, is the result of a change in photosynthesis activity in response to decreased light intensity, and the assimilation of recycled CO_2 from the decomposition of forest litter and soil respiration (Tieszen 1991; van der Merwe and Medina 1991; Heaton 1999; Drucker *et al.* 2008). This canopy effect occurs in both tropical and temperate forests (Drucker *et al.* 2008). Therefore, plants grown on forest floors, and the animals that eat them, will have more negative δ^{13}C values (by up to 5‰) than those in open terrestrial ecosystems (Ambrose 1993).

(b) Climatic and Environmental Variations

On a global scale, climatic factors, namely temperature, humidity and irradiance, can significantly affect the $\delta^{13}C$ values of terrestrial plant species, creating spatial patterning in $^{13}C/^{12}C$ ratios (van Klinken *et al.* 1994; van Klinken *et al.* 2000). A negative correlation is observed between temperature and $\delta^{13}C$, with an average depletion of 0.3‰ per °C increase, as above optimum temperatures reduce the ability of carboxylation enzymes to take up CO_2 (Chisholm 1989; Tieszen 1991). Similarly, a negative correlation also exists with humidity, in the order of -0.1‰ per increase in the percentage of relative humidity. In conditions of low humidity stomatal closure occurs in an attempt to prevent water loss, leading to decreased discrimination and $\delta^{13}C$ enrichment (Tieszen 1991; Heaton 1999). Increases in the levels of light intensity will also lead to enrichment of isotopic values (up to 3‰) as carboxylation efficiency increases with higher levels of irradiance (Smith *et al.* 1976; O'Leary 1981). Low light intensity is one of the main contributory factors for the depletion of $\delta^{13}C$ values of understory species in forests (see above).

A general regional patterning of $\delta^{13}C$ has been observed across Western Europe, producing a northwest-southeast cline of 2 to 4‰ (van Klinken *et al.* 2000). This regional variation introduces systematic non-dietary differences in the $\delta^{13}C$ values observed in the countries encompassed by the Roman Empire, with a 1.6‰ difference in bone collagen $\delta^{13}C$ values observed between Britain and Italy (van Klinken *et al.* 2000). Therefore, it is necessary to ensure that comparisons of stable isotope data within the Roman Empire acknowledge and correct for these differences.

In addition to large scale climatic variations, localised differences within the microhabitats of plants can also lead to significant deviations from recognised mean $\delta^{13}C$ values. Within the soils that plants are grown, variations in type and drainage can lead to differences of up to 2‰. In addition, poor soil nutrition is thought to lead to depletion in $\delta^{13}C$ values due to its effects on carboxylation (Chisholm 1989; Heaton 1999). However, as plants grown in poor soil will have low yields, their contribution to dietary $\delta^{13}C$ is thought to be minimal.

Further variations in $\delta^{13}C$ are observed with water availability, as plants subject to water stress can be enriched by 3-4‰ compared to unstressed plants. This enrichment is attributed to stomatal closure in an attempt to avoid water loss, resulting in decreased discrimination against ^{13}C (O'Leary 1981). In addition, altitude has a strong and consistent effect on plant $^{13}C/^{12}C$ ratios, increasing by a magnitude of 0.5 to 1.5‰ per 1000m. This is because decreasing

O_2 partial pressure increases enzymatic carboxylation efficiency (Smith *et al.* 1976; Livingstone and Clayton 1980; Ambrose 1993; Heaton 1999).

(c) Genetic variations

Within C3 and C4 classifications, genetic differences occur between plant species and plant forms that can lead to average differences of up to 3‰ in the $\delta^{13}C$ values observed. Within the same geographic region, short-lived shrub species exhibit $\delta^{13}C$ values up to 5‰ higher than evergreen species as a result of differences in the rate of photosynthesis (Heaton 1999).

In addition to inter-species variations, intra-species genetic diversity introduces small disparities in a plant's physiological response to its environment, altering its $\delta^{13}C$ value. Studies of individual plants of the same species at the same site have demonstrated that deviations of ±0.8 to ±1.5‰ are not uncommon in areas covering only a few hectares (Heaton 1999). While it is difficult to establish the extent of intra-species variation in the absence of environmental factors, differences of up to 3‰ might be observed.

Further significant variations in $\delta^{13}C$ are observed within individual plants themselves. Studies of isotopic variation between whole plant $\delta^{13}C$ values and those of their summative parts have identified shifts from bulk values of -1.3‰ for grains, legumes and fruit (Deines 1980). A difference of +3.8‰ has been recorded between seeds and leaves of the same plant (Deines 1980). These differences are thought to be due to variations in the concentration of isotopically distinct biochemical fractions (proteins, carbohydrates and lipids) within different plant tissues (O'Leary 1981). For example, lipids are depleted in $\delta^{13}C$ by 5‰ compared to whole plants, making any tissue with large concentrations of lipids isotopically lighter than bulk values (Chisholm 1989). This is potentially important for palaeodietary studies as preferential selection of specific plant parts (such as seeds and grain) may not be accurately represented by average $\delta^{13}C$ values derived from whole plant values or those derived from leaves (Tieszen 1991).

3.2.2. Exploitation of Marine Resources

Another archaeological application of carbon to palaeodietary analysis is the determination of the role of marine resources in coastal communities. In marine ecosystems, photosynthesising plants and phytoplankton derive their carbon from dissolved inorganic bicarbonates (DIC), which are isotopically heavier than atmospheric CO_2 by ~7‰, with a mean $\delta^{13}C$ value of 0‰ (Michener and Schell 1994). Although the majority of these organisms follow the C_3

photosynthetic pathway, fractionating carbon at a similar level to terrestrial C_3 plants (-19‰), this difference in source carbon is reflected in the average $\delta^{13}C$ of marine plants and phytoplankton, (-19.0‰), producing a range of results intermediate between C3 and C4 plants (-13 to -26‰) (Schoeninger and DeNiro 1984; Michener and Schell 1994) (Figure 3.1).

Studies by Chisholm *et al.* (1982) and Tauber (1981) have demonstrated that this difference in $\delta^{13}C$ is passed on throughout the food chain, with marine consumers exhibiting more enriched values compared to those with terrestrial C_3 diets. The identification of this fractionation pattern has allowed the assessment of the impact of agriculture on marine resource exploitation at the onset of the Neolithic (Schoeninger and DeNiro 1984; Richards *et al.* 2003; Smits *et al.* 2010). However, its application is limited by the presence of C_4 plants within the same food web, for both result in an increased enrichment of $\delta^{13}C$ compared to terrestrial C_3 values, thereby making it impossible to determine which dietary input is responsible (Chisholm *et al.* 1982).

As the inclusion of C_4 plant species in Romano-British diets cannot necessarily be excluded, additional isotopes, namely nitrogen, must be utilised to discern reliance on marine resources.

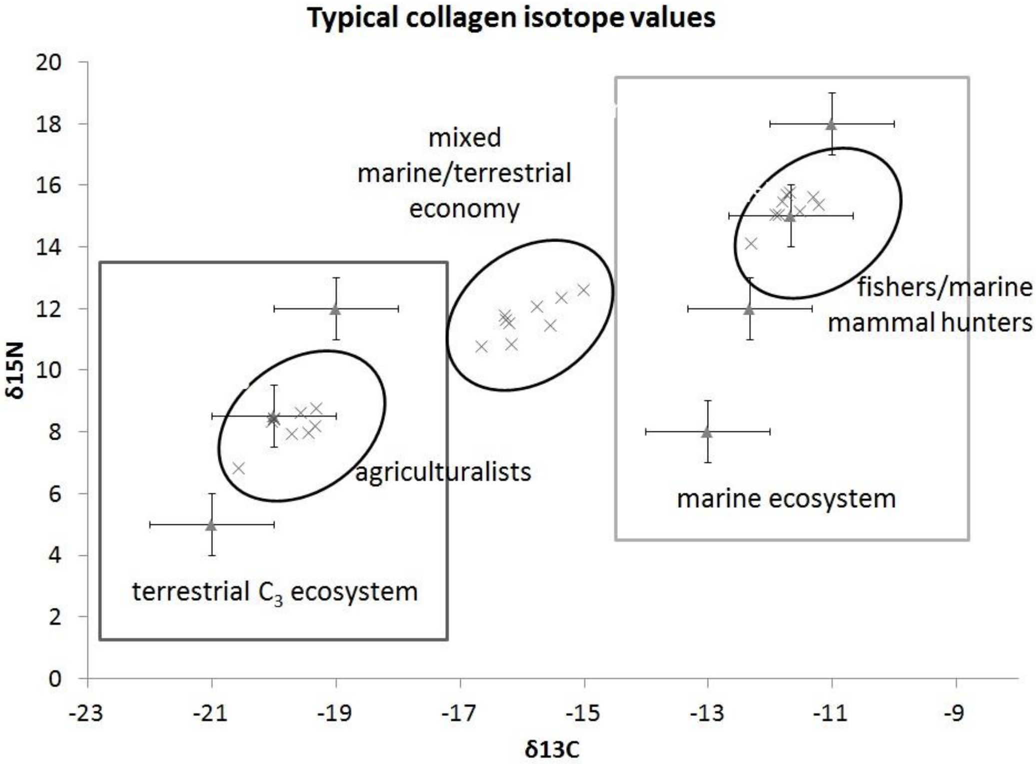

Figure 3.1: A typical isotope plot indicating the positions of collagen isotope data from terrestrial and marine ecosystems from temperate Europe

3.3. Nitrogen

Almost all of the world's nitrogen exists as N_2 in its atmosphere and oceans. Atmospheric nitrogen, with a worldwide constant $\delta^{15}N$ value of 0‰, represents the largest of these reservoirs (Mariotti 1983). The transfer of nitrogen to the biosphere is largely determined by two major processes: N_2 fixation (the conversion of gaseous N_2 into any nitrogen compound either by soil microorganisms or cyanobacteria in the aquatic environments), and the decomposition of organic matter through nitrification and denitrification reactions (Schwarcz and Schoeninger 1991). Archaeologically, these variations in the source of nitrogen have been used to identify the exploitation of plants utilising different nitrogen sources, such as leguminous plants v non-leguminous plants, and discerning between marine and terrestrial environments. In addition, the identification of stepwise trophic enrichments in nitrogen throughout food webs allows the reconstruction of trophic systems and the identification of breastfeeding.

3.3.1 Leguminous v Non-Leguminous Plants

As terrestrial plants cannot incorporate the nitrogen required to form proteins directly from the atmosphere, they must instead acquire it from the soil. Most plants obtain nitrogen in the form of nitrates produced from the decomposition of organic materials by soil micro-organisms (Dawson *et al.* 2002). The complex nitrification and denitrification steps involved in the production of these nitrates leads to the isotopic enrichment of their $\delta^{15}N$ values relative to the atmosphere (Ambrose and DeNiro 1986). In contrast, leguminous plants have developed a symbiotic relationship with nitrogen-fixing Rhizobium bacteria, which allows them to directly fix atmospheric N_2 (Ambrose 1991; Katzenberg 1992; Katzenberg 2000). A corollary of this direct fixation is that these "N-fixers" tend to have $\delta^{15}N$ values much closer to atmospheric N_2 values (average range of 0 to 4‰) than "non-fixers", which tend to possess values of over 5‰ (Schwarcz 1991; Koch *et al.* 1994). Commonly exploited legumes include alfalfa, clover, peas, beans, and lentils, and their consumption can lead to lower $\delta^{15}N$ relative to those eating non-leguminous plants. In Roman London, environmental sampling has identified the presence of lentils in large quantities where preservation conditions were favourable, as well as smaller quantities of peas and various bean varieties (Willcox 1978; Cowan and Wardle 2009).

Whilst the nitrogen source will ultimately determine the $\delta^{15}N$ values of plants, the biological processes that govern nitrogen fixation and nitrification/denitrification are highly sensitive to various climatic and environmental factors, resulting in highly variable nitrogen isotopic ratios in both soils and plants (Ambrose 1991; Lajtha and Marshall 1994). On a global scale, the climatic effects of temperature and rainfall appear to be strongly correlated with $\delta^{15}N$ values, with arid soils exhibiting higher $\delta^{15}N$ enrichment than cold/wet soils (Heaton *et al.* 1986; Amundson *et al.* 2003). This climatic effect seems to be governed by the inhibition of N-fixation and increased evaporation of ^{14}N-enriched ammonia from within arid soils (Schwarcz *et al.* 1999; Amundson *et al.* 2003). Heaton *et al.* (1986) also observed a positive correlation with salinity, with $\delta^{15}N$ values of plants grown within saline soils enriched by up to 10‰. Those plants grown in close proximity to coastal areas were also shown to exhibit similar $\delta^{15}N$ enrichments of 5-10‰ due to the deposition of additional ^{15}N enriched nitrogen by sea spray. A negative correlation with altitude was also noted.

On a local scale, the culmination of these factors can lead to large variations of up to 10‰ in plants grown within the same area, with additional inter-species and intra-plant genetic differences resulting in variations of up to 2‰ (Dawson *et al.* 2002). In addition to these natural factors, the anthropogenic use of $\delta^{15}N$ –enriched animal manures to replenish agricultural soils has been shown to significantly enrich the $\delta^{15}N$ values of cereal crops grown within them by +3 to +8‰, depending on the manuring intensity (Bogaard *et al.* 2007). Whilst the majority of these differences will be averaged out by the slow turnover rates of consumer tissues, the incorporation of these significantly enriched $\delta^{15}N$ values could result in the erroneous interpretations of high levels of animal or marine exploitation. Therefore, in order to avoid introducing non-dietary spatial variations into diet reconstructions, comparison with local values is essential.

3.3.2 The Exploitation of Marine Resources

As in terrestrial environments, the $\delta^{15}N$ of primary producers in marine ecosystems directly reflect the nitrogen source utilised. In off-shore temperate oceans, the most important source of nitrogen available to phytoplankton is dissolved nitrates, transported into the euphotic zone by vertical upward movement via water columns (Michener and Schell 1994). As the production of these nitrates is dominated by denitrification processes with large fractionation factors, they exhibit higher $\delta^{15}N$ values than terrestrial sources of nitrogen (Michener and Schell 1994). The incorporation of these ^{15}N-enriched nitrates by marine plants is reflected in their $\delta^{15}N$ values, with primary producers in marine ecosystems exhibiting $\delta^{15}N$ values up to 9‰ more positive than terrestrial plants (Schoeninger and DeNiro 1984). These enriched $\delta^{15}N$

values are then passed on to consumers, with subsequent stepwise trophic shifts of 3-4‰ throughout the food web, leading to the overall enrichment of marine ecosystems over terrestrial ones (Schwarcz and Schoeninger 1991). Furthermore, additional divergence occurs as longer food chains in marine ecosystems add more trophic enrichment steps, resulting in marine mammals being significantly more enriched in $\delta^{15}N$ than their terrestrial counterparts (Schoeninger and DeNiro 1984). Therefore, populations that exploit marine resources will have higher $\delta^{15}N$ values than those who consume only terrestrial resources.

As well as the recycling of nitrates, new nitrogen sources are introduced into marine ecosystems by N_2 fixing cyanobacteria. As these cyanobacteria directly fix atmospheric N_2, their $\delta^{15}N$ values are much nearer to 0‰ than those plants that utilise dissolve nitrates (Michener and Schell 1994). Whilst their contribution to nitrogen in most marine systems tends to be small (0.1g per m^2/per year), in ecosystems where they dominate, such as marine coral reefs and mangroves (25g per m^2), they deplete consumer $\delta^{15}N$ values to similar levels seen in terrestrial environments (Sealy 2001). Low $\delta^{15}N$ values are also observed in Antarctic food chains, despite high levels of nitrates, due to the slow growth of phytoplankton in this area (Michener and Schell 1994).

Further variations in $\delta^{15}N$ values of nitrogen sources are observed in littoral and supra littoral marine ecosystems. Unlike pelagic systems where one form of primary producer dominates, in coastal and estuarine systems multiple primary producers contribute to the $\delta^{15}N$ values of consumers, introducing greater variation in enrichment factors (Schoeninger *et al.* 1983; Schoeninger and DeNiro 1984). Furthermore, additional nitrogen from terrestrial runoff and the release of ^{15}N-enriched human and animal sewage into seawater can also lead to greater degrees of $\delta^{15}N$ variation. These variations in $\delta^{15}N$ must be considered when analysing populations of coastal dwellers (Ambrose 1993).

3.3.3 The Exploitation of Freshwater Resources

Unlike marine fish, the identification of freshwater resources cannot be achieved through the analysis of $\delta^{13}C$ variations. This is largely due to the influx of multiple carbon sources available to primary producers, resulting in $\delta^{13}C$ ranges similar to, or slightly more depleted than terrestrial resources (-37 to -27‰) (Katzenberg and Weber 1999). Conversely, like marine fish, freshwater resources exhibit $\delta^{15}N$ values more enriched than their terrestrial counterparts. Therefore, the consumption of freshwater resources may be recognised in archaeological populations as an increase in $\delta^{15}N$ values unaccompanied by an associated enrichment in $\delta^{13}C$, as would be seen with marine consumption (Katzenberg and Weber 1999).

Large variations in δ^{15}N values occur between freshwater species in the same bodies of water and even within species in different lakes or rivers, with large δ^{15}N ranges of +6.5 to +14.9‰ reported for European freshwater fish (Dufour *et al.* 1999; Drucker and Bocherens 2004). Whilst some of these differences reflect trophic level enrichment through long food chains, spatial variations are also observed. For example, as nitrogen enrichment increases with depth, detritivores that feed in benthic zones (bottom feeders) have more enriched δ^{15}N than those that feed in pelagic zones (Katzenberg and Weber 1999). Variations may also occur in those species that move between marine and freshwater systems, such as anadromous and catadromous fish, and migratory birds (Katzenberg and Weber 1999). Anthropogenic factors, such as the discharge of ^{15}N-enriched faecal matter into freshwater systems, may also introduce variations in isotopic end-members (Katzenberg and Weber 1999).

As Roman London is located on the River Thames, it is likely that freshwater resources may have been exploited. Therefore, consideration of anthropogenic enrichment in freshwater resources in this locality is essential. Given the high levels of variability between freshwater resources and potential for anthropogenic contamination, the analysis of contemporary freshwater dietary components from associated archaeological deposits within the city is recommended. However, due to their poor preservation and an absence of widespread wet sieving, fish remains are rarely recovered from archaeological deposits.

3.3.4 The Incorporation of δ^{15}N Values into Consumers - the "Trophic Level Effect"

Laboratory testing of animals with known diets has demonstrated the δ^{15}N values observed in a consumer's tissues are a direct reflection of dietary intake, albeit with a systematic enrichment in δ^{15}N relative to that of diet (DeNiro and Epstein 1981). Almost all of the nitrogen ingested by animals is in the form of proteins. These proteins are denatured and hydrolysed into their constituent peptide chains and amino acids in the stomach, before being transported to the liver to be catabolised from urea synthesis (Sillen *et al.* 1989). It is believed that kinetic isotope effects that occur during the conversion of amines to urea result in the preferential excretion of the lighter ^{14}N isotope, leaving residual amines utilised in protein synthesis enriched in the heavier ^{15}N (Minagawa and Wada 1984; Ambrose and DeNiro 1986; Hedges and Reynard 2007). This isotopic enrichment in δ^{15}N ratios is passed on to the consumer, resulting in a consumer's tissues being isotopically heavier than its diet.

This process of nitrogen fractionation occurs stepwise throughout the food chain in both marine and terrestrial ecosystems, with δ^{15}N values increasing at each trophic level (Minagawa and Wada 1984). The extent of this “trophic level” enrichment is poorly understood and is known to vary between ecosystems and between species. For example, $\delta^{15}N$ enrichments of up to 3‰ above normal trophic level shifts have been observed between plants and animals from xeric environments (Ambrose and DeNiro 1986; Heaton *et al.* 1986; Ambrose and DeNiro 1987; Sealy *et al.* 1987). Conflicting theories have attributed these enriched values to greater urea concentrations as a physiological response to water stress (Ambrose and DeNiro 1986), or increased catabolism of existing nitrogen due to protein deprivation (Sealy *et al.* 1987). Fluctuations in enrichment may also occur under anabolic (e.g. growth) and catabolic (e.g. nutritional and water stress) conditions (see Section 4.4.3).

Regardless of these variations, a fractionation factor (Δ_{d-c}) of +3 to +5‰ between plants, herbivores and carnivores is commonly accepted (Schwarcz and Schoeninger 1991). Omnivorous species, such as humans, exhibit $\delta^{15}N$ values between herbivores and carnivores as they derive protein from both plant and meat sources (O’Conell and Hedges 1999). In order to ensure accurate food chain reconstruction, comparisons of plants and animals derived from the local area are required, avoiding the use of general averages. Where plant remains are unavailable, herbivores serve as proxies for baseline plant $\delta^{15}N$.

It was initially believed that trophic level enrichment could be used to elucidate the percentage of meat consumption. This involved measuring the extent to which human $\delta^{15}N$ lay above the $\delta^{15}N$ of dietary protein, with herbivores and carnivores providing estimates of 0% and 100% meat consumption, respectively. A recent study by Hedges and Reynard (2007) identified that the use of this technique can lead to large overestimations of animal consumption, with improbably high estimates of 60-80% meat consumption in Neolithic populations during a time of transition to an agricultural subsistence. Hedges *et al.* (2007) attributes these overestimations to a lack of understanding of the way $\delta^{15}N$ values are incorporated into the body, citing imprecise Δ_{d-c} values, unknown variables (such as inter-individual variability and the effect of protein quality), and the introduction of errors caused by the assumption of $\delta^{15}N$ values for isotopic end-members. This kind of analysis is also confounded by an inability to distinguish between different animal proteins, such as meat and milk, using $\delta^{15}N$ (O’Conell and Hedges 1999). Hedges *et al.* (2007) found that by controlling for these possible variables, they could obtain animal protein contributions as low as 35%. Therefore, until these issues can be solved, the identification of animal protein in diet remains qualitative, rather than quantitative.

(i) Breastfeeding and weaning

As well as enabling the reconstruction of food webs, the identification of trophic levels utilising nitrogen isotope ratios allows for the detection of breast-feeding and weaning in past populations. The complex process of weaning is of particular interest for childhood studies as it is associated with elevated infant mortality, and provides information concerning maternal behaviour and infant feeding practices (Katzenberg *et al.* 1996). Traditional methods of elucidating weaning rely on the assessment of a non-specific stress marker, i.e. the study of enamel hypoplasia, which provides only indirect evidence of weaning age (Katzenberg *et al.* 1996). It is now recognised that stable isotope analysis provides the only direct method for the identification of this process in archaeological populations.

Nursing infants that are exclusively fed on breast milk will exhibit a $\delta^{15}N$ enrichment of 2-3% over that detected from their mothers (Katzenberg *et al.* 1996 and Figure 3.2). This enrichment reflects a trophic level shift similar to that seen between a carnivore and herbivore, as the child becomes a consumer of its mother's tissues. This "suckling effect" is only observed as a peak in collagen $\delta^{15}N$ values several weeks after birth, the timescale required for the deposition of collagen synthesised from this enriched nitrogen (Katzenberg 2008). As a result of this delay, new-borns in the skeletal record will show no indication of having being breast fed, and instead have $\delta^{15}N$ values similar to that observed in the adult population. As supplementary food is introduced into the diet, a gradual decrease in $\delta^{15}N$ values is observed, with complete cessation of breast feeding denoted by a return to adult values.

Due to the uncertainties surrounding the timescale of $\delta^{15}N$ incorporation into collagen, these analyses provide only a general timeframe (Fuller *et al.*2006b). It must also be remembered that children within the archaeological record are those that failed to attain adulthood and, as such, may have had different diets or suffered from malnutrition, potentially affecting the extent of enrichment observed (Katzenberg *et al.* 1996) (see Section 4.4.3).

Few studies of breastfeeding and weaning have been undertaken on Romano-British populations. The most prominent of these is that conducted for the Romano-British settlement at Dorchester-on-Thames by Fuller *et al.* (2006a). Whilst a lack of individuals in the 0-1.5 year age category prohibited the detection of the age at which weaning commenced, Fuller *et al.* (2006a) were able to identify a gradual decline in $\delta^{15}N$ values after 2 years, with complete cessation of breastfeeding at 3-4 years. Another smaller study of subadults from Roman Dorset seemingly supported these findings, as well as identifying a potential special breastfeeding diet within the province (Redfern *et al.* 2012 and see Section 2.3.3 (v) for further discussion).

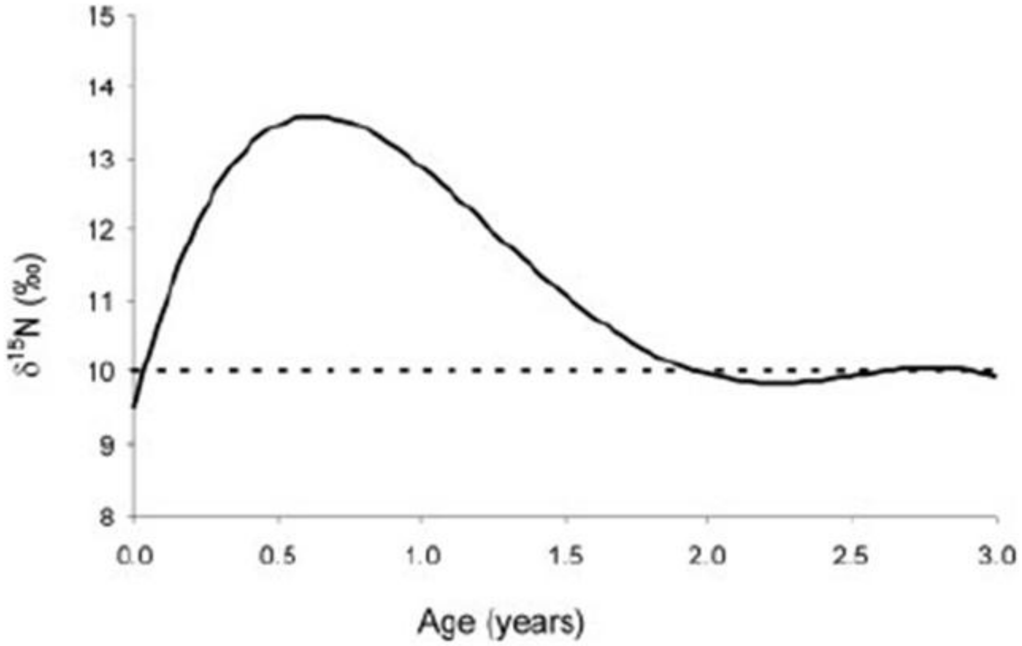

Figure3.2 : Graphic representation of expected pattern for bone collagen δ15N associated with breastfeeding and weaning process (Jay *et al.* 2008 : figure 1)

3.4 Bone Chemistry

Laboratory-based experiments and field observations have demonstrated that the isotopic signals incorporated into all biological tissues reflect dietary sources, albeit with systematic differences, making it possible to conduct palaeodietary analysis on any tissue that contains the necessary isotopes (DeNiro and Epstein 1978; DeNiro and Epstein 1981). For carbon and nitrogen, this includes hair, skin, and fingernails, all of which have been used for dietary assessment in modern and past populations (Macko *et al.* 1981; Fogel *et al.* 1989; O'Conell and Hedges 1999). However, the preservation of such tissues is rare in archaeological contexts, therefore the more commonly preserved calcified tissues, such as bone and teeth, are more routinely utilised for palaeodietary analysis.

Bone is a composite material composed of an organic matrix of structural protein (30% of dry weight) embedded within inorganic calcium phosphate crystals, largely in the form of hydroxyapatite (70% by dry weight) (Schwarcz and Schoeninger 1991). Palaeodietary analysis of both biochemical components of bone have been routinely undertaken (Sullivan and Krueger 1983; Lee-Thorp *et al.* 1989), but the utilisation of the inorganic mineral fraction is hampered by its high susceptibility to diagenetic change within the burial environment, and the absence of nitrogen in its elemental composition (Schoeninger and DeNiro 1982). In contrast, collagen, the primary component (85-90%) of the organic fraction of bone, incorporates both nitrogen and carbon and, due to its relative insolubility and protected position within bone, is extremely resistant to post-mortem diagenetic change, making it the most popular choice for stable isotope analysis (Armelagos *et al.* 1989).

3.4.1 Structural Composition of Collagen

Within the human body, collagen is the most common protein present, accounting for up to a quarter of total body proteins. Collagen found within bone is a type 1 collagen, characterised by tropocollagen molecules, constructed from triple helical structures of polypeptide strands, arranged into fibrils, which intertwine to make slightly elastic, flexible fibres (Schwarcz and Schoeninger 1991). It is this structural arrangement that gives collagen its great tensile and compression strength. While most of the collagen in bone is laid down in childhood, bone is not a static tissue and therefore undergoes continuous remodelling throughout life (Libby *et al.* 1964). The isotopic signals recorded in an individual are said to be an average of the diet consumed during the time it takes for a tissue to be completely replaced. The turnover rate of bone collagen is one of the slowest of any animal tissue, with current research estimating a timescale of approximately 10-30 years for complete collagen replacement (Stenhouse and Baxter 1979; Hedges *et al.* 2007). However, the rate of turnover of bone collagen is variable, with differences attributed to age/growth, metabolic effects and skeletal element composition (see Section 4.4.3). Nevertheless, it is considered that bone collagen represents a lifetime average of dietary consumption.

3.4.2 Dietary Isotopic Signals in Collagen

Collagen is ultimately composed of amino acids directly obtained from dietary materials (Chisholm 1989). As the only source of nitrogen available from dietary intake is derived from protein, collagen $\delta^{15}N$ values must reflect only the protein fraction of diet (Schwarcz and Schoeninger 1991). In contrast, carbon may be obtained from all dietary macronutrients (proteins, lipids, and carbohydrates) and, as a result, exactly what fractions of the diet are represented by the $\delta^{13}C$ values of bone collagen has been debated (Sillen *et al.* 1989).

Approximately 20% of the carbon isotopic signal in collagen is derived from essential amino acids (Jim *et al.* 2004). As essential amino acids cannot be synthesised by the body they therefore must be obtained directly from dietary protein, thereby representing a minimum contribution of 20% by dietary protein to overall $\delta^{13}C$ values (Jim *et al.* 2004). The remaining 80% of carbon in collagen is contributed by non-essential amino acids. Non-essential amino acids are those that can be synthesised de novo by the body without dietary input, utilising an internal metabolic pool of carbon derived from the “scrambling” of all dietary biochemicals (Jim *et al.* 2004). Initial studies assumed that, as the majority of carbon in collagen was derived from these internally synthesised non-essential amino acids, δ^{13}C values detected in collagen represented total dietary input and linearly reflected the proportions of the various foods consumed (Burleigh and Brothwell 1978). However, the extent to which this internal synthesis of non-essential amino acids occurs has been questioned.

Controlled feeding experiments to investigate the biochemical routing of carbon from the diet has identified disproportionately large, non-linear contributions of dietary protein to bulk collagen δ^{13}C values (Ambrose and Norr 1993; Tieszen and Fagre 1993; Jim *et al.* 2004). Experimental data obtained by Ambrose and Norr (1993) demonstrated dietary protein contributed 51% of total carbon to collagen δ^{13}C values in diets, where it represented only 5% of total intake. These findings are well above the expected minimum 20% from essential amino acids, indicating a large number of non-essential amino acids are also taken directly from dietary protein, referred to as protein routing (Jim *et al.* 2004). It is believed that protein routing is an energy conservation strategy, as less energy is expended in the incorporation of exogenous non-essential amino acids than is required for endogenous de novo synthesis (Jim *et al.* 2004). Therefore, if an individual’s diet consists of sufficient amounts of protein, greater levels of protein routing will occur, resulting in a collagen δ^{13}C value that predominantly reflects dietary protein and underrepresents the carbohydrate and lipid components of diet (Ambrose and Norr 1993). In cases where dietary protein and energy fractions have significantly different isotopic compositions, e.g. C_3 protein and C_4 energy, it is believed collagen δ^{13}C will be poorly correlated with whole diet (Ambrose and Norr 1993).

While the prevailing consensus suggests that collagen δ^{13}C values are largely determined by dietary protein, there is still some contribution from other biochemical fractions to bulk collagen values, particularly under conditions of low protein intake where substantial amounts of carbon are still derived from the energy (lipid and carbohydrate) portion of diet (Schwarcz 2000). Ambrose and Norr (1993) identify a 49-58% contribution of energy source δ^{13}C to bulk collagen values when protein forms 5% of dietary intake. Therefore, under conditions of nutritional stress, the isotopic composition of carbon in collagen may be better correlated with whole diet.

Most diets contain more than one dietary source of protein, but they are rarely nutritionally equivalent. Animal sources of protein contain significantly more protein by weight (90%) than plant sources, such as grains, vegetables and nuts (10-20%) (Ambrose and Norr 1993). Concomitantly, in most situations it is expected that plant proteins will make up a minor proportion of the isotopic composition of collagen. These findings have implications for palaeodietary reconstructions of coastal populations, where evidence of terrestrial plants may be significantly underrepresented due to the preferential incorporation of $\delta^{13}C$ into collagen from protein-rich marine resources (Parkington 1991; Hedges 2004).

3.4.3 Endogenous Variations in Bone Collagen

The utilisation of stable isotopes for the reconstruction of palaeodiets is based on the principle that the isotopic signatures detected within an animal's tissues are a direct and constant function of its diet (Ambrose 1993). However, this principle is based on the assumption that the isotopic composition of collagen is unaffected by endogenous variations, such as differences between an individual's skeletal elements, between individuals themselves, and physiological differences associated with sex, age and nutritional status. Failure to consider the potential variations introduced by such factors may lead to erroneous dietary reconstructions; therefore, a summary of each is given below.

(i) Intra-skeletal variability

In order to obtain an accurate record of a population's diet through stable isotope analysis, it is necessary to ensure that the sampling strategy used does not affect the information obtained. Therefore, when selecting samples for analysis, it is important to identify the extent of variability within an individual bone and the potential differences between skeletal elements. This ensures that the isotopic signal detected in a particular bone analysed is representative of the same average isotopic composition of all bones sampled. The recognition of these differences is particularly pertinent for archaeological samples where poor preservation of bone may not allow the same bone to be sampled from all skeletons.

At an individual bone level, Katzenberg and Lovell (1999) have demonstrated that no significant differences are observed within the same bone in a healthy individual, with variations of only ±0.3‰ for carbon and ±0.2‰ for nitrogen recorded between bone segments. In addition, Waters-Rist and Katzenberg (2010) demonstrated no significant difference in the isotopic values observed in the epiphysis, metaphysis and diaphysis of the same bone. Therefore, it is purported that the isotopic signal detected for an individual bone is consistent regardless of the area selected for analysis.

On an intra-skeletal level, a comparative analysis of the carbon and nitrogen values detected within the long bones of individual minks showed no significant differences between the values of the femora and humerii in the same animal (DeNiro and Schoeninger 1983). However, it has been identified that turnover rates in skeletal elements differ depending on their structure, with those containing large amounts of cancellous bone, such as the ribs and vertebrae, remodelling much faster than those composed of largely compact lamellar bone, such as that of the femora and humerii (Sealy *et al.* 1995). As the isotopic composition of collagen is an average of diet during the time it takes to turnover, it has been posited that those with faster turnover rates reflect more recent dietary consumption than those with slower turnover rates, thus recording different dietary signals. Nevertheless, a difference between bones of different structural composition may only occur if a significant difference in diet occurs in the latter years of a person's life. For example, Schoeninger (1989) found an identical carbon and nitrogen isotopic signal in both the vertebrae and femora of individuals, despite the difference in their turnover rates.

Whilst the differences in isotope values between skeletal elements appear to be small, in order to minimise introducing sampling errors, the selection of elements of comparable structure is recommended. In the case of young children, the selection of element may not significantly affect the results obtained, as during active growth all bones undergo rapid turnover.

(ii) Inter-population variability

Another area of possible uncertainty within dietary reconstruction is what variation is expected between individuals eating the same diet and what variation represents a true dietary difference. Furthermore, how many individuals in a population eating the same diet need to be sampled to represent an accurate depiction of the diet consumed? These concerns are of particular importance for archaeological populations where a small sample size is derived from an already unrepresentative population, biased by skeletal preservation (DeNiro and Schoeninger, 1983).

Laboratory-controlled animal feeding experiments (DeNiro and Schoeninger 1983) and analyses of wild populations of deer and vole with known diets (Hobson and Schwarcz 1986) conducted to address this issue have identified variations of less than 1‰ between individuals consuming the same diet. In contrast, Schoeninger and DeNiro (1984) identified differences of over 1‰ ($\delta^{13}C$ = +1.9‰ ± 2.4, $\delta^{15}N$ = +1.8‰ ± 1.2) between individuals of the same species in a large study of over 100 animals. However, as the species in this study were taken from wild populations drawn from multiple food webs, these variations may represent differential consumption of dietary components. The study of variation amongst human populations consuming the same diet is limited by an inability to perform controlled feeding studies.

However, in a test of possible endogenous sources of variations in δ^{13}C values, an average variation of only 0.3‰ was identified within a single archaeological population of bison hunters representing 2000 years of habitation (Lovell and Nelson 1986).

As a result of these analyses, it is commonly held that differences above 1‰ represent actual dietary differences between individuals, with outliers possibly portending to different status or migrations. Differences below 1‰ are rarely interpreted as actual dietary differences. For archaeological populations, these small variations between individuals indicate that the small sample sizes available for analysis are sufficient to allow interpretation of a population's diet. However, the study by Schoeninger and DeNiro (1984) highlights the potential for variation that may be introduced when diets may be derived from multiple locations/food webs, and the necessity to sample several individuals from a species to derive an accurate average isotopic value. This is particularly important for studies of Roman London where imports of goods from the continent may lead to more than one potential dietary source.

(iii) Sex

In the reconstruction of diet for children, for whom the confirmation of sex is usually unattainable, the consideration of physiological shifts in isotopic composition ascribed to biological sex is essential. In both controlled feeding experiments of birds (Hobson and Clark 1992a; 1992b) and mink (DeNiro and Schoeninger 1983), and field observations of wild elephants (Tieszen *et al.* 1986), no trends attributable to sex were observed. No significant difference was apparent for the average carbon and nitrogen isotopic signals obtained for males and females consuming the same diet. Furthermore, in a study of both modern and archaic humans (Lovell and Nelson 1986), no correlation has been found between isotopic composition and sex, with mean variations of much less than 1‰ along sex lines. As a result of these analyses, it is concluded that any diversity reported between males and females is the result of real dietary differences. Therefore, when a child's diet is not influenced by sex, any isotopic divergence observed between adults and children can be interpreted as real dietary variation. However, in cultures where gender-based dietary differences amongst children occur, the interpretation of dietary patterns may be subject to the introduction of irresolvable ambiguity (Lovell and Nelson 1986).

(iv) Age

The identification of isotopic variations between adults and subadults within the same population has led researchers to question whether such differences are true reflections of differences in diet (Katzenberg 1993). Childhood is a time of rapid growth and the effects of these physiological changes on the isotopic composition of carbon and nitrogen are poorly understood (Waters-Rist and Katzenberg 2010). This perceived uncertainty regarding the effect of age on stable isotope ratios often leads to the exclusion of infants from a population's dietary reconstruction, and inhibits the comparison of adult and sub-adult diets.

Available data derived from the investigation of growing animals has identified a lack of an age effect on the isotopic composition of muscles, fish (Minagawa and Wada 1984), and birds (Hobson and Clark 1992a; 1992b). Results from archaeological populations (Lovell and Nelson 1986) consuming the same diet have demonstrated no significant difference between age and $\delta^{13}C$ values. In populations where age-related $\delta^{13}C$ variations have been observed, it is possible to attribute such changes to differential dietary consumption (Katzenberg 1993). In contrast, recent observations of lowered $\delta^{15}N$ ratios in growing organisms have been attributed by some researchers to a "growth effect" (Fuller *et al.* 2005).

During periods of growth the body is said to be in positive nitrogen balance, ingesting more nitrogen than it expels. As new tissue synthesis increases the demand for nitrogen, greater proportions of both essential and non-essential amino acids are routed directly from dietary sources to sites of new tissue synthesis, bypassing the transamination and deamination reactions that lead to stepwise isotopic fractionation (Waters-Rist and Katzenberg, 2010). Researchers suggest that this lack of participation in metabolic reactions results in a depression of the diet-tissue spacing and a decreased $\delta^{15}N$ value (Trueman *et al.* 2005). It is also suggested that where transamination and deamination does occur, increases in the speed of these metabolic reactions as a result of rapid growth may also decrease $\delta^{15}N$ values, because less time is available for the preferential selection of the desired lighter ^{14}N isotope (Hare *et al.* 1991). The existence of a "growth effect" on the $\delta^{15}N$ values of children is particularly pertinent as $\delta^{15}N$ ratios are utilised to identify weaning. It has been suggested that the identification of trophic shifts of less than the expected 3‰ between suckling infants and the adult population may be the result of a depression in the diet-tissue spacing caused by the "growth effect" (Fuller *et al.* 2005). However, Millard (2000) argues that any depression due to growth in infants is likely to be very small.

As the majority of the studies claiming a "growth effect" were conducted on animals or tissues with faster accretion rates than collagen, the preferred tissue for stable isotope analysis, a recent study by Waters-Rist and Katzenberg (2010) was undertaken to investigate the expression of a "growth effect" in the collagen $\delta^{15}N$ of post-weaning sub-adult skeletons. They found no significant difference in the $\delta^{15}N$ values amongst epiphyses, metaphyses and diaphyses of growing bones, nor did they find a significant difference between faster and slower growing metaphyses, or bones undergoing growth compared to those where growth had ceased. Waters-Rist and Katzenberg (2010) therefore conclude that growth does not have a significant effect on the $\delta^{15}N$ values of collagen in children, with any manifestation negligible compared to that detected for weaning or changes in dietary behaviours.

This lack of a growth effect is in accordance with the mathematical model devised by Ponsard and Averbach (1999), which demonstrated that growth does not have a direct effect on the diet-tissue spacing of nitrogen, with those ingesting the equivalent of their adult weight in nitrogen throughout growth periods exhibiting similar results to those observed in adults. Instead, the quality of protein during the growth period may have a more significant effect (Ponsard and Averbuch 1999). However, the results presented by Waters-Rist and Katzenberg (2010) do not necessarily contradict the findings of a “growth effect” on $\delta^{15}N$ ratios and greater work is therefore required to resolve this issue.

(v) Nutritional Status and Pathology

Any osteological investigation of childhood health requires the use of a skeletal sample of “non-survivors”, those children who failed to reach adulthood. While it is impossible in all but the rarest cases to assign cause of death to an individual, it is likely that some of these children may have died due to increased frailty caused by nutritional stress or disease (Katzenberg *et al.* 1996). Studies into the effects of these conditions on stable isotope ratios are limited, but investigations have identified associated elevations in $\delta^{15}N$ values.

During periods of nutritional stress where dietary protein intake is insufficient to meet nitrogen requirements for protein synthesis, additional nitrogen is derived from the catabolism of existing body proteins (Katzenberg, 2008; Hobson and Clark 1992b). As this nitrogen is already enriched in $\delta^{15}N$ compared to diet, ensuing participation in the same biochemical processes that led to initial isotopic enrichment creates an additional trophic shift within the animal, increasing the $\delta^{15}N$ of body tissues (Fuller *et al.* 2005). Elevated $\delta^{15}N$ values as a result of nutritional stress have been confirmed in the muscles of birds raised under controlled conditions and in animals fasting in the wild (Hobson *et al.* 1993). Elevated $\delta^{15}N$ values have also been detected in the hair of pregnant women during periods of morning sickness, where nitrogen intake was insufficient to meet the increasing demands of pregnancy (Fuller *et al.* 2005)

The extent to which a nutritional stress effect would be observed in bone collagen is questionable, as the tissues used in the above studies have significantly faster turnover rates that would allow the incorporation of elevated δ^{15}N in a much shorter period of time (Mundee 2010: 32). Due to its slow turnover rate, a prolonged period of nutritional stress would need to be endured to afford an elevation in the δ^{15}N value of collagen (Mundee 2010: 32). Such a prolonged period of nutritional stress would not be conducive to life and therefore it is supposed that many individuals would die before a difference in δ^{15}N was registered in their bone collagen.

A possible exception to this could be those organisms in anabolic states, such as during growth or under some pathological conditions (see below), whose increased tissue synthesis would require the catabolism of higher proportions of nitrogen under the conditions of nutritional stress than those in a steady state of tissue maintenance (Katzenberg and Lovell 1999). The quicker turnover rates occurring during these periods would incorporate elevated δ^{15}N into bone collagen at a much quicker rate. For example, under conditions of controlled nutritional stress, an elevated δ^{15}N value was obtained from the bone collagen of juvenile quails (Hobson *et al.* 1993). These findings have implications for the dietary reconstruction of young infants where an elevated δ^{15}N value is readily interpreted as a trophic shift induced by breastfeeding (Katzenberg and Lovell 1999).

Pathological conditions may affect bones at the macroscopic, microscopic or chemical level, yet little is known about the effect of these changes on the stable isotope ratio of collagen (Armelagos *et al.*1989). A study of modern pathological bones obtained from individuals with known causes of death identified above normal isotopic variation in three of the four diseased bones examined (Katzenberg and Lovell, 1999). Whilst δ^{13}C variations between the normal and pathological bones of an individual were only slight, elevations of up to 2‰ in δ^{15}N were observed in association with pathological new bone formation and wasting. This increased δ^{15}N was attributed to the formation of new bone under conditions of nutritional stress, with larger proportions of newly deposited bone synthesised from catabolised amino acids (Katzenberg and Lovell, 1999). If the pathological condition is localised to a particular bone, as in the aforementioned study, it is possible to avoid sampling of a pathological bone. However, in the case of those diseases that affect metabolism and cause significant changes in the form and structure of collagen, the identification and removal of pathological variation may be more complex (Armelagos *et al.* 1989).

3.4.4. Diagenesis

In order to ensure the accurate reconstruction of diet in archaeological populations, it is essential that the isotopic composition detected within skeletal remains represents that identifiable in vivo. However, following the death and burial of an individual, the body is subject to a complex course of biological, chemical and physical processes, referred to as diagenesis, which can cause both contamination and loss of collagen (Millard 2001).

The intimate relationship between the organic and inorganic fractions of bone affords collagen a degree of protection from the burial environment, as the small micropore size (<8nm) inhibits the infiltration of the much larger soil micro-organisms and fungi capable of breaking down collagen (60-130kDa), making the collagen biologically unavailable (Collins *et al.* 1995; Gernaey *et al.* 2001). Therefore, in order for these collagenase molecules to gain access to bone collagen, the mineral phase of bone must first be destabilised and put into solution. This process is largely controlled by pH level and water movement, with greatest organic preservation observed in water-logged anoxic conditions (Gernaey *et al.* 2001). As the bone mineral is lost and leached into the burial environment, the organic fraction of bone becomes more susceptible to both chemical and microbial degradation (Collins *et al.* 2002).

As well as affecting collagen yield, microbial degradation may also affect the original isotopic composition of carbon and nitrogen in the collagen that remains. The amino acids that make up collagen each have their own $\delta^{13}C$ and $\delta^{15}N$ ratios, and therefore selective destruction of a particular amino acid may alter the bulk collagen isotopic ratios (Grupe *et al.* 1993). With increased porosity, contamination may be introduced by the intrusion of exogenous organic material from the burial environment, such as humic acids able to bind to collagen molecules (van Klinken and Hedges 1995). The survival of collagen within the burial environment may also depend on the biostratinomic processes present prior to burial. For example, bones that have been processed, through butchery, burning, or excarnation, are more likely to survive than those buried as part of an articulated body, as putrefaction of the soft tissues enables early microbial attack by endogenous bacteria (Millard 2001).

All skeletal material recovered from archaeological contexts are subject to post-mortem degradation, but diagenesis is not a predictable process, nor does it occur in a uniform way throughout the skeleton, or even the within the same bone (DeNiro 1985). Therefore, in order to determine the viability of the sample derived from archaeological material, it is necessary to ascertain if the organic material sampled is actually collagen. As collagen has a unique amino acid composition, its presence within a sample can be best demonstrated by quantitative amino acid analysis. However, this form of analysis is both time consuming and expensive, placing it beyond the reach of most isotopic analyses (van Klinken 1999). Therefore, an alternative set of criteria have been determined to identify acceptable levels of collagen

Criteria	Modern Bone Values	Acceptable Archaeological Range
Collagen Yield	22%	>1%
C:N Ratio	2.9-3.5	2.9-3.6
% of Nitrogen	11-16%	11-16%
% of Carbon	26-44%	26-44%

Table 3.2: Criteria for Acceptance (figures taken from van Klinken (1999) and DeNiro 1985)

obtained from archaeological samples (see Table 3.2). It is these criteria that are utilised in this thesis. The failure of a sample to fulfil these criteria will lead to its exclusion.

3.5 Conclusions

This chapter has provided an overview of the main principles and applications of carbon and nitrogen stable isotope analyses for the identification of dietary intake. Issues and problems were also highlighted with particular reference to the thesis. Further discussion of the isotopic protocols will be provided in Chapter 5. The next chapter will now discuss the historical and archaeological perspective of life in Roman London.

Chapter 4: Roman London

This chapter will introduce the historical and archaeological evidence for the Roman occupation of London. This chapter will bring together evidence from a variety of primary and secondary sources to highlight key background information regarding the nature of this Roman town and the lives of the people who lived within it. Importantly, it is within this contextual evidence that the palaeodemographic, palaeopathological and isotopic evidence will be interpreted. The first section will introduce the archaeological background and development of the settlement, with further sections focusing on the economy, living conditions and diet. The final section of the chapter will address evidence for population composition and the presence of children in Roman London, before addressing the nature of the buried population.

4.1 Archaeological Background

Roman London, *Londinium*, was a distinctly Roman settlement located on the banks of the River Thames at the site occupied by the modern City (Figure 4.1). Despite evidence for the casual exploitation of the Lower Thames Basin stretching back to the Mesolithic era (Cotton 2000), there appears to have been no established settlements within the area at the time of the Claudian invasion of AD 43 (Perring 1991: 3). The landscape that the town would eventually inhabit was one dominated by its rivers. Alongside the River Thames, the topography of the north bank was carved out by several rivers and streams that would eventually influence the boundaries of the settlement, particularly the River Fleet to the west and the Lorteburn Stream to the east (Milne 1995: 40). The eastern and western hills (Cornhill and Ludgate respectively), which would become the foci for development, were further shaped by the Walbrook stream that met the Thames, where the modern Cannon Street Station is today (Rowsome 2008: 26). South of the Thames, banks and islands of dry gravel would provide the focus for occupation here (Rayner 2009: 42).

The origins of the Roman town have been much debated. With no pre-existing indigenous settlements present in the area, it was initially believed that *Londinium* had military origins, arising in conjunction with an invasion period fort to fulfil the needs of the army (Merrifield 1965: 32-35; Merrifield, 1969: 29ff; Perring 2011). This hypothesis was further supported by the strategic importance of the river crossing and the subsequent road network that placed *Londinium* at its centre (Heard *et al.* 1990: 611; Yule 2005, 86). However, little evidence of such a fort or associated military buildings has been recovered and much of the archaeological evidence points to a later foundation date (Millett 1990; Hill and Rowsome 2011: 438),

Figure 4.1: Map of Roman London (© Museum of London)

recently revised by dendrochronology to AD 48 (Tyers 2011). Instead, the general consensus now favours a civilian origin, with Roman London established as a *conventus civium Romanorum*, a self-governing unofficial entrêpot founded by opportunistic Roman citizens and merchants who recognised the potential of its favourable location (Haverfield 1911; Marsden 1980: 17; Millett 1990; 1996; Wallace 2011).Its position on the boundaries of native tribal borders provided it with a market without encroaching on existing settlements, while its location at the tidal head of the River Thames enabled goods to be brought directly into the city (*Ibid*). The early first century AD epitaph of Aulus Alfidius Olussa (RIB I. 9) found within the city lends further support to this hypothesis. Although his profession is not specifically recorded in the epitaph, it is believed that he was a foreign *negotiator* or merchant. Originally it was suggested that Aulus Alfidius Olussa came from Athens, Greece (Collingwood and Wright 1965: 4), though it has been argued that this was the result of an error in translation, suggesting he came from Atina, Italy instead (Simelon 1988).

Despite this, the initial feats of civil engineering observed within the town makes it unlikely there was no direct involvement of the provincial government, with military personal probably responsible for overseeing some of the early infrastructure projects (Marsden, 1980: 20-1; Perring 1991: 17). Evidence for this is provided by the identification of military stamps on building materials used to construct the town (*Ibid*). As such, the origins of Roman London are unique amongst the towns of Roman Britain.

Initial construction within *Londinium* was limited to the south side of the Cornhill, focused at the T-junction formed by the main N-S and E-W roads (Perring 1991: 7) (Figure 4.2). While influenced by topography, this early development was planned from the outset on an orthogonal street grid, with simple buildings built along the main road system (Rowsome 2008). The town grew rapidly in its first decade and by AD 60 covered an area 36 hectares in size, with ribbon developments expanding out from the Cornhill, particularly to the west (Rowsome 2008). Settlement on the south bank began in the early AD 50s and by the end of the decade extended along the main N-S road just beyond the Borough Channel (Cowan *et al* 2009: 14-16). Despite the lack of public buildings observed at this time, the town had become crowded with houses and workshops and had a population estimated to be in the region of 7,000-10,000 people (Swain and Williams 2008).

This early growth and expansion would be curtailed in AD 60/61 by perhaps the most famous incident in Roman London's history – the Boudiccan revolt. Following the confiscation of her tribal land, the rape of her daughters and her own public flogging, Queen Boudicca of the Iceni led a rebellion against the Roman forces in Britain that culminated in the destruction of three prominent towns, including Roman London (for a full account see Tacitus *Annals XIV*; Cassius Dio *Roman History* 62; Sealey 2004).

The event is seen archaeologically as a layer of burnt debris that, while concentrated in the areas around the Cornhill, is observed as far as the western suburbs and the south bank (Marsden 1980: 32-5; Drummond-Murray and Thompson 2002: 40-53; Hill And Rowsome 2011: 73-82). While clearing of the debris and repairs to the road system occurred quickly after the suppression of the revolt, recovery was gradual with rebuilding delayed by up to a decade (Perring 1991: 22-3).

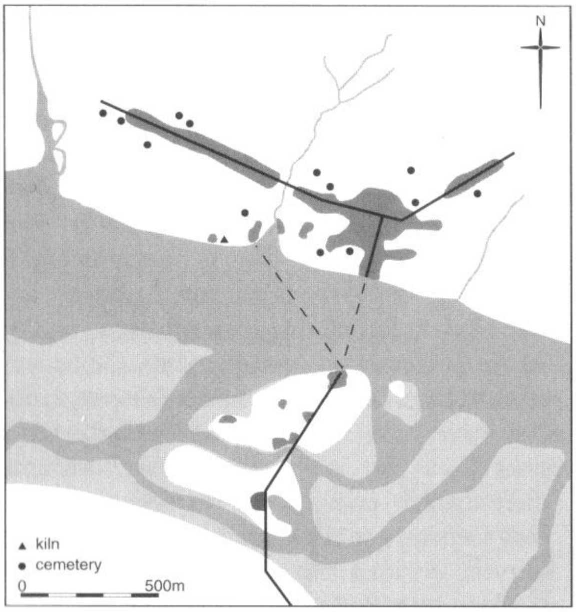

Figure 4.2: Early development within Roman London (Milne 1995: 43)

Despite this slow start, the period of AD 70-90 saw the undertaking of a large-scale co-ordinated building programme that included the construction of the town's first public buildings. It appears that the first public building constructed from c. AD 72 was the *forum-basilica* complex at the heart of the town (Marsden 1987). The *forum-basilica* was the principle Roman public building where much of the administration of the town would be undertaken. It's construction, and the presence of the provincial financial administrator (*procurator*) from at least AD 60, as witnessed by Tacitus (*Annals* xiv, 32), the burial of the procurator Classicianus in the town (RIB 1.12) and official stationary and buildings materials found within the town (Betts 1995), suggests that by this time London had probably become the de facto capital of the province and home to the financial arm of the provincial government (Hassall 1996; 2000). Issues arise with the application of the term "provincial capital" to Roman London at this time, as the seat of power was situated with the governor, who would have been peripatetic during this early period (Millett 1998). Despite this, the governor would have maintained a substantial presence in London at this time, with epigraphic evidence identifying him as a civil benefactor (e.g. RIB III. 3001). This issue is less problematic by the end of the first century when the governor appears to have had a permanent base within the town (Hassall 2000). It may also have been at this time that Roman London received some form of legal status, for most provincial capitals on the continent appear to have held either *municipum* or *colonia* status (Hassall 2000: 57; Tomlin 2006).

Other public works at this time included the construction of a fort and amphitheatre to the north-west of the existing settlement (Bateman *et al.* 2008; Shepherd 2012), an extensive overhaul of the town's waterfront (Milne 1985: 27-8; Swift 2007), and the building of some of the town's public baths (Rowsome 1998; Rowsome 2000a). These early timber public buildings would later be enlarged and/or replaced by new stone buildings in a second wave of development that took place between AD 100 and AD 150 (Perring 1991: 57). Elsewhere within the town, continued redevelopment and expansion of the suburbs had increased its size to 125ha by the mid second century AD (Perring 1991: 67-70). This expansion was greatly aided by the early second century reclamation of large areas of marsh land for industrial activity in the upper Walbrook Valley, as well as previously waterlogged land south of the river (Maloney 1990; Rowsome 2008: 31; Cowan *et al.* 2009: 18-24). As the town grew, so too did its population, reaching in excess of 20,000 (Swain and Williams 2008). This period is often referred to as the peak time for both Roman London and the Roman Empire as a whole, and a time when Roman London was at its most prosperous (Perring 1991; Milne 1995; Marsden 1980).

This peak would prove to be short lived and the emerging picture of the latter half of the second century appears to have been one of contraction and decline. An examination of archaeological deposits throughout the city suggests a potential decline of up to two-thirds of the population during this period (Marsden and West 1992). A number of potential reasons for the decline in Roman London at this time have been hypothesised, including the disruption of continental trade links by barbarian incursions into Gaul and Spain, and the Antonine plague that devastated the Western Empire between AD 165-90 (Perring 1991: 87-8; Perring 2011). However, the most significant factor appears to have been the stabilising of the province's frontiers under the Emperor Hadrian (Perring 1991: 88-89). Stable borders meant that it was now possible to source supplies locally and safely move trade routes north. As a result, York appears to have prospered at London's expense (Perring 1991: 89). With a reduction in trade and traffic through the town, it is suggested that there was less demand for commercial and industrial activity and many people abandoned the town (Perring 1991: 89; Watson with Heard 2006: 55). The loss of such a substantial proportion of the population is cited as the reason for the demolition of the Huggins Hill bath house at the end of the second-century AD (Marsden 1980: 115). The effect of this decline in trade and commerce is also apparent on the continent, with other trading centres such as Lyon, Milan and Ostia also contracting at this time (Perring 1991: 87).

While it is not disputed that there appears to have been some economic and social change at this time, the extent of the decline has been challenged. Much of the debate regarding the depopulation of Roman London has centred on the appearance of “dark earth” deposits within the town. Initially it was believed that these deposits represented soil brought in to facilitate the creation of gardens in depopulated areas within the town, with the underlying mid second century layers representing the end of the structural sequence (Merrifield 1983: 143; Perring 1991: 78-81). However, a reassessment of the deposits by Yule (1990) suggests that these “dark earth” deposits may have instead formed through the post-depositional reworking and truncation of the late Roman occupation layers. Indeed, on sites with good preservation, such as No.1 Poultry (ONE94), there is a continuity of occupation without significant decline until at least the fourth century AD (Hill and Rowsome 2011). Based on these findings, it is suggested that there has been an overstatement of the amount of contraction observed at this time, which may affect current population and density estimations (Yule 1990).

Certainly, Roman London at this time had by no means become a backwater, associated with decay and dereliction. Instead, evidence suggests that many of the public buildings in the town remained in use (Rogers 2011), and further reclamation projects that led to the development of warehouses (Wheeler 2009) and the construction of the Winchester Palace Complex (Yule 2005) are observed on the south bank during the late second century AD. Throughout the town, further investment in personal property is witnessed by an increase in the number of large lavishly decorated stone and timber “town houses” from the mid second century AD (see 4.3.1). This is particularly apparent in the Middle Walbrook Valley, where a decrease in commercial vitality is accompanied by an increase in the residential character of the area (Hill and Rowsome 2011: 445). This increase in personal investment and the appearance of large “town houses” has been associated with a fundamental change in the function of the town that saw it transformed from a commercial entrêpot to an important and prestigious administrative centre (Perring 1991). Further evidence for the political vitality of the town is observed in the events of the late second century AD, which saw the governor of Britain, Clodius Albinus, attempt to seize control of the empire following the assassination of the Emperor Commodus in AD 193 (Morris 1982: 289). A potential long term consequence of this rebellion was the division of the province of *Britannia* into *Britannia Superior* and *Britannia Inferior* in the early third century AD (Wacher 1974: 84). The impact on *Londinium* was the reduction of its importance, now being the capital of *Britannia Superior* only (Perring 1991).

Efforts to restore the town’s fortunes at the beginning of the third century AD is suggested by renewed public buildings projects, the most apparent being the construction of the town’s wall between AD 190-240 (Maloney 1983; Lyon 2007). The wall, which probably stood at a height of 6.4m, enclosed an area of approximately 125ha on the north bank, with much of the land left outside the wall given over to the provision of cemeteries (Perring 1991) (see section

4.5.3). Analysis of the construction techniques and the long duration of the project suggest the wall was not solely built for defensive needs, providing the town with a customs barrier that allowed controlled collection of duties and taxation (Marsden 1980). Other public works at this time included the final phase of expansion at the waterfront (Milne 1985: 32-3) and large religious buildings in the south-west of the town that included a screen of the gods and a monumental arch (Williams 1993). A second resurgence of building occurred in the mid-third century AD that included the reclamation of the remaining areas of the Walbrook Valley, the construction of a partial riverside wall on the north bank, a large palace complex, the temple of Mithras, and a refurbishment of the temple of Isis (Perring 1991: 103-5).

Evidence for occupation and population density within the walls is complicated by the loss of late Roman levels due to their truncation and post-depositional reworking (see above). As a result, it is currently not possible to provide estimations of the number of inhabitants living in the town during the third and fourth centuries AD, although an estimate of 24,894 at the start of the period has been hypothesised by Swain and Williams (2008: 39). While a contraction in the overall size of the settlement on both banks seems certain, there was continued investment in private housing, and maintenance of the principal road system until the mid-fourth century AD (Rowsome 2008). Further evidence for a significant population within the town at this time is alluded to by the continued use of the main cemeteries surrounding the town (Barber and Hall 2000; Mattingly 2006: 343). A particular loss to the townscape during the late-third and early fourth centuries was the demolition of the public buildings that dominated the early life of *Londinium*, most notably the *forum-basilica* in c. AD 300 (Marsden 1987). While the loss of these buildings have been associated with the decline of urban living in the late Roman period, Esmonde-Cleary (2004) suggests that it instead reflects a change in administrative style and a shift in focus towards private investment. One clear indication of this is a concomitant rise in the number of villa estates that surrounded the town (Esmonde-Cleary 2004). An increase in the appearance of high status burials is also observed at this time, alongside the use of high status burial rites such as chalk burials (see Section 4.5.3)

By the end of the third century AD it is believed that central reforms had replaced much of the traditional ruling aristocracy of the town with military officials and administrators (Perring 1991; Milne 1995). The Emperor Diocletian's reforms in the late third-early four centuries AD also resulted in a further subdivision of Roman Britain into four provinces, grouped together into a diocese (Southern 2004: 393). Overall control of the *diocese* was now held by a *Vicarius,* whose base and provincial treasury and mint appears to have been within Roman London (Southern 2004: 393). As such, whilst the town was now only capital of one of these provinces, *Maxima Caesariensis*, it remained the centre of provincial administration (Wacher1995).

Perhaps it was in recognition of its importance that Roman London was granted the title of *Augusta* sometime in the mid-fourth century AD (Hassall 1996: 25). The third and fourth centuries AD in Britain were also marked by further political rebellions by ambitious leaders, with four attempted coups by governors based in London recorded (see Salway 2001; Southern 2004 for full discussion).

From AD 340, *Britannia* had increasingly become a focus of barbarian raids. Perhaps the most notable of these was the Barbarian Conspiracy of AD 367, when multiple co-ordinated attacks by the Scottish, Irish, Saxons and Franks led to the complete loss of Roman control that would take years to restore (Frend 1992; Mattingly 2006). Roman London itself appears to have been attacked by Saxons and it is perhaps in response to this that bastions were added to the east town wall (Salway 2001). The riverside wall was also completed slightly later towards the end of fourth century AD (Maloney 1983). Despite this public investment, the terminal decline of the settlement had seemingly already begun. Although a small number of new houses and refurbishments have been dated to the end of the century, many of the town's buildings were increasingly abandoned by the mid-fourth century (Marsden 1980; Perring 1991; Milne 1995). Furthermore, the overall area of the settlement had reduced substantially, with settlement on the south bank appearing to have contracted to the area immediately surrounding the bridgehead (Milne 1995: 86; Cowan *et al* 2009: xv). The increasingly administrative role of the town has been given as a possible reason for its depopulation at this time, pushing more people out to rural estates and small towns in search of occupation (Marsden 1980; Milne 1995). The removal of the provincial army by AD 400 (Southern 2004) and the expulsion of the Roman administration in AD 409 (Webb 2011: 130) perhaps signalled the end of the town.

The final demise of Roman Britain is often dated to c. AD 410, following the refusal of the Emperor Honorius to send an army to aid in the protection of the province's borders (Salway 2001). Within Roman London, occupation appears to have continued on some small level until the first quarter of the fifth century AD, although its identification is complicated by a lack of datable material and the cessation of new Roman coins from c. AD 380 (Cowie 2008). It would not be until the instigation of a new settlement by King Alfred in AD 886 that the town would again be inhabited (Webb 2011: 136).

4.2 Economy

From Roman London's inception, trade and commerce were a key part of the town's economy. Indeed, Tacitus (*Annals* xiv, 33), in one of the few ancient literary descriptions of early

Figure 4.3: Artefacts recovered from No. 1 Poultry including two copper alloy brooches, a mount in the form of a panther and an iron knife handle (Wardle 1998: 85)

Londinium, describes it as being a famous centre of commerce by AD 60. Mercantile trade within the early town was encourage by the importation of military supplies into the province by private contractors, providing subsidised shipment routes for other luxury imported goods (Milne 1985: 103-126; Millett 1990, 1996). This was further aided by the town's location at the tidal head of the River Thames, allowing goods to be easily transported straight into the town by boat (Millett 1990). Evidence for the kinds of vessels that arrived at the harbour has been discovered within the River Thames, most being flat-bottomed sailing barges and small vessels that allowed the transportation of goods from larger ships to the riverside (Milne 1985: 97-102; Perring 1991: 28).

Despite considerable activity along the town's foreshore within Roman London's early years, the first expansion of the waterfront did not take place until AD 70-90 (Milne 1985: 25-27). This large-scale public venture included the revetment and terracing of the waterfront on both sides of the Thames and the provision of large warehouses and a possible market (Milne 1985: 27-29). A further two phases of expansion occurred in the second century AD and a final one in the early third century AD, resulting in the reclamation of an additional 50m of land in total (Brigham 1993). As quayside expansion moved the foreshore further into the Thames, those warehouses left beyond the waterfront were converted into other commercial ventures, such as those renovated into shops at Pudding Lane (Milne 1985: 30; Perring 1991: 28, 66).

Evidence for the kinds of items imported into the town suggests a considerable range of luxury goods would have been available. The roman tastes of the settlers provided a ready market for the wine, oil, fruits, spices, and garum known to have been imported from Roman London's beginnings (Willcox 1977) as well as pottery and smaller items of jewellery, textiles and even decorative marble veneers (Perring 1991; Cowan and Wardle 2009: 91-100; Hill and Rowsome 2011) (Figure 4.3). The peak period for the importation of goods appears to have been between the late first to early second century AD, providing not only a steady supply of goods for the town's markets but also revenue from the associated duties and taxes (Milne 1985).

Away from the waterfront, the main focus for commercial activity was the *forum-basilica* complex located at the centre of the town on the Cornhill (Milne 1985: 71). Even prior to its construction, the gravelled area where it was situated appears to have been the location of a flourishing market (Marsden 1987). This market place was formalised with the construction of the forum, with commercial spaces provided along the east, west and south wings of the complex overlooking a courtyard area that continued to provide space for regular markets (Marsden 1987). A further possible aisled market hall (*macellum*) has also been uncovered at Fenchurch Street near the bridgehead on the South bank, dating to AD 70-160 (Cowan and Wardle 2009: 102). The western suburbs in the vicinity of the Walbrook Valley were also an important area for commercial enterprise, with excavations at ONE94 identifying shops trading imported goods along Watling Street from at least the AD 50's (Hill and Rowsome 2011).

Further evidence for commercial activity in the Walbrook Valley is represented by a large number of iron styli and business contracts recovered on wooden tablets and a possible tavern (Hill with Rayner 2011; Hill and Rowsome 2011: 389). A building that has been interpreted as an inn (*mansio)* has also been identified on the south side of the river at Southwark Street (Beard and Cowan 1988: 376-8).

Although never the centre of any major manufacturing, there is abundant evidence for small and medium scale industrial activity across *Londinium*. One of the most commonly observed throughout Roman deposits is metalworking, including that of gold, copper, bronze, silver, tin and iron (Brigham and Woodger 2001: 46; Hammer 2003; Cowan and Wardle 2009; Dungworth and Bowstead Stallybrass 2011; Wardle 2011a). The western areas of the settlement on both the north and south bank appear to have been particular foci for this activity (Hammer 2003; Watson with Heard 2006). Leatherworking and tanning were also important industries within the town (Milne 1985: 61-2; Perring 1991: 53; Hill and Rowsome 2011). Other industrial activity present included pottery (Seeley and Drummond-Murray 2005), glass (Maloney 1990; Shepherd and Wardle 2009), jewellery and gem manufacturing (Henig

2008) as well as service industries such as butchery (Cowan and Wardle 2009: 111; Pipe 2011a) and grain processing (Perring 1991: 53). Alongside this, the demand for housing and commercial/public amenities would have promoted a flourishing building trade (Perring 1991: 42-3, 54-55). This trade would also have supported additional industries surrounding the town, such as forestry and quarrying, to provide sufficient building material, as London had no such natural sources (Perring 1991: 42-3, 54-55).

Following the decline in the town's fortunes in the mid-second century AD, a marked decrease in imports, road traffic and overall population appears to have led to a contraction in the town's economy (Perring 1991: 84-86; Perring 2011). As such, parts of the town that had once been important for industrial and commercial activity became increasingly more residential or abandoned, particularly within the western suburb (Watson with Heard 2006; Hill and Rowsome 2011). This downturn was coupled with a general movement of large-scale industries away from urban centres to rural locations, such as that seen in the pottery industry (Esmonde-Cleary 2004). Despite this, not all commercial and industrial areas were affected by these changes, for example, leather and glass working in the Upper Walbrook Valley in the north of the settlement appears to have flourished into the late third century AD (Maloney with de Moulins 1990). Furthermore, areas left open by the demolition of public buildings were increasingly given over to industrial activities such as metalworking in the third and fourth centuries AD (Rowsome 2008; Rogers 2011). In spite of a fall in volume, trade still remained an important part of the economy, with luxury goods continuing to be imported into the town as late as the late fourth century AD (Milne 1985: 33). Indeed, an inscription dating to the late-second century AD provides direct evidence for the presence of a sailor (*mortix*) from Beauvais, France called Tiberinius Celerianus in the town (RIB III. 3014) following the initial period of decline (Dondin-Payre and Loriot 2008).The building industry would also have been reinvigorated by new public and private building in stone, and investment in private housing would continue to support specialised trades such as the school of mosaicists based in London in the late Roman period (Perring 1991: 102).

4.3 Living Conditions

4.3.1 Housing

While the earliest structures identified within Roman London appear to have been little more than rudimentary timber shelters, within a decade of its establishment more substantial dwellings have been recorded from across the town (Perring 1991: 7-14). From this time, most of the houses would have consisted of simple single-storey rectangular roadside strip buildings positioned with the shortest sides at right angles to the road (Figure 4.4) (Drummond-Murray

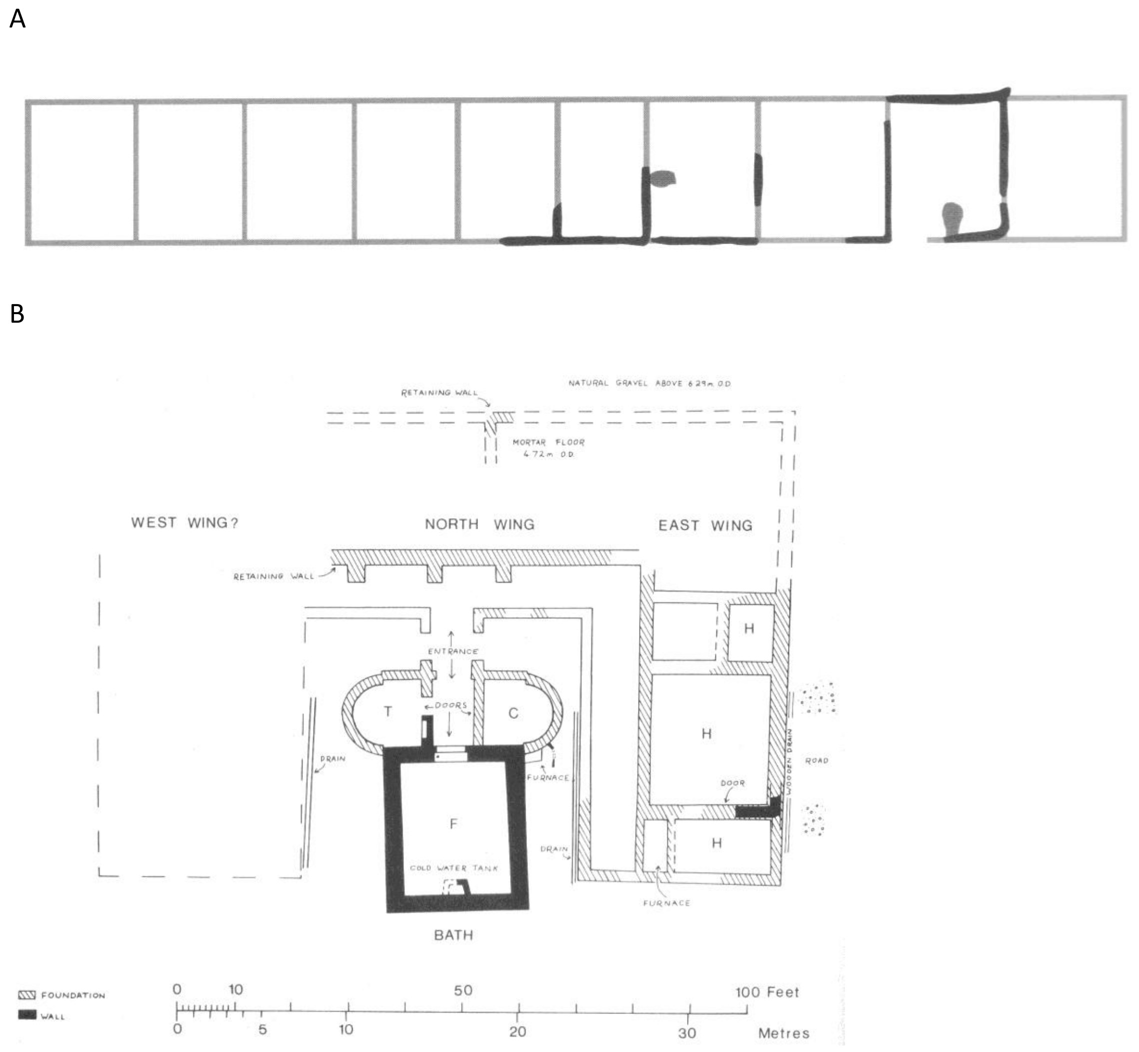

Figure 4.4: A typical early period timber strip dwelling (A) and later larger stone town house (B) (Milne 1995: 51, Marsden 1980: 154)

and Thompson 2002: 36; Perring 2002: 56). At the settlement level, these houses were grouped into grid blocks or *insulae*, with individual properties separated by narrow alleyways (Perring 2002: 55; Goodman *et al.* 2011). The majority of the strip buildings observed would have consisted of a simple two room arrangement, providing commercial space at the front of the property and living quarters for the entire family to the rear (Perring 2002: 55-60) (Figure 4.4). More rooms have been observed in larger dwellings, and additional rooms to the rear of some properties appear to have been intended for individual tenancies (Perring 2002: 56, 193). With increasing population levels, living in such a densely packed urban environment would have undoubtedly exposed the town’s inhabitants to increased levels of infectious diseases that spread easily with close contact, such as tuberculosis, as well as aided in the transmission of new pathogens brought over by a succession of newcomers from the continent (Roberts and Buikstra 2003; Roberts and Cox 2003; 2004).

Without locally available stone, most houses were constructed from timber frames and wattle-and-daub or mudbrick walls (Perring and Roskam 1991: 74-7; Perring 2002: 87, 92). Roofs would have predominantly been either thatched or boarded, although some would have had ceramic tiles (Williams 1971). As little window glass has been recovered in the earliest buildings, most windows would have probably been closed by wooden shutters (Goodman *et al.* 2011: 425-6). The most common floor material appears to have been compacted earth or clay, but a range of materials, including mortar, opus signinum, and stone and ceramic tesserae have all been identified (Williams 1971). The nature of the materials utilised in the construction of these strip buildings meant that they would require frequent repair and replacement, with an average lifespan for a timber and clay dwelling estimated to be approximately 20 years (Hill and Rowsome 2011: 450). Initially the sequences of replacement buildings appear to have respected pre-existing boundaries, but from the late second century AD houses tend to become more substantial in size (Goodman *et al.* 2011). The internal decoration of most homes would initially have been plain, but throughout the second to mid-third century AD, an increase in the use of painted wall plaster and tessellated floors is observed (Perring 2002: 130-3). While oil lamps and candles of animal fat were utilised, the main source of light and heat would have come from hearths or open fires within the property (Hill and Rowsome 2011). As well as creating a potential fire hazard, without chimneys or sufficient ventilation, these fires would have created smoky conditions that would have deleterious effects on respiratory health (Roberts and Cox 2003; 2004).

Although small numbers of well-appointed stone houses have been identified from the pre-Boudiccan period (e.g. Cowan and Pringle 2009: 82), a general movement towards the use of stone for domestic properties is observed from the mid second century AD (Perring 2002: 11). Alongside this change in building material, there appears to have been less conformity to pre-existing boundaries, and the commercial strip building styles previously observed were replaced by wing and courtyard style housing, perhaps as a response to a decline in population density and decrease in commercial trade (Hill and Rowsome 2011: 367-9) (Figure 4.4). While many of these stone buildings were modest dwellings or extensions to existing timber structures, some were more substantial multi-roomed urban “town houses” set back from the main roads (Hill and Rowsome 2011: 445-6). It is suggested that these large properties represent an increase in the importance of privilege and privacy amongst the wealthy classes, further reflected by the richly decorated interiors, hypocaust floors and bath suites present in some of the best examples (Millett 1990: 127-51). Continuity is observed in the materials utilised for interior decoration, although the use of painted wall plaster, ceramic tessellated floors and mosaics seem to have become widespread in the later Roman period (Williams

1971; Goodman *et al.* 2011: 329). It appears that many of these large houses were maintained and remained in use well into the fourth century AD (Hill and Rowsome 2011: 447).

While conventional hypotheses imply a wholesale shift in building materials from timber to stone in the later Roman period, evidence from recent excavations appear to contradict this traditional view. Indeed, on sites where good preservation is encountered, timber dwellings have been uncovered alongside those of stone well into the third and fourth centuries AD (Bluer *et al.* 2006: 69; Goodman *et al.* 2011: 416). As stone was locally unavailable, it remained an expensive commodity out of reach for most people; therefore it is unlikely that its use would have been adopted by all of Roman London's inhabitants. Instead, it is suggested that the poor representation of timber dwellings during this later period is the result of their poor survival and truncation of their wholly organic materials, leading to a biased archaeological record that favours the recovery of the more sturdy stone homes (Esmonde-Cleary 2004: 96). These findings emphasise the difficulty in determining the nature of urbanism in the late Roman period, and have important implications for population density numbers in the late Roman period (Esmonde-Clearly 1998; Rogers 2011).

4.3.2 Water supply and Drainage

One of the key concerns for the siting of any settlement is reliable access to clean water. As a riverine settlement established on a spring line, Roman London's location ensured it an ample supply without the need for an aqueduct (Wilmot 1984; Williams 2003). Access to these sources determined the location of major water consumers within the town, with all but one of the known large bathhouses constructed below the spring line and areas of industry focused on the Walbrook Valley (Wilmott 1982; Rowsome 2011). A high water table also meant that these overground sources could be further supplemented by wells located across the settlement (Merrifield 1965: 146; Wilmott 1984; Rowsome 2011). While most were simple box-framed wells that served local properties (240-500 people per day) (Williams 2003), excavations within the western suburbs have uncovered a series of substantial wells with water lifting machines capable of providing water to a substantial proportion of the settlement (Blair *et al.* 2006). This intramural water distribution system was in use from AD 63 until the mid-second century, when it appears to have been superseded by a greater reliance on smaller wells (Blair *et al.* 2006). Evidence for large scale provisions of wells are also observed at Queen Victoria Street (Wilmott 1982). This local availability of water in Roman London appears to have negated the need for an extensive water network and very little archaeological evidence for an extramural aqueduct has been uncovered (Williams 2003; Blair *et al.* 2006). Although limited evidence for a piped water supply is observed, predominantly in association with public buildings and settlement on the eastern hill (Wacher 1974: 100; Philip 1977; Williams 2003), few individual properties would have had access to piped water, and wells would have remained the most prevalent source of water for most (Williams 2003; Blair *et al.* 2006).

As well as providing water, the rivers of Roman London also appear to have provided the means to remove effluence and industrial waste from the town (Maloney 1990: 124-5; Williams 2003). No evidence for substantial sewers or an integrated sewage system has been uncovered, with the exception of a small number of culverts such as the substantial one discovered at Monument House (Blair and Sankey 2008). Few individual properties appear to have had access to their own drainage or latrines, and excavations within the city have identified a noticeable absence of cess pits within the Roman levels, with only two identified with any certainty within the recent western suburb excavations (Goodman *et al.* 2011: 428). Instead, it appears that the majority of drainage took the form of roadside drains, directly emptying the town’s effluence into its rivers and watercourses (Rowsome 2011). While archaeological evidence suggests that many of these drains and associated pipes were regularly maintained in many areas until at least the fourth century AD (Rowsome 2011), Wacher (2000: 76) emphasises the “skin-deep” nature of these provisions in a scene akin to that portrayed by Scobie (1986) for Rome itself.

Indeed, the presence of these open sewers would have had a detrimental effect on the lives of the town’s inhabitants, with putrid smells and rotting material attracting insects and vermin that would have serious ramifications for human health (Scobie 1986; Dobney *et al.* 1999; Williams 2003; Hill and Rowsome 2011; Smith 2012). This would have included the black rat species found within Roman London that was first introduced to Britain by the Romans (Pipe 2011b; 2011c). The contamination of the town’s watercourses would have had serious health implications, providing an ideal breeding ground for water-borne diseases, such as dysentery, cholera and typhoid, and endoparasites, such as roundworm and tapeworm (Jones 1993; Williams 2003). Further to this, exposure to the waste products of the town’s industries could have led to the development of a variety of sores, skin diseases and even tumours (Roberts and Cox 2004: 255) While increasing contamination of the rivers could be negated by a greater reliance on wells, the positioning of these wells in close proximity to dwellings and street drains would have meant that they too could have been easily contaminated. The situation would have been further exacerbated by the use of rubbish pits located with yards to the rear of properties and the keeping of domestic animals, such as pigs and chickens, all of which would have added to the filth and potentially have compounded health problems (Scobie 1986; Davis and Smith 2011: 412).

4.3.3 Provision of Health Care

Evidence for the provision of health care in Roman London, and the province of *Britannia* as a whole, is sparse. Currently, no medical texts proper have been recovered from Roman Britain and it is uncertain to what extent the medical theories and practices known in Rome were adopted within the province (Jackson 2011). Furthermore, it is uncertain how, if present, these practices would have been utilised across different social, cultural and economic groups or how they would have interacted with native healing traditions (Nutton 2004; Jackson 2011). The migration of wealthy citizens and merchants to Roman London would have undoubtedly included healers eager to capitalise on a new market, as well as those brought to the province as part of the staff of imperial officials, the Roman army, and wealthy households (Jackson 2008). Soldiers garrisoned within the town would also have been accompanied by their own army medics (Baker 2004). Native healers would are also likely to have been drawn to the potential earnings available in an emerging town (Jackson 2008). Although the numbers of healers within the town would have been significantly smaller than that observed in Rome, Jackson (2008) has calculated that as many as five to ten may have been present. Their location within the town is unknown due to the lack of structurally identifiable architecture associated with the profession, but evidence from Pompeii suggests that they would have been evenly distributed through the town (Jackson 2008).

Within the Graeco-Roman texts, a preventative approach to health through exercise, bathing and the regulation of diet is advocated (Baker 2010). While the extent to which this would have been adopted by the inhabitants of Roman London is unknown, the presence of numerous bathhouses and finds of bathing equipment (oil flasks (*aryballoi*) and strigils (*strigiles*)) and toiletry instruments, including tweezers, ear scoops and nail cleaners, suggest that these approaches were adhered to by some sections of society (Crummy with Pohl 2011; Wardle 2011b). When intervention was required, most illnesses and minor injuries were likely to have been treated within the extended family through the use of herbal and religious cures (Jackson 2011). While religious cures are unlikely to have left material remains (Jackson 2008), evidence for the use of herbal medicines have been recovered from *Londinium* in the form of collyria stamps used to mark semi-solid eye ointments (Jackson 1996). Evidence for further surgical intervention within the town comes from a small number of isolated finds of surgical instruments that would have formed part of the basic toolkit of ancient surgery, such as scalpels, needles, hooks, probes and spring forceps (Jackson 2008). Due to the utilitarian nature of many of the items, the instruments recovered could have been used in a wide variety of surgical treatments as well as having potential cosmetic applications (Jackson 2011). Secondary evidence for the successful treatment of injuries, such as fractures and dislocations,

Figure 4.5: A feeding vessel (*tettina*) recovered from Roman London (© Museum of London 2012)

identified in the skeletal record also provides tentative evidence for some knowledge of bone surgery in Roman Britain (Jackson 2008; Redfern 2010). Two scraped type trepanations have been identified in Roman London at Lant Street (Redfern *pers comm.*) and Spitalfields (Powers *pers comm.*).

Although it is likely that some of the healers drawn to the town may have dealt with aspects of female and child health (Flemming 2000; 2007), evidence for specific child care practices in *Londinium* is extremely limited. Currently, the only direct evidence of childcare practices in the town is a small number of feeding vessels, or *tettina*, associated with infant feeding practices (Figure 4.5). The style of these vessels are similar to those previously recovered on the continent and are referred to by Soranus in his *Gynaecology* (2. 46.115) for the administering of supplementary liquids (Fildes 1986). However, these feeding vessels provide only incidental evidence for infant feeding practices and are too few in number to allow for the identification of any patterns. Furthermore, the function of these vessels may not have been restricted solely to the feeding of infants, with the feeding of elderly or disabled people also a possibility that should be considered (Gourevitch 1990).

Overall, the evidence from *Londinium* suggests the presence of a diversity of medical practitioners and various herbal and surgical provisions within the town. However, it is likely that most access to professional healers would have been the preserve of the wealthy and beyond the means of many of the town's inhabitants (Jackson 2008). It should also be remembered that even access to the treatments available in antiquity would have undoubtedly been insufficient to treat severe infections associated with pre-industrialised towns, such as cholera, typhoid and tuberculosis (*Ibid*).

4.4 Diet in Roman London

The primary evidence for dietary consumption from Roman London is largely derived from palaeobotanical and palaeofaunal evidence recovered from archaeological deposits and environmental samples. While this evidence, summarised below, gives us an indication of the types of foodstuffs present within the town, it does not allow us to ascertain the exact proportions they represented within the diet nor evaluate potential differences associated with age, sex or social status. Another issue with this form of evidence that must also be acknowledged is that the sampling strategy adopted at excavation and the poor preservation of organic materials may lead to biases in the food items recovered.

4.4.1 Cereals and Pulses

A principal part of the diet consumed during the Roman period would have been provided by cereals, and evidence for their consumption across London is widespread (Cool 2006: 69). Spelt wheat is the most abundant cereal recovered from London and would have been ground to make bread and cakes or added to water to make porridge (*puls*) (Cowan and Wardle 2009: 113; Davis 2011a). Barley, considered by Romans as unfit for human consumption, is also commonly recovered across London, albeit in smaller quantities than wheat (Cowan and Wardle 2009: 114; Davis 2011a). As it makes poor-quality bread, barley was more likely to have been used to make porridges, pottages and griddle cakes (Cool 2006: 78; Davis 2011a). In addition, barley could also be brewed to make beer, although as yet no evidence for brewing has been recovered from the city (Cool 2006: 140-3). Other grains, such as oats and rye, are seldom recovered, suggesting that they were rarely exploited (Cowan and Wardle 2009: 114; Davis 2011a). The only evidence recovered for imported cereal species is a single grain of millet from a second century deposit in Southwark (Willcox 1978).

In comparison to cereals, pulses are less commonly recovered in London, although this may be due to their poor preservation rather than a lack of their exploitation. Nevertheless, a small number of cultivated pulses seem to have been available including varieties of peas, beans, and lentils (Willcox 1978; Cowan and Wardle 2009: 114; Davis 2011a). Lentils in particular seem to have been an important part of the diet, as large numbers have been recovered where conditions are favourable to preservation, such as waterlogged deposits in Southwark (Willcox 1978), and destruction deposits associated with the Boudiccan and Hadrianic fires on both the north and south bank (Tyers 1988; Davis 2011b). Whilst most of these pulses were not native to Britain, they could have been locally cultivated, with the exception of lentils which would have been imported from the Mediterranean (Callender 1965: 37; Davis 2011a).

4.4.2 Meat and Dairy

While cereals and pulses certainly formed a staple part of the Roman diet, it is often assumed that they dominated it, with historical evidence from Rome indicating that most of the "non-elite" individuals ate an almost vegetarian diet with very limited meat (Garnsey 1999; Alcock 2006). However, large collections of butchered animal bones (e.g. Pipe 2011c) and isotopic investigations of diet at other Romano-British settlements (Cummings 2009) attest to the regular consumption of meat during this period within the province.

From its initial occupation, beef appears to have been the most popular meat consumed in London, with cattle accounting for 70-90% of the animal bone assemblage, followed by pork and mutton respectively (Cowan and Wardle 2009: 116; Pipe 2011b: 411). While it is often not possible to distinguish between sheep and goat osteologically, evidence suggests that goats were not utilised as a food source at this time and therefore most of the sheep/goat bones are thought to be sheep (Cool 2006). A high proportion of cattle and pig within the diet is identified as a "Romanised" diet, compared to the more typical sheep-based diet found at Iron Age settlements, and is a feature of most urban and military sites throughout Roman Britain (King 1984; 1999). However, the high proportion of cattle seen in the Romano-British diet is thought to be a reflection of the "militarisation" of the native diet, influenced by the Gallo-Germanic army, as pork not cattle was the most utilised meat in Roman Italy (*Ibid*). While cattle remain the most utilised species, fluctuations are observed across London throughout the Roman period, perhaps reflecting possible social and ethnic differences in consumption (King 1999; Bluer *et al.* 2006: 164; Cowan and Wardle 2009: 116). Evidence for the consumption of goat and horse meat appears to have been rare both in Roman London and the rest of Roman Britain, suggesting neither formed a substantial part of the townspeople's diet (Bluer *et al.* 2006: 166; Cool 2006: 87, 91-2; Hill and Rowsome 2011: 320). Whilst hunting was a popular leisure activity at this time, evidence for the consumption of game is also rare in London, and the province as a whole, being mostly confined to high status contexts (Bluer *et al.* 2006: 166; Cool 2006: 83; Cowan and Wardle 2009: 117; Hill and Rowsome 2011: 385). Of the game species, deer is the most common, with instances of hare, woodcock, partridge, teal, small passerine and common crane also observed (Bluer *et al.* 2006: 166; Cowan and Wardle 2009: 117; Hill and Rowsome 2011: 385).

In addition to the three main domesticates, another source of meat available in London was poultry and domestic fowl. Chicken bones dominate the poultry and fowl represented in the animal bone assemblages in London (c.90%), with ducks and especially geese being much rarer (Cowan *et al.* 2009: 173; Hill and Rowsome 2011: 320). While it has been suggested that poultry could have been easily kept by most in the gardens and yards of the town, there are indications that the actual consumption of poultry was linked to high status occupations and the elite Roman lifestyles (Cool 2006: 101). This is further supported by the presence of chicken bones and whole skeletons within ritual deposits and graves within the city (Cowan 1992; Barber and Bowsher 2000; Mackinder 2000; Watson 2003), and Roman Britain more generally (Philpott 1991). Instead, the consumption of eggs, a particular feature of urban rather than rural environments during this time (Cool 2006: 102), appears to have been much more common, with eggshells recovered from areas across the settlement (Drummond-Murray and Thompson 2002: 51; Cool 2006: 102; Sidell 2011).

As the production of dairy items often leaves little archaeological traces, and evidence for their incorporation into the diet at Roman London is sparse. While it is certain that milk-producing animals were present within the town and its hinterland, the extent to which they were exploited for milk production is unknown (Cool 2006: 93). The identification of small numbers of neonate and very young calves within archaeological deposits at sites on the Cornhill provides some evidence for local milk production, albeit tentative (Bluer *et al.* 2006: 168). Goats are another animal that could have also been exploited, perhaps explaining their presence within the archaeozoological record of the town (Cool 2006: 94). Although little evidence for cheese production has been recovered from Roman London itself, evidence of a ceramic cheese press from Threadneedle Street, as well as other presses and strainers at other post-conquest Roman towns, suggests that cheese may have also been a favoured food item (Cool 2006: 94-7).

4.4.3 Fish

The extent to which fish were exploited in the past is often difficult to determine as they are commonly underrepresented in the archaeological record due to the need to wet-sieve soil samples in order to recover their bones. Despite this, the available evidence suggests that the level of fish consumption in Roman London was considerably lower than in later medieval contexts (Locker 2007). The most commonly exploited fish appear to have been freshwater and estuarine species, with eel and flounder/flatfish being the most prevalent (Locker 2007). Other such species recovered include: pike, cyprinid, dace, roach, gudgeon, chub and trout (Locker 2007). Salmonids are less well represented and found in lower proportions than in any other Roman town, perhaps due to the increasingly polluted nature of the Thames and Walbrook (Locker 2007: 151). Marine species, including cod, mackerel, haddock, herring, sea bream, smelt, grey mullet, and sprat, are also present in the fish bone assemblages (Locker

2007; Cowan and Wardle 2009: 105; Hill and Rowsome 2011: 264, 320; Wardle and Rayner 2011: 290). There is little evidence for imported fish, with the discovery of Spanish mackerel in an amphora containing garum (see below) the only notable exception (RIB II.6 no. 2 2492.24). Overall, it appears that the exploitation of fish within Roman London was casual and based on what was readily available (Cool 2006: 105; Cowan and Wardle 2009: 168). However, against this backdrop of sporadic consumption, isotopic and archaeozoological studies of fish consumption in the Romano-British period have linked increased consumption of marine fish to higher status occupations (Richards *et al.* 1998; Locker 2007), although this is not universally upheld (Cheung *et al.* 2012).This connection is also observed in London, with fish particularly seen as a luxury, such as cod and sturgeon, and only being recovered in high status settlement contexts (Drummond-Murray and Thompson 2002: 121; Cowan and Wardle 2009: 116).

Another source of fish consumption was through the use of garum, a pungent sauce made from fermented oily fish. Used as a seasoning, evidence from amphorae suggests that it was originally imported from Spain until the third century, when supplies came from provinces in North Africa instead (Cool 2006: 59). While it appears that the importation of garum may have decreased in the third century, evidence for local production in London at this time near Bishopsgate suggests that it still remained an important foodstuff here (Bateman and Locker 1982). The consumption of oysters also increased throughout the Roman period, both in Roman London and across the rest of the province (Cool 2006: 106-9), and large first and second century AD dumps of oyster shells have been recovered from Roman London's waterfront (Milne 1985: 91-3).

4.4.4 Fruit, Nuts, Vegetables, Herbs and Spices

Throughout its occupation, the inhabitants of Roman London appear to have had access to a wide variety of both native and imported fruits and nuts (Van der Veen 2008). Of the non-native fruit species, fig and grape are the most frequently observed, with figs in particular being ubiquitous throughout the Roman period (Cool 2006: 121; Cowan and Wardle 2009: 101; Davis 2011a: 404; Davis 2011b: 410; Wardle and Rayner 2011: 290). Other non-native species commonly observed include: dates, mulberry, damsons, walnuts, and stone pine, alongside new varieties of apple, cherry, and plums (Cool 2006: 119-125; Van der Veen *et al.* 2008; Cowan and Wardle 2009: 101-2, 114; Davis 2011a: 403; Davis 2011b: 410). Less commonly recovered imports include olives and almonds, and species only observed in London includes peach, for which a single stone has been recovered, and cucumber, originally native to Africa (Willcox 1977). These imported fruits had a variety of uses and were probably imported either fresh or dried, or as wine in the case of grapes (Cowan and Wardle 2009: 101, 114; Wardle and Rayner 2011: 290). While it is possible that many of these species could have been cultivated locally, dates and olives were certainly imported amphorae-borne commodities (Davis 2011b: 410; Wardle and Rayner 2011: 290). In addition to these "exotic" fruit and nut species, native species such as blackberry/raspberry, crab apples, sloe/blackthorn, wild strawberry, cherry and hazelnut are also commonly observed in London's Roman deposits (Cool 2006: 123; Cowan and Wardle 2009: 115; Davis 2011b: 410).

Unlike fruit and nuts, the range of vegetables available is more difficult to ascertain due to their poor preservation archaeologically. Nevertheless, seed and pollen evidence suggests that vegetable species such as parsnips, carrots, beets, and the Brassica/Sinapis family (which includes cabbage, turnip, swede, cauliflower and sprouts) were not uncommon at most sites (Cool 2006: 126-8; Cowan and Wardle 2009: 115; Davis 2011b: 410; Wardle and Rayner 2011: 290). The extent to which these vegetables were consumed and cultivated is uncertain, as it is often not possible to identify whether the species were domestic or wild varieties (Davis 2011b: 410). Another group of plant species recovered from Roman London are herbs and spices. Non-native species observed include: coriander, dill, fennel, white mustard, poppy seeds, summer savoury, black cumin and anise (Willcox 1977). As well as having a number of culinary uses, such as the seasoning of bread and meats, evidence for a rare pottery strainer from a pre-Boudiccan context suggests that spices may have also been infused into wine (Cool 2006: 143-7). The presence of these imported herbs and spices in early pre-Boudiccan deposits identifies they were available soon after the town's inception, with their addition to the diet seen as a particularly Roman introduction (Davis 2011a: 403).

While most of the culinary plant species discussed above are observed within deposits across Roman London throughout its occupation, recent evidence from the western suburbs suggests a possible contraction in the abundance of non-native species that would have been available after the mid second century AD (Davis 2011a: 403). This decline has been attributed to a decline in commercial activity at the site, concomitant with a reduction of amphora-borne trade with the Mediterranean at the same time (Milne 1985: 112). It is uncertain to what extent this contraction was borne out in the remaining areas of the town, and the truncation of later Roman deposits and the environmental sampling strategies undertaken at other areas of the town must be considered as potential biases in the archaeological record.

4.5. The People of Roman London

4.5.1 Population Composition – "Foreigners" and "natives"

Over the four centuries of Roman occupation, it is estimated that one million people would have lived within Roman London (Barber and Hall 2000: 112). Despite this, little is known about the composition of people who called this town their home and the names of only 235 individuals are known (Holder 2007: 29).

Without an existing settlement or nearby native centre from which to draw its population, it is thought that a significant number of people, particularly in its early years, would have come from outside the province. Indeed, the establishment of a *conventus civium Romanorum,* and the level of importation observed from Roman London's inception, would have required contacts with the established Roman world that precluded these initial settlers from being native Britons (Millett 1996). Rather, they were more likely to have been wealthy citizens, traders and merchants from the Mediterranean or nearby provinces seeking to enlarge pre-existing trade networks (Millett 1996). One such individual known to have lived in *Londinium* is Aulus Alfidius Olussa, a Greek merchant from Athens who died and was buried in London within the first century AD (RIB I, 9).

Another group of incomers that would have been resident within Roman London would have been imperial administrators. As the base of the provincial governor, procurator and later the *vicarus*, numerous officials would have been present to assist them with their duties (Perring 1991: 38-42, 109-112; Mattingly 2008). Consequently, it is thought that Roman London would have had the highest number of citizens and officials of any town in Roman Britain prior to the universal bestowing of citizenship throughout the empire by Caracalla in 212 AD (Millett 1996: 36). Amongst these officials would undoubtedly have been imperial slaves and freedman, at least two of which (Anencletus and Aquilinus) are known epigraphically (RIB I: 21 and Hassall 1980). Unfortunately, the full extent of slavery within Roman London is at present unknown as only one further inscription concerning slavery, namely an instruction to sell a slave, has been recovered (RIB II.4, 2443.7) (see Section 4.5.2).

Alongside the imperial officials, the governor, and later the vicarus, was also accompanied by a military contingent made up of men from every legion stationed in Britain , themselves consisting of men drawn from across the different provinces of the empire (Hassall 2000: 54). Furthermore, various military campaigns, particularly in the third and fourth century, would have also brought additional Roman troops to the city, albeit on a temporary basis in some cases (Marsden 1980: 166). Epigraphic evidence for at least three of the six legions stationed in Britain has been recovered from London (Yule and Rankov 1998), alongside coincidental finds of uniform, weaponry, and tombstones (Hassall 1973). In addition to active soldiers, evidence for veterans settling within the town has also been recovered in the form of a second century AD bronze military diploma conferring citizenship on its recipient (Roxan 1983).

Due to the paucity of recovered inscriptions, further identification of non-natives within the general population must be derived from Roman London's cemeteries. The presence of rare and fine burial goods is one method that has been utilised to identify potential non-natives (Cool 2010; Pearce 2010). However, the often portable nature of many of these items makes assigning geographical origins problematic as their presence may instead be a reflection of the range of goods available within a Roman town (see Pearce 2010 for issues with identifying migration using grave goods). One method that circumvents this issue is the analysis of the skeletal remains themselves. Isotopic investigations of the ratios of strontium, oxygen and lead found within the skeleton have been successfully used to ascertain geographical origins (Killgrove 2010; Prowse *et al.* 2010). Within Roman London, three such studies have identified the presence of non-natives, including a high-status female whose lead ratios are consistent with a childhood spent in the Mediterranean (Montgomery *et al.* 2010; Shaw 2013; Millard *et al.* in prep). Further to this, a previous examination of stress markers within *Londinium*'s cemetery population also alludes to the presence of non-natives (Gowland and Redfern 2010) (see 2.3).

While it appears that a significant proportion of its population came from outside the province, Roman London was not just a town of foreigners. The establishment of a new town would have undoubtedly created social and economic opportunities that would have encouraged the migration of native Britons from the countryside (Pearce 2010). This rural-urban migration would have been further facilitated by the breakdown of existing social networks after the Roman conquest, enabling an increased degree of population mobility for those within province as well as those coming into it (Pearce 2010). As Reece (2008: 46) surmised '[while] the person hoisting the packages out of the hold, or off the deck of the ship was foreign, the person on the dock guiding the packages down to the ground was probably British'.

Despite this, direct evidence for native Britons within Roman London is sparse, predominantly consisting of a limited number of inscriptions of names containing Celtic language elements, or words thought to have had Celtic roots, such as "Thames" or "*Londinium*" itself (Holder 2007). Further indirect evidence for their presence within the first years of the town's establishment is attested to by the discovery of several Iron Age-style circular buildings dated to the c. AD 50s (Watson with Heard 2006: 14). However, the small amount of evidence found for the presence of native Britons within the town should not be seen as an indication of their absence, or small numbers (Holder 2007: 31). Rather, the blurring of British and Roman identities over time, particularly in major towns such as Roman London, would have meant the adoption of Romanised forms of names, dress, and buildings, something that Morris (1982: 204-6) suggests would have happened surprisingly quickly, inhibiting the identification of native portions of the population from material culture alone.

Overall, the current evidence described above does not allow us to quantify the extent of migration to Roman London throughout its occupation, nor does it enable us to ascertain the ratios of “foreigners” and “natives” that made up its population. However, the evidence suggests that Roman London had a remarkably complex and heterogeneous community.

4.5.2 The Children of Roman London

Although children were undoubtedly ubiquitous in Roman London, direct evidence for their presence is extremely limited. Within the epigraphic record, a small number of individual children are known from inscriptions taken from tombstones. These include that of Marciana who lived to 10 years of age, and Marcus Aurelius Eucarpus who lived to the age of just 15 years and 6 months (RIB No.10) (Figure 4.6a). A further potential reference to a female child comes from a wooden tablet that records the sale of a slave girl [*puella*] called Fortunata (Tomlin 2011) (Figure 4.6b). While the age of Forunata is not recorded, it is clear from the inscription that she was not a small child (Tomlin 2003). It is important to note however that Roman slaves were often referred to as boy (*puer*) or girl (*puella*) regardless of age; hence, caution is needed in its consideration (Joshel 2010; George 2013).

In addition to these depictions, further evidence for children within the town comes from a few examples of their material culture. Leatherworking was an important industry within *Londinium* and therefore it is not surprising that shoes, including those belonging to children, are founded within Roman deposits (MacConnoran 1982; Keily 2011). A more interesting discovery was that of a leather bikini brief, sized to fit a small girl (Wilmott 1982: 52-55) (Figure 4.6c). Few items that could be considered “toys” have been found, although a sculpture of a small child with a ball in his hand is one exception (Figure4.6d). Another poignant plaything found within the grave of a 2 year old child is a well-polished broken boar’s tusk found clutched within the child’s hand (Bentley and Pritchard 1982: 153-4). Game counters and dice suggest that board games were played, but few of these items have been found in direct association with children, either within settlement or cemetery contexts (Barber and Bowsher 2000: 135-6).

While, together these instances give us with a snapshot of a small number of the children of Roman London, this extremely limited evidence cannot provide us with a detailed understanding of childhood within the Roman town. This situation is mirrored at other

A

The inscription reads [..] EMORIAE | [..] TVITATI |[..] MARCIANAE | [..]IT ANNX | [..] AVREL | [..]ECC | [..] | [..]RTI | [..]VS F C. translated as "to the spirits of the departed (and to) the everlasting memory of ... Marciana who lived 10 years ... months and ... days, Aurelius ... had this set up" (Museum of London)

AVR(ELIO) EUCARPO FIL(IO) PIENTISSIMO, VIXIT ANN (OS) XV M(ENSES) VI, AUR(ELIA) EVCARPIA MA(TER) POSSVIT. translated as "To Marcus Aurelius Eucarpus, my most devoted son; aged 15years 6 months; set up by his mother, Aurelia Eucarpia." (RIB 10)

Figure 4.6: Evidence for the children of Roman London: a) tombstones of children from Roman London, a young girl called Marciana (left), and a young boy called Marcus Aurelia Eucarpia (right) (©Museum of London); b) a wooden tablet detailing the sale of the slave girl Fortunata, dated to AD80-120 (© Andy Chopping, MoLA); c) the lower half of a girl's leather bikini dated to AD43-100, found within a Roman well at Queen Victoria Street; d) children's toys – a fragment of a sculpture depicting a young child with a ball (©Museum of London) (left), and a boar's tusk found clasped in the hand of a two year old buried at St. Bartholomew's Hospital cemetery site (BAR79) (©Museum of London).

Romano-British settlements, where evidence for children also remains extremely poor. Alternative approaches could include the identification of children from funerary contexts in the town's cemeteries; however a detailed analysis of the skeletal remains or burial contexts of the children of Roman London has yet to be published.

4.5.3 The Buried Population

Under Roman law (*Lex Duodecim Tabularum)*, burial in the Roman Empire was forbidden within the boundaries of any urban settlement (Cicero *De Leg* ii, 23, 58. Therefore, as with most Roman towns, the cemeteries of *Londinium* were located near the city gates alongside the main roads leading away from the settlement (see Figures 4.1 and 5.1). Hall (1996) was the first to give an overview of the cemeteries of *Londinium* as a whole, dividing them into the cardinal divisions that continue to influence discussions of the cemeteries today. While noticeable differences were observed by Hall (1996) between the cemeteries, it remains unclear what, if any, relationship burial location may have had in the town. Some intramural burials are observed (Sayer 2012), though most reflect either the early boundaries of the settlement or involve neonates and infants whose burial within domestic contexts is well attested to throughout the empire (Scott 1999).

Over 187 excavations within the modern city have uncovered Roman burials, but our knowledge of the buried population of Roman London is limited by the lack of available published data and the incomplete or lost archives of many of the sites excavated prior to the 1990's by the Department of Urban Archaeology (DUA) and the Department of Greater London Archaeology (DGLA) (Barber and Bowser 2000). This is particularly problematic for burials uncovered before the twentieth century, where often all that is available is anecdotal information. This situation is further complicated by the fact that most of the site reports that have been published feature information on individual excavations rather than entire cemeteries (e.g. Watson 2003). Indeed, a published synthesis of only the eastern cemetery is currently available, although new synthesises are currently being undertaken (Barber and Bowsher 2000). Despite this, a generalised overview of burial practice for Roman London is provided below (for discussions of individual cemeteries please see Hall 1996; Barber and Hall 2000)

As within the rest of the province of *Britannia*, cremation was the dominant burial practice performed in *Londinium* until the second century AD, from which point it was increasingly superseded by inhumation (Philpott 1991). Unlike many other Romano-British towns, early inhumations prior to this shift in burial practices are present right from the town's origins, suggesting that Roman London was the first town within the province to adopt new burial traditions emanating from the centre of the Empire (Barber and Hall 2000). From the available population information published, it appears that, as in other Romano-British urban cemeteries, men were more frequently represented than females (M: F ratio of 1.7:1) (Barber and Hall 2000: 113). The recovery of subadults from the cemeteries appears to be low, although this could be a reflection of the incomplete excavation of many of the cemetery sites. Indeed, while the recorded number of Roman burials from the town exceeds 10,000, the available evidence represents a small portion of the original population of the town throughout its 400 year history (Barber and Hall 2000).

In order to obtain the palaeodemographic, palaeopathological and isotopic evidence need for this thesis, the investigation is limited to inhumation burials. It is acknowledged that the use of solely inhumation burials to investigate the population of Roman London may introduce biases into the data, as sections of society that tended to favour the cremation burial rite will be excluded from the sample. This is particularly problematic in the early period when cremation was the dominant mortuary rite practiced by the vast majority of the population. As a result, large sections of the town's population will be excluded from the study. This would particularly include high status citizens from the Mediterranean region and individuals from other provinces that came to London and chose to continue the cremation rite. As such, it is likely that the individuals available for study from the early period cannot be considered as "characteristic" of the entire town's population at this time. Instead, the early population is a reflection of a minority of individuals who chose the less popular rite of inhumation, the composition and identity of whom is unknown. This bias in the early population has implications for comparisons of demography, palaeopathology, status and diet with the late population, as the increased popularity of inhumation would have resulted in the inclusion of a wider section of society in the available later sample. However, it is important to remember that few cemetery populations are representative of the population from which it was drawn and bioarchaeological investigations are often limited to available sources. Furthermore, though not thoroughly inclusive, evidence for the health stress and diet of subadults and individuals from the early period still provide important information regarding life in the early town, albeit it of a reduced minority.

As this thesis involves the investigation of inhumation burials, only these will be given further consideration below (for more information regarding cremation burial practices please see Philpott 1991; Hall 1996).

As in the rest of Roman Britain, the most prevalent inhumation practice observed at Roman London was an extended supine burial, most commonly within a wooden coffin (Barber and

Bowsher 2000; Barber and Hall 2000) (Figure 5.2). Evidence for the marking of graves or masonry structures is not commonly observed, and only a few examples of high status burial features such as the use of lead, stone and tile are recorded (Barber and Hall 2000). An exception to this is the cemetery uncovered at Great Dover Street (GDV96) within the southern cemetery, where inhumations and cremations occurred within a walled cemetery and mausolea (Mackinder 2000). No particular orientation appears to have been favoured, with most burial positions following cemetery alignments (Barber and Hall 2000). A small number of deviant burials, such as those in a prone or flexed position, or decapitation burials, have been discovered, although these are in the minority (Barber and Bowsher 2000; Mackinder 2000; Taylor 2008). During the third and fourth century AD, the practice of burials within chalk/plaster is observed, although whether it represents a Christian tradition or just a willingness to preserve the body is not fully understood (Philpott 1991).

Analysis of the distribution of grave goods amongst the inhumation burials suggests that their inclusion was the exception, with over three-quarters of burials lacking any form of grave goods (Hall 1996; Barber and Bowsher 2000). Where they are present, there appears to have been a rich diversity in the kinds of goods deposited, ranging from small personal possessions to large vessels, perhaps reflecting the multitude of ethnic origins and religious beliefs present within the town (Hall 1996). As such, the lack of any clear pattern of grave goods or high status burial features makes it difficult to ascertain different status levels amongst the buried population, with the London burials seemingly less wealthy than those known elsewhere in Roman Britain (Farwell and Molleson 1993; Booth *et al.* 2010). It has been suggested that the actual action of burial within the cemeteries themselves may be a marker of status that excluded the poor of the town (Philpott 1991).

4.6 Conclusions

This chapter has provided an overview of current information regarding the archaeological and limited historical evidence of the history of Roman London. Elements of the economy were highlighted alongside information regarding the nature of living conditions, health care, dietary intake and the population composition. The chapter also highlighted the lack of available evidence for the presence of children within the town, reaffirming the need for further investigations into subadult life and health at Roman London. The following chapter will now detail the materials and methods utilised within the thesis to address the research aims and objectives.

Chapter 5: Materials and Methods

This chapter describes the skeletal sample used to address the research aims of this thesis. It presents data collection methods, including the sampling strategy utilised for both the skeletal and isotopic samples. In addition, it details the statistical analysis employed.

5.1 Materials

Roman London provides a unique opportunity to study childhood health and care in a Romano-British context as extensive excavations over the last three decades have uncovered substantial cemetery sites within and around the City, providing an extensive skeletal collection for analysis. In order to address the research aims of this study (see Chapter 1), a large sample size that incorporated subadults and adults from sites across the entirety of Roman London was required. As the focus of the collaborative project with the Centre for Human Bioarchaeology (CHB) at the Museum of London was to investigate health and dietary patterns across Roman London, the reanalysis of such a large sample size was beyond the scope of this project. Therefore, this research employed the biological data recorded on the Wellcome Osteological Research Database (WORD).

The CHB was established and funded by the Wellcome Trust (2003-6) to record cemetery populations of more than 30 individuals in the Museum's collections for the WORD project (Redfern and Bekvalac 2013). As archaeological excavations in London are developer-led, many smaller cemetery samples or single inhumations have also been uncovered, and since 2006, curators at the CHB have been recording these legacy sites from the 1970-1990s using WORD. As the CHB is part of the London Archaeological Archive and Research Centre (LAARC), which is responsible for curating all of the archaeological archives in the City and Greater London area, the CHB has also been entering data from skeletons which had previously not been recorded using WORD standards (e.g. Lant Street LTU03) (Redfern and Bekvalac 2013). Recently excavated skeletons have also been entered onto WORD because, until 2013, the commercial field unit, Museum of London Archaeology (MoLA), was part of the Museum group, and their osteology team was responsible for recording individuals from the northern and southern cemeteries of Roman London (i.e. Spitalfields Market, SRP98). The collaborative nature of this research has allowed access to all the Roman data on WORD recorded by the CHB and MoLA staff, some of which would not have been available otherwise. As such, the database provides a compilation of all of the currently available skeletal evidence for the town of Roman London.

As part of the recording process, every skeleton entered onto WORD is analysed (or reanalysed) by trained osteologists following the WORD human osteology method statement (Powers 2012a). The aforementioned statement is a set of standards devised to ensure the same up-to-date recording criteria were consistently used by all osteologists recording data on WORD. This procedure ensures consistency in the data collected by different osteologists, making it possible to compare information from multiple sites of different excavation date.

Each individual skeleton is entered separately onto the database, identified by a site code and its context number. Dating evidence is also noted to allow data to be extracted by date period. Following the WORD human osteology statement (Powers 2012a), a skeletal and dental inventory is compiled, and age and sex estimations are conducted and recorded (see Section 5.2.2 for further description of the criteria used). A rigorous examination of the skeleton is then conducted to identify pathological conditions. In order to diagnose pathology, the WORD human osteology method statement (Powers 2012a) provides specific diagnostic criteria standards that must be applied for both the collection of data and diagnoses. The individual criteria for each of the pathologies studied in this thesis are detailed in section 5.2.3. Once identified, the pathology is recorded by disease code, with different pathological categories being assigned different code prefixes. For example, infectious disease codes begin with the prefix 2, with non-specific infection being assigned the code 21 and specific infections designated as 22. Further subdivisions allow for more specific diagnoses to be recorded, for example tuberculosis would be assigned the code 221. A full catalogue of codes is provided in Powers (2007).For pathology, descriptions are provided according to the appropriate standards identified in the method statement. By cataloguing the data in this way it is possible to retrieve information at the individual or population level, as queries can be run to identify the number of individuals within a specific site or time period with a particular pathology. For this thesis, data from all available Roman individuals were extracted from the database at the individual level and recorded in Excel spreadsheets. The details of the data extracted are given in Sections 5.2.2 and 5.2.3.

The data available in WORD therefore provides:

- An accessible database of all available Roman skeletal data from Roman London
- A sample size large enough to address the aims of the thesis and allow statistical analyses of potential relationships
- Comparable data compiled under modern recording standards by trained osteologists

However, it is acknowledge that the use of data from WORD is subject to a number of limitations:

- The constraints of the database limit the amount of information provided for each pathology. For example, while a score is given for *cribra orbitalia*, information regarding the stage of healing is not given. The individual descriptions of pathologies are also limited, featuring less information than would have been recorded if primary research had been conducted, for example in descriptions of non-specific infection.
- Due to the limited amount of data available, the data collected is reliant on the diagnoses of other individuals. While all analyses are conducted by trained osteologists, there is still a potential for under- or over-diagnosis of pathologies.
- Despite the use of a standard methodology to ensure comparability, the collection of data by multiple individuals introduces potential unknown comparability biases. For example, in the assignment of individuals to age and sex categories, and the identification of pathologies. However, the use of only trained osteologists for skeletal analyses mitigates against these issues as much as possible.

As a result, the large database available ensures a sufficient quantity of data is available to meet the research aims of the thesis. However, the data presented provides a broad overview of the presence and absence of the studied stress markers in the sample.

5.1.1 Criteria for Inclusion in the Sample

As all skeletal data for this study was to be drawn from existing analyses, to avoid inconsistencies between site reports and ensure all data was accurate and comparable, only cemetery sites where osteological and palaeopathological information had been reanalysed and entered into the WORD database were included in this study. For example, the cemetery from Giltspur Street (WES89) had previously been recorded by Waldron in the late 1980’s but was re-examined by the WORD project, and therefore only WORD data were employed in this study. The only exceptions permitted were that of Drapers Garden (DGT06) and Trinity Street (TIY07). This was because the standards utilised for the skeletal analysis of these sites, conducted by Pre-Construct Archaeology (PCA), proved similar to those used by the Museum of London Group. PCA permitted access to their original skeletal database, allowing data comparable to WORD to be extracted.

In addition, in order for a site to be included in the sample it had to fulfil a further 3 criteria:

1) inhumation burials from a secure Roman context had to have been recovered from the site,

2) the skeletal material had to be curated and accessible to ensure isotopic sampling could take place, and
3) mortuary data had to be available in either a published/pre-publication report or in an accessible archive.

This often meant that not all of the recorded burials at a site were included in the sample and the number available for study differed from that in the published reports (see Appendix 1 and 2 for further detail).

Following the aforementioned criteria, 39 sites excavated between 1980 and 2007, with a total population of 967 individuals, were selected to form the basis of the sample (Figure 5.1). An index of all the individual sites is given in Appendix 1.

The distribution of the overall and subadult sample between the four cemeteries of Roman London is given in Table 5.1. By far the largest contribution to the sample comes from the Eastern cemetery. The greater representation of individuals from this cemetery is the result of large-scale excavations that were undertaken in this area during the 1980's-1990's. The lower proportions of individuals in the remaining cemeteries is the result of a lack of large-scale investigation in these areas, though more recent excavations have begun to increase the number of individuals recovered from the northern (e.g. SRP98, BDC03, ENS03) and southern (e.g. LTU03, TIY07) cemeteries.

The dominance of the eastern cemetery, and that of the combined north and east (67.8%) over that of the south and west (30.9%), may have repercussions for the nature of the sample, particularly if each cemetery represents different sections of Roman London's population. However, a lack of in-depth analyses into the different cemeteries means it is at present not possible to determine what sections of the population each of these cemeteries contained (Barber and Hall 2000: 117). In the eastern cemetery, which has been the focus of most investigation, researchers note the homogenous nature of the buried population, but concede that, without comparative data from the other cemetery populations, the identification of the representativeness of the Eastern cemetery is not possible (Barber and Bowsher 2000: 328; Barber and Hall 2000: 115-119). In the few comparative studies that have been conducted (Hall 1996; Barner and Hall 2000), no clear observable difference in the cemeteries is observed overall, all displaying a similar array of burial rites, a general absence of grave goods, and the underrepresentation of women and children. Therefore, while it is important to be aware of a potential bias in the sample, without further detailed analyses of the cemeteries, it is currently not possible to assess its overall impact on the sample population.

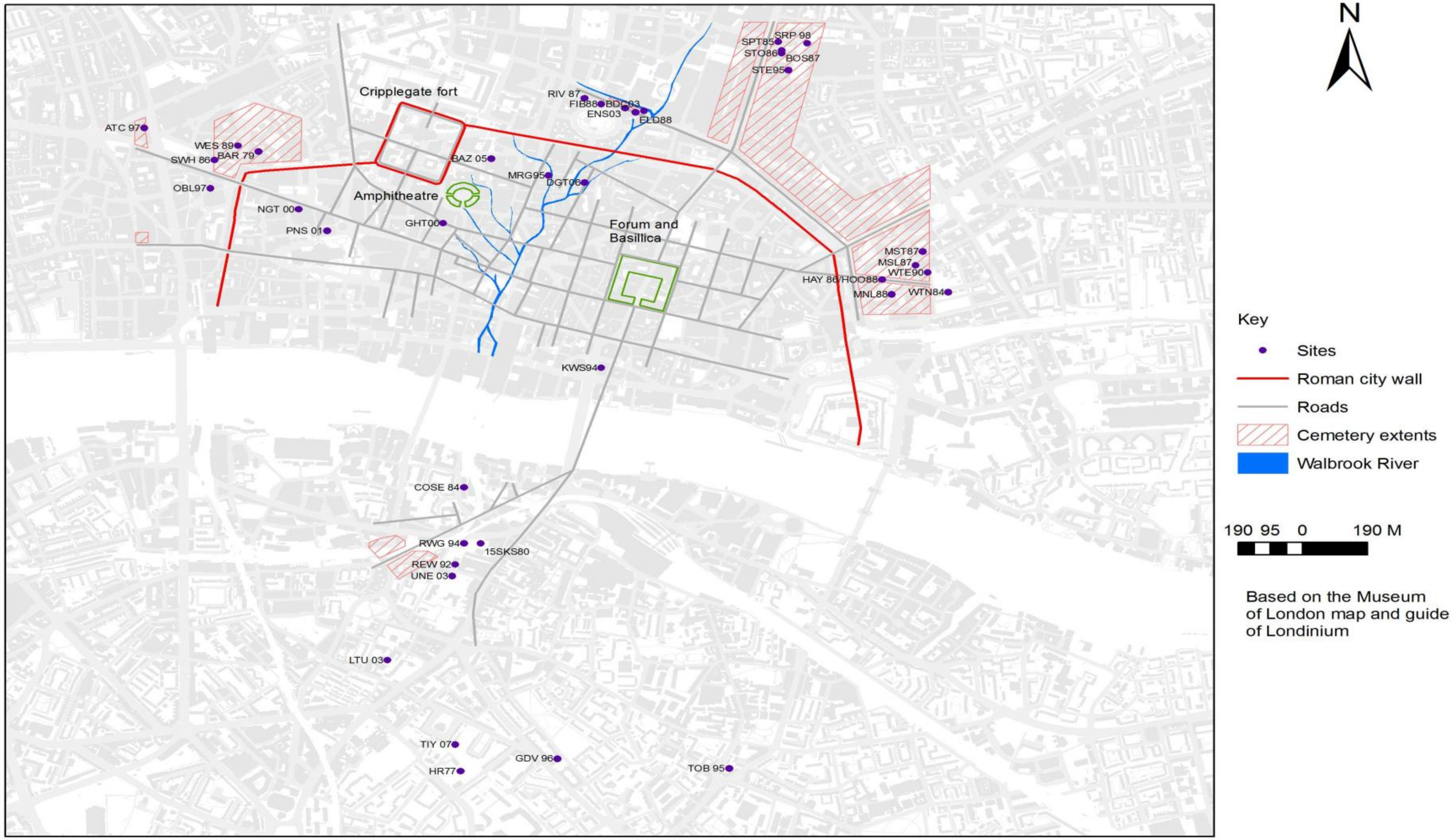

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Figure 5.1: Distribution map of the sites included in this study (© Museum of London). See Appendix 1 for site directory.

Overall Sample			Subadult Sample		
Cemetery	N	%	Cemetery	N	%
North	264	27.3	North	72	25.6
South	145	15.0	South	50	17.8
East	392	40.5	East	104	37.0
West	154	15.9	West	45	16.0
Intramural	12	1.2	Intramural	10	3.6
Total	967	-	Total	281	-

Table 5.1: Sample composition by cemetery

5.2 Methods - Data Collection

5.2.1 Mortuary Data

In order to identify potential chronological and status-based trends in the health and diet of subadults from Roman London, mortuary data was collated from site archives and available pre-publication and/or published reports.

(i) Chronology

The life course of the Roman settlement of *Londinium* stretched almost 400years, over which time various changes in the fortunes, population and economy of the town were observed (see Chapter 4). In order to identify how these changes may have potentially impacted the health and diet of the subadult and adult population, dating evidence (i.e. spot find dates and strategraphic chronology) was utilised to divide the sample population into two time periods:

- Early – AD43- AD250
- Late – AD250 – AD450.

Where dating evidence overlapped categories, the category containing the greater period of time was favoured. The reasons for using two large time periods, rather than several smaller ones, were twofold. Firstly, the large range of years assigned to most individuals would have made it extremely difficult to have divided burials into any smaller time periods with accuracy. Secondly, two of the largest cemetery collections, i.e. Spitalfields (BOS87, ELD88, SPT85, STE95, STO86), and the Walbrook cemetery (RIV87, FIB88, BDC03, ENS03), already favour these time periods.

(ii) Status – Burial Container

As one of the aims of the thesis is to identify potential status-based differences in subadult health and diet, it was necessary to record potential status indicators found within the burial environment. Determining status within a funerary context is often complicated by an uncertainty regarding what elements may be regarded as "high-status" within a particular society, and the loss of other potential aspects of funerary treatment through taphonomic processes (Philpott 1991; Pearce 2000; 2013). One potential method to identify status is through the identification of the quantity and quality of grave goods buried with an individual. However, the majority of Romano-British burials tend to be devoid of grave goods (Philpott 1991; Cool 2011: 309-312). Previous analysis of the distribution of grave goods at Roman London show only around a quarter of burials contained any form of grave good, with those present lacking any clear pattern of status association (see 4.5.3).

Unlike grave goods, the presence and type of material used to construct a coffin in the Romano-British world appears to be more positively correlated with status, with those requiring greater financial investment, such as stone and/or lead, signifying higher status individuals (Philpott and Reece 1993). Furthermore, the use of coffin type as a status indicator has been successfully applied in previous Romano-British isotopic investigations (e.g. Richards *et al.* 1998; Redfern *et al.* 2010). Therefore, it was decided that the presence of and type of coffin would be used as a proxy for status in this thesis. However, as some of the burial types observed in Roman London would not be traditionally considered coffins, i.e. biers and cists, the term "burial container" is preferred hereafter.

Firstly, the presence or absence of a form of burial container was identified from published reports and/or original site archives. It is acknowledged that the absence of evidence of a burial container may not be evidence of its absence. For example, taphonomic processes may have led to the complete removal of traces of organic burial containers, such as wooden coffins constructed without the use of nails or metal fittings. However, it is felt that a comparison of those individuals with direct evidence for the presence of a burial container with those without may still allow the identification of potential trends.

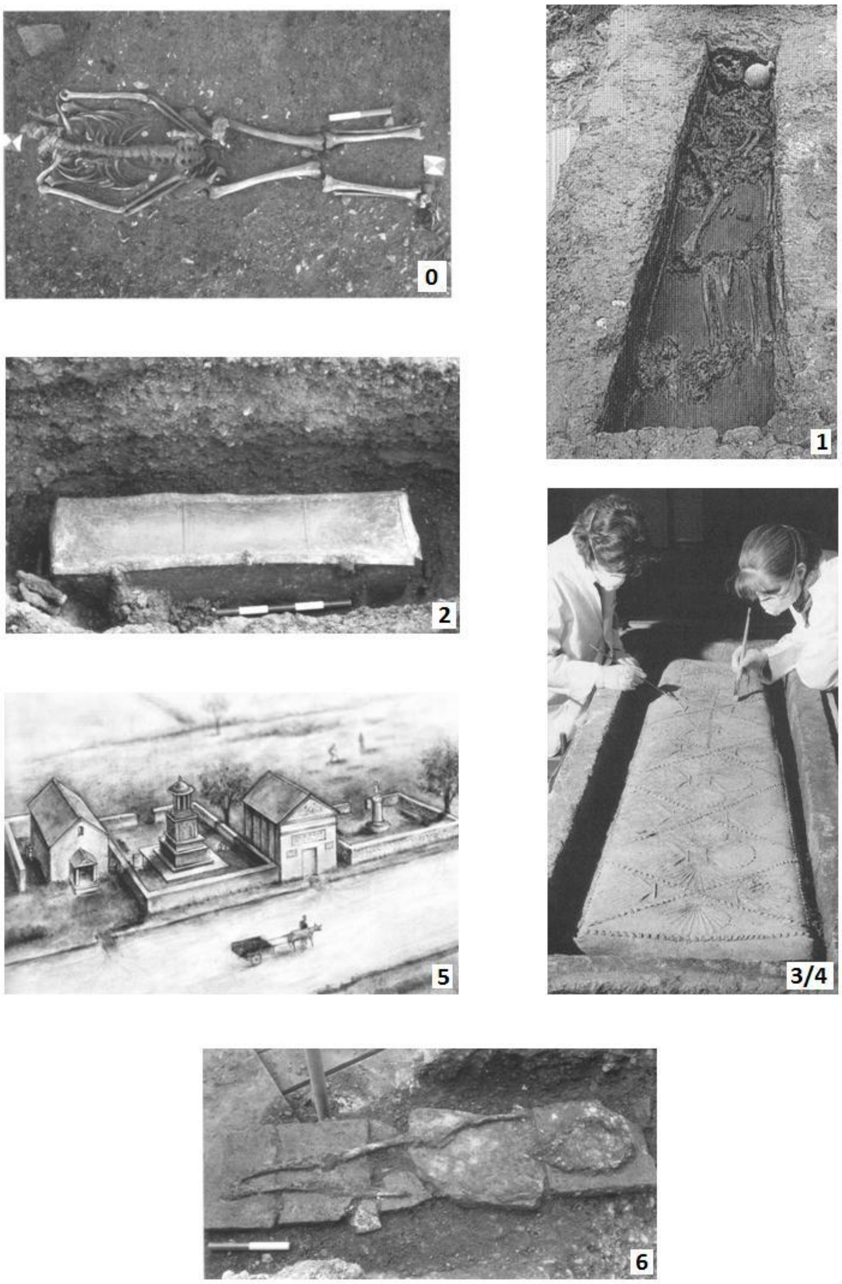


Figure 5.2: container types used in this study: 0) inhumation without burial container, 1) wooden coffin, 2) lead coffin, 3) stone coffin, 4) stone and lead combination, 5) built structure such as a mausolea/tomb; 6) other funerary container including tile burials (Barber and Bowsher 2000: 96, Barber and Hall 2000: 108-109, Mackinder 2000: 31, Watson and Heard 2006: 67).

Secondly, those buried within burial containers were further divided into categories. Due to the large amount of variation in burial types observed, burial containers were assigned to one of seven categories to allow comparison, based on the scheme proposed by (Hamlin 2007) (see Figure 5.2):

1) Wooden coffin – as identified by either the presence of coffin nails and/or fittings, coffin stains, or preserved wood;
2) Lead coffin;
3) Stone coffin;
4) Stone/lead combination;
5) Built structure such as a mausolea/tomb;
6) Other funerary containers (includes biers, wooden platforms, stone cists, and tile cists).

5.2.2 Osteological Data

As stated in section 5.1, all osteological data utilised in this study was extracted from data previously entered onto WORD. The following sections detail the criteria utilised for the compilation of skeletal inventories, age and sex estimations, and the recording and diagnosis of pathologies (all taken from Powers 2007, and Powers 2012a). Following these details, the nature of the data captured for this thesis is given in each section. For further information regarding the WORD project see White (2007), Powers (2012a), and Redfern and Bekvalac (2013).

(i) WORD Database: Context Information

The data held on WORD is primarily differentiated and captured using the unique site code and context number combination of each individual skeleton (Connell 2012a: 9). Every archaeological site in the City and Greater London area is issued a unique site code by the LAARC, and this designator and the context number assigned at the point of excavation to each individual is entered onto WORD. The name of the person recording the individual and the date when the record was opened is also captured.

Fields for the cemetery phase and burial dates are also present, and these data are entered manually by the recorder or through the migration of field data from a compatible database used by MoLA. The burial dates are established by a range of dating techniques (i.e. find spot dates or ^{14}C dating) and are fully presented in each cemetery’s archive report and/or published site report. The database also allows information about coffin type, the presence of intrusive human or animal bone, staining and truncation (Powers 2007: 3). Fields are also present to record the presence of ossified cartilage, ear ossicles, sampling history, and if any bones had to be “artificially deleted” from the record, e.g. if multiple hand bones could not be separated into individuals (Powers 2007: 3).

For this thesis, each skeletal entry will be identified using the site code and context number of the skeleton given in the WORD database. Where this differs from the publication data, the WORD context number is favoured.

(ii) WORD Database: Assessment of Overall Skeletal Preservation

Skeletal preservation is visually assessed and graded using a three point grading system (see Table 5.2). Where skeletal preservation varied across the skeleton, the most prevalent grade was recorded (Connell 2012a: 2).

Skeletal Preservation Grading System	
Grade	Description
1	Bone surface is in good condition with no erosion, fine surface detail such as coarse woven bone deposition would be clearly visible (if present) to the naked eye
2	Bone surface is in moderate condition with some post-mortem erosion on long bone shafts but the margins of articular surfaces are eroded and some prominences are eroded
3	Bone surface is in poor condition with extensive post-mortem erosion resulting in pitted and eroded cortical surfaces and long bones with articular surfaces missing or severely eroded

Table 5.2: Skeletal preservation grading system (taken from Connell 2012a: Table 1)

(iii) WORD Database: Bone Inventory

For each individual skeleton, each bone that is present is entered into the WORD database. In order to allow accurate recording, some bones are divided into components that are recorded separately (Connell 2012b: 11). For example, long bones are recorded in three components – the proximal third, middle third (shaft), and distal third. In order to be included, at least 50% of a bone or component had to be present. Each bone or component is then entered using a binary array (1= present, 0 = absent), e.g. a complete femur would be recorded as 111

(Powers 2007: 6). For a full list of binary arrays for each individual bone, please see Powers (2007: 4-6).

A full bone inventory for each individual skeleton was compiled for the thesis, given in Appendix 6. Each bone is identified as present (1) or absent (0). For bones recorded by components in WORD, two of the three were required to be present for the bone to be recorded as present in thesis bone inventory.

(iv) WORD Database: Dental Inventory

For each individual skeleton, a dental inventory is recording using the Fédération Dentaire Internationale (FDI) recording system (1971) that gives each tooth a unique identifier (Hillson 1996: 8) (Connell 2012b: 12). Each tooth and tooth position is recorded as present or absent using a set of numeric codes (see Table 5.3) (Connell 2012b: 12).

Code	Description
1	Tooth present
2	Post-mortem loss
3	Ante-mortem loss
4	Congenital absence
5	Tooth Present (no socket observed)
6	Tooth erupting
7	Deciduous retention
Null	Area Absent

Table 5.3: WORD dental inventory codes (taken from Connell 2012b: Table 2)

For the thesis, each individual was identified as having dentition present (1) or absent (0), if they had at least one tooth present (Appendix 6).

(v) Age Estimation: Subadults

As identified in Chapter 2, a multifactorial approach to ageing is considered to be the most reliable method of estimating age in skeletal material. Therefore, all age estimations conducted by osteologists entering data for the WORD database employ a number of macroscopic methods (Powers 2012b: 13-15). A combination of metrical, dental, and epiphyseal fusion assessments are utilised for the estimation of age of sub-adults (see Table 5.4) (Powers 2012b: 13-14). The age estimates from all the techniques applied are combined to produce an overall age, given in years or weeks, as appropriate (Powers 2012b: 14-15). Where age estimates between methods are contradictory, the dental age estimation is favoured due to its greater reliability (Lewis and Garn 1960; Powers 2012b: 14).

Where preservation or skeletal incompleteness did not permit the determination of a specific age-at-death, but morphology and other developmental features showed the individuals were not adult, these individuals are recorded on WORD as unassigned subadult <18 years (Powers 2012b: 15).

Sub-adult Ageing Methodologies			
Subadult Age	Methodology Type	Methodology	References
Foetal/Neonate	Metric	Linear Regression Equations using diaphyseal lengths	Scheuer and Black, 2000
Sub-adults over 2 months old		Diaphyseal Lengths	Maresh, 1970
		Maximum dimensions of ilium	Buikstra and Ubelaker, 1994; Scheuer and Black, 2000
		Basioccipital Dimensions	Scheuer and MacLaughlin-Black, 1994
	Dental	Dental Eruption Data	Gustafson and Koch, 1974
		Tooth Formation Data	Moorees *et al* 1963a and 1963b
	Epiphyseal Fusion	Epiphyseal Fusion Data	Buikstra and Ubelaker, 1994; Scheuer and Black, 2000; Powers 2012b

Table 5.4: Subadult age estimation methodologies (after Powers 2012b:13-14)

The aims of this study required a more nuanced age-group approach compared to those used by WORD (Powers 2007: 9-10; 2012b: 13-14). Therefore, the results of each ageing technique were extracted by Redfern at the individual context level for all individuals from foetal to 25 years old. Individuals aged between foetal and 20 years old were considered to be subadults, with all other individuals classed as adult individuals.

The age-group ranges employed in this study are narrower and based on developmental transitions (after Redfern 2007) (see Table 5.5). Although the use of age categories is not ideal as it imposes potential social bias onto the data that has no bearing on social age (see Chapter 2), they are necessary to organise the osteological data and permit temporal and spatial comparison of the results (Halcrow and Tayles 2008).

WORD Subadult Age Categories			Subadult Age Categories Used in This Study		
Age Code	Description	Age Range	Age code	Description	Age Range
1	Inter-uterine/neonate	< 4wks	1	Preterm	<37wks gestation
2	Early post-natal infant	1-6mths	2	Full Term	37-42wks gestation
3	Later post-natal infant	7-11mths	3	Infancy	>42wks gestation – 3.0 years
4	Early Child	1-5 years	4	Childhood	3.5-7.5 years
5	Later Child	6-11 years	5	Juvenile	8.0-16.5 years
6	Adolescent	12-17 years	6	Adolescent	17.0-20.0 years
12	Unassigned Subadult	< 18 years	12	Unassigned Subadult	< 20 years

Table 5.5: Subadult age categories used within the study compared to those adopted by WORD (after Powers 2012b, Table 4)

(vi) Age Estimation: Adults

The methodologies utilised for adult age estimation focus on degenerative changes in the pelvis, namely that of the pubic symphysis (Todd 1921a; 1921b; Brooks and Suchey 1990) and auricular surface (Lovejoy *et al.* 1985) as detailed in Buikstra and Ubelaker (1994: 21-32)(Powers 2012b: 15). Other areas examined include the sternal rib morphology (İşcan *et al.* 1984; 1985) and dental attrition (Brothwell 1981: 72) (Powers 2012b: 15). As many different ageing methods as preservation allowed were applied and combined to assign a skeleton to

WORD Adult Age Categories			Adult Age Categories Used in This Study		
Age Code	Description	Age Range	Age code	Description	Age Range
7	Young Adult	18-25 years	7	Young Adult	20-25 years
8	Early Middle Adult	26-35 years	8	Early Middle Adult	26-35 years
9	Later Middle Adult	36-45 years	9	Later Middle Adult	36-45 years
10	Mature Adult	≥ 46 years	10	Mature Adult	≥ 46 years
11	Unassigned Adult	> 18 years	11	Unassigned Adult	> 20 years

Table 5.6: Adult categories used within the study compared to those adopted by WORD (after Powers 2012b, Table 5)

one of the four adult age categories (see Table 5.6) (Powers 2012b: 15). In fragmentary remains where the appropriate areas were not preserved to allow age to be assessed, adulthood is confirmed by the identification of widespread epiphyseal fusion and the individual is recorded as an unassigned adult >18yrs (Powers 2012b: 15).

(vii) Adult Sex Estimation

For adult sex estimation (individuals over the age of 20 years old), in order to account for the different levels of preservation in the skeletal material, macroscopic assessment of a number of morphological features of the cranium and pelvis is undertaken (see Table 5.7) (Bekvalac 2012: 16).

Each feature is graded using a five-point scale (see Table 5.8) and overall sex is estimated through the combination of all available scores, with each individual assigned to one of the five categories (Bekvalac 2012: 15). If there is disagreement between the sex estimated for the cranium and pelvis, the sex determined by the pelvic scores is given preference (Powers 2007). In cases where sex could not be determined due to poor preservation, the individual was assigned as undetermined (code 9) (Bekvalac 2012: 15). Sub-adults assigned to subadult age categories 1-5 were not sexed due to the lack of accepted standards for sexing sub-adult material (Bekvalac 2012: 15).

In this study, biological sex was recorded for adult individuals only. For statistical analyses, both probable categories are combined with the appropriate male and female category. Any individuals who could not be assigned a sex (including sub-adults) were not included in statistical analyses investigating biological sex.

Skeletal Element	Morphological Feature	Reference Given
Skull	Supraorbital ridges	Brothwell (1981)
	Inion Protuberance	
	Nuchal Crest	
	Mastoid process	Bass (1987: 82)
	Slope of Forehead	
	Zygoma root	Ferembach *et al.* (1980)
Mandible	Gonions	Brothwell (1981)
Pelvis	Ventral Arc	Phenice (1969)
	Medial portion of pubis	
	Greater Sciatic Notch	Bass (1987: 203-05)
	Preauricular Sulcus	
	Subpubic Angle	
	Subpubic Concavity	
	Median Ischiopubic Ridge	

Table 5.7: Morphological features utilised for sex estimation (taken from Bekvalac 2012: Table 6)

Code	Description
1	Male
2	Probable Male
3	Indeterminate
4	Probable Female
5	Female
9	Undetermined adult/ features not present

Table 5.8: Categories assigned for biological sex estimation (taken from Bekvalac 2012: 10)

5.2.3 Diagnosis and Recording of Pathologies

The diagnosis of pathology within past populations relies on the observation of abnormal changes of the skeleton. Therefore, it is not possible to identify those disease processes that leave no osteological trace, resulting in the underestimation of the true pattern of disease within the past (Waldron 2007: 59ff). The pathological changes observed in the skeleton are the result of two processes: bone formation or bone destruction, or a combination of the two (Ortner 2012: 252). The first and most important stage in palaeopathological diagnosis is the careful macroscopic examination and accurate description of all pathological lesions present (Lovell 2000: Table 8.1 for recommended terminology). Radiography, histology, or biochemical techniques may also be utilised to ascertain additional information (Donoghue 2008; Mays 2008a; Turner-Walker and Mays 2008). The identification of the bone processes present (i.e. bone formation/destruction/both) and the type and location of a lesion will provide evidence regarding the nature of the pathology and the individual’s stage of healing (Roberts and Manchester 2005: 8). For example, rapidly deposited woven bone occurs during the active stage of lesion formation, while smooth compact lamellar bone is indicative of healed or chronic, long-standing conditions (Grauer 2008: 62). Following this, it is essential to determine the location of the lesion(s) and their skeletal distribution.

From this information it should then be possible to assign pathological changes to a particular disease classification – e.g. trauma, metabolic disease, infectious disease, etc (Lovell 2000: 219; Ortner 2012: 262). Utilising knowledge gleaned from clinical and palaeopathological literature, it may be possible to be more specific regarding the type of disease process (important palaeopathological texts include amongst others: Aufderheide and Rodríguez-Martín 1998; Ortner 2003; Roberts and Manchester 2005; Pinhasi and Mays 2008; Waldron 2009; Grauer 2012; Larsen 2015). For example, particular features of a lesion, or the nature of the lesion distribution observed within a skeleton may be indicative, or pathognomonic, of a specific disease (e.g. Roberts and Buikstra 2003; Brickley and Ives 2008). For example, eburnation is considered to be pathognomonic of osteoarthritis (Waldron 2009: 28), while rhinomaxillary syndrome is considered pathognomonic of lepromatous leprosy (Andersen and Manchester 1992: 122). However, due to the limited capability of bone to react to pathological stimuli, similar lesions may be observed for a number of different diseases (Roberts and Manchester 2005: 9). For example, periosteal new bone formation is associated with a number of different infectious diseases, such as leprosy and syphilis, as well as trauma, and neoplastic disease (Weston 2008: 49-50). Therefore, the differential diagnosis of all likely disease processes implicated in the production of a pathological change is necessary. The age of an individual should also be considered when interpreting pathological changes, as differences in the type and distribution of lesions caused by the same disease process may be observed in subadults and adults (Lewis 2007: 133ff). For example, due to age-related differences in bone vascularity, haematogenous osteomyelitis in subadults is most commonly found within the metaphyseal region of long bones, whereas in adults the vertebrae are more often affected (Rosenberg *et al.* 2010: 341-344). Differential diagnosis may not always allow further specificity beyond a disease classification, and it is important to avoid over-diagnosis in the absence of sufficient evidence (Ortner 2012: 252).

The skeletal pathologies utilised in this analysis are taken from the WORD database. The WORD recording methodology and diagnostic criteria for each indicator used in this research are described below (Powers 2007, and Powers 2012a). All osteological examinations were undertaken by professional osteologists following the step-by-step procedure of diagnosis recommended by Roberts and Connell (2004). All lesions were examined macroscopically and, where appropriate, radiographs of skeletal elements were taken to ascertain definitive diagnoses. In this study, in order to ensure consistency in the data collection, pathologies were only recorded as present if they had been positively diagnosed recorded on WORD in the appropriate disease categories. For example, for an individual to be recorded as having tuberculosis, it must have been recorded specifically under the disease code for tuberculosis (i.e. 221).

As discussed in chapter 2, Goodman *et al.* (1988) advocate the assessment of multiple skeletal indicators of both chronic and acute stress in order to evaluate the adaptation of a population to environmental and cultural stressors. In addition, they demonstrated that the use of this methodology allows for the identification of the members of a community that are most affected. The stress indicators utilised for this analysis include: *cribra orbitalia*, porotic hyperostosis, enamel hypoplastic defects, and non-specific infection (periostitis and maxillary sinusitis). These stress indicators were selected as they are the most commonly studied stress markers in subadult populations and they were consistently recorded in WORD. As the radiography of long bones was not consistently undertaken, the presence of Harris Lines could not be assessed. The fragmentary nature of the skeletal collections meant that many of the subadult remains could not be used for the metrical analysis of growth, and this stress marker was also excluded from the study. Other potential stress markers identified by Goodman *et al.* (1988) were excluded due to their absence in the sample (i.e. trauma), or a lack of available data (i.e. vertebral canal stenosis, skull base height). Due to the primary focus on subadult individuals, those stress indicators recorded solely in adults, such as a lack of sexual dimorphism and adult stature, were also not included. In addition to the aforementioned stress markers, two metabolic diseases indicative of nutritional deficiency were also included in the analysis, namely vitamin D deficiency (rickets and osteomalacia) and vitamin C deficiency (scurvy). These deficiency diseases are considered with the stress indicators in this study to identify overall levels of stress within the sample population.

The occurrence of each of the studied pathologies within the sample is either given as a:

- Crude prevalence rate (CPR) - the percentage of individuals within the sample affected as a percentage of the total population, or
- True prevalence rate (TPR) - the percentage of individual elements affected as a percentage of the total number of elements available for analysis.

The type of data presented for each of the pathologies is given in the following sections.

(i) *Cribra orbitalia*

In WORD, the presence and absence of the left and right orbits are recorded for each individual (Mikulski 2012: 52). If an orbit is not present, it is coded as unobservable (code 9). Each orbital roof present is examined macroscopically and lesions are recorded as present or absent, following the grading system by Stuart-Macadam (1991: 109) (see Table 5.9) (Mikulski 2012: 52).

For this study, the presence and absence of the orbital roofs of each individual was recorded. An individual had to have at least one orbital roof present in order to be included in the prevalence rate calculations for the sample. Those individuals with no orbital roofs were excluded. In the remaining individuals, *cribra orbitalia* was recorded as present if at least one of the orbital roofs was affected. The prevalence of *cribra orbitalia* in the sample is presented as a CPR, giving the number of individuals affected as a percentage of the total number of individuals with at least one orbit present.

Following this, the *cribra orbitalia* score assigned to each orbit was recorded (Table 5.9). Where right and left orbits had different degrees of expression, the larger score was used for analysis by lesion score.

Code	Description
0	Normal Bone Surface
1	Capillary like impressions on the bone
2	Scattered foramina
3	Large and small isolated foramina
4	Foramina have linked into a trabecular structure
5	Outgrowth in trabecular form from the outer table surface
9	Not present/unobservable

Table 5.9: Pathological codes for the description of *cribra orbitalia* (after Stuart-Macadam 1991: 109)

(ii) Porotic Hyperostosis

Porotic hyperostosis is recorded in WORD by presence or absence in the miscellaneous blood disorder category, under the code 1010, with descriptions given of the lesion and its distribution (Powers 2007:26). The diagnostic criteria followed is that of Stuart-Macadam (1987).

In this study, porotic hyperostosis is recorded at the individual level as present or absent. Porotic hyperostosis was only recorded as present when it was specifically diagnosed, under the pathology code 1010. In order to calculate prevalence rates, individuals were included within counts if one or more of the bones of the cranial vault (namely the frontal, parietal, squamous temporal or squamous occipital bones) were available for macroscopic inspection. Therefore, the prevalence of porotic hyperostosis in the sample is presented as a CPR, giving the number of individuals affected as a percentage of the total number of individuals with at least one bone of the cranial vault present.

(iii) Enamel Hypoplasia

The diagnosis of enamel hypoplasia in WORD is based on criteria obtained from Hillson (1996: 167) (Kausmally 2012: 24). Each individual tooth is examined and the presence of any enamel hypoplastic defect is scored by severity and location (Table 5.10). If more than one defect is present on an individual tooth, the location recorded was that of the most severe defect (Powers 2007: 17).

In this study, enamel hypoplasia is recorded at the individual level as present or absent, with individuals exhibiting one or more defects being recorded as affected. If an individual had no teeth present, they were recorded as unobservable and removed from prevalence rate calculations. Therefore, the presence of enamel hypoplasia in the sample is presented as a CPR, giving the number of individuals affected as a percentage of the total number of individuals with at least one tooth present. As no measurements from the cemento-enamel junction were available, it was not possible to determine the age at which the person developed the defect.

Enamel Hypoplastic Defect Grading System				
Location Of Enamel Hypoplastic Defect		Severity of Enamel Hypoplastic Defect		
Code	Location of Defect	Code	Severity of Hypoplastic Defect	Definition
1	Cusp/Upper Crown	1	Linear Enamel Hypoplasia – Just discernible	Can be seen but not felt with fingernail
2	Middle Crown	2	Linear Enamel Hypoplasia – Clear groove on tooth surface	Clearly felt with the fingernail
3	Lower Crown	3	Linear Enamel Hypoplasia – Gross Defect (Ridges/dentine exposed)	Clear brown ridges on enamel surface
		4	Hypoplastic Pit	Circular Defect on Crown

Table 5.10: Grading system for enamel hypoplastic defects (taken from Powers 2007: 17)

(iv) Non-Specific Infection

On the WORD database, infectious diseases are recorded according to the involvement of the bone, i.e. periosteal involvement, osteitis, and non-specific osteomyelitis. The WORD diagnostic criteria for each of these are as follows:

- Periosteal involvement is diagnosed when the presence of either abnormal pitting/porosity of the bone surface or periosteal new bone formation overlying the original bone surface is observed. (Powers 2012c: 37).
- Osteitis is diagnosed when a swelling or expansion of the original bone surface is observed without the presence of a cloaca (Powers 2012c: 38).

- Osteomyelitis is diagnosed when a swelling or expansion of the original bone surface is observed alongside an involvement of the medullary cavity in the form of a cloaca (Powers 2012c: 38). Other indicative elements include the presence of a sequestrum and involucrum (Powers 2012c: 38).

Following the identification of a lesion, descriptions of the location are recorded, including: the type of new bone (woven, striated, lamellar, spiculated, etc.) and a classification of healed or active at time of death is given following the guidelines of Roberts and Connell (2004: 35). Analysis of the type of lesions and their distribution are conducted to determine the potential infectious process and, if possible, the specific infection (see Section 5.2.3 (v)). If a specific infection is identified, the lesions observed will be coded to that particular pathology (e.g. tuberculosis is 221). Where a specific infection cannot be identified, the lesion is recorded as non-specific infection (i.e. 211 for periostitis, 214 for osteitis, and 213 for osteomyelitis).

For this study, the presence of non-specific infection (i.e. periostitis, osteitis, and osteomyelitis that cannot be attributed to a specific infection) was recorded for each individual. The location of each lesion was recorded by element, along with the available description included on WORD. Only individuals that were specifically recorded as having evidence of non-specific infection on WORD were identified as having non-specific infection present. Furthermore, as they have multiple aetiologies (Weston 2012), all periosteal lesions that could be attributed to another diagnosed pathology, such as trauma or metabolic disease, were removed from prevalence counts.

For analytical purposes, non-specific infection is first considered at the individual level to ascertain general levels of non-specific infection within the population, giving a CPR of the number of individuals affected as a percentage of the total population. Unfortunately, the descriptions of lesions given in WORD varied and detailed information was not consistently recorded. Therefore, the prevalence of lesion type can only be given at the level of bone affected (i.e. periosteal involvement, osteitis, or osteomyelitis). The available description of each lesion given on WORD is recorded in Appendix 6. As CPR's are affected by preservation, TPR's for individual bones are also presented, i.e. the number of individual elements affected as a percentage of the total number of observable elements. Laterality of the lesions was also recorded.

As it was not possible to ascertain the extent to which sinus cavities were studied within the sample, sinusitis was excluded from overall non-specific infection counts and presented as a separate category. Sinusitis was diagnosed if new reactive bone was observed within any of the sinus cavities, most notably those of the maxillary and frontal bones (Powers 2012c: 39).

As it was not possible to identify the number of individuals with exposed sinuses (i.e. broken post-mortem, thus enabling direct observation) that could be examined, TPR could not be calculated.

(v) Specific Infectious Disease

Where assessment of the type and distribution of pathological lesions allows the identification of a specific disease, the lesions are assigned to a specific disease code. As with non-specific infection, all elements affected were recorded, alongside the type (i.e. destructive or proliferative) and severity of bony changes (periosteal new bone formation, osteitis, and/or osteomyelitis) following the guidelines of Roberts and Connell (2004: 34-37) (Powers 2012c: 38). In order for a diagnosis of a specific infection to be recorded on WORD, disease specific diagnostic criteria had to be satisfied. For example, tuberculosis is diagnosed macroscopically using the diagnostic criteria of Rogers and Waldron (1989), Resnick and Niwayama (1995); Aufderheide and Rodríguez-Martín (1998: 133-140); and Ortner (2003: 227-262) (Powers 2012c: 38-39). For subadults, further information is obtained from Lewis (2011).

In this study, the presence of a specific infection was only recorded when it was positively diagnosed and coded in WORD. Prevalence rates for specific infection are given as CPR’s, i.e. the number of individuals affected as a percentage of the total number of individuals within the sample.

(vi) Metabolic Diseases

The WORD diagnostic criteria for the metabolic diseases considered in this study follow the criteria and guidelines described in Ortner (2003: 383-418) and Aufderheide and Rodríguez-Martín (1998: 305-344) (Mikulski 2012: 51). Further guidelines considered for specific diseases are given below. In this study, metabolic diseases are identified as present or absent at the individual level as CPRs. The metabolic diseases were only considered as present if they had been diagnosed as that metabolic condition in the database, or the original osteologists identified it as the most likely diagnosis.

(a) Vitamin D Deficiency - Rickets

In WORD, rickets is diagnosed based on the criteria of Mays *et al*. (2006) and Ortner and Mays (1998) (Mikulski 2012: 51). The subadult remains were also re-examined by Dr. Rebecca

Redfern in 2012 using the methods published by Brickley and Ives (2008). All infant cases were also digitally radiographed to aid diagnosis.

Diagnostic changes include:

- Bowing of the long bones
- Lack of cortical density towards the metaphyses
- Thickening of the cranium by sub-periosteal new bone deposition
- Flaring and cupping of metaphyseal ends
- Decreased curvature of the ribs
- Rachitic rosary characterised by enlarged or flared sternal rib ends

(b) Vitamin D Deficiency - Osteomalacia

Osteomalacia was diagnosed following the guidelines of Brickley *et al.* (2007) (Mikulski 2012: 51-52). Diagnostic criteria included:

- Healed and unhealed fractures at or around the base of the acromial spine (considered the most diagnostic)
- Vertebral collapse
- Angular "kinking" of the sacrum
- Stress fractures
- Accentuated cupping of vertebral end plates leading to angular kyphosis in severe cases, usually at the level of T8-9
- Decreased curvature in the ribs
- Angular deformation to the sternum
- Abnormal morphology of the pelvic girdle – severe reduction of sub-pubic angle and narrowing of the pelvic canal

(c) Vitamin C Deficiency - Infantile Scurvy

Infantile scurvy is considered following the diagnostic criteria of Brickley and Ives (2006) (Mikulski 2012: 52). As with vitamin D deficiency, subadult human remains were re-examined by Dr. Rebecca Redfern in 2012 using the methods published by Brickley and Ives (2008). All infant cases were also digitally radiographed to aid diagnosis.

Diagnostic changes include:

- Profuse irregular porous new bone plaques on ectocranial surfaces (with “honeycomb” appearance), pitting to the lingual aspects of the mandibular rami, and new bone on the diaphyses of long bones (in particular the humerii, femora, tibiae, and fibulae)
- New bone formation in the orbits
- Flaring of sternal rib ends – “scorbutic” rosary
- Porosity or porous new bone formation on the muscle attachment sites, such as the suprascapular fossae.

(d) Vitamin C Deficiency - Scurvy in Adults

Scurvy in adults was considered following the diagnostic criteria of Aufderheide and Rodríguez-Martín (1998: 313) (Mikulski 2012: 52). Diagnostic criteria included:

- Symmetrical periosteal lesions with a shell of lamellar bone attached to the original cortex via woven bone
- Evidence of haematoma
- Pathological fractures
- Gingival haemorrhage leading to tooth loss
- Orbital lesions (new bone formation)

5.2.4 Collection of Stable Isotope Data

In order to examine the relationship between the skeletal indicators of poor health (detailed above), age, burial status, and evidence for age-at-weaning and dietary intake, stable isotope analysis of carbon and nitrogen was undertaken.

(i) Criteria for Inclusion in the sample

(a) Human Bone Samples

From the overall sample population of 967, 120 individuals were selected for isotopic sampling (see Appendix 4 for full sample list). Permission to sample the collections held by the Museum of London and MoLA only permitted the sampling of bone, and not the dentition. As different bones vary in their expression of isotopic signatures (Katzenberg 2008; Jørkov *et al.* 2008), it was decided that only rib bones would be selected for sampling; this also permitted samples from non-MoL collections to be used, and allowed for comparison with other published studies

(Prowse *et al.* 2008). The sampling of ribs is considered less destructive due to their greater abundance, post-mortem fragmentation, and less diagnostic morphology. Therefore, only individuals with ribs preserved were considered for isotopic sampling.

Due to the focus of this work on childhood health and care, 100 of the samples were allocated to sub-adult individuals. Preference was given to the preterm, full term and infancy age categories, with approximately 30 samples taken from these groups. This was to ensure that the full weaning signal could be detected and an age-at-weaning could be identified (see Chapter 3). The remaining 70 samples were distributed equally between the other subadult age categories where possible. The last 20 samples were allocated between the adult age categories 7, 8, 9 and 10, to provide an adult comparison for childhood diet. Where insufficient individuals from an age category were available, the remaining quota was redistributed among the other groups. Individuals that could not be assigned an age or sex, in the case of adults, were not considered for isotopic sampling (see Appendix 4).

Within each age category, samples were evenly distributed, where possible, amongst four groups designed to allow the relationship between burial treatment, stress indicators, and dietary intake to be examined. These were:

1) Individuals with burial container present and no stress markers
2) Individuals with burial container present and stress markers
3) Individuals without burial container present and no stress markers
4) Individuals without burial container present and stress markers

In addition, care was taken to select samples equally across all four cemeteries and from both time periods.

Alongside the above samples, results from a further 4 individuals (3 adults and 1 subadult) were obtained from on-going research undertaken by Millard *et al.* (in prep) (see Appendix 4).

(b) Animal Bone Samples

In additional to the human samples taken, in order to interpret dietary intake from the isotopic ratios obtained, it is necessary to determine the isotopic ratios of the different food elements consumed. In order to obtain the isotopic end points of the animal portion of the diet, samples were taken from 50 animals (5 chicken, 5 cow, 5 pig, 5 sheep, and 5 marine fish) from domestic contexts at two sites from Roman London (MFI 89 and ONE 94) (see Appendix 5). The faunal bones were identified by Redfern and Pipe, and only diagnostic bones were selected. Due to other ongoing research projects between LAARC and English Heritage, it was not possible to obtain samples for freshwater fish. Therefore, stable isotope values from other Romano-British sites and London excavations are used as proxies.

(ii) Sampling Protocol – Collagen Preparation

All bone samples were prepared in the Archaeology Department at Durham University. The collagen extraction method followed was a modified Longin (1971) method, with an additional ultrafiltration step (Brown *et al.* 1988).

From each individual, 2-3g of bone was taken by hand or, where necessary, using a hacksaw. Samples were cleaned either by hand or by shot blasting to remove markings or larger dirt deposits. Following cleaning, approximately 200mg of bone was weighed out and placed into 15ml test tubes. Dilute refrigerated 0.5M Hydrochloric acid (HCL) was then added to each test tube in order to demineralise the bone fragment. A regime of shaking the sample, and replacing the HCL acid on alternate days for a period of approximately two weeks was adopted to maintain optimum demineralisation. Once the bone sample was demineralised, the extant material was rinsed three times in purified water to achieve a near neutral solution.

In order to gelatinise the protein, a weak acid solution (pH3) was added to the remaining bone tissue and the sample was heated in a heater block at 75°C for 24-48hrs, with each test tube sealed with a marble to prevent evaporation. The supernatant liquid was then filtered using an Ezee* filter (Evergreen Scientific, 5-8 microns) and centrifuged in an ultrafilter to remove degraded polypeptides and contaminants with a molecular weight of less than 30kDa. The supernatant was then placed in sealed, pre-weighed plastic test-tubes and freeze-dried (lyophilised) for 24-48hrs to remove any organic solvents and remaining water. Following lyophilisation, the remaining solid collagen tissue was then weighed, with the final weight subtracted from the starting weight to determine collagen yield.

If a sufficient yield has been obtained (see Chapter 4 for acceptable collagen criteria), 0.3mg of the extracted collagen was then weighed out and placed into a tin capsule to allow combustion in the IRMS. Each sample was weighed out in duplicate in order to allow measurement in separate runs, ensuring the results obtained were repeatable.

(iii) Stable Isotope Analysis

The carbon and nitrogen ratios of all the samples prepared for this study were analysed using a Costech elemental analyser online with a Thermo-Finnegan Delta V Advantage Isotope Ratio

Mass Spectrometer. Internal standards and laboratory controls (nylon and gelatine of known isotopic ratio) were run alongside samples to ensure measurement quality.

5.3 Statistical Analysis

All statistical analyses conducted for this study were performed using SPSS for windows version 0.2 and PAST palaeontological statistics software version 2.17c (Hammer *et al.* 2001). For the palaeopathological data obtained, Pearson's Chi-squared (χ^2) tests and Fisher's exact tests were conducted to determine potential differences in the prevalence rates of selected pathologies by age. Further Chi-squared and Fisher's exact tests were conducted to determine potential differences in the prevalence rates of the selected pathologies between time periods and burial treatment within the subadult population.

For the isotopic data, the isotopic ratios of individuals were compared to determine differences between dietary intake, burial treatment, stress markers, and age (including the cessation of breastfeeding). Kruskal-Wallis and Mann-Whitney U tests were applied to identify significant differences within the results.

5.4 Conclusions

This chapter has outlined the materials and methods utilised within the thesis, detailing the selection criteria for both the osteological and isotopic samples. The following two chapters will now give the results of the thesis, first presenting the palaeodemographic and palaeopathological results (Chapter 6), followed by that of the stable isotope analyses (Chapter 7).

Chapter 6: Results – Palaeodemography, Palaeopathology, and Funerary Status

This chapter presents the results and statistical tests of the demographic and palaeopathological analyses. The palaeopathological data are presented in three sections: age category, date period and burial status. All of the data presented here was obtained from the WORD database in 2012. The database available on WORD allowed the collation of a sufficiently large enough sample population to ensure the research questions of the thesis could be answered and allowed statistical analyses to be undertaken. However, due to the constraints of the database, detailed information could not always be consistently obtained (see Chapter 5). Therefore, the results presented here provide a broad overview of the presence and absence of the studied stress markers in the Roman London sample.

6.1 Demography

Table 6.1 presents the demography of the sample by adult and subadult age divisions (967 individuals). Adults are the majority of the individuals studied (n = 686, 70.9%), with subadults representing just 29.1% (n = 281) of the total sample.

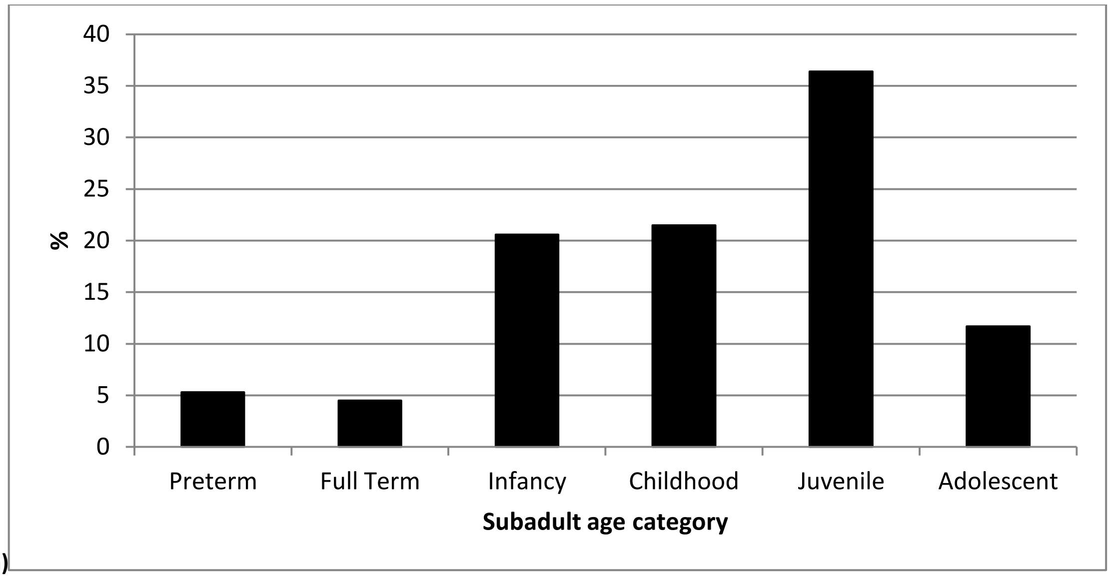
Age Category	Total Number of Individuals	%
Subadult (0-20yrs)	281	29.1
Adult (21+yrs)	686	70.9
Total	967	

Table 6.1: Subadult and adult demography of selected cemeteries from Roman London

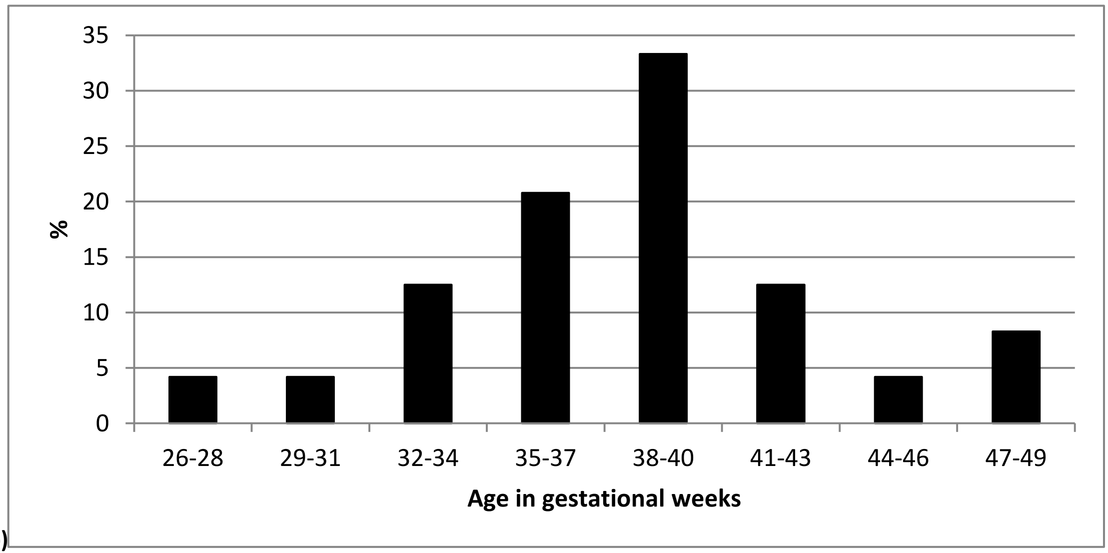
Table 6.2 and Figure 6.1 present the demography of subadults by assigned age categories. Due to poor preservation, 34 individuals could not be assigned to a specific age category and were removed from subsequent subadult age category analyses. As Figure 6.1a shows, all of the subadult age categories are represented within the Roman London cemeteries. The highest numbers of subadults are found within the infancy, childhood, and juvenile age categories, each representing 5-10% of the overall population. Due to the small numbers of individuals within the preterm and full term age categories, these groups are combined for all statistical

Age Category	Number of Individuals	% Subadult population	% Total Population
Preterm (<37wks gestation)	13	5.3	1.3
Full Term (37-42wks gestation)	11	4.5	1.1
Infancy (>42wks – 3yrs)	51	20.6	5.3
Childhood (3.1 -7.9yrs)	53	21.5	5.5
Juvenile (8-16yrs)	90	36.4	9.3
Adolescent (17-20yrs)	29	11.7	3.0
Total	247	-	-

Table 6.2: Demography of subadults by age category



a)



b)

Figure 6.1: Roman London Subadult Demography: a) by subadult age category, b) perinate and neonate demography by gestational weeks

analyses to fulfil the necessary test criteria. Where the combined totals from the preterm and full term categories are zero, the category is removed from statistical analyses.

Further division of the demographic profile of the Roman London perinates and neonates are given in Figure 6.1b. A peak is observed at 38-40 weeks gestation, or full term.

6.2 Prevalence Rates of Stress Indicators by Age Category

This section presents the palaeopathological data derived from the entire Roman sample, encompassing all of the subadult and adult individuals selected from across Roman London's cemeteries (see Chapter 5). The main aim of this section is to ascertain to what extent the chosen skeletal indicators of stress and poor living environment were present amongst the Roman London subadults. As a means of comparison, the subadult data are first presented as a whole alongside their adult counterparts, then by subadult age category.

6.2.1 Total Pathology (Individuals with One or More of the Studied Stress Indicators)

(i) Subadult and Adult Comparisons

The overall crude prevalence rate of individuals exhibiting one or more of the studied stress markers (*cribra orbitalia,* enamel hypoplasia, porotic hyperostosis, non-specific infection, and vitamin D and C deficiency diseases) is 51.3%. Subadults exhibit a slightly higher prevalence rate than adults, although this difference proved to be statistically insignificant (χ^2 = 1.579, df = 1, p = 0.209) (Table 6.3).

	Total Pathology		
Age Category	N	n	%
Subadult	281	153	54.4
Adult	686	343	50.0
Total	967	496	51.3

N = Total number of individuals, n = number affected

Table 6.3: CPR of total pathology by subadult and adult age category

(ii) Subadult Age Category

Table 6.4 and Figure 6.2 present the prevalence rates of subadults exhibiting at least one of the studied stress markers by subadult age category. As is apparent from Figure 6.2, the prevalence of individuals affected by at least one stress indicator increases with age. This result is statistically significant (χ^2= 30.240, df = 4, p <0.000).

Age Category	Total Pathology		
	N	Affected	%
Preterm	13	1	7.7
Full Term	11	2	18.2
Infancy	51	27	52.9
Childhood	53	27	50.9
Juvenile	90	58	64.4
Adolescent	29	24	82.8
Total	247	139	56.3

Table 6.4: CPR of total pathology by subadult age category

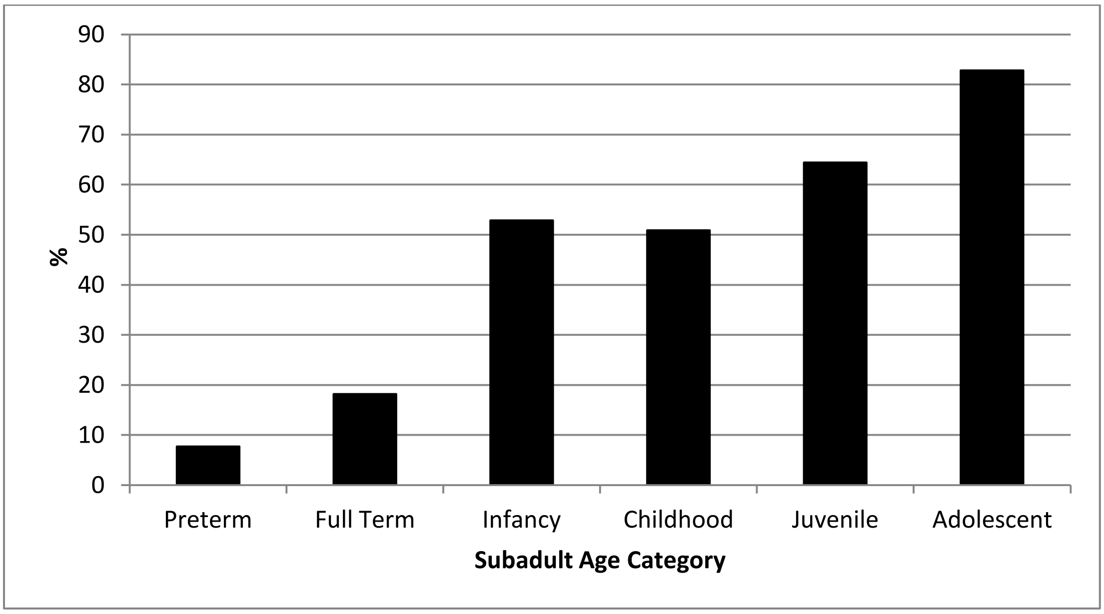


Figure 6.2: CPR of total pathology by subadult age category

6.2.2 *Cribra orbitalia*

(i) Subadult and Adult Comparisons

The CPR of *cribra orbitalia* within the entire sample is 46.6%. Within the sample, subadults have a significantly higher CPR of *cribra orbitalia* in comparison to their adult counterparts ($\chi^2 = 11.228$, df= 1, p=0.001) (Table 6.5).

Age Category	*cribra orbitalia*			
	N	n	Affected	%
Subadult	281	120	71	59.2
Adult	686	258	105	40.7
Total	967	378	176	46.6

N = total number of individuals, n = total number with at least one orbit present

Table 6.5: CPR of *cribra orbitalia* by subadult and adult age category

(a) *Cribra orbitalia* Severity Scores by Subadult and Adult Age Categories

Table 6.6 and Figure 6.3 show the Stuart-Macadam (1991) *cribra orbitalia* grades for the individuals within the sample by subadult and adult age categories. For those individuals with *cribra orbitalia* within the subadult sample, the highest prevalence rates are within the middle three categories, with grade 2 (scattered fine formina) being the most common. The lowest grades are the most prevalent amongst those adults with *cribra orbitalia*, with an overall trend of decreasing prevalence with increasing severity observed.

Age Category	*Cribra orbitalia* Stuart-Macadam Severity Grades						
	0	1	2	3	4	5	Total
Subadult	49 (40.8%)	11 (9.2%)	25 (20.8%)	19 (15.8%)	15 (12.5%)	1 (0.8%)	120
Adult	153 (59.3%)	46 (17.8%)	38 (14.7)	15 (5.8%)	5 (1.9%)	1 (0.4%)	258
Total	202 (53.4%)	57 (15.1%)	63 (16.7%)	34 (9.0%)	20 (5.3%)	2 (0.5%)	378

Table 6.6: Distribution of Stuart-Macadam (1991) *cribra orbitalia* severity grade*s* by subadult and adult age categories.

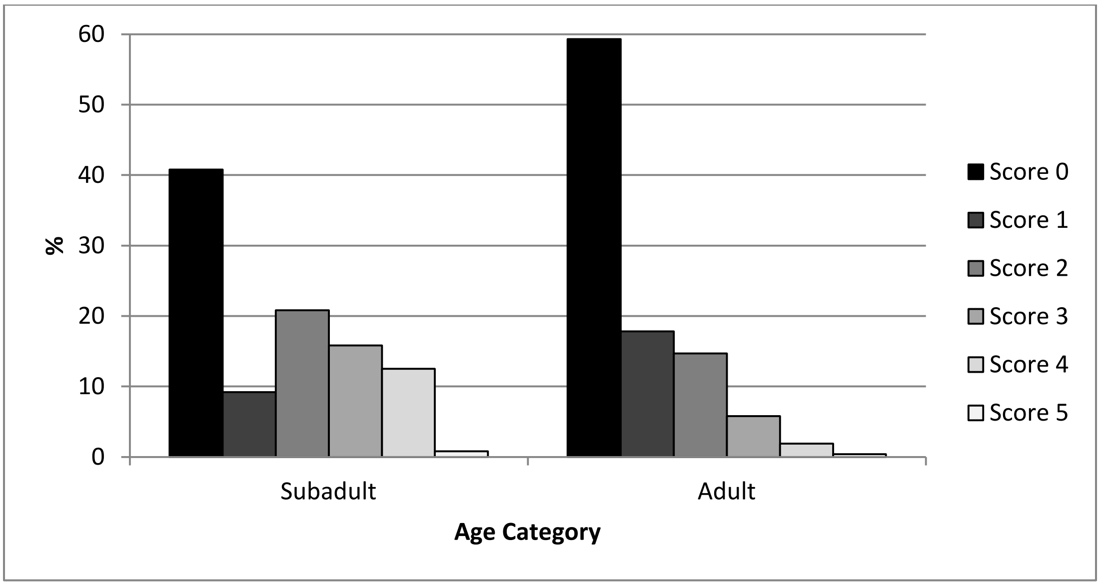


Figure 6.3: Stuart-Macadam (1991) *cribra orbitalia* severity grades by subadult and adult age category

(ii) Subadult Age Categories

Table 6.7 and Figure 6.4 show the CPR of *cribra orbitalia* by subadult age categories. From Figure 6.4, it is evident that full term individuals are the most affected; however, due to poor preservation, this group is only represented by one individual. Overall, no statistical difference is observed for the CPR of *cribra orbitalia* by subadult age category (χ^2 = 0.323, df = 3, p = 0.956), with the remaining older age categories exhibiting similar CPRs to the younger subadults.

Age Category	*Cribra orbitalia*			
	N	n	Affected	%
Preterm	13	4	1	25.0
Fullterm	11	1	1	100.0
Infancy	51	29	16	55.2
Childhood	53	20	12	60.0
Juvenile	90	43	25	58.1
Adolescent	29	19	12	63.2
Total	247	116	67	57.8

N = total number of individuals, n = total number with at least one orbit present

Table 6.7: CPR of *cribra orbitalia* by subadult age category

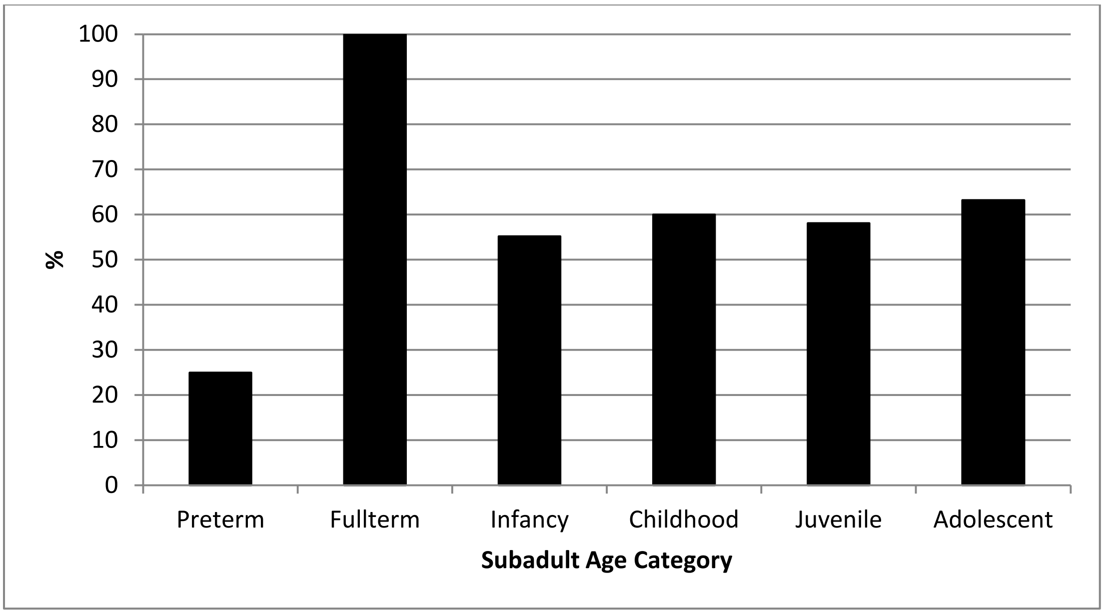


Figure 6.4: CPR of *cribra orbitalia* by subadult age category

(a) *Cribra orbitalia* Severity Scores by Subadult Age Categories

Table 6.8 and Figure 6.5 present the Stuart-Macadam (1991) *cribra orbitalia* grades by subadult age category. Within the infancy age category, the lowest *cribra orbitalia* scores seem to be the most prevalent, with much lower rates of the severest scores. However by the childhood age category, there is a noticeable absence of lesions given a score of 1, with the severity scores observed within this age group being equally distributed between the middle three scores. Within the remaining older age categories, one of the lower two scores remain the most prevalent, although both demonstrate moderate levels of 3 and/or 4 scores. The noticeably high peak at score 4 for full term individuals represents only one individual and therefore should not be seen as indicative for the entire age category. No individuals with a lesion severity score of 5 were observed amongst the aged subadults.

Age Category	*Cribra orbitalia* Stuart-Macadam Severity Grades						
	0	1	2	3	4	5	Total
Preterm	3 (75.0%)	0 (0.0%)	1 (25.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	4
Fullterm	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0%)	1 (100%)	0 (0.0%)	1
Infancy	13 (44.8%)	5 (17.2%)	7 (24.1%)	2 (6.9%)	2 (6.9%)	0 (0.0%)	29
Childhood	8 (40.0%)	0 (0.0%)	4 (20.0%)	4 (20.0%)	4 (20.0%)	0 (0.0%)	20
Juvenile	18 (41.9%)	2 (4.7%)	10 (23.3%)	8 (18.6%)	5 (11.6%)	0 (0.0%)	43
Adolescent	7 (36.8%)	4 (21.1%)	2 (10.5%)	4 (21.1%)	2 (10.5%)	0 (0.0%)	19
Total	49 (42.2%)	11 (9.5%)	24 (20.7%)	18 (15.5%)	14 (12.1%)	0 (0.0%)	116

Table 6.8: Distribution of Stuart-Macadam (1991) *cribra orbitalia* severity grades by subadult age categories.

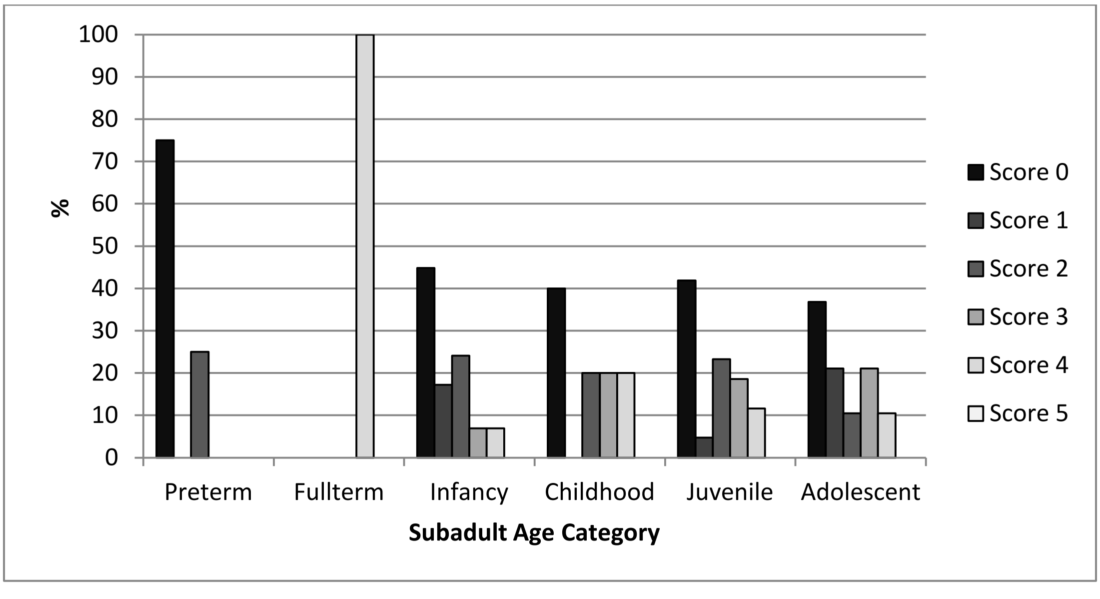


Figure 6.5: Stuart-Macadam (1991) *cribra orbitalia* severity grades by subadult age categories

6.2.3 Enamel Hypoplasia

(i) Subadult and Adult Comparisons

The overall CPR of enamel hypoplasia within the sample is 57.6% (Table 6.9). The CPR of enamel hypoplasia is higher amongst the adults within the sample at 60.2%, although no statistically significant difference ($\chi^2 = 1.710$, df = 1 p=0.191) is observed between subadult and adult age categories.

Age Category	Enamel Hypoplasia			
	N	n	Affected	%
Subadult	281	175	91	52.0
Adult	686	389	234	60.2
Total	967	564	325	57.6

N = total number of individuals, n = total number with teeth present

Table 6.9: CPR of enamel hypoplasia by subadult and adult age category

(ii) Subadult Age Categories

Table 6.10 and Figure 6.6 show the CPR of enamel hypoplasia by subadult age category. From Figure 6.6, the CPR of enamel hypoplasia increases with age, with the older subadult age categories being significantly more affected ($\chi^2 = 27.264$, df = 3 p<0.000).

Age Category	Enamel Hypoplasia			
	N	n	Affected	%
Preterm	13	1	0	0
Full Term	11	2	0	0
Infancy	51	36	7	19.4
Childhood	53	44	21	47.7
Juvenile	90	65	43	66.2
Adolescent	29	26	20	76.9
Total	247	174	91	52.3

N = total number of individuals, n = total number with teeth present

Table 6.10: CPR of enamel hypoplasia by subadult age category

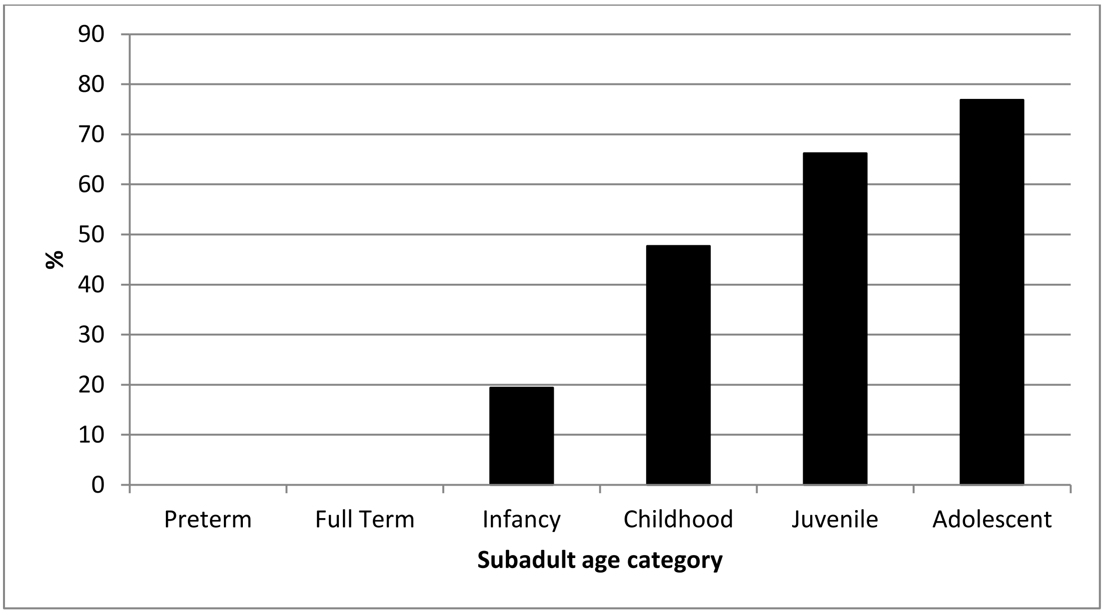


Figure 6.6: CPR of enamel hypoplasia by subadult age category

6.2.4 Porotic Hyperostosis

(i) Subadult and Adult Comparisons

The overall CPR of porotic hyperostosis within the sample was 3.8%. A higher CPR of porotic hyperostosis is observed within the adult age category (Table 6.11); however, the difference is not statistically significant ($\chi^2 = 0.637$, df = 1, p = 0.425).

	Porotic Hyperostosis			
Age Category	N	n	Affected	%
Subadult	281	204	6	2.9
Adult	686	424	18	4.2
Total	967	628	24	3.8

N = total number of individuals, n = total number with at least one cranial vault bone present

Table 6.11: CPR of porotic hyperostosis by subadult and adult age categories

(ii) Subadult Age Categories

Table 6.12 and Figure 6.7 show the CPR of porotic hyperostosis by subadult age category. The majority of cases occur in the two oldest age categories and there is a distinct absence of any cases in the childhood age category. The numbers affected are too small to allow statistical comparison of CPR by subadult age category.

Age Category	Porotic Hyperostosis			
	N	n	Affected	%
Preterm	13	8	0	0
Full Term	11	5	0	0
Infancy	51	44	1	2.3
Childhood	53	42	0	0
Juvenile	90	66	2	3
Adolescent	29	25	3	12
Total	247	190	6	3.2

N = total number of individuals, n = total number with at least one cranial vault bone present

Table 6.12: CPR of porotic hyperostosis by subadult and adult age categories

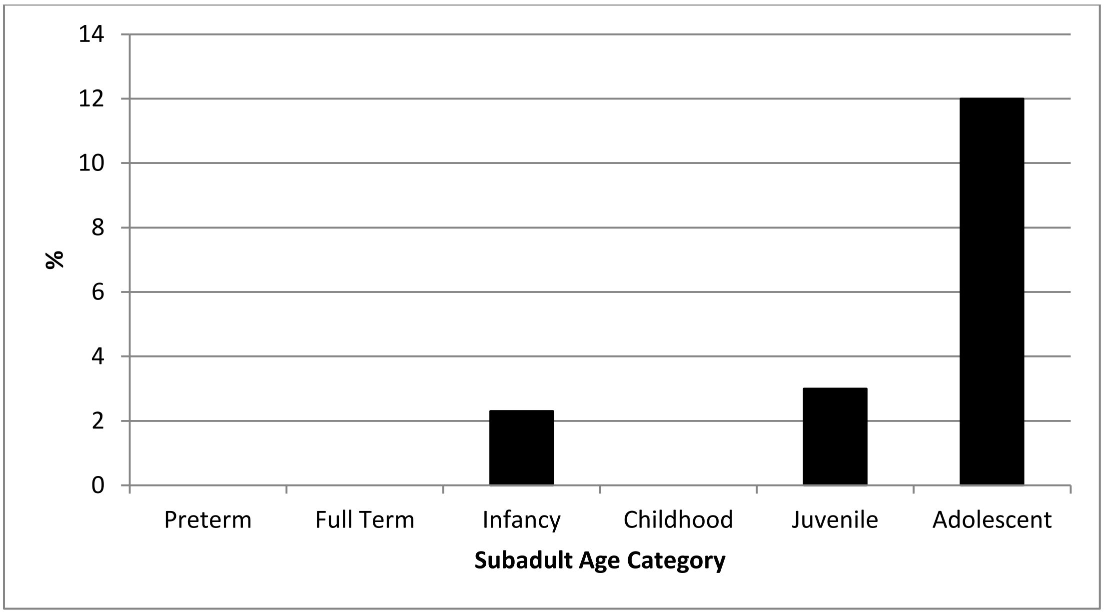


Figure 6.7: CPR of porotic hyperostosis by subadult age category

6.2.5 Non-Specific Infection

In order to ascertain the general level of non-specific infection within the sample, this section will first present overall CPRs (i.e. the number of individuals with some form of non-specific infection as a percentage of the population). Instances of sinusitis were excluded from the overall CPR of non-specific infection as it is not possible to identify the extent to which examination of the sinus cavities had been undertaken at all sites. Therefore, counts of sinusitis are given separately. As CPR's are affected by preservation rates, the second part of the section will provide more detailed TPR's for individual aspects of the skeleton to identify which areas of the skeleton are most affected.

(i) Crude Prevalence Rates

(a) Subadult and Adult Comparison

The overall CPR of non-specific infection within the sample is 22.1% (Table 6.13). Subadults and adults within the sample are similarly affected, and no statistically significant difference was observed ($\chi^2 = 0.675$, df = 1, p = 0.411). Of the 214 individuals affected, 98.6% only had involvement of the bone surface (n = 211).Of these, 205 individuals had evidence of periosteal lesions (i.e. 62 subadults and 143 adults) and 6 individuals had evidence of increased porosity of the bone surface (i.e. 5 subadults and 1 adult). Only two individuals in the sample had evidence of osteitis (COSE84 1886 – left fibula; MSL87 32 – right tibia) and one individual had evidence of osteomyelitis (ENS03 142 – Lumbar vertebra). All three of these individuals were adults. Further descriptions of each lesion are provided in Appendix 6.

In the sample, 12.8% of individuals (n = 124) had evidence of periosteal new bone formation affecting the tibia. Adults were slightly more affected (14.0%, n = 96) than subadults (10.0%, n = 28), though this difference was not statistically significant ($\chi^2 = 1.964$, df = 1, p = 0.1611).Of the individuals with involvement of the tibia, 49.2% (n = 61) had new bone formation bilaterally. Adults had a slightly higher CPR of bilateral new bone formation of the tibiae (53.1%, n= 51) than subadults (35.7%, n = 10), though this proved to be statistically insignificant ($\chi^2 = 0.617$, df = 1, p = 0.4320).

	Non-Specific Infection		
Age Category	N	Affected	%
Subadult	281	67	23.8
Adult	686	147	21.4
Total	967	214	22.1

Table 6.13: CPR of non-specific infection by subadult and adult age categories

(b) Subadult Age Categories

Table 6.14 and Figure 6.8 show the CPR of non-specific infection by subadult age categories. The highest CPR is observed within the infancy category. Interestingly, there is a noticeable decrease in the CPR of non-specific infection in the childhood category. No statistically significant difference is observed in the overall distribution of non-specific infection between age categories ($\chi^2 = 6.906$, df = 4, p = 0.141).

	Non-Specific Infection		
Age Category	N	Affected	%
Preterm	13	0	0
Full Term	11	2	18.2
Infancy	51	16	31.4
Childhood	53	9	17.0
Juvenile	90	25	27.8
Adolescent	29	7	24.1
Total	247	59	23.9

Table 6.14: CPR of non-specific infection by subadult age category

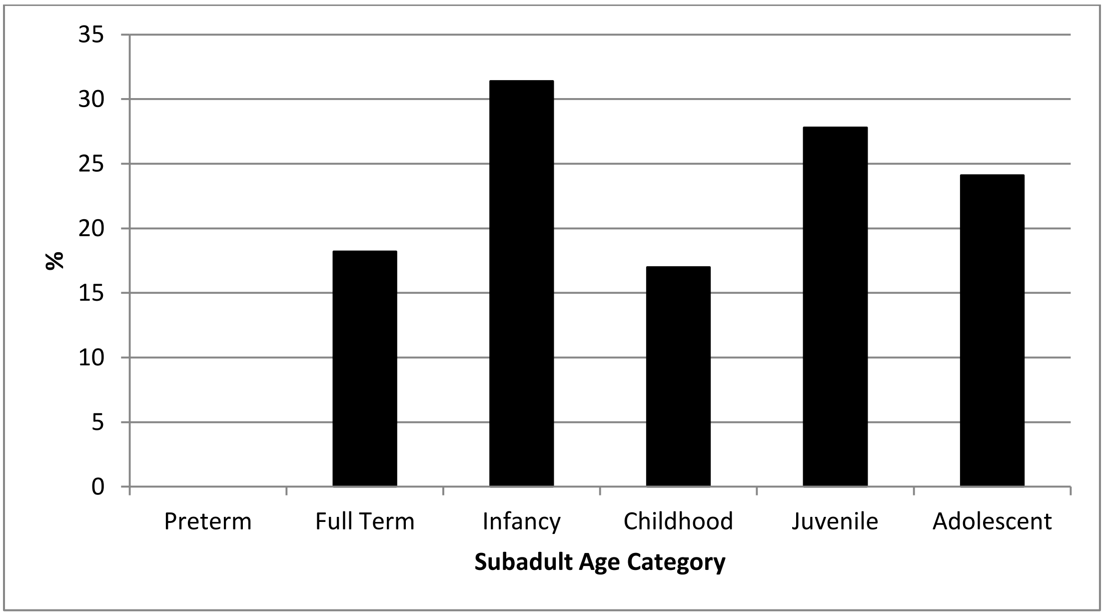


Figure 6.8: CPR of non-specific infection by subadult age category

Age Category	N	Total Sinusitis		Maxillary Sinusitis		Frontal Sinusitis		Sphenoidal Sinusitis	
		Affected	%	Affected	%	Affected	%	Affected	%
Subadult	281	4	1.4	4	1.4	0	-	0	-
Adult	686	30	4.4	27	3.9	7	1.0	1	0.1
Total	967	34	3.5	31	3.2	7	0.7	1	0.1

Table 6.15: CPR of sinusitis by subadult and adult age category

(c) Sinusitis

Table 6.15 presents the CPR of sinusitis by subadult and adult age categories. A total of 34 individuals are identified as having new bone formation within at least one of their sinus cavities (3.5%). For five of these individuals, two separate sinus cavities were affected, e.g. HOO88 [518] had evidence of sinusitis in both their maxillary and frontal sinuses. Maxillary sinusitis is most commonly observed (3.2%), with adults having the highest CPR in all three of the cavities affected. Of those subadults affected, three of the four individuals are assigned to the juvenile age category, with the remaining individual assigned to the adolescent age category.

(ii) True Prevalence Rates

(a) Subadult and Adult Comparisons

Figure 6.9 depicts the TPR of non-specific infection within the sample and by subadult and adult age category (see Appendix 3 Table 1 for absolute figures). Within the whole sample and both subadult and adult age categories, the highest TPR is observed for the tibiae, followed by the fibulae and ribs. For the majority of skeletal elements, subadults have higher TPR than adults, with tibiae, fibulae, lumbar vertebrae and the sacrum being the only exceptions. For five of these skeletal elements, subadults are significantly more affected than adults: the mandible (Fisher’s exact p = 0.0079), scapulae (Fisher’s exact p = 0.0349), femora (Fisher’s exact p = 0.0439), metacarpals (Fisher’s exact p = <0.0001), and metatarsals (Fisher’s exact p = 0.0175).

For both the total sample, and the subadult and adult age categories, no significant difference was observed for the laterality of long bones affected (see Appendix 3 Table 2 for TPR by laterality).

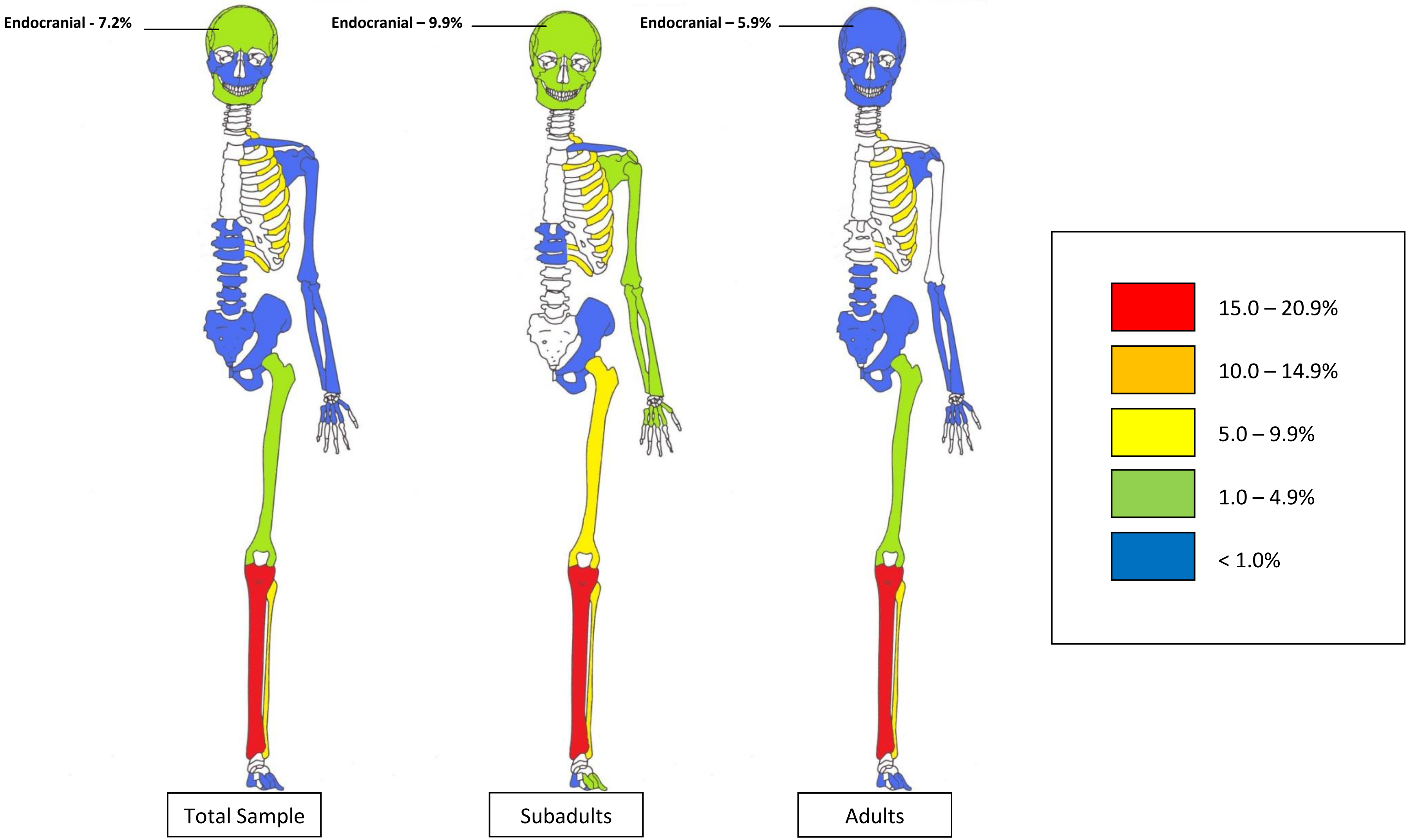


Figure 6.9: TPR of non-specific infection by subadult and adult age categories

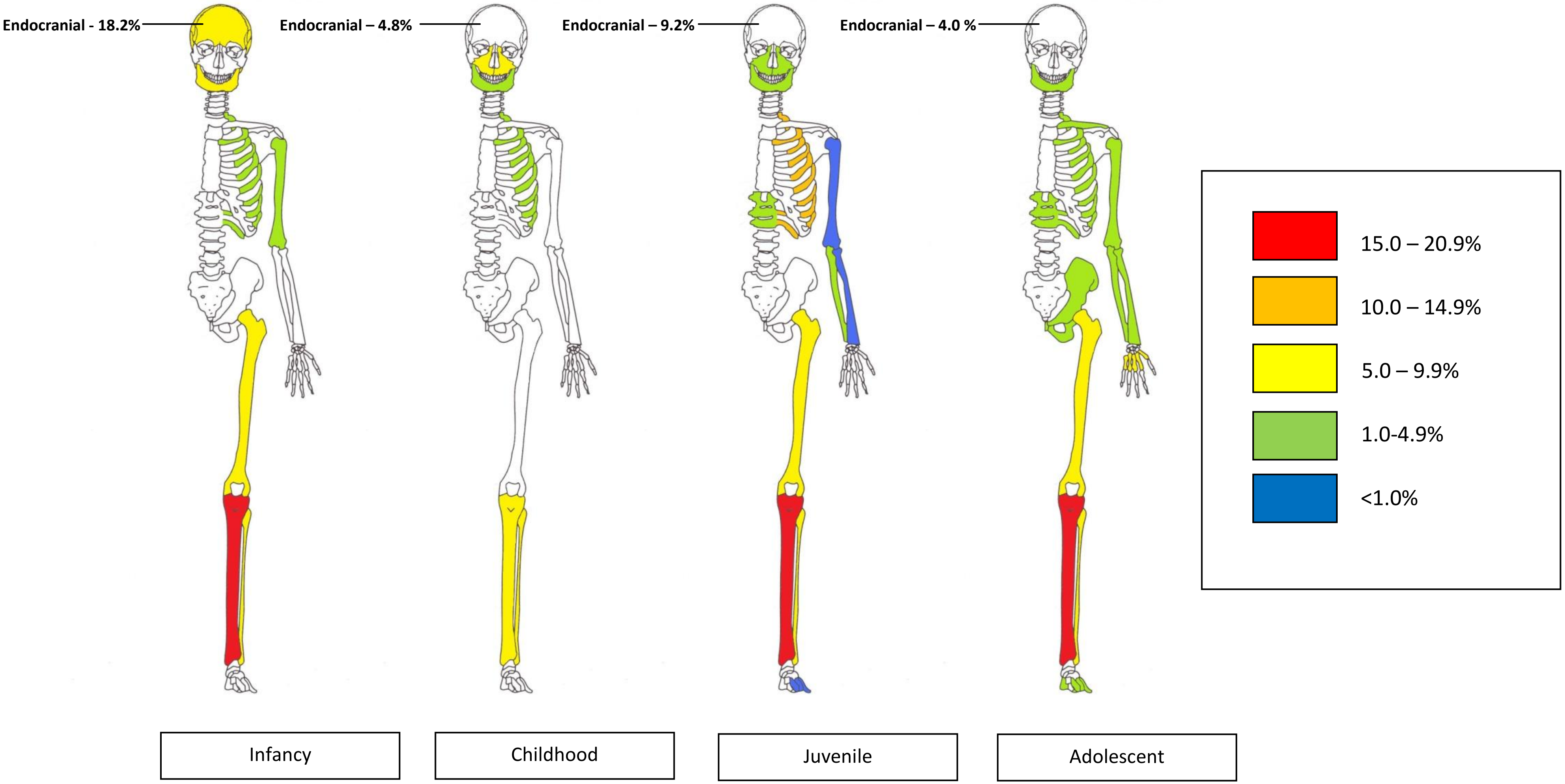


Figure 6.10: TPR of non-specific infection by subadult age categories

(b) Subadult Age Categories

Figure 6.10 depicts the TPR of non-specific infection by subadult age category. In all of the depicted age categories (infancy, childhood, juvenile and adolescent), tibiae are the most affected, with non-specific infection also observed on the fibulae, ribs, and mandibles across the categories. Amongst the juveniles and adolescents, a greater degree of diversity is observed in the number of different elements affected when compared to their younger counterparts. It is within the childhood age category that the least number of elements affected is observed. Of the remaining age categories not depicted here, no non-specific infection is observed amongst preterm individuals and the only area affected for those that reached full term is the endocranium (40%, n = 2). It is amongst the lowest age categories that the highest TPR of non-specific infection located within the endocranium is observed; whilst in the older age categories an increase in the TPR of non-specific infection within the upper limb is noticeable.

6.2.6 Specific Infectious Disease - Tuberculosis

In addition to instances of non-specific infection, three cases of specific infectious disease were identified within the sample, all of which were diagnosed as tuberculosis (Table 6.16). Subadults are more affected than adults, although this difference was not statistically significant (Fisher's exact p = 0.204). Both of the subadults identified as having tuberculosis fell within the childhood age category (3.1-7.9yrs).

	Specific Infection - TB		
Age Category	N	Affected	%
Subadult	281	2	0.7
Adult	686	1	0.1
Total	967	3	0.3

Table 6.16: CPR of specific infectious disease (TB) by subadult and adult age categories

Skeleton 1714 from MSL87 (4 years age-at-death) appears to have destructive changes to the ventral bodies of the 4th to 6th thoracic vertebrae, and these consisted of a mixture of possible lytic focuses which had exposed the cancellous bone of the body. Evidence for remodelling is observed. New bone formation was also observed on the visceral aspect of the majority of the shafts of the left ribs, with at least one exhibiting a "scalloped" defined erosive-looking lesion (Figure 6.11).

Figure 6.11: MSL87 [1714] Lesions associated with tuberculosis: left – possible lytic focus within the 4th and 6th thoracic vertebrae; right – scalloped lesion on visceral rib surface

6.2.7 Vitamin D Deficiency Diseases

Due to the low prevalence of individuals identified with vitamin D deficiency within the sample, CPRs of individuals affected are given in the subsequent sections. As it was not possible in all instances to ascertain whether the pathology was active or healed, data is presented by presence and absence only. All individuals identified by the osteologists and entered onto the WORD database as possible cases of vitamin D deficiency diseases are included within the positive category.

(i) Subadult and Adult Comparison

The overall CPR of vitamin D deficiency diseases within the sample is 2.1% (Table 6.17). Subadults are significantly more affected than adults by the skeletal manifestations of this condition (χ^2 = 18.695, df = 1, p = <0.0001).

	Vitamin D Deficiency Diseases		
Age Category	N	Affected	%
Subadult	281	15	5.3
Adult	686	5	0.7
Total	967	20	2.1

Table 6.17: CPR of vitamin D deficiency diseases by subadult and adult age categories

(ii) Subadult Age Categories

Table 6.18 and Figure 6.12 show the CPR of vitamin D deficiency diseases by subadult age category. In Figure 6.11, we can see that the highest affected age category is that of infancy, accounting for 50% of the total number of subadults identified as having a vitamin D deficiency. The numbers affected are too small to allow statistical comparison of CPR by subadult age category.

	Vitamin D Deficiency		
Age Category	N	Affected	%
Preterm	13	0	0
Full Term	11	0	0
Infancy	51	6	11.8
Childhood	53	1	1.9
Juvenile	90	4	4.4
Adolescent	29	1	3.4
Total	247	12	4.9

Table 6.18: CPR of vitamin D deficiency diseases by subadult age category

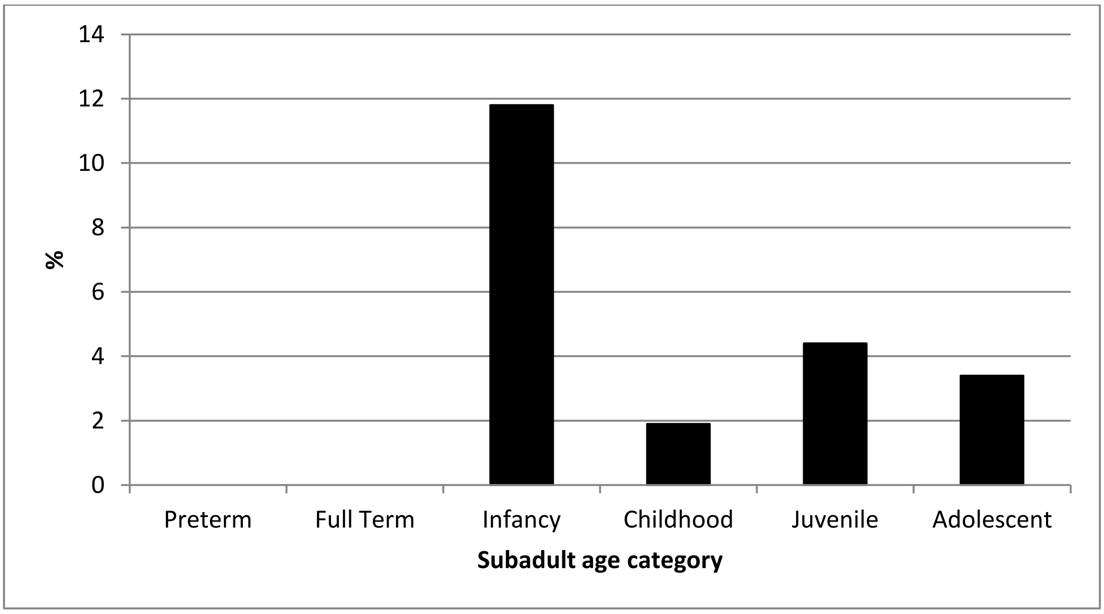


Figure 6.12: CPR of vitamin D deficiency diseases by subadult age category

6.2.8 Vitamin C Deficiency Disease

(i) Subadult and Adult Comparisons

Within the sample, only two cases of scurvy are observed, giving a CPR of 0.2% (Table 6.19). Both cases occurred within the subadult age category.

	Total Population		
Age Category	N	Affected	%
Subadult	281	2	0.7
Adult	686	0	0
Total	967	2	0.2

Table 6.19: CPR of vitamin C deficiency diseases by subadult and adult age categories

(ii) Subadult Age Categories

The only observed case of vitamin C deficiency diseases in the aged subadult sample is within the infancy age category (Table 6.20). This individual (HAY86 [516]), aged 6 months at the time of death, had severe porous new bone formation on the endocranial aspects of their supraoccipital, parietal, and squamous part of the temporal bones, with vessel impressions apparent (Figure 6.13). On the endocranial aspect of the frontal bone, a remodelling woven bone plaque of the type classified as “fiber bone formation” by Lewis (2004: 89) is observed. A fine layer of new bone formation is also present within the left orbit. The right orbit was not available for examination. In addition to this new bone formation, marked porosity to the endocranial aspects of the left greater wing of the sphenoid bone and the lingual aspect of the mandibular ramii is present. Some pitting is also observed on the ectocranial aspects of the left squamous part of the temporal bone.

	Total Population		
Age Category	N	Affected	%
Preterm	13	0	0
Full Term	11	0	0
Infancy	51	1	2
Childhood	53	0	0
Juvenile	90	0	0
Adolescent	29	0	0
Total	247	1	0.4

Table 6.20: CPR of vitamin C deficiency diseases by subadult age categories

Figure 6.13: Periosteal new bone formation on the endocranial surface of HAY86 [516]

6.2.9 Summary of Prevalence Rates of Stress Indicators by Age Category

(i) Subadult v Adult Comparisons

Table 6.21 and Figure 6.14 present the summary statistics for the prevalence rates of all the stress indicators studied by subadult and adult age categories. The outcomes were as follows:

- The overall prevalence rate of individuals exhibiting one or more stress markers is slightly higher amongst subadults, although this difference proved to be insignificant.
- Higher prevalence rates for subadults are observed in four of the six individual stress indicators - *cribra orbitalia*, non-specific infection, and both vitamin deficiency diseases. Of these, *cribra orbitalia* (χ^2 = 11.228, df = 1, p=0.001) and vitamin D deficiency (χ^2 = 20.909, df = 1, p<0.0001) proved to be statistically significant.
- Higher prevalence rates of enamel hypoplasia and porotic hyperostosis were identified in the adult population, although neither of these proved to be statistically significant.

Stress Indicator	Subadult			Adult			Total		
	N	n	%	N	n	%	N	n	%
*Cribra orbitalia**	120	71	59.2	258	105	40.7	378	176	46.6
Enamel Hypoplasia*	175	91	52.0	389	234	60.2	564	325	57.6
Porotic Hyperostosis*	204	6	2.9	424	18	4.4	628	24	3.8
Non-Specific Infection*	281	67	23.8	686	147	21.4	967	214	22.1
Vitamin D Deficiency*	281	15	5.3	686	5	0.7	967	20	2.1
Vitamin C Deficiency*	281	2	0.7	686	0	0	967	2	0.2
Individuals with 1+ stress indicators*	281	153	54.4	686	343	50.0	967	496	51.3

N = total number of individuals, n = total number affected, * denotes data given as CPR

Table 6.21: Prevalence rates of stress indicators by subadult and adult age categories.

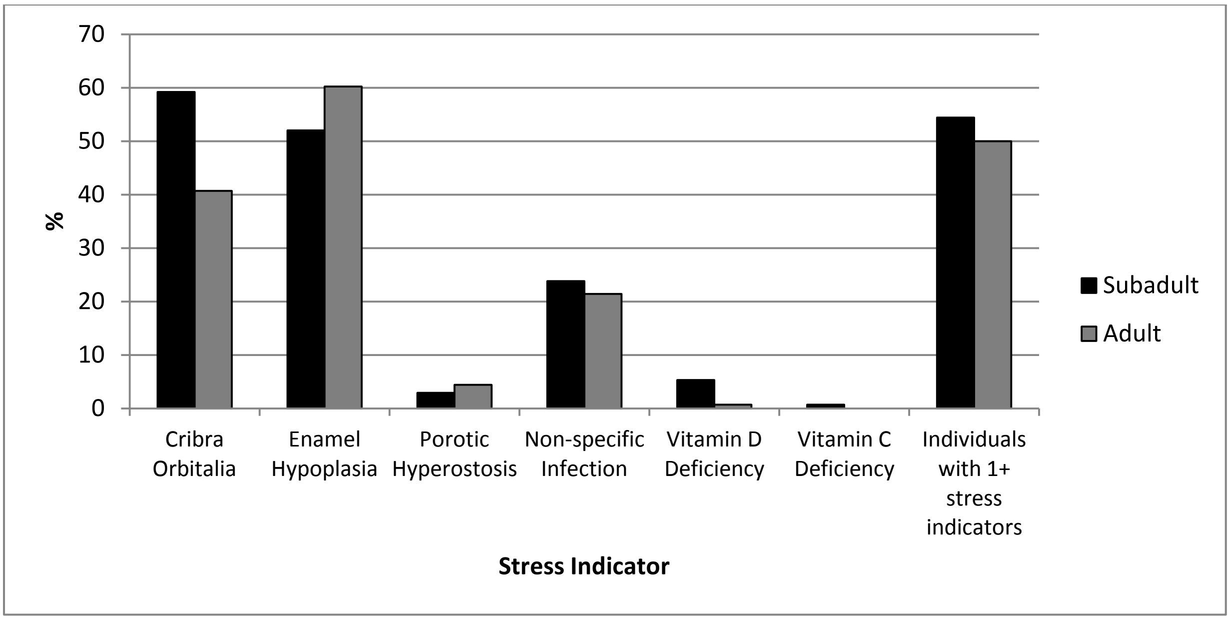


Figure 6.14: Prevalence rates of stress indicators by subadult and adult age categories

(ii) Subadult Age Categories

Table 6.22 and Figure 6.15 present the summary statistics of all stress indicators by subadult age category.

- A peak is observed in almost all stress indicators at the infancy age category, followed by a subsequent decline in prevalence in the childhood age category
- Noticeable exceptions to this are seen for enamel hypoplasia, where increasing prevalence with increasing age is apparent, and *cribra orbitalia*, although the large peak in the full term category reflects just one individual.

Stress Indicator	Age Categories					
	Preterm	Full-term	Infancy	Childhood	Juvenile	Adolescent
*Cribra Orbitalia**	25	100	55.2	60	58.1	63.2
Enamel Hypoplasia*	0	0	19.4	47.7	66.2	76.9
Porotic Hyperostosis*	0	0	2.3	0	3.0	12.0
Non-Specific Infection*	0	18.2	31.4	17	27.8	24.1
Vitamin D Deficiency*	0	0	11.8	1.9	4.4	3.4
Vitamin C Deficiency*	0	0	2	0	0	0
Number with 1+ stress indicators*	7.7	18.2	52.9	50.9	64.4	82.8

*** denotes data given as CPR**

Table 6.22: Prevalence rates (%) of stress indicators by subadult and adult age categories

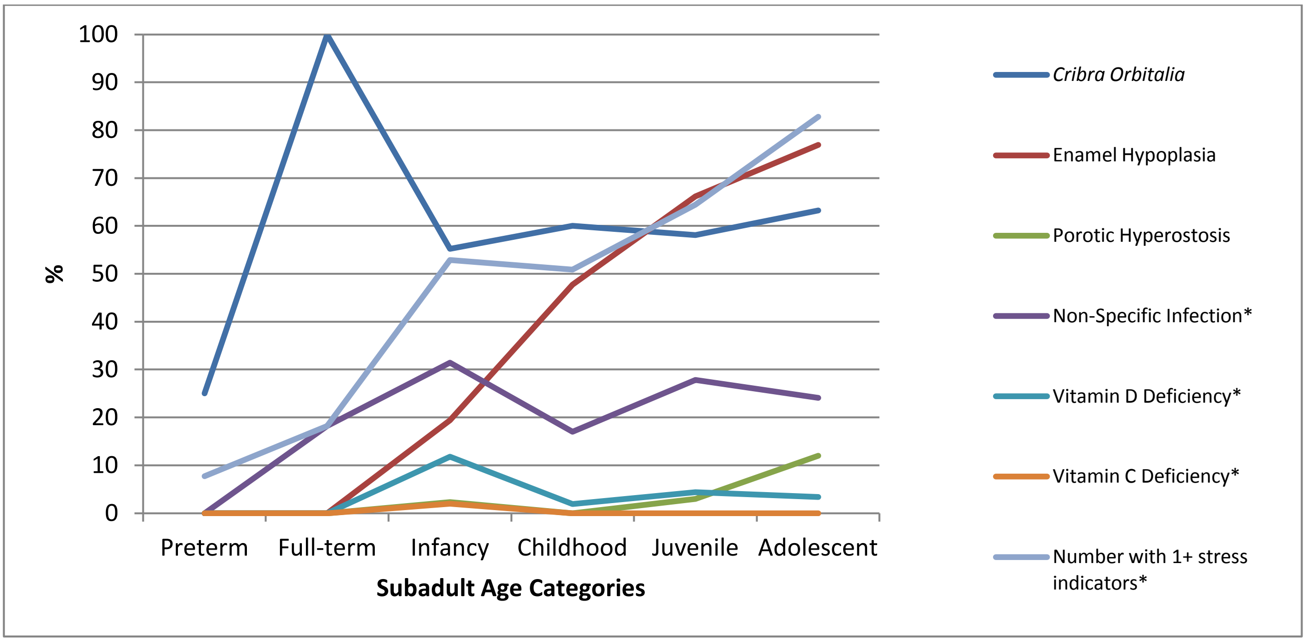


Figure 6.15: Prevalence rates of stress indicators by subadult age categories

(iii) Mean Age at Death

In order to identify if there was an association between stress indicators and mortality, mean ages-at-death for aged subadults were calculated for those with and without stress indicators (Table 6.23). In all cases, subadults exhibiting stress indicators lived longer than those without stress indicators.

Stress Indicator	Mean-Age-At-Death	
	With Stress Marker	Without Stress Marker
Cribra orbitalia	9.09 ± 6.380	8.60 ± 6.672
Enamel Hypoplasia	11.28 ± 5.561	6.80 ± 5.509
Porotic Hyperostosis	14.92 ± 5.970	7.99 ± 6.160
Non-Specific Infection	8.87 ± 6.468	7.96 ± 6.132
Total	9.76 ± 6.207	6.20 ± 5.661

Table6.23: Mean age at death for subadults with and without stress indicators

6.3 Time Period

The following section presents the summary results of the analysis by time period. Roman London is one of the few Romano-British towns with sufficient numbers of burials from across the Roman period to allow for the determination of differences in living conditions across the Roman occupation. Therefore, the aim of this section is to identify potential changes in the subadult prevalence rates of the selected pathologies between the early (AD 43-250) and late (AD250-410) Roman period that may relate to a change in health or levels of stress.

6.3.1 Demography by Time Period

(i) Subadult and Adult Demography

Table 6.24 and Figure 6.16 detail the demography of the sample by date period. Of the 967 individuals within the sample, insufficient dating evidence was available for 47 individuals to allow assignment of a more specific date period than Roman. These individuals were excluded from all subsequent analyses of chronology. Within both the subadult and adult age categories, approximately 60% of the individuals dated to the later Roman period. This higher proportion of individuals within the later period is expected as cremation was the dominant funeral rite performed in the town until the second century AD. Nevertheless, the ratio of subadults to adults between time periods remains the same, with no statistically significant difference observed ($\chi^2 = 0.001$, df = 1, p =0.973).

Age Category	Total No. Individuals	AD43-250		AD250-410	
		N	%	N	%
Subadult	267	105	29.1	162	29.0
Adult	653	256	70.9	397	71.0
Total	920	361	39.2	559	60.8

Table 6.24: Subadult and adult sample demography by time period

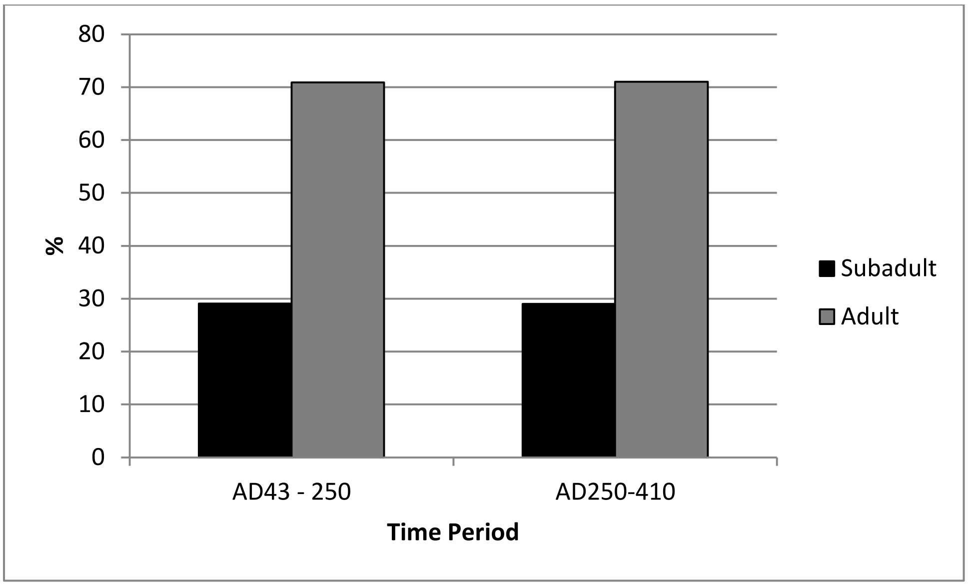


Figure 6.16: Subadult and adult demography by time period

(ii) Demography by Subadult Age Category

Table 6.25 and Figure 6.17 present the subadult age category distribution by period date. Of the 247 subadults assigned an age category, 14 individuals could not be assigned to a specific period and are excluded from further analyses of subadult age categories by date. In the youngest three age categories, there is a decrease in representation between time periods. The opposite is observed in two of the later age categories, with a noticeable increase in the percentage of children observed between time periods. This difference in the distribution of subadult age categories between time periods proved to be statistically significant ($\chi^2 = 11.439$, df = 4, p=0.022).

Age Category	Number of Individuals	AD43-250		AD250-410	
		N	%	N	%
Preterm	11	7	7.5	4	2.9
Full Term	9	7	7.5	2	1.4
Infancy	46	20	21.5	26	18.6
Childhood	51	15	16.1	36	25.7
Juvenile	88	31	33.3	57	40.7
Adolescent	28	13	14.0	15	10.7
Total	233	93	39.9	140	60.1

Table 6.25: Subadult age category demography by time period

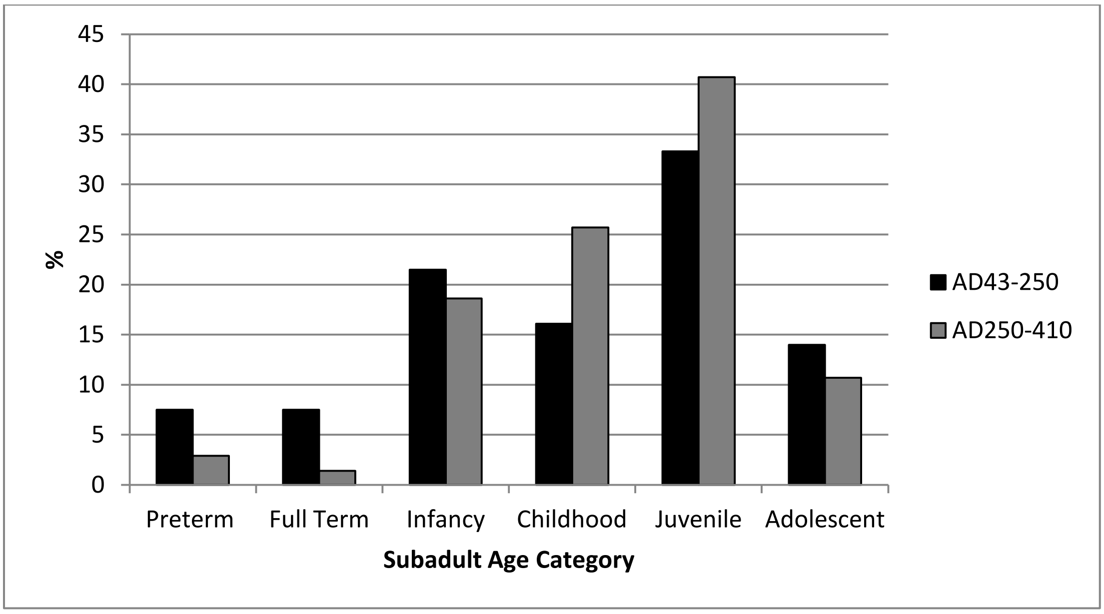


Figure 6.17: Subadult age category by time period

6.3.2 Prevalence Rates of Stress Indicators by Time Period

(i) Total Pathology (Individuals with One or More of the Studied Stress Indicators)

(a) Subadult and Adult Comparisons

Table 6.26 and Figure 6.18 present the CPR of subadults and adults affected by one or more pathologies by time period. Overall, there is a 14.2% increase in the CPR of pathology between time periods. This increase in the skeletal pathologies examined proved to be statistically significant (χ^2 = 8.692, df = 1, p <0.0001). In both subadult and adult age categories there is a significant increase in the number of individuals affected between time periods (subadults χ^2=

	AD43-250			AD250-410		
Age Category	N	Affected	%	N	Affected	%
Subadult	105	44	41.9	162	99	61.1
Adult	256	111	43.4	397	220	55.4
Total	361	155	42.9	559	319	57.1

Table 6.26: Subadult and adult CPR of total pathology by time period

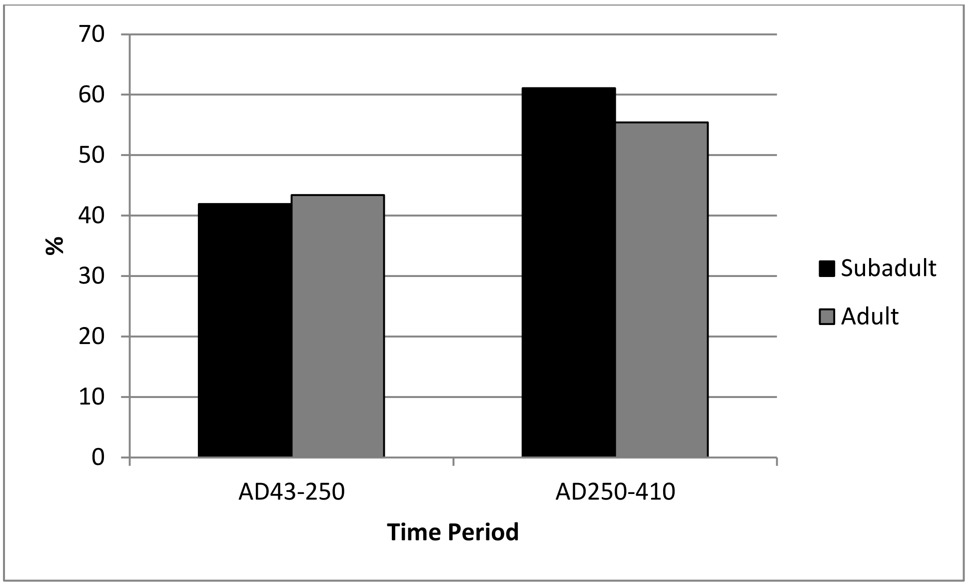


Figure 6.18: Subadult and adult CPR of total pathology by time period

8.692, df = 1, p=0.0032; adults χ^2= 8.575, df = 1, p = 0.0034). Within each time period, no significant difference is observed between the number of subadults and adults with at least one of the studied skeletal pathologies (AD43-250 χ^2=0.019, df = 1, p = 0.8914, AD250-410 χ^2= 0.912, df = 1, p=0.3396). However, between time periods, there is a shift in the most affected group, with subadults becoming more affected than adults in later time period.

(b) Subadult Age Categories

Table 6.27 and Figure 6.19 present the CPR of total pathology by subadult age category and time period. In both time periods there is an increase in CPR with age, and the relationship between subadult age category and total pathology CPR in both time periods proved to be statistically significant (AD43-250 χ^2 = 15.663, df = 4, p=0.004; AD250-410 χ^2 = 9.134, df = 3, p=0.026).

Within each individual age group, there is also an increase in the CPR of individuals affected by one or more stress markers. The largest increase between periods is within the infant age category, where prevalence rates almost double. The only exception to this increase in CPR

Age Category	AD43-250			AD250-410		
	N	Affected	%	N	Affected	%
Preterm	7	0	0.0	4	0	0.0
Full Term	7	1	14.3	2	0	0.0
Infancy	20	7	35.0	26	16	61.5
Childhood	15	6	40.0	36	19	52.8
Juvenile	31	17	54.8	57	39	68.4
Adolescent	13	10	76.9	15	14	93.3
Total	93	41	44.1	140	88	62.9

Table 6.27: Subadult age category total pathology CPR by time period

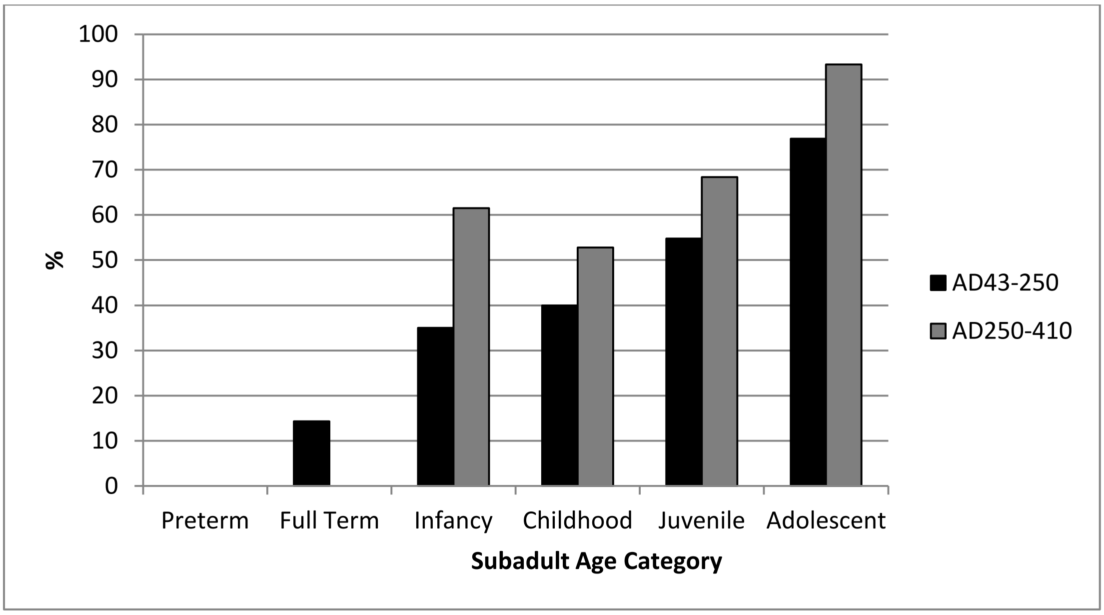


Figure 6.19: Subadult age category total pathology CPR by time period

between time periods is within the full term age category; however, this may be the result of poor preservation and the small sample size within this age/date group.

(ii) *Cribra orbitalia*

(a) Subadult and Adult Comparisons

Table 6.28 and Figure 6.20 present the *cribra orbitalia* CPR of subadults and adults by time period. There is a 10% increase in the overall CPR of *cribra orbitalia* between time periods; however this increase is not statistically significant (X^2= 3.410, df = 1, p = 0.0687). Within both time periods, subadults had the highest CPR; however, the difference between subadults and

Age Category	AD43-250				AD250-410			
	N	n	Affected	%	N	n	Affected	%
Subadult	105	45	22	48.9	162	72	47	62.3
Adult	256	97	35	36.1	397	154	66	42.9
Total	361	142	57	40.1	559	226	113	50.0

N = total number of individuals, n = total number with at least one orbit present

Table 6.28: Subadult and adult CPR of *cribra orbitalia* by time period

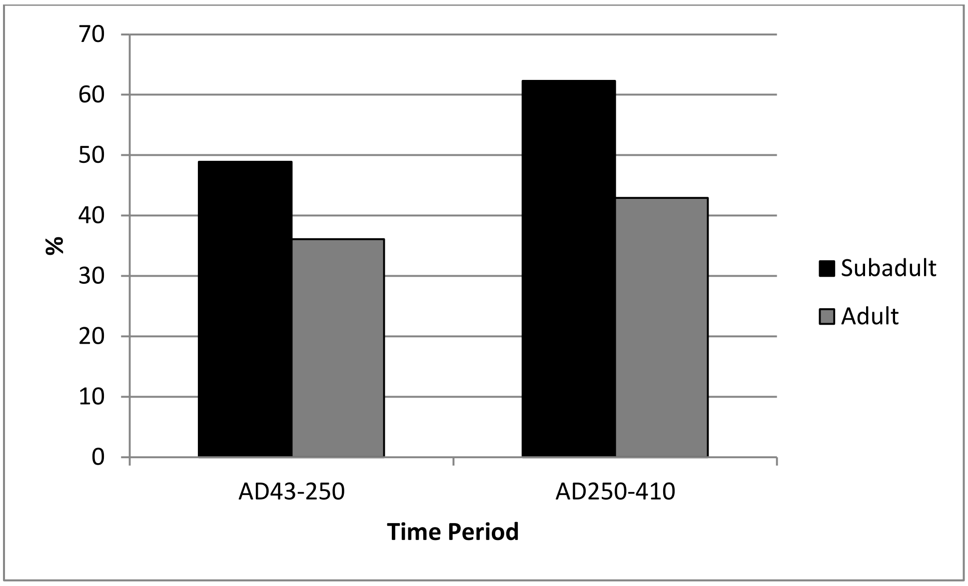


Figure 6.20: Subadult and adult CPR of *cribra orbitalia* by time period

adults is only significantly greater in the later period (AD43-250 X^2= 2.098, df = 1, p= 0.147; AD250-410 X^2 = 2.098, df = 1, p =0.002). An increase in CPR between time periods is observed for both subadult and adult age categories; however this increase is not statistically significant in either category (subadults X^2 = 3.074, df = 1, p = 0.08; adults X^2= 1.136, df = 1, p =0.2865).

(b) Subadult Age Categories

Table 6.29 and Figure 6.21 present the CPR of *cribra orbitalia* by subadult age category and time period. In three of the categories, there is an increase in the CPR between time periods, with the largest increase (40.6%) observed within the infant age category. The two exceptions are within the full term category, although this is probably the result of poor preservation of orbits within this age group/date period, and adolescence, where a slight decrease between periods is observed. No statistically significant difference is observed within individual age categories by time period (Infancy Fisher's exact p = 0.0568, Childhood Fisher's exact p = 0.6424, Juvenile Fisher's exact p = 0.2035, Adolescent Fisher's exact p= 1.0000).

Age Category	AD43-250				AD250-410			
	N	n	Affected	%	N	n	Affected	%
Preterm	7	1	0	0	4	2	0	0
Full Term	7	1	1	100	2	0	-	-
Infancy	20	10	3	30.0	26	17	12	70.6
Childhood	15	6	3	50.0	36	14	9	64.3
Juvenile	31	16	7	43.8	57	27	18	66.7
Adolescent	13	9	6	66.7	15	10	6	60
Total	93	43	20	46.5	140	70	45	64.3

N = total number of individuals, n = total number with at least one orbit present

Table 6.29: Subadult age category *cribra orbitalia* CPR by time period

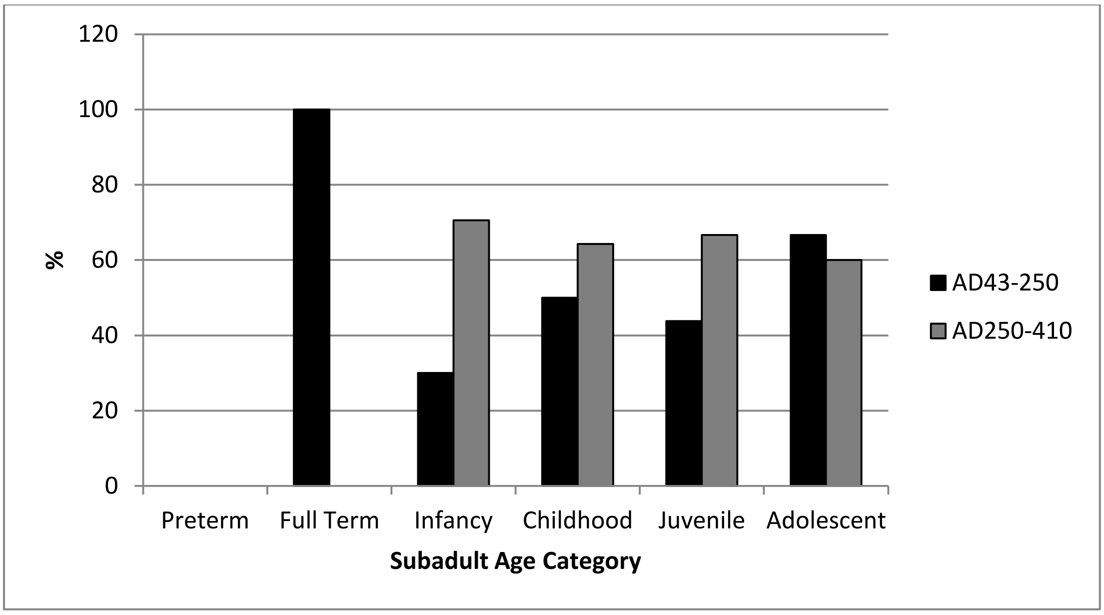


Figure 6.21: Subadult age category *cribra orbitalia* CPR by time period

(iii) Enamel Hypoplasia

(a) Subadult and Adult Comparisons

Table 6.30 and Figure 6.22 present the CPR of enamel hypoplasia for subadult and adult age categories by time period. The overall CPR of enamel hypoplasia for the sample increases significantly ($\chi^2 = 5.202$, df = 1, p=0.0226) between time periods. In both time periods, adults are more affected than subadults, with the largest difference between age categories observed in the earlier time period. The difference between subadult and adult CPR is not statistically significant in either time period (AD43 – 250 $\chi^2 = 2.866$, df = 1, p = 0.090, AD250-410 $\chi^2 = 1.338$, df = 1, p = 0.247). Within each age category, there is an increase in CPR

Age Category	AD43-250				AD250-410			
	N	n	Affected	%	N	n	Affected	%
Subadult	105	64	27	42.2	162	103	58	56.3
Adult	256	142	78	54.9	397	235	148	63.0
Total	361	206	105	51.0	559	338	206	60.9

N = total number of individuals, n = total number of individuals with teeth present

Table 6.30: Subadult and adult CPR of enamel hypoplasia by time period

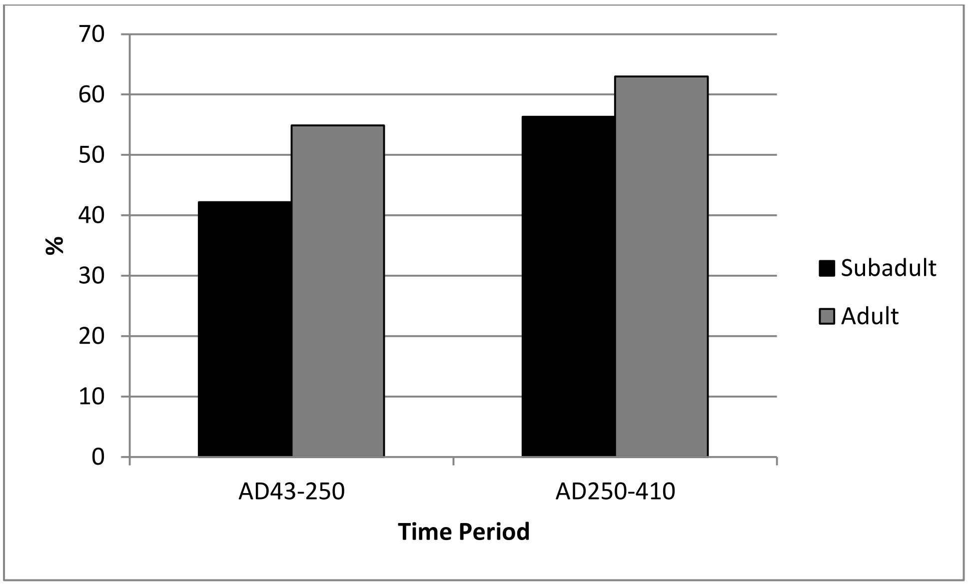


Figure 6.22: Subadult and adult CPR of enamel hypoplasia by time period

between time periods; however neither increase is statistically significant (subadults χ^2= 3.150, df = 1, p = 0.0759; adults χ^2 = 2.388, df = 1, p = 0.1222).

(b) Subadult Age Categories

Table 6.31 and Figure 6.23 show the CPR of enamel hypoplasia by subadult age category and time period. As expected, there is an increase in the CPR of enamel hypoplasia between subadult age categories in both time periods. However, the number of observed cases was too small to allow statistical analyses. Within each age category where enamel hypoplasia is observed, there is an increase in CPR between time periods, although no statistically significant difference was observed (infancy Fisher's exact p = 0.6367; childhood Fisher's exact p = 0.7393; juvenile Fisher's exact p = 0.0610; Adolescent Fisher's exact p = 1.0000).

Age Category	AD43-250				AD250-410			
	N	n	Affected	%	N	n	Affected	%
Preterm	7	1	0	0	4	0	-	-
Full Term	7	2	0	0	2	0	-	-
Infancy	20	11	1	9.1	26	21	4	19.0
Childhood	15	13	5	38.5	36	29	14	48.3
Juvenile	31	24	12	50.0	57	39	29	74.4
Adolescent	13	12	9	75.0	15	14	11	78.6
Total	93	63	27	42.9	140	103	58	56.3

N = total number of individuals, n = total number with at teeth present

Table 6.31: Subadult age category enamel hypoplasia CPR by time period

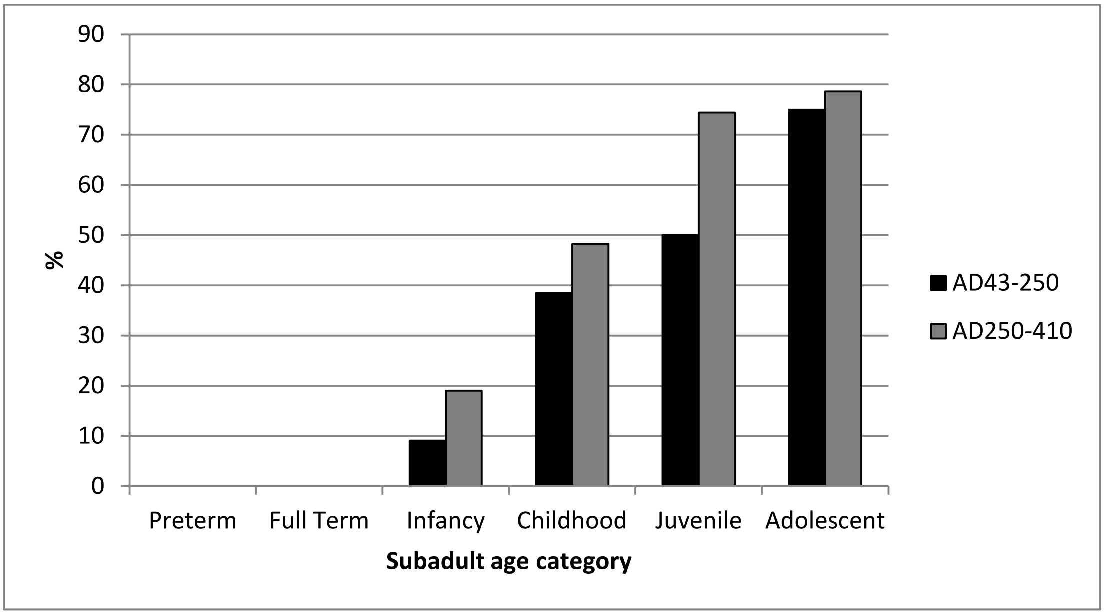


Figure 6.23: Subadult age category enamel hypoplasia CPR by time period

(iv) Porotic Hyperostosis

(a) Subadult and Adult Comparisons

Table 6.32 and Figure 6.24 present the CPR of porotic hyperostosis between subadult and adult age categories by date period. The overall CPR of the sample decreases by 1.2% between time periods, however, this decrease is not statistically significant (Fisher's exact p = 0.5222). No significant difference is observed in the CPR between subadults and adults in either time period (AD43-250 Fisher's exact p = 0.7552; AD250-410 Fisher's exact p = 0.3600). However, there is a change in the age category most affected between time periods, with adults becoming more affected in the later date period. For both age categories, there is a decrease

Age Category	AD43-250				AD250-410			
	N	n	Affected	%	N	n	Affected	%
Subadult	105	77	4	5.2	162	116	2	1.7
Adult	256	156	7	4.5	397	256	11	4.3
Total	361	233	11	4.7	559	372	13	3.5

N = total number of individuals, n = total number with at least one cranial vault bone present

Table 6.32: Subadult and adult porotic hyperostosis CPR by time period

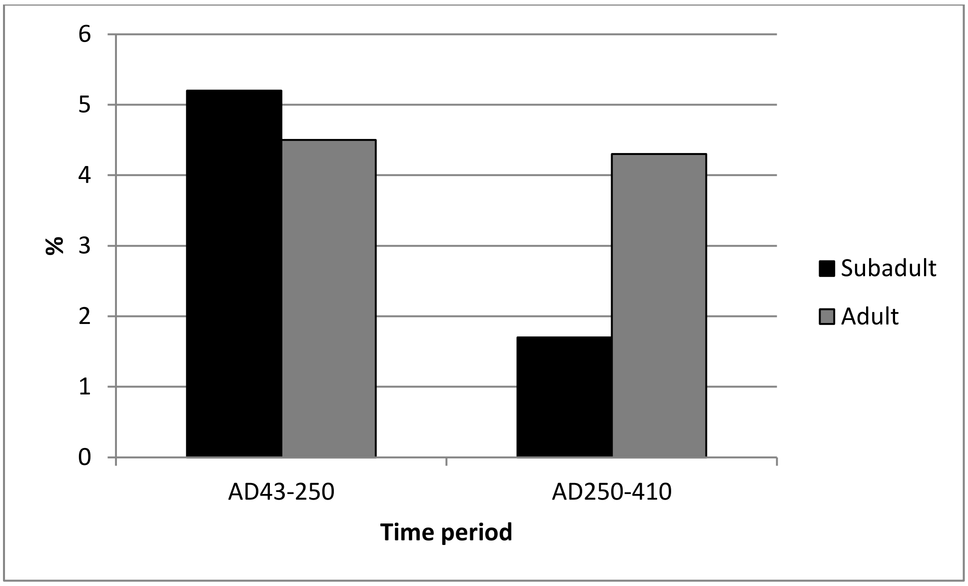


Figure 6.24: Subadult and adult porotic hyperostosis CPR by time period

in the CPR of porotic hyperostosis between time periods, although the decrease is much greater in the subadult age group. Despite this, no statistically significant difference was observed within age categories by time period (subadults Fisher's exact p = 0.2188; adults Fisher's exact p = 1.0000).

(b) Subadult Age Categories

Table 6.33 and Figure 6.25 present the CPR of porotic hyperostosis by subadult age category and time period. From Figure 6.25, it is observed that unlike in the earlier period, all cases of porotic hyperostosis in the later period are only observed within the adolescent category. In both time periods, adolescents are the most affected but there is an increase of 5.2% between time periods. The number of affected individuals was too small to allow for statistical comparison.

Age Category	AD43-250				AD250-410			
	N	n	Affected	%	N	n	Affected	%
Preterm	7	4	0	0	4	3	0	0
Full Term	7	4	0	0	2	0	-	-
Infancy	20	18	1	5.6	26	21	0	0
Childhood	15	12	0	0	36	28	0	0
Juvenile	31	24	2	8.3	57	40	0	0
Adolescent	13	11	1	9.1	15	14	2	14.3
Total	93	73	4	5.5	140	106	2	1.9

N = total number of individuals, n = total number with at least one cranial vault bone present

Table 6.33: Subadult age category CPR porotic hyperostosis by time period

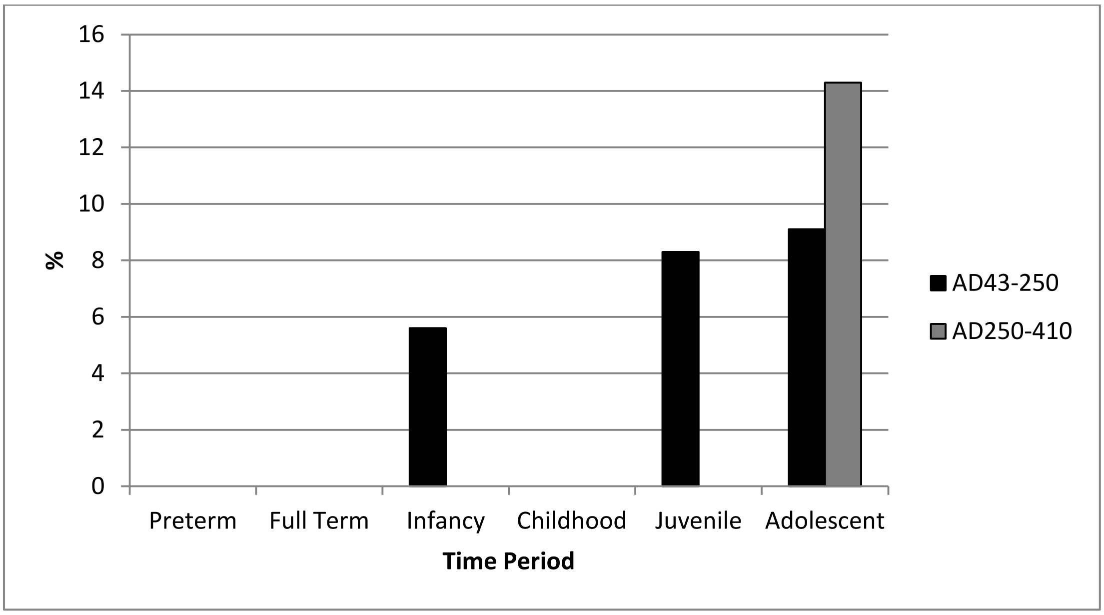


Figure 6.25: Subadult age category CPR porotic hyperostosis by time period

(v) Non-Specific Infection

(a) Crude Prevalence rates

(1) Subadult and Adult Comparisons

Table 6.34 and Figure 6.26 present the CPR of non-specific infection by subadult and adult age categories and time period. The overall CPR of non-specific infection in the sample increases by 6.2% between time periods, which is statistically significant (χ^2 = 4.944, df = 1, p = 0.0262). Within the earlier time period, subadults have a higher CPR of non-specific infection compared to adults. By the later period, subadult and adults demonstrate a similar rate of non-specific

Age Category	AD43-250			AD250-410		
	N	Affected	%	N	Affected	%
Subadult	105	22	21.0	162	39	24.1
Adult	256	44	17.2	397	98	24.7
Total	361	66	18.3	559	137	24.5

Table 6.34: Subadult and adult CPR non-specific infection by time period

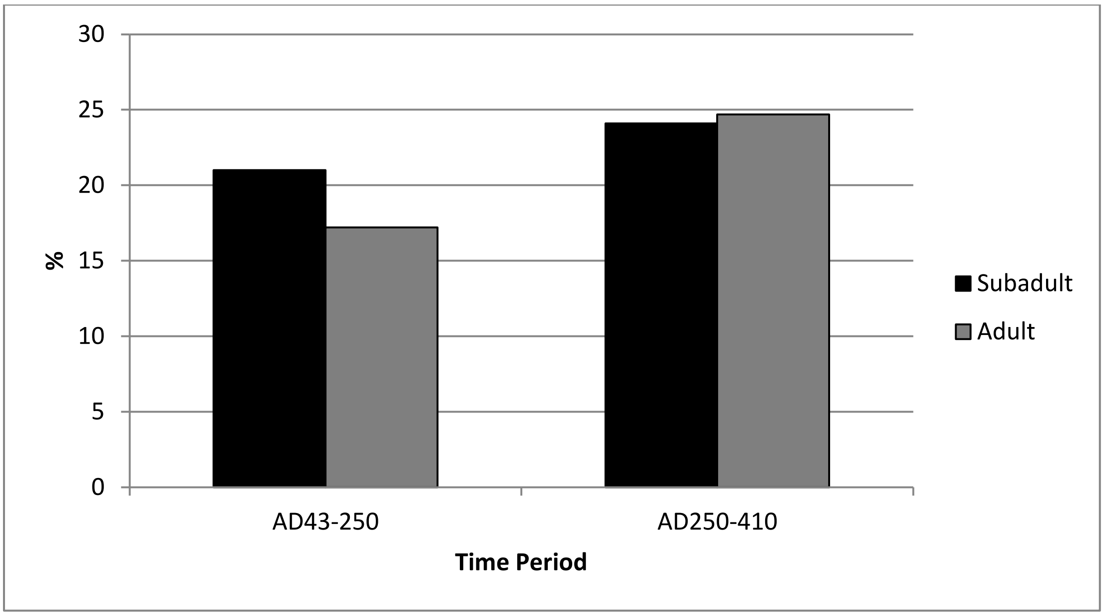


Figure 6.26: Subadult and adult CPR non-specific infection by time period

infection, although the adult CPR is slightly higher. No statistically significant difference is observed between subadult and adult CPR by time period. Within age categories, an increase in CPR between time period is present for both subadults and adults, but only that seen in the adult age category proved to be statistically significant (subadult $\chi^2 = 0.352$, df = 1, p = 0.5529, adult $\chi^2 = 5.141$, df = 1, p = 0.0234).

(2) Subadult Age Categories

Table 6.35 and Figure 6.27 present the CPR of non-specific infection by subadult age categories and time period. In four of the five age categories where non-specific infection is observed, a decrease in CPR is observed between time periods. The only category where we see an increase in the CPR over time is within the infant age category. Interestingly, there is a noticeable decline in the CPR of non-specific infection within the childhood and adolescent age groups in the later time period. However, no significant difference is observed within individual age categories or across time periods (infancy Fisher's exact p = 0.5086; childhood Fisher's exact p = 1; juvenile p = 0.6066, adolescent Fisher's exact p= 0.6703).

	AD43-250			AD250-410		
Age Category	N	Affected	%	N	Affected	%
Preterm	7	0	0	4	0	0
Full Term	7	1	14.3	2	0	0
Infancy	20	4	20.0	26	8	30.8
Childhood	15	3	20.0	36	6	16.7
Juvenile	31	9	29.0	57	15	26.3
Adolescent	13	4	30.8	15	3	20.0
Total	93	21	22.6	140	32	22.9

Table 6.35: Subadult age category CPR non-specific infection by time period

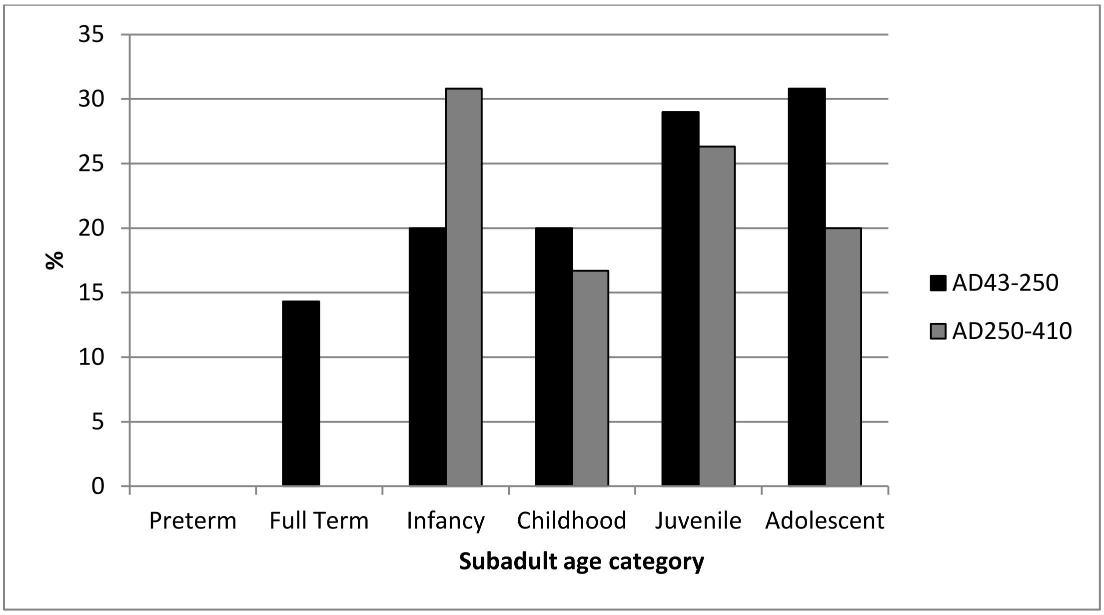


Figure 6.27: Subadult age category CPR non-specific infection by time period

(3) Sinusitis

The CPR of sinusitis by subadult and adult age category and time period is given in Table 6.36. For overall sinusitis CPR, there is a small increase in the prevalence rate between time periods though this is not statistically significant (χ^2 = 0.086, df = 1, p = 0.7692). A similar increase in between time periods is seen for maxillary and sphenoidal sinusitis, with a decrease observed for frontal sinusitis. Numbers are too small to allow statistical comparisons within the subadult age categories. For all types of sinusitis, adults are more affected than subadults.

Age Category	AD43-250			AD250-410		
	N	Affected	%	N	Affected	%
Combined Sinusitis						
Subadult	105	0	-	162	4	2.5
Adult	256	12	4.7	397	16	4.0
Total	361	12	3.3	559	20	3.6
Maxillary Sinusitis						
Subadult	105	0	-	162	4	2.5
Adult	256	11	4.3	397	15	3.8
Total	361	11	3.0	559	19	3.4
Frontal Sinusitis						
Subadult	105	0	0	162	0	0
Adult	256	4	1.6	397	2	0.5
Total	361	4	1.1	559	2	0.3
Sphenoidal Sinusitis						
Subadult	105	0	-	162	0	-
Adult	256	0	-	397	1	0.3
Total	361	0	-	559	1	0.2

Table 6.36: CPR of sinusitis by subadult/adult age category and time period

(vi) Specific Infectious disease – Tuberculosis

Table 6.37 gives the CPR of specific infectious diseases by subadult/adult age category and time period. Between time periods, the prevalence of specific infectious disease remains almost the same. The two instances of specific infectious disease (i.e. tuberculosis) in subadults come from individuals from the later time period. The opposite is seen in the adult age category, with the only individual affected dating to the earlier period.

Age Category	AD43-250			AD250-410		
	N	Affected	%	N	Affected	%
Subadult	105	0	-	162	2	1.2
Adult	256	1	0.4	397	0	-
Total	361	1	0.3	559	2	0.4

Table 6.37: CPR of specific infectious disease (TB) by subadult/adult age category and time period

(vii) Vitamin D Deficiency Diseases

(a) Subadult and Adult Comparisons

Table 6.38 and Figure 6.28 present the CPR of vitamin D deficiency diseases by subadult and adult age categories and time period. The overall CPR of vitamin D deficiency diseases increases slightly by 0.8% between time periods, although this is not significant ($\chi^2 = 0.503$, df = 1, p = 0.4780). Within both time periods, subadults are more affected than adults, with the only evidence for vitamin D deficiency diseases in adults observed in the later period. Between time periods, the CPR of vitamin D deficiency diseases amongst subadults remains the same and no statistically significant difference is observed ($\chi^2 = 0.003$, df = 1, p = 0.9561).

	AD43-250			AD250-410		
Age Category	N	Affected	%	N	Affected	%
Subadult	105	6	5.7	162	9	5.6
Adult	256	0	0	397	5	1.6
Total	361	6	1.7	559	14	2.5

Table 6.38: Subadult and adult CPR vitamin D deficiency diseases by time period

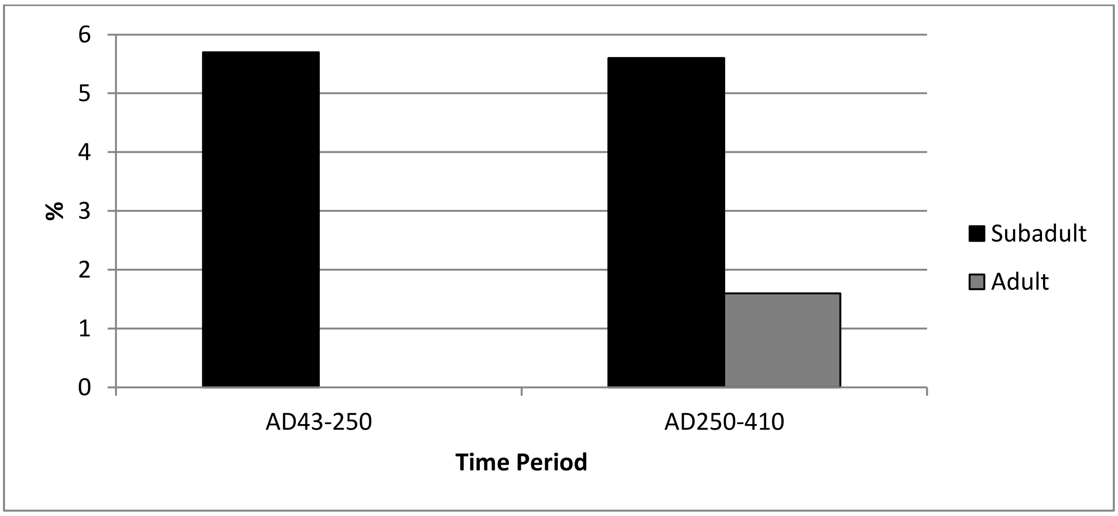


Figure 6.28: Subadult and adult CPR vitamin D deficiency diseases by time period

(b) Subadult Age Categories

Table 6.39 and Figure 6.29 show the CPR of vitamin D deficiency diseases by subadult age categories and time period. Between time periods, there is a small decline in the CPR of vitamin D deficiency diseases of 1.1%, although this was not statistically significant ($\chi^2 = 0.148$, df = 1, p = 0.7007). In both time periods, the infant age group has the highest CPR, although the CPR within this group was halved between periods.

Age Category	AD43-250			AD250-410		
	N	Affected	%	N	Affected	%
Preterm	7	0	0	4	0	0
Full Term	7	0	0	2	0	0
Infancy	20	3	15.0	26	2	7.7
Childhood	15	1	6.7	36	0	0
Juvenile	31	0	0	57	4	7.0
Adolescent	13	1	7.7	15	0	0
Total	93	5	5.4	140	6	4.3

Table 6.39: Subadult age category CPR vitamin D deficiency diseases by time period

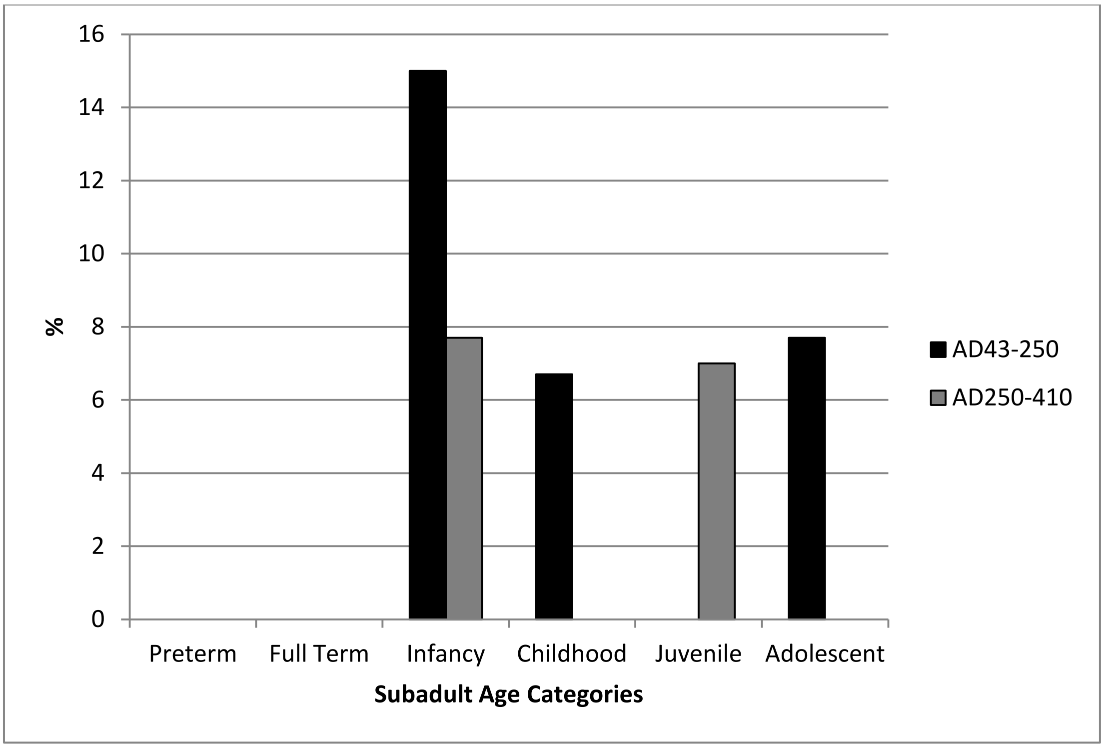


Figure 6.29: Subadult age category CPR vitamin D deficiency by time period

(viii) Vitamin C Deficiency Disease

(a) Subadult and Adult Comparisons

Both cases of vitamin C deficiency diseases are observed in subadults within the later period (Table 6.40).

Age Category	AD43-250			AD250-410		
	N	Affected	%	N	Affected	%
Subadult	105	0	0	162	0	0
Adult	256	0	0	397	2	0.5
Total	361	0	0	559	0	0

Table 6.40: Subadult and adult CPR of vitamin C deficiency disease by time period

(b) Subadult Age Categories

Within the aged subadult sample that could be assigned a date, a single case of vitamin C deficiency disease is found within the infancy age category from the AD250-410 time period (CPR = 3.8%).

6.3.3 Summary

Within the overall sample:

- A statistically significant increase in total pathology is observed from the early to late time periods
- An increase in prevalence rates between time periods is observed for all but one of the individual pathologies – porotic hyperostosis. Only the increases seen with enamel hypoplasia and non-specific infection proved to be statistically significant

Within the subadult and adult age categories:

- An increase in prevalence rates is observed between time periods for almost all of the stress indicators studied. The only exceptions observed were for porotic hyperostosis, where a decrease in prevalence rates is observed for both subadults and adults, and vitamin D deficiency diseases in subadults, which remained the same.

- A change in the most affected age category between time periods is observed in three instances – for non-specific infection and porotic hyperostosis the shift occurs from subadults to adults having the highest prevalence rates; for total pathology the opposite is observed

Within subadult age categories:

- An increase in total pathology between time periods is observed for all age categories, although in the infancy age category the CPR almost doubles
- Within the infancy age category, an increase in pathology between time periods is observed for all of the studied stress markers, with the exception of porotic hyperostosis.
- Within the remaining age categories, decreases in the prevalence of porotic hyperostosis, vitamin deficiency diseases, and non-specific infection are observed alongside increases in the CPR of *cribra orbitalia* and enamel hypoplasia.

6.4 Burial Status

The aim of this section is to identify whether the health status of subadults from Roman London differed with burial status (see Section 5.2.1 (ii)). Within this study, the presence and absence of burial containers, and their materials, are used as an indicator of burial status. This section will firstly present the results by a simple presence and absence, with the adult age group providing a comparison for relationships observed amongst subadults. In the second section, the prevalence rates of stress indicators will be presented by container type (see 5.2.1 for container types).

6.4.1 Burial Container Presence and Absence

(i) Demography by Burial Container Presence and Absence

(a) Subadult and Adult Comparisons

Table 6.41 shows the presence and absence of burial containers by subadult and adult age category. Within the sample, 60.1% of individuals were buried in a form of container. Between age categories, significantly more subadults were buried in a form of container than adults ($\chi^2 = 9.372$, df = 1, p=0.002).

Age Category	Burial Container Presence		
	Total Number of Individuals	Total Number with a Burial Container	%
Subadult	281	190	67.6
Adult	686	391	57.0
Total	967	581	60.1

Table 6.41: Burial container presence by subadult and adult age category

(b) Subadult Age Categories

Table 6.42 and Figure 6.30 show the presence and absence of burial container by subadult age category. From Figure 6.30, it is evident that the infancy age category has the highest percentage of individuals buried with some form of container. The lowest percentages are observed in the preterm and full term age categories, with the remaining subadult categories having similar prevalence rates. No significant difference is observed in the presence and absence of funerary treatment by subadult age category (χ^2 = 6.584, df = 5, p = 0.253).

Age Category	Burial Container Presence		
	N	n	%
Preterm	13	7	53.8
Full Term	11	5	45.5
Infancy	51	40	78.4
Childhood	53	37	69.8
Juvenile	90	63	70
Adolescent	29	21	72.4
Total	247	173	70

N = total number of individuals, n = total number with a burial container present

Table 6.42: Burial container presence by subadult age category

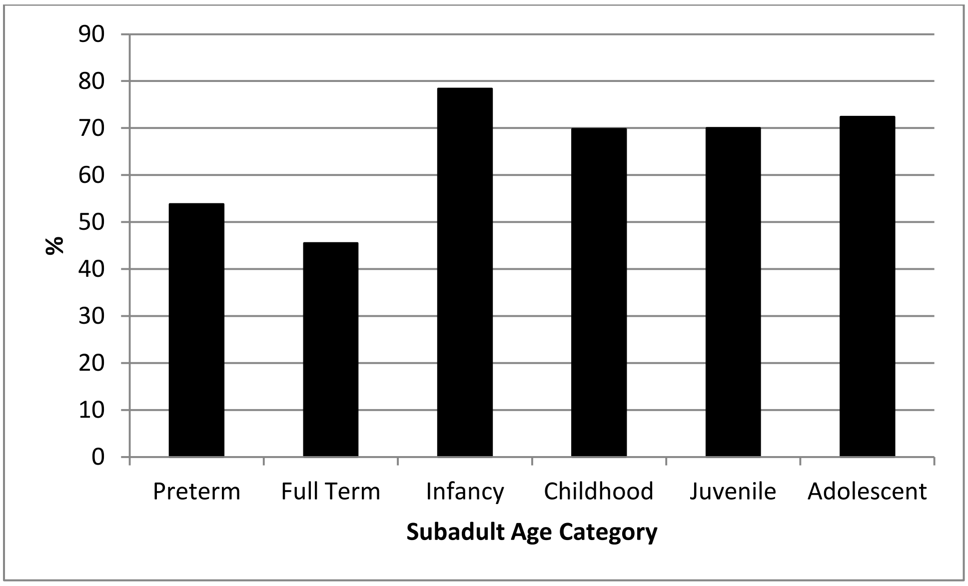


Figure 6.30: Burial container presence by subadult age category

(ii) Total Pathology (Individuals with One or More of the Studied Stress Indicators) by Burial Container Presence and Absence

(a) Subadult and Adult Comparisons

Table 6.43 and Figure 6.31 show the CPR of individuals with one or more of the studied indicators of stress by subadult/adult age category and burial container presence and absence. Within the overall sample, those individuals buried within some form of container have a significantly higher CPR (59.0%) of total pathology than those without a burial container (39.6%) (χ^2 = 34.933, df = 1, p <0.0001). Within both age categories, individuals with burial containers present have a higher CPR of total pathology than those without. This relationship was statistically significant within the adult age category (χ^2 = 31.694, df = 1, p <0.001), and almost statistically significant in the subadult age category (χ^2 = 3.733, df = 1, p = 0.0533).

	Burial Container					
	Present			Absent		
Age Category	N	n[1]	%	N	n[2]	%
Subadult	190	111	58.4	91	42	46.2
Adult	391	232	59.3	295	111	37.6
Total	581	343	59.0	386	153	39.6

N = total number of individuals, n[1] = total number with a burial container present, n[2] = total number without a burial container

Table 6.43: CPR of total pathology by subadult/adult age category and presence/absence of burial container

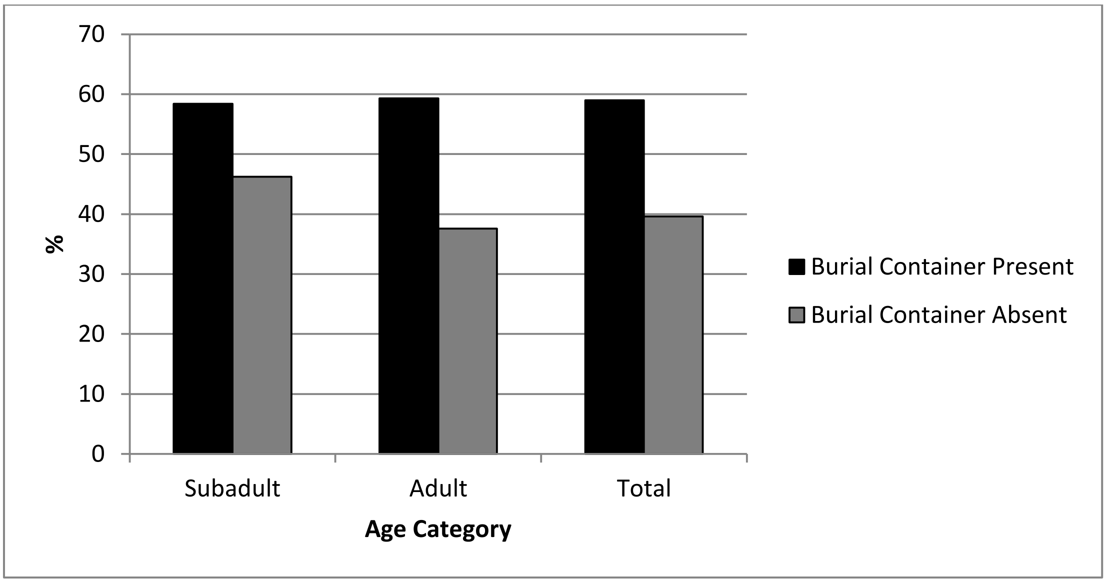


Figure 6.31: CPR of total pathology by subadult/adult age category and presence/absence of burial container

(b) Subadult Age Categories

Table 6.44 and Figure 6.32 show the CPR of individuals with one or more indicators of stress by subadult age category and burial container presence and absence. For both those with burial containers present and absent, an increase in CPR with increasing age is observed. The only exception is the small decline in CPR for those with burial containers in the childhood age category. Unfortunately, these relationships could not be statistically tested due to the small numbers of individuals within the categories. In the preterm and full term age categories, the only individuals with pathology have no evidence of burial containers. Within the remaining individual age categories, higher CPRs of pathology are observed for those with a burial container present, although none proved to be statistically significant (infant Fisher's exact p = 0.3095; childhood Fisher's exact p = 1.0000, juvenile Fisher's exact p = 0.6314, adolescent Fisher's exact p = 0.5968).

	Burial Container					
	Present			Absent		
Age Category	N	Affected	%	N	Affected	%
Preterm	7	0	0	6	1	16.7
Full Term	5	0	0	6	2	33.3
Infancy	40	23	57.5	11	4	36.4
Childhood	37	19	51.4	16	8	50.0
Juvenile	63	42	66.7	27	16	59.3
Adolescent	21	18	85.7	8	6	75.0
Total	173	102	59.0	74	37	50.0

Table 6.44: CPR of total pathology by subadult age category and presence/absence of burial container

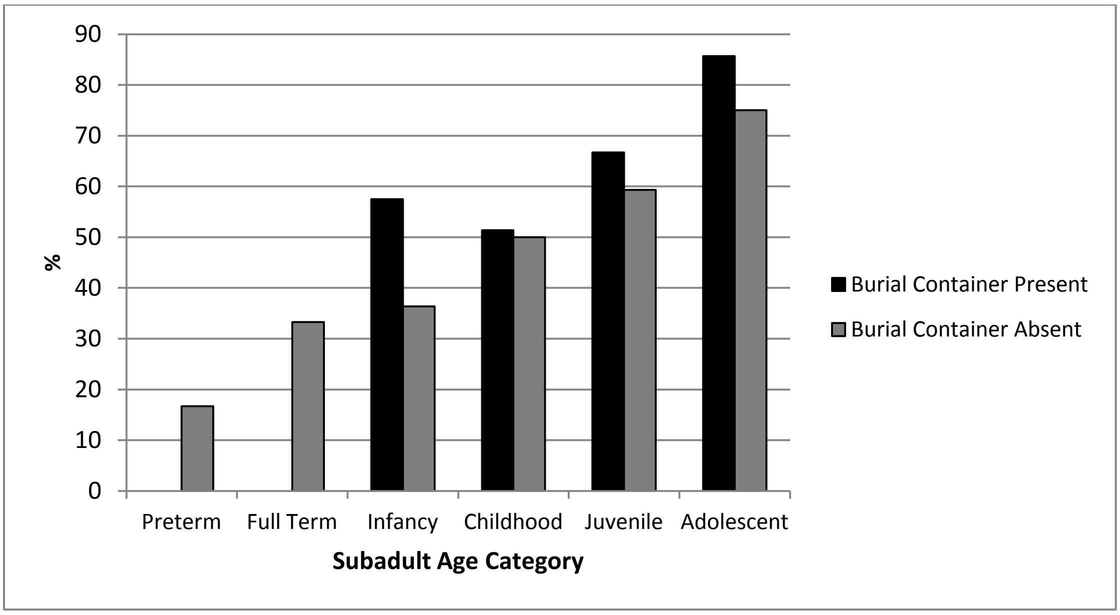


Figure 6.32: CPR of total pathology by subadult age category and presence/absence of burial container

(iii) *Cribra orbitalia* by Burial Container Presence and Absence

(a) Subadult and Adult Comparisons

Table 6.45 and Figure 6.33 show the CPR of *cribra orbitalia* by subadult and adult age categories and presence and absence of a burial container. Within the total sample, a significantly higher CPR of *cribra orbitalia* is observed in those individuals with some form of burial container (χ^2 = 22.042, df = 1, p <0.0001). Between age categories, a significantly higher CPR of *cribra orbitalia* is observed in subadults with burial containers compared to their adult counterparts with burial containers (χ^2 = 9.941, df = 1, p= 0.0016). No significant difference is observed in the CPR of subadults and adults without evidence of burial containers (χ^2 = 1.573, df = 1, p = 0.2098). Within age groups, while adults appear to have been similarly affected by *cribra orbitalia* regardless of the presence or absence of a burial container, subadults with burial containers have a higher CPR than those without. Neither of these relationships are statistically significant (subadults χ^2 = 0.761, df = 1, p = 0.3830; adults χ^2 = 0.010, df = 1, p = 0.9193).

Age Category	Burial Container							
	Present				Absent			
	N	n	Affected	%	N	n	Affected	%
Subadult	190	86	53	61.6	91	34	18	52.9
Adult	391	176	72	40.9	295	82	33	40.2
Total	581	262	125	47.7	386	116	51	44.0

N = total number of individuals, n = total number with at least one orbit present

Table 6.45: CPR of *cribra orbitalia* by subadult/adult age category and presence/absence of burial container

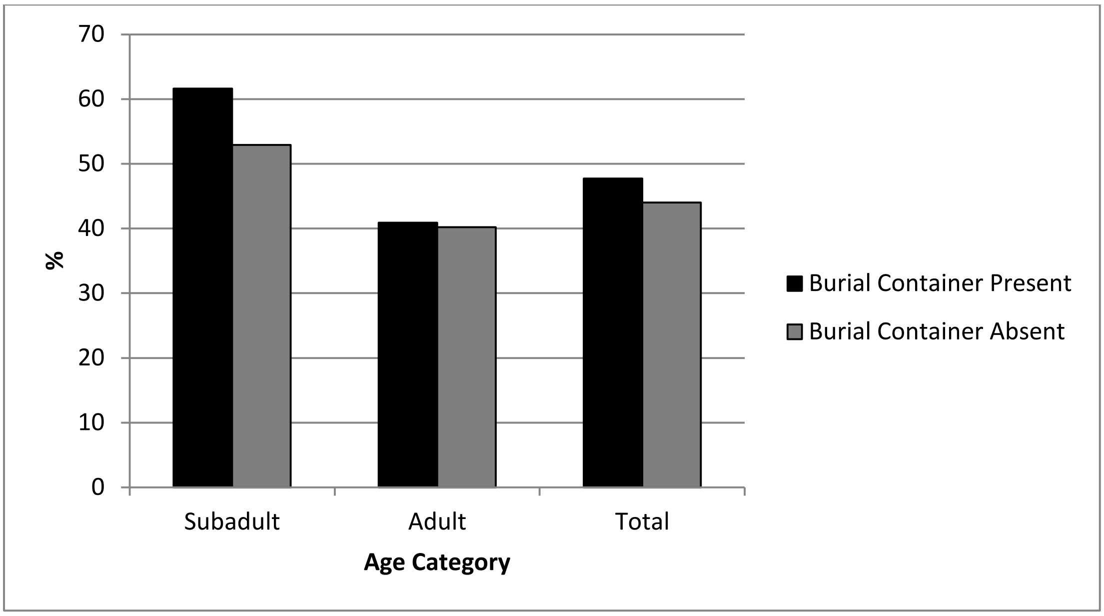


Figure 6.33: CPR of *cribra orbitalia* by subadult/adult age category and presence/absence of burial container

(b) Subadult Age Categories

Table 6.46 and Figure 6.34 present the CPR of *cribra orbitalia* by subadult age category and presence of burial container. For those with some form of burial container, the highest CPRs are observed in the adolescent category (76.9%), following a noticeable dip in CPR in the juvenile age category (53.1%). For those without evidence of a burial container, the highest CPR is observed in the full term age category (100%); however, this is the result of low numbers of individuals within this group. In the remaining categories, a peak is observed in the juvenile age category (72.3%), where prevalence rates are 22.3% higher than all other age categories.

Within the preterm and full term age categories it was apparent that *cribra orbitalia* is only observed in those without a burial container, but this is due to the low numbers of individuals available in these age categories. A higher CPR of *cribra orbitalia* in those individuals buried with some form of burial container is observed in all of the remaining age categories, with the exception of the childhood category where the opposite is observed. Within age categories where numbers were sufficient to allow statistical analysis, no significant difference was observed in the CPR by burial container (Fisher's Exact – Infancy p = 0.4058; Childhood p = 0.3473; Juvenile p = 0.3090; Adolescent p = 0.1287).

	Burial Container							
	Present				Absent			
Age Category	N	n	Affected	%	N	n	Affected	%
Preterm	7	2	0	0	6	2	1	50
Full Term	5	0	0	0	6	1	1	100
Infancy	40	21	13	61.9	11	8	3	37.5
Childhood	37	15	10	66.7	16	5	2	40
Juvenile	63	32	17	53.1	27	11	8	72.3
Adolescent	21	13	10	76.9	8	6	2	33.3
Total	173	83	50	60.2	74	33	17	51.5

N = total number of individuals, n = total number of individuals with at least one orbit present

Table 6.46: CPR of *cribra orbitalia* by subadult age category and presence/absence of burial container

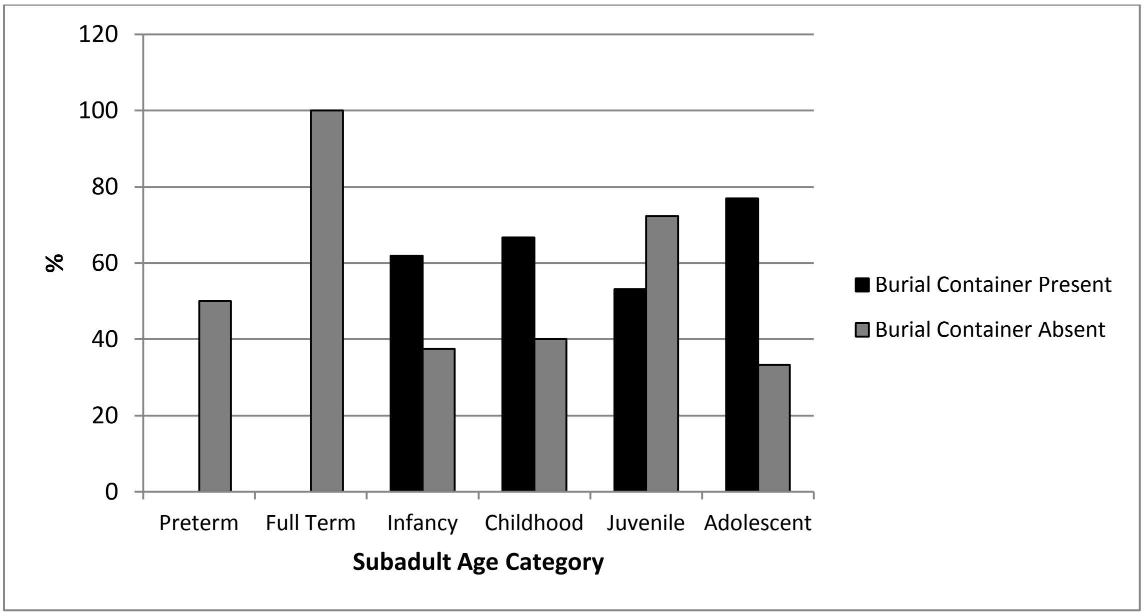


Figure 6.34: CPR of *cribra orbitalia* by subadult age category and presence/absence of burial container

(iv) Enamel Hypoplasia by Burial Container Presence and Absence

(a) Subadult and Adult Comparisons

Table 6.47 and Figure 6.35 show the CPR of enamel hypoplasia by subadult and adult age categories and the presence and absence of a burial container. Within the sample, the CPR of enamel hypoplasia is significantly higher for those with a burial container (χ^2 = 6.305, df = 1, p = 0.0120). For those with a burial container, adults have a significantly higher CPR than the subadults within the sample (χ^2 = 6.580, df = 1, p = 0.0103). No statistically significant difference in the CPR between subadult and adult age categories is observed for those without any evidence for a burial container (χ^2= 0.002, df = 1, p = 0.9690).

Within age categories, no significant difference in enamel hypoplasia CPR is observed between subadults with and without evidence of burial treatment (χ^2 = 0.089, df = 1, p = 0.7660). Amongst the adults in the sample, a significant difference is observed (χ^2 = 9.495, df = 1, p = 0.0021), with those with a burial container exhibiting a higher enamel hypoplasia CPR than those without.

Age Category	Burial Container							
	Presence				Absence			
	N	n	Affected	%	N	n	Affected	%
Subadult	190	133	70	52.6	91	42	21	50.0
Adult	391	242	160	66.1	295	147	74	50.3
Total	581	375	230	61.3	386	189	95	50.3

N = total number of individuals, n = total number with teeth present

Table 6.47: CPR of enamel hypoplasia by subadult/adult age category and presence/absence of burial container

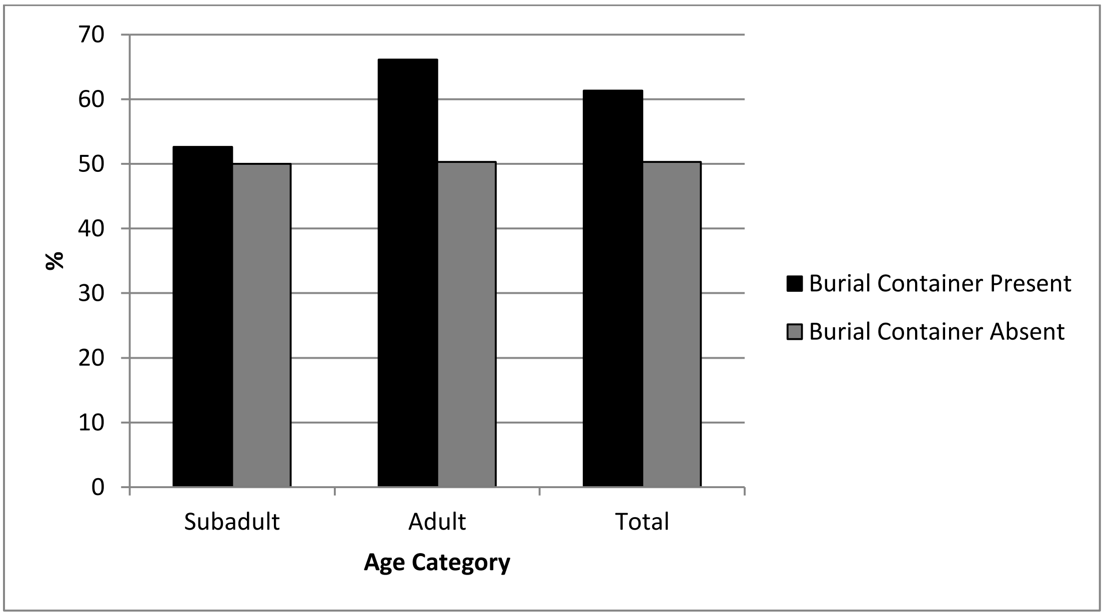


Figure 6.35: CPR of enamel hypoplasia by subadult/adult age category and presence/absence of burial container

(b) Subadult Age Categories

Table 6.48 and Figure 6.36 present the CPR of enamel hypoplasia within subadult and adult categories by burial container presence and absence. For those with burial containers, a steady increase in CPR with increasing age is observed. For those with no burial container present, a large increase between infancy and childhood is observed, followed by a small decline in the juvenile age category. Within age categories, higher CPRs are observed for those with burial containers in all categories except childhood, where the opposite is observed. No statistically significant difference was observed for CPR by burial container within age categories (infancy Fisher's exact p = 1.0000; childhood Fisher's exact p = 0.5037; juvenile Fisher's exact p = 0.3724; adolescent Fisher's exact p = 0.5960).

Age Group	Burial Container							
	Present				Absent			
	N	n	Affected	%	N	n	Affected	%
Preterm	7	1	0	0	6	0	-	-
Full Term	5	2	0	0	6	0	-	-
Infancy	40	29	6	20.7	11	7	1	14.3
Childhood	37	32	14	43.8	16	12	7	58.3
Juvenile	63	49	34	69.4	27	16	9	56.3
Adolescent	21	20	16	80	8	6	4	66.7
Total	173	133	70	52.6	74	41	21	51.2

N = total number of individuals, n = total number with teeth present

Table 6.48: CPR of enamel hypoplasia by subadult age category and presence/absence of burial container

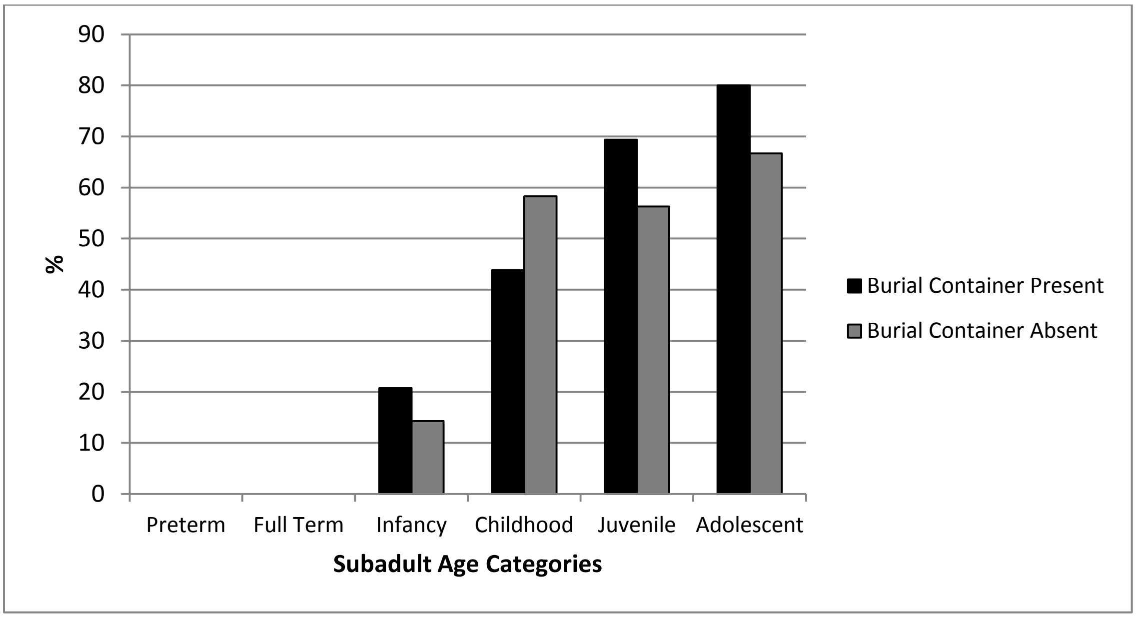


Figure 6.36: CPR of enamel hypoplasia by subadult age category and presence/absence of burial container

(v) Porotic Hyperostosis by Burial Container Presence and Absence

(a) Subadult and Adult Comparisons

Table 6.49 and Figure 6.37 show the CPR of porotic hyperostosis by subadult/age categories and presence and absence of burial container. In the entire sample, those individuals without burial containers have slightly higher CPR of porotic hyperostosis than those with burial containers. This relationship was not statistically significant (χ^2 = 0.096, df = 1, p = 0.7570). Within both age categories, a higher CPR was observed for those without burial containers, but no statistically significant differences are observed (subadult Fisher’s exact p = 1.0000; adult Fisher’s exact p = 1.0000).

Age Category	Burial Container							
	Presence				Absence			
	N	n	Affected	%	N	n	Affected	%
Subadult	190	145	4	2.8	91	59	2	3.4
Adult	391	266	11	4.1	295	158	7	4.4
Total	581	411	15	3.6	386	217	9	4.1

N = total number of individuals, n = total number with at least one cranial vault bone present

Table 6.49: CPR of porotic hyperostosis by subadult/adult age category and presence/absence of burial container

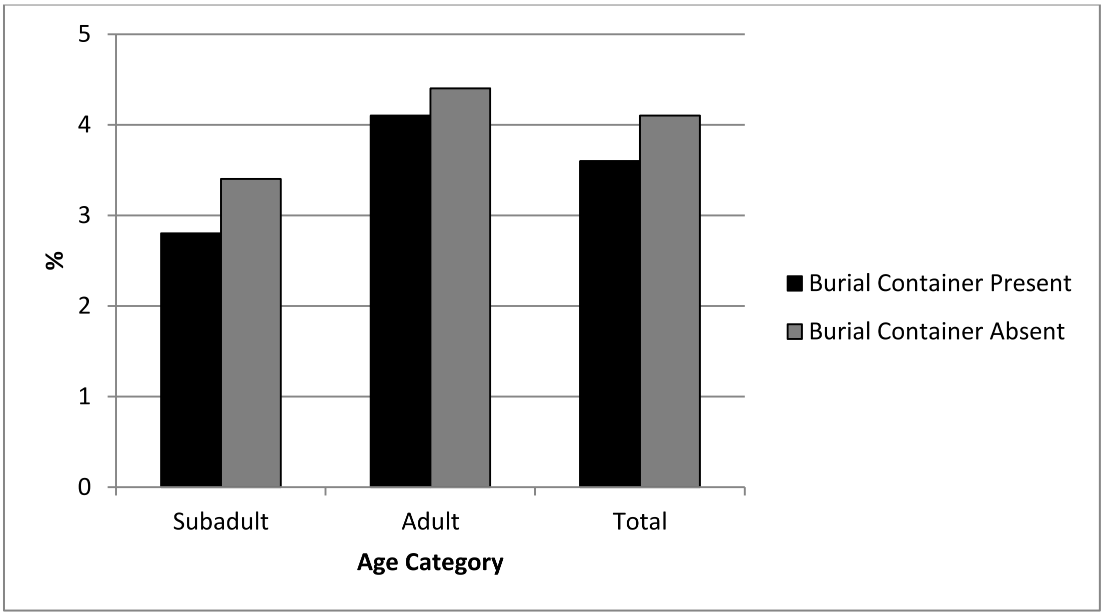


Figure 6.37: CPR of porotic hyperostosis by subadult/adult age category and presence/absence of burial container

(b) Subadult Age Categories

Table 6.50 and Figure 6.38 show the CPR of porotic hyperostosis by subadult age categories and the presence of a burial container. For both those with and without a burial container, an increase in CPR is seen with increasing age. The only infant identified with porotic hyperostosis had evidence of a burial container present. Within the remaining age groups where porotic hyperostosis is identified, higher CPRs of porotic hyperostosis are observed in those without a burial container. Unfortunately, the available sample numbers were too small to allow statistical analysis to be conducted.

Age Group	Burial Container							
	Present				Absent			
	N	n	Affected	%	N	n	Affected	%
Preterm	7	5	0	0	6	3	0	0
Full Term	5	1	0	0	6	4	0	0
Infancy	40	34	1	2.9	11	10	0	0
Childhood	37	30	0	0	16	12	0	0
Juvenile	63	46	1	2.2	27	20	1	5.0
Adolescent	21	19	2	10.5	8	6	1	16.7
Total	173	135	4	3.0	74	55	2	3.6

N = total number of individuals, n = total number with at least one cranial vault bone present

Table 6.50: CPR of porotic hyperostosis by subadult age category and presence/absence of burial container

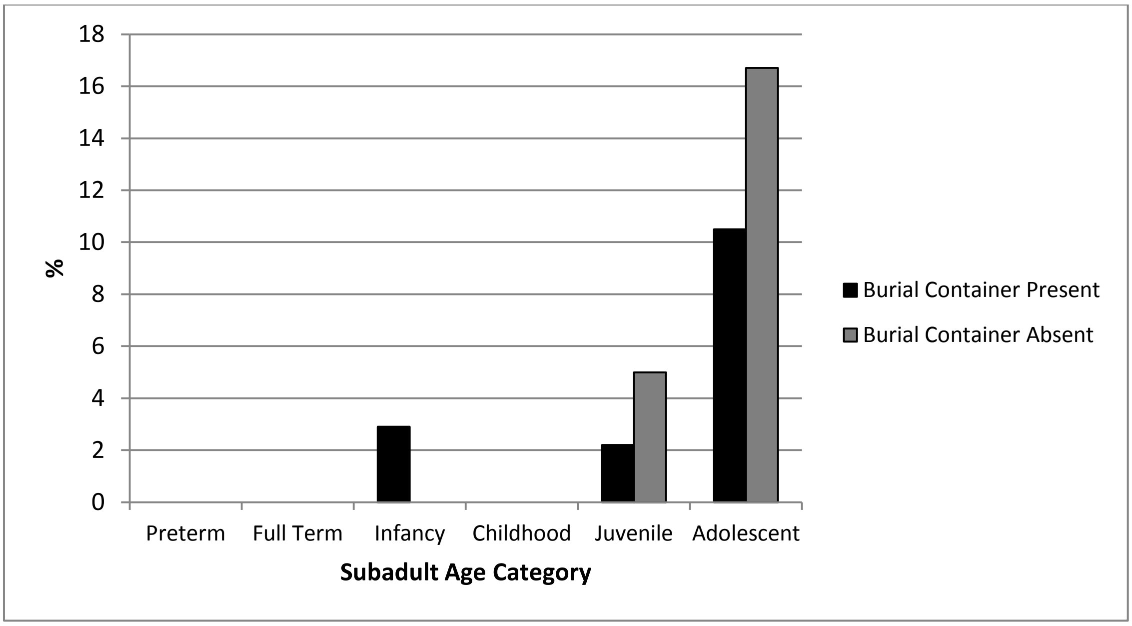


Figure 6.38: CPR of porotic hyperostosis by subadult age category and presence/absence of burial container

(vi) Non-Specific Infection (CPR) by Burial Container Presence and Absence

(a) Subadult and Adult Comparisons

Table 6.51 and Figure 6.39 show the CPR of non-specific infection within subadult and adult age categories by burial container presence and absence. Within the overall sample, the CPR of non-specific infection is significantly higher in those with a burial container (χ^2 = 11.483, df = 1, p = 0.0007). Within both age categories, those with a burial container have higher CPRs of non-specific infection, although this was only significant in the adult age category (subadult χ^2 = 0.066, df = 1, p = 0.7979; adult χ^2 = 14.434, df = 1, p = 0.0001).

Age Category	Burial Container					
	Present			Absence		
	N	Affected	%	N	Affected	%
Subadult	190	46	24.2	91	21	23.1
Adult	391	104	26.6	295	43	14.6
Total	581	150	25.8	386	64	16.6

Table 6.51: CPR of non-specific infection by subadult/adult age category and presence/absence of burial container

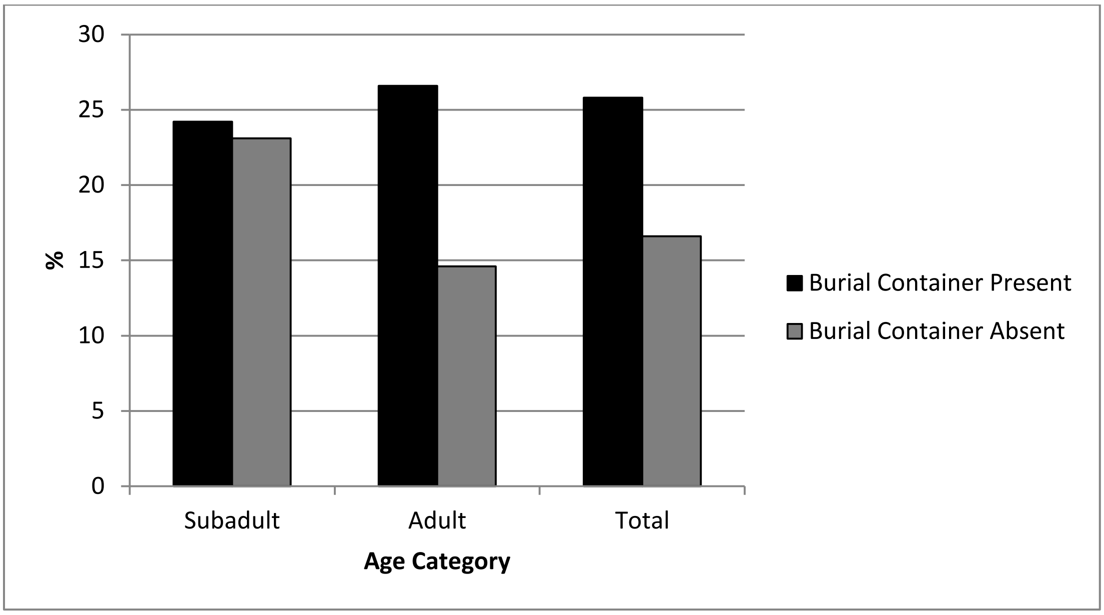


Figure 6.39: CPR of non-specific infection by subadult/adult age category and presence/absence of burial container

(b) Subadult Age Categories

Table 6.52 and Figure 6.40 present the CPR of non-specific infection within subadult age categories by burial container presence and absence. In three of the subadult age categories – infancy, childhood, and juvenile – a decline in the CPR of non-specific infection is observed between time periods. The largest decline is seen in the infant age category, where the CPR almost halves, with the decline in subsequent categories being smaller. In the oldest subadult age category, the opposite is observed, with an almost doubling of the CPR between time periods. Despite this, none of these relationships proved to be statistically significant (infancy Fisher’s exact p = 0.4663, childhood Fisher’s exact p= 0.7062, juvenile Fisher’s exact = 1.0000, adolescent Fisher’s exact p = 0.3568).

Age Group	Burial Container					
	Present			Absent		
	N	Affected	%	N	Affected	%
Preterm	7	0	0	6	0	0
Full Term	5	0	0	6	2	33.3
Infancy	40	14	35	11	2	18.2
Childhood	37	7	18.9	16	2	12.5
Juvenile	63	18	28.6	27	7	25.9
Adolescent	21	4	19.0	8	3	37.5
Total	173	43	24.9	74	16	21.6

Table 6.52: CPR of non-specific infection by subadult/adult age category and presence/absence of burial container

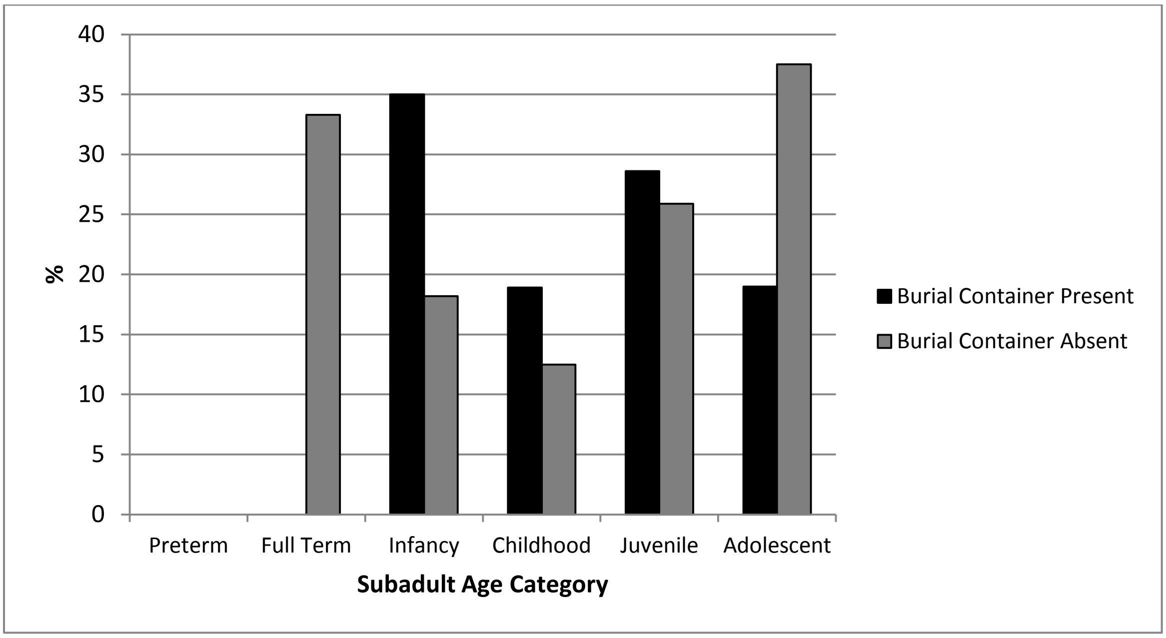


Figure 6.40: CPR of non-specific infection by subadult/adult age category and presence/absence of burial container

(c) Sinusitis

Table 6.53 gives the CPR of sinusitis by burial container presence amongst subadult and adult age categories. The pattern for total sinusitis both overall and within age categories is a higher crude prevalence rate for those with a burial container, though this relationship proved to be insignificant (overall Fisher's exact p = 0.2179; subadult Fisher's exact p = 1.0000; adult Fisher's exact p = 0.1865). The same higher prevalence rate with burial containers is also observed with maxillary sinusitis and sphenoidal sinusitis, though again no statistically significant differences are observed (maxillary sinusitis – overall Fisher's exact p =0.4463, subadults Fisher's exact p = 1.0000, adults Fisher's exact p = 0.4708). The opposite relationship is observed with frontal sinusitis, with prevalence rates being twice as high for those without a burial container.

Age Category	Burial Container					
	Present			Absent		
	N	n	%	N	n	%
Combined Sinusitis						
Subadult	190	3	1.6	91	1	1.1
Adult	391	21	5.4	295	9	3.1
Total	581	24	4.1	386	10	2.6
Maxillary Sinusitis						
Subadult	190	3	1.6	91	1	1.1
Adult	391	20	5.1	295	7	2.4
Total	581	23	4.0	386	8	2.1
Frontal Sinusitis						
Subadult	190	0	-	91	0	-
Adult	391	3	0.8	295	4	1.4
Total	581	3	0.5	386	4	1.0
Sphenoidal Sinusitis						
Subadult	190	0	-	91	0	-
Adult	391	1	0.3	295	0	-
Total	581	1	0.2	386	0	-

Table 6.53: CPR of sinusitis by burial container presence and absence

(vii) Specific Infectious Disease (Tuberculosis) by Burial Container Presence and Absence

Table 6.54 presents the CPR of specific infectious disease (i.e. tuberculosis) by subadult/adult age category and burial container presence. Within the overall population, the crude prevalence rate of specific infection is the same regardless of burial container presence. For subadults, the crude prevalence rate of specific infection is twice as high for those without a burial container (1.1%).

Age Category	Burial Container					
	Present			Absence		
	N	Affected	%	N	Affected	%
Subadult	190	1	0.5	91	1	1.1
Adult	391	1	0.3	295	0	-
Total	581	2	0.3	386	1	0.3

Table 6.54: CPR of specific infection by subadult/adult age categories and burial container presence/absence

(viii) Vitamin D Deficiency Diseases by Burial Container Presence and Absence

(a) Subadult and Adult Comparisons

Table 6.55 and Figure 6.41 show the CPR of vitamin D deficiency diseases by subadult/adult age category and burial container presence. Within the entire sample, the CPR of vitamin D deficiency disease is significantly higher for those buried within a container (Fisher's exact p = 0.0048). Within the subadult age category, the CPR is three times higher for those with a burial container, although this was not statistically significant (Fisher's exact p = 0.1554). Within the adult age category, the only cases of vitamin D deficiency diseases are observed in individuals buried within a container.

Age Category	Burial Container					
	Present			Absence		
	N	Affected	%	N	Affected	%
Subadult	190	13	6.8	91	2	2.2
Adult	391	5	1.3	295	0	0.0
Total	581	18	3.1	386	2	0.5

Table 6.55: CPR of vitamin D deficiency diseases by subadult/adult age category and presence/absence of burial container

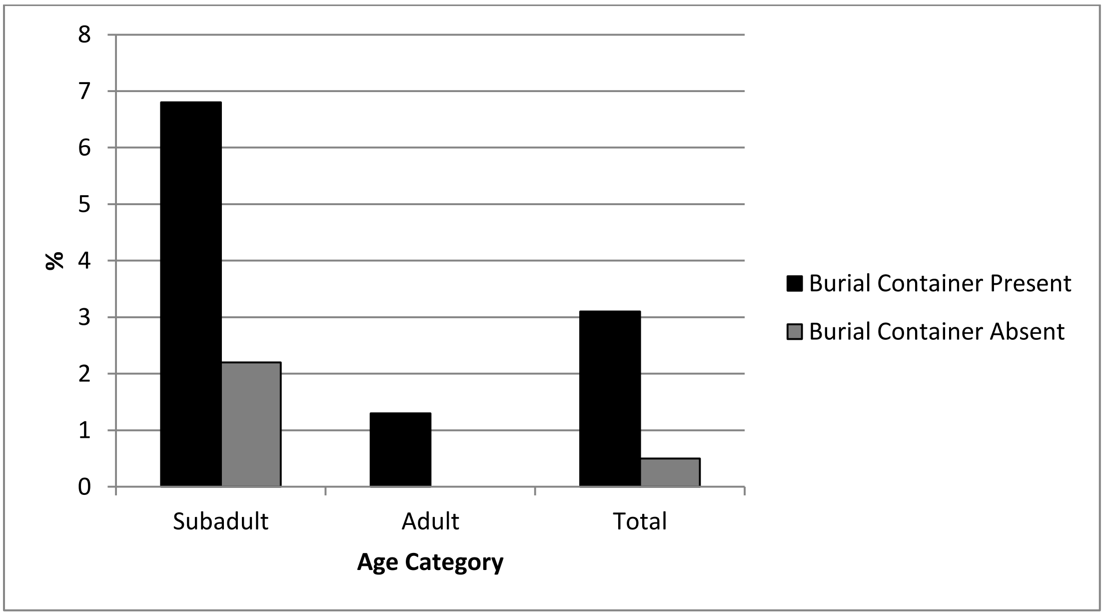


Figure 6.41: CPR of vitamin D deficiency diseases by subadult/adult age category and presence/absence of burial container

(b) Subadult Age Categories

Table 6.56 and Figure 6.42 show the CPR of vitamin D deficiency diseases by subadult age category and presence of burial container. Within the infant category, the highest CPR is observed in those with a burial container. In the remaining age categories, instances of vitamin D deficiency diseases are only observed in those with burial containers in the childhood and juvenile age categories, while amongst adolescents only individuals without burial containers are affected.

	Burial Container					
	Present			Absent		
Age Group	N	Affected	%	N	Affected	%
Preterm	7	0	0	6	0	0
Full Term	5	0	0	6	0	0
Infancy	40	5	12.5	11	1	9.1
Childhood	37	1	2.7	16	0	0
Juvenile	63	4	6.3	27	0	0
Adolescent	21	0	0	8	1	12.5
Total	173	13	7.5	74	2	2.7

Table 6.56: CPR of vitamin D deficiency diseases by subadult age category and presence/absence of burial container

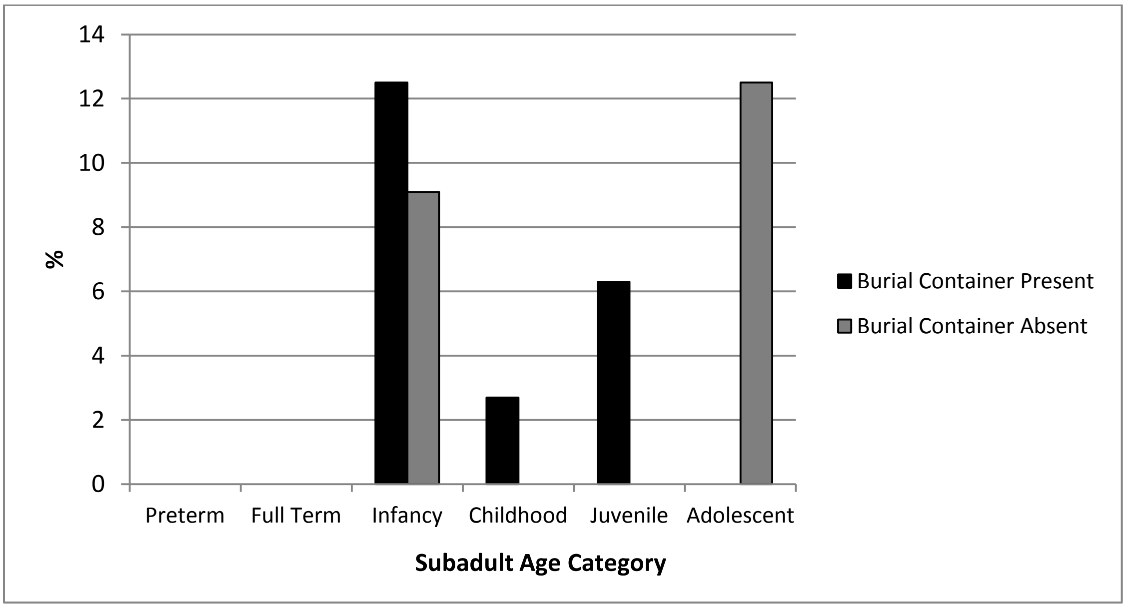


Figure 6.42: CPR of vitamin D deficiency diseases by subadult age category and presence/absence of burial container

(ix) Vitamin C Deficiency Disease by Burial Container Presence and Absence

The two instances of vitamin C deficiency observed within the sample affected subadults buried with some form of burial container. By subadult age category, the single individual affected was an infant who had evidence of a burial container.

(x) Summary

Within the entire sample:

- 60.1% of individuals are buried in some form of burial container
- For all stress indicators examined, with the exception of porotic hyperostosis, individuals with a burial container had higher prevalence rates than those without evidence of a burial container. This higher prevalence rate was statistically significant for all categories, except vitamin C deficiency disease which had too few individuals to be tested statistically.

Within subadult and adult age categories:

- Subadults are significantly more likely to have been buried within a burial container than their adult counterparts.
- Subadults with burial containers had higher prevalence rates for all of the examined stress indicators, with the exception of porotic hyperostosis, though the only one of these relationships that proved to be statistically significant was for total pathology
- Adults with burial containers had higher prevalence rates for all of the examined stress indicators, with the exception of porotic hyperostosis. Of these, three are statistically significant – total pathology, enamel hypoplasia and non-specific infection. No comparisons could be made for adults and vitamin C deficiency disease as no adults were identified as being affected.

Within subadult age categories:

- No statistically significant difference was observed for the presence and absence of burial containers.
- Within the preterm and full term age categories, only those individuals without burial containers are affected by the pathologies examined.

- The overall trend is a higher prevalence rate of the studied stress indicators associated with burial containers than without. Exceptions are observed for individual categories: juveniles without burial containers have higher rates of *cribra orbitalia*; individuals within the childhood age category without burial containers have a higher prevalence rate of enamel hypoplasia; and adolescents without burial containers have higher CPRs of non-specific infection and vitamin D deficiency diseases. Another exception is for porotic hyperostosis where all individuals without burial containers have the highest CPR.

6.4.2 Burial Container – Types

As stated in Section 5.2.1 burial containers observed within the Roman London cemeteries were assigned to one of six potential categories: wooden coffin, lead coffin, stone, stone and lead combination, mausolea/tomb, and other burial container types. Images of these different burial container types can be found in Section 5.2.1 (Figure 5.2)

(i) Demography by Container Type

(a) Subadult and Adult Comparisons

Table 6.57 and Figure 6.43 present the types of burial container observed within the sample by subadult and adult age category. Within both age categories, burials in wooden coffins account for almost all of the burial containers observed. Whilst excavation reports have identified both stone and lead coffins from the Roman cemeteries of London, few have been “paired” with skeletal remains due to taphonomic processes or post-excavation losses. Within the sample studied here, only two instances of a lead coffin and one combination of lead and stone were associated with skeletal remains, all of which were within the adult age category. Another form of burial container previously associated with high status individuals is the mausolea or tomb. In the sample population, subadults were almost four times more likely to be found within a mausolea/ tomb than their adult counterparts, although this was not statistically significant (Fisher’s exact p = 0.0651).

Within the other burial containers category, the use of wooden biers (n = 3) were found only in association with the adult age group. The use of tile in the construction of burial containers was also found to differ between subadult and adult age groups. Within the subadult category, two individuals were associated with the use of tile, with the tiles laid out to form a bed on which the body was then laid out. In the case of PNS01 [9], a seven year old child, multiple tiles were used to create the tile bed, whilst for the other individual, REW92 [223] (38 weeks gestation), a single tengula was utilised (Figure 6.44). In the adult category, only one individual (MST87 [201] a 26-35 year old female) was associated with the use of tile, though this was in the form of a tile cist rather than the tile bed associated with subadults. Unfortunately no picture or plan was provided within the publication of this burial.

Burial Container Type	Subadult		Adult	
	N	%	N	%
Wooden Coffin	180	94.2	377	96.2
Lead Coffin	0	0	2	0.5
Stone Coffin	0	0	0	0
Stone/Lead Combination	0	0	1	0.3
Mausolea/Tomb	6	3.1	3	0.8
Other Burial Containers	4	2.1	9	2.3
Total	191	-	392	-

Table 6.57: Burial container type by subadult and adult age categories

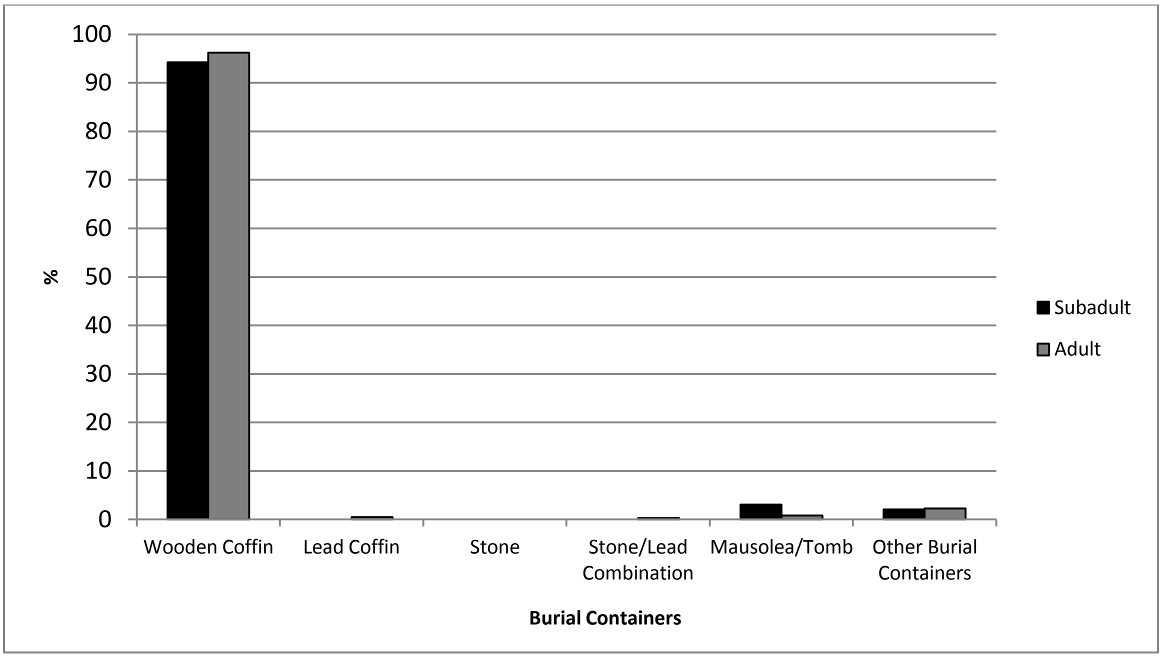


Figure 6.43: Burial container type by subadult and adult age categories

Figure 6.44: Subadult tile burial – Skeleton PNS01 C[225] (Watson and Heard 2006: 67)

(b) Subadult Age Categories

Table 6.58 and Figure 6.45 present the burial container types by subadult age category. In all age categories, the majority of individuals with some form of container are buried within wooden coffins. In four of the six age categories, additional types of burial containers as well as wood are observed, with only preterm and adolescent individuals being the only categories where wooden coffins represent the entire array of burial containers for the category. Within the mausolea/tomb category of burial containers, infants represent the largest subadult age category, followed closely by juveniles.

Subadult Age Category	Total Number of Individuals	Number of Individuals with a Burial Container	Wooden		Mausolea/Tomb		Other Burial Container	
			N	%	N	%	N	%
Preterm	13	7	7	100	0	-	0	-
Full Term	11	5	4	80.0	0	-	1	20.0
Infancy	51	40	38	95.0	2	5.0	0	-
Childhood	53	37	34	91.9	1	2.7	2	5.4
Juvenile	90	63	59	93.7	3	4.8	1	1.6
Adolescent	29	21	21	100.0	0	-	0	-

Table 6.58: Burial container type by subadult age categories

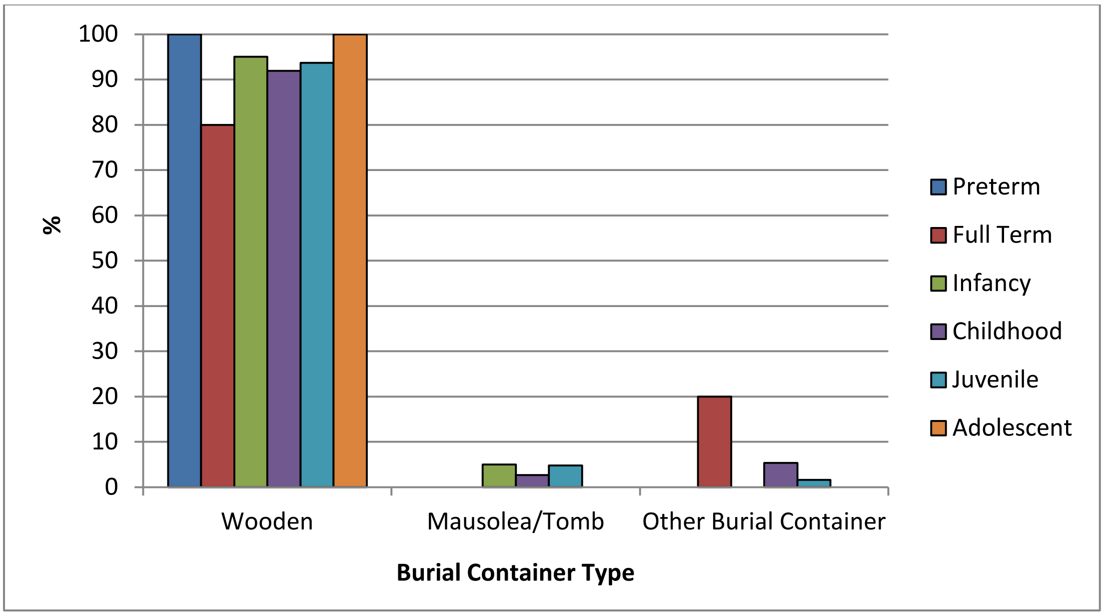


Figure 6.45: Burial container type by subadult age categories

(ii) Prevalence of Stress Indicators by Burial Container Type

(a) Subadult Stress Marker Prevalence

Table 6.59 and Figure 6.46 show the subadult prevalence rates of stress indicators by burial container type. Interestingly, those individuals buried within mausolea/tombs have the highest CPR of overall pathology within the sample and two of the individual stress markers studied – *cribra orbitalia* and non-specific infection. Individuals within mausolea/tombs appear to have been unaffected by vitamin D or C deficiency diseases. Those individuals without a burial container have a lower CPR of total pathology than those with a wooden coffin or mausolea/tomb. They also have lower CPRs for four of the six individual stress indicators studied (see Table 6.59). Within the other burial container category, no individuals are affected by the studied pathologies, although this may be due to the small number of individuals within this category.

Stress Indicator	Burial Container Type			
	No Burial Container	Wooden Coffin	Mausolea/Tomb	Other Burial Container
*Cribra orbitalia**	52.9	59.3	100	0.0
Enamel Hypoplasia*	50.0	53.6	50.0	0.0
Porotic Hyperostosis*	3.4	2.9	0.0	0.0
Non-Specific Infection*	23.1	23.9	50.0	0.0
Vitamin D Deficiency*	2.2	7.2	0.0	0.0
Vitamin C Deficiency*	0.0	1.1	0.0	0.0
Total Pathology*	46.2	58.9	83.3	0.0

Table 6.59: Subadult prevalence rates of studied pathologies by burial container type (* indicates CPR)

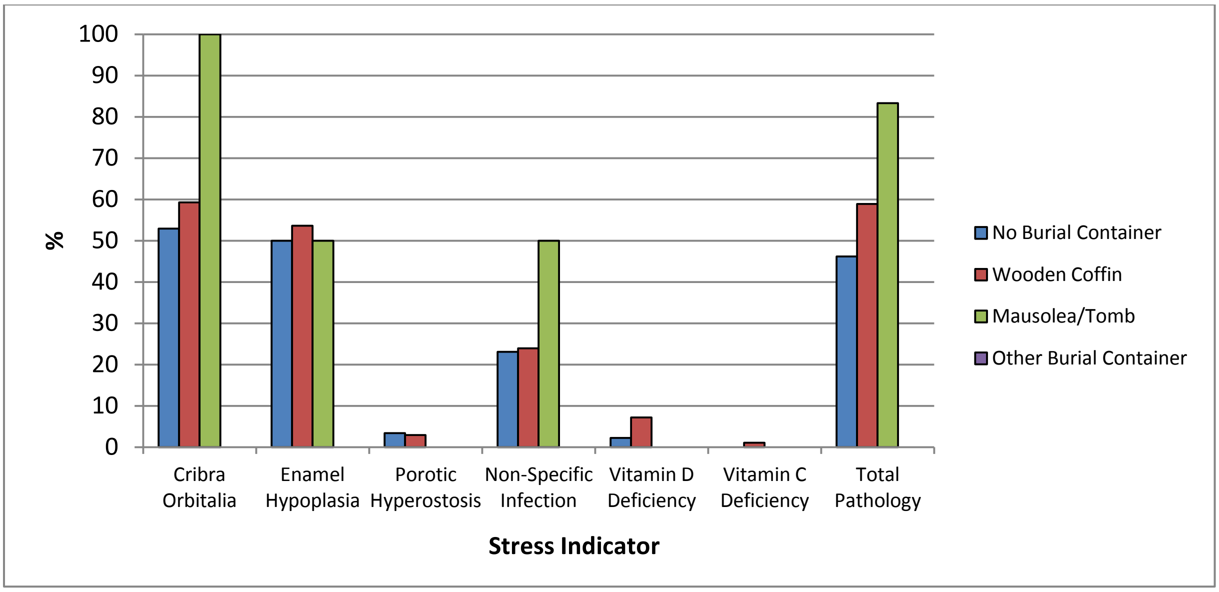


Figure 6.46: Subadult prevalence rates of studied pathologies by burial container type

(b) Adult Stress Marker Prevalence

Table 6.60 and Figure 6.47 show the adult prevalence rates of the studied pathologies by burial container type. Whilst it appears that those individuals buried within either a lead or lead/stone combination burial container have the highest prevalence rates in three of the pathologies addressed in this study, it must be emphasised that this is due to the small number of individuals represented within these categories. As within the subadult age category, the prevalence rates of all but one category (i.e. porotic hyperostosis) is higher amongst adults within wooden coffins than those without a burial container. Unlike their subadult counterparts, adults buried within mausolea had the lowest CPR of overall pathology, with the only pathology observed within this category being non-specific infection. However, one of the possible reasons for these low prevalence rates may be the poor preservation of the small number of individuals (n=3) within this group, particularly regarding CPR. The only instances of vitamin D deficiency in the adult population were amongst those with wooden coffins.

Stress Indicator	Burial Container Type					
	No Burial Container	Wooden Coffin	Lead	Stone/Lead Combination	Mausolea/Tomb	Other Burial Container
Cribra orbitalia	40.2	41.1	100	0	0	40.0
Enamel Hypoplasia*	50.3	65.8	100	100	0	75.0
Porotic Hyperostosis	4.4	3.9	0	0	0	16.7
Non-Specific Infection*	14.6	26.3	0	0	44.4	33.3
Vitamin D Deficiency*	0	1.3	0	0	0	0
Vitamin C Deficiency*	0	0	0	0	0	0
Total Pathology*	37.6	58.9	50.0	100	33.3	77.8

Table 6.60: Adult prevalence rates of studied pathologies by burial container type (* indicates CPR instead of TPR)

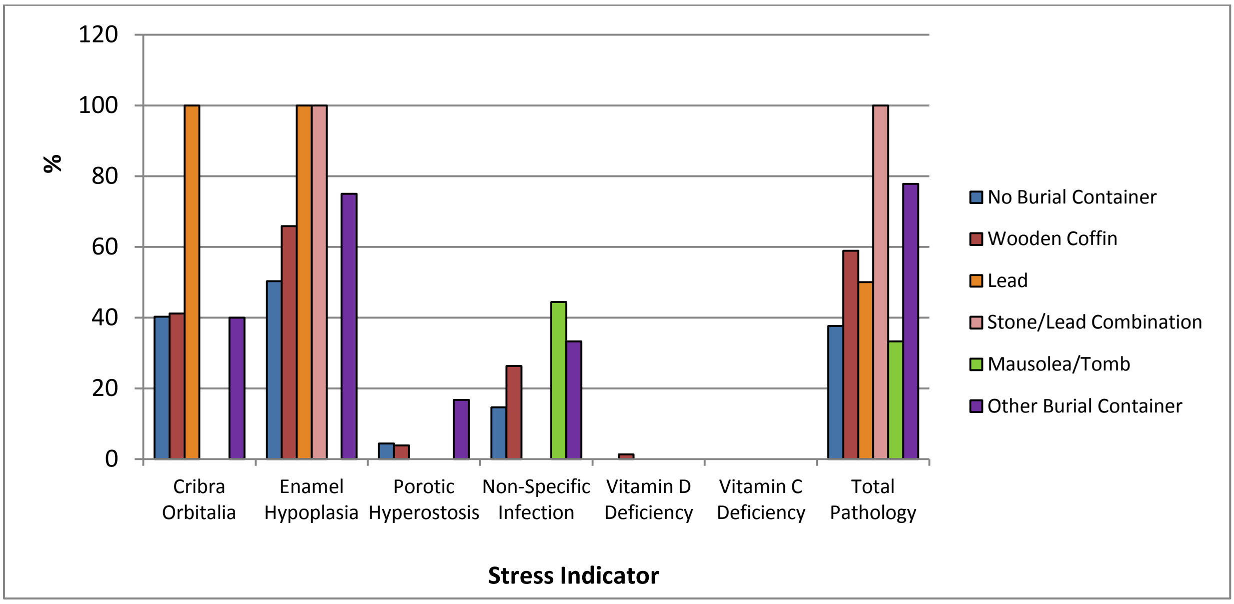


Figure 6.47: Adult prevalence rates of studied pathologies by burial container type

(c) Summary

Demography

- Wooden coffins were the most prevalent type of burial containers observed for both subadults and adults, accounting for 95.5% of all instances of burial containers
- While high status lead and lead/stone coffins (n = 3) were only associated with adults, subadults were four times more likely to be buried within a mausolea/tomb
- From the other burial container category, wooden biers were only found in association with adults, while the use of tile as a burial container differed between subadult and adult age categories
- Preterm and full term subadults were only associated with wooden coffins

Stress Indicators

- For both subadult and adults, individuals buried within wooden coffins tend to have higher prevalence rates of the stress indicators than those without evidence of a coffin. The only exception is observed for porotic hyperostosis amongst subadults
- While subadults buried within mausolea had the highest CPR of total pathology and three of individual stress indicators, adults buried within mausolea had the lowest CPR of total pathology. However, the role of preservation of the skeletal remains may be a factor in this.

Chapter 7: Results – Stable Isotope Analysis

This chapter presents the results of the stable isotope analysis for Roman London. Following the assessment of collagen preservation and analytical error, the faunal and human data are considered regarding overall diet within the settlement. Subsequently, in order to identify intra-population differences, the isotopic data are presented in four sections: by age category, by date period, burial status and pathology. For individual stable isotope results and collagen preservation information, please see Appendix 4 and 5. In order to avoid the enrichment of isotopic values associated with breastfeeding complicating the assessment of diet, all individuals below the age of three years were excluded from all dietary analyses (see Section 7.3.1 for further discussion of breastfeeding and weaning practices observed within Roman London).

7.1 Collagen Preservation and Analytical Error

From the original 120 human rib samples taken, 27 samples failed to yield any collagen, despite multiple extraction attempts and the use of additional bone samples (see Appendix 4). A further individual (GDV96 281) also had to be excluded as collagen yield was below acceptable levels (<1%). As this meant 23% of the original samples were lost, a further 16 individuals were sampled, of which 4 failed to yield collagen. For the remaining 104 samples, collagen yields ranged between 1.1% and 15.9% ($\bar{x}$ = 6.0%). Collagen preservation was good overall, with only one individual excluded due to an abnormal C:N ratio (>3.6). With the additional four samples identified in the Lant Street Report, this gave an overall sample population of 107 individuals (77 subadults and 30 adults) taken from across Roman London (see Appendix 4 for a full breakdown of sample composition).

Of the 26 faunal samples taken, three samples (two fish and one sheep/goat) had no, or insufficient, collagen yield (see Appendix 5). The collagen yields of the remaining samples tended to be higher than those amongst the human samples, ranging from 2.4% and 28.2% ($\bar{x}$ = 8.4%). Assessment of collagen quality indicators identified two further samples (one pig and one fish) that had abnormal C:N ratios and these were therefore excluded from further analyses.

The analytical error and technical error of measurement for the human and animal collagen samples and internal samples are given in Table 7.1. Overall, reproducibility of results from

Sample Type	Carbon			Nitrogen		
	Mean Difference	Range	TEM	Mean Difference	Range	TEM
Human Collagen	0.05	0.00-0.51	0.06	0.05	0.00-0.55	0.06
Animal Collagen	0.02	0.00-0.07	0.02	0.07	0.01-0.29	0.07
Standard – Pure Gelatine	0.04	0.00-0.06	0.03	0.05	0.02-0.09	0.04
Standard – Nylon	0.09	0.01-0.18	0.08	0.03	0.01-0.06	0.03

Table 7.1: Analytical error and technical error of measurement for human and animal collagen samples and internal standards

duplicate measurements was good, with the mean difference of <0.1‰ for both $\delta^{13}C$ and $\delta^{15}N$. Similar values were also obtained for the technical error of measurement.

7.2 Roman Diet at *Londinium*

7.2.1 Faunal Data

The results of the stable isotope analysis of the Roman London faunal data are plotted on Figure 7.1, alongside summary statistics in Table 7.2.

A comparison of the two herbivore species – cow and sheep/goat – shows similar mean $\delta^{13}C$ and $\delta^{15}N$ values with no statistically significant difference observed between them ($\delta^{13}C$ – U = 6, p = 0.3889; $\delta^{15}N$ – U = 8.5, p = 0.7778). This close comparability is often observed within isotopic studies unless significant differences in animal husbandry techniques are apparent (Cummings 2008: 146). Indeed, the large range of $\delta^{15}N$ values for cattle (4.1‰) within Roman London could be a reflection of such differences, with cattle being brought from various locations into the city. Despite this, the range of $\delta^{13}C$ and $\delta^{15}N$ values observed in these species are typical of herbivore species feeding within temperate Europe, and are in agreement with those reported for other Romano-British sites (Müldner 2005: 125).

As omnivores, the diet of pigs can be wide ranging, with the incorporation of animal protein potentially resulting in $\delta^{13}C$ and $\delta^{15}N$ values enriched over that of terrestrial herbivores. However, the mean enrichment of pigs over the terrestrial herbivores at Roman London is very small ($\Delta^{13}C$ = 0.6‰; $\Delta^{15}N$ = 0.4‰), with all values falling within the terrestrial herbivore range. Furthermore, no statistically significant difference was observed between the three species (Kruskal-Wallis $\delta^{13}C$ - $H(\chi^2)$ = 4.619, p = 0.098; $\delta^{15}N$ - $H(\chi^2)$ = 0.469, p = 0.7884). These results

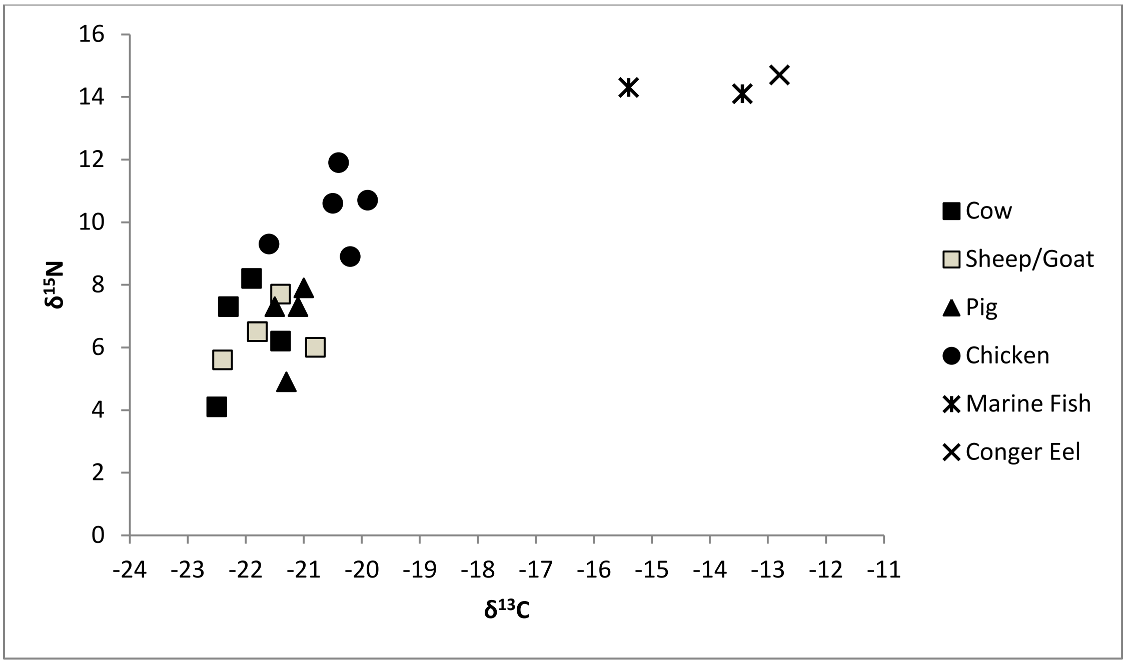


Figure 7.1: δ^{13}C and δ^{15}N ratios for the faunal species from Roman London

Species	N	δ^{13}C (‰)				δ^{15}N (‰)			
		Min.	Max.	Mean ± 1σ	Median	Min.	Max.	Mean ± 1σ	Median
Cow	5	-22.5	-21.4	-22.0 ± 0.4	-21.9	4.1	8.2	6.5 ± 1.5	6.5
Sheep/ Goat	4	-22.4	-20.8	-21.6 ± 0.7	-21.6	5.6	7.7	6.5 ± 0.9	6.3
Herbivore	9	-22.5	-20.8	-21.8 ± 0.6	-21.8	4.1	8.2	6.5 ± 1.2	6.5
Pig	4	-21.5	-21.0	-21.2 ± 0.2	-21.2	4.9	7.9	6.9 ± 1.3	7.3
Chicken	5	-21.6	-19.9	-20.5 ± 0.6	-20.4	8.9	11.9	10.3 ± 1.2	10.6
Marine Fish	2	-15.4	-13.4	-14.4 ± 1.4	-14.4	14.1	14.3	14.2 ± 0.1	14.2

Table 7.2: Summary statistics for the faunal samples from Roman London

suggest that the pigs tested derived most of their dietary protein from C_3 plant-based material. While a herbivorous diet for pigs is supported both by Roman agricultural writings (Cummings 2008: 197) and previous isotopic analyses within the empire (Prowse *et al.* 2004), it stands in contrast to the isotopic results from other Romano-British sites, where the δ^{13}C and δ^{15}N values of pigs proved significantly different from terrestrial herbivores (Cummings 2008: 148).

Indeed, a closer examination of the individual results for the pigs of Roman London reveals conflicting results, with three of the four pigs having Δ^{15}N values enriched by an average of 1‰ over that of the herbivore mean, suggesting a mixed diet of both plant and animal protein for these animals. The reverse was seen for the remaining pig (P4), whose Δ^{15}N value was depleted by 1.6‰ from the herbivore mean, suggesting a predominantly plant-based diet.

Such a difference in the diet of pigs within Roman London may be a reflection of differences in management strategies of the animals brought to slaughter, with pigs raised outside the urban environs perhaps having a more herbivorous diet than the food waste offered to their urban counterparts

As the most commonly observed domestic fowl observed amongst the animal bone record, chickens were also sampled. Overall, the Δ^{13}C and Δ^{15}N values of the chickens were enriched over that of the terrestrial herbivores by 1.3‰ and 3.8‰ and over pigs by 0.7‰ and 3.4‰ respectively. This enrichment is the equivalent of a trophic level shift and plots within the results observed for the human population (see section 7.2.2). This trophic level enrichment of chicken δ^{13}C and δ^{15}N values above other animals is one reported in a number of isotopic studies of faunal remains (Müldner and Richards 2005; 2007; Cummings 2008: 149-50; Redfern *et al.* 2010), with chickens raised within the yards of urban dwellers perhaps sharing the wide range of food waste of their owners. Other potential reasons for the increase in δ^{13}C and δ^{15}N values observed in chickens could be the consumption of insect animal protein (Müldner 2005: 131), and fattening processes involving the use of bread and milk (Cummings 2008).

Of the two marine fish samples that yielded sufficient collagen to allow isotopic analysis, both produced enrichment in δ^{13}C and δ^{15}N values consistent with those expected from marine ecosystems (see Chapter 3). As the eel species sampled – conger eel – spends the majority of its lifetime at sea, it is not surprising that its δ^{13}C and δ^{15}N values are also comparable to those from marine ecosystems. With so few fish samples available from Roman London itself, additional isotopic values for marine, freshwater, and anadromous species (salmonids and eel) were sought from other British archaeological sites (Cummings 2008; Müldner 2005; Müldner and Richards 2005, 2007; Redfern *et al.* 2010). The summary statistics of these values are given in Table 7.3 and are plotted in Figure 7.2 against mean faunal values from Roman London. When compared to the Roman London marine samples, the British archaeological marine fish have similar isotopic values, with both carbon and nitrogen ranges overlapping.

Species	N	δ^{13}C (‰)				δ^{15}N (‰)			
		Min.	Max.	Mean ± 1σ	Median	Min.	Max.	Mean ± 1σ	Median
Marine	22	-16.1	-11.8	-13.5 ± 1.4	-13.0	10.1	17.2	13.1 ± 2.1	13.5
Freshwater	11	-25.4	-14.2	-21.7 ± 3.3	-22.7	10.2	23.4	13.7 ± 3.7	12.5
Eel	11	-25.7	-17.6	-23.2 ± 2.4	-23.5	8.8	12.8	11.2 ± 1.3	11.5
Salmonid	6	-15.6	-14.0	-15.0 ± 0.6	-15.2	8.6	13.9	11.2 ± 2.5	11.3

Table 7.3: Summary statistics for the additional British archaeological fish samples (taken from Cummings 2008; Müldner 2005; Müldner and Richards 2005, 2007; Redfern *et al.* 2010)

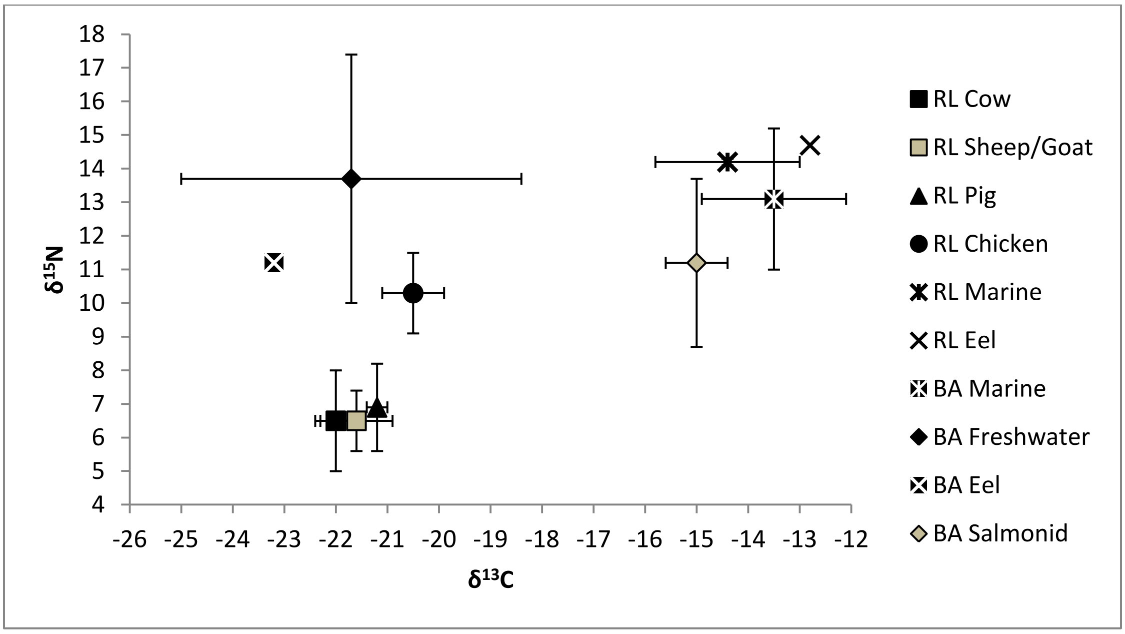


Figure 7.2: Mean $\delta^{13}C$ and $\delta^{15}N$ ratios (±1σ) for British archaeological (BA) fish species in comparison with mean $\delta^{13}C$ and $\delta^{15}N$ ratios (±1σ) of Roman London (RL) faunal samples. British archaeological fish species compiled data taken from Cummings 2008; Müldner 2005; Müldner and Richards 2005, 2007; Redfern *et al.* 2010)

7.2.2 Human Isotope Data

Figure 7.3 presents the $\delta^{13}C$ and $\delta^{15}N$ results from the human population of Roman London, excluding those subadults whose enrichment of isotopic values may be associated with breastfeeding (i.e. < 4 years) (n=84). The $\delta^{13}C$ values range from -22.2‰ to -18.2‰ (range = 4‰), with a mean of values of -19.8‰. The $\delta^{15}N$ values range from 6.8‰ to 13.6‰ (range = 6.8‰), with a mean value of 10.7‰. An analysis of the distribution of isotopic values within the sample identifies three individuals as statistical outliers (LTU03 10; LTU03 157; SRP98 12147), although none of these are considered extreme (Figure 7.3).

One of these outliers, LTU03 [10], a young adult male, had $\delta^{13}C$ and $\delta^{15}N$ values more comparable to those of the terrestrial herbivores, suggesting he ate a diet almost completely devoid of any animal protein. However, using isotopic modelling for potential Roman diets, Cummings (2008) demonstrated the inclusion of moderate amounts of animal protein in a diet of predominantly grain/plant foodstuffs (c.75%) will still result in an isotopic signature within the range observed for terrestrial herbivores. Therefore, while LTU03 [10] appears to have had a vegan/vegetarian diet, the inclusion of small amounts of animal protein cannot be totally ruled out.

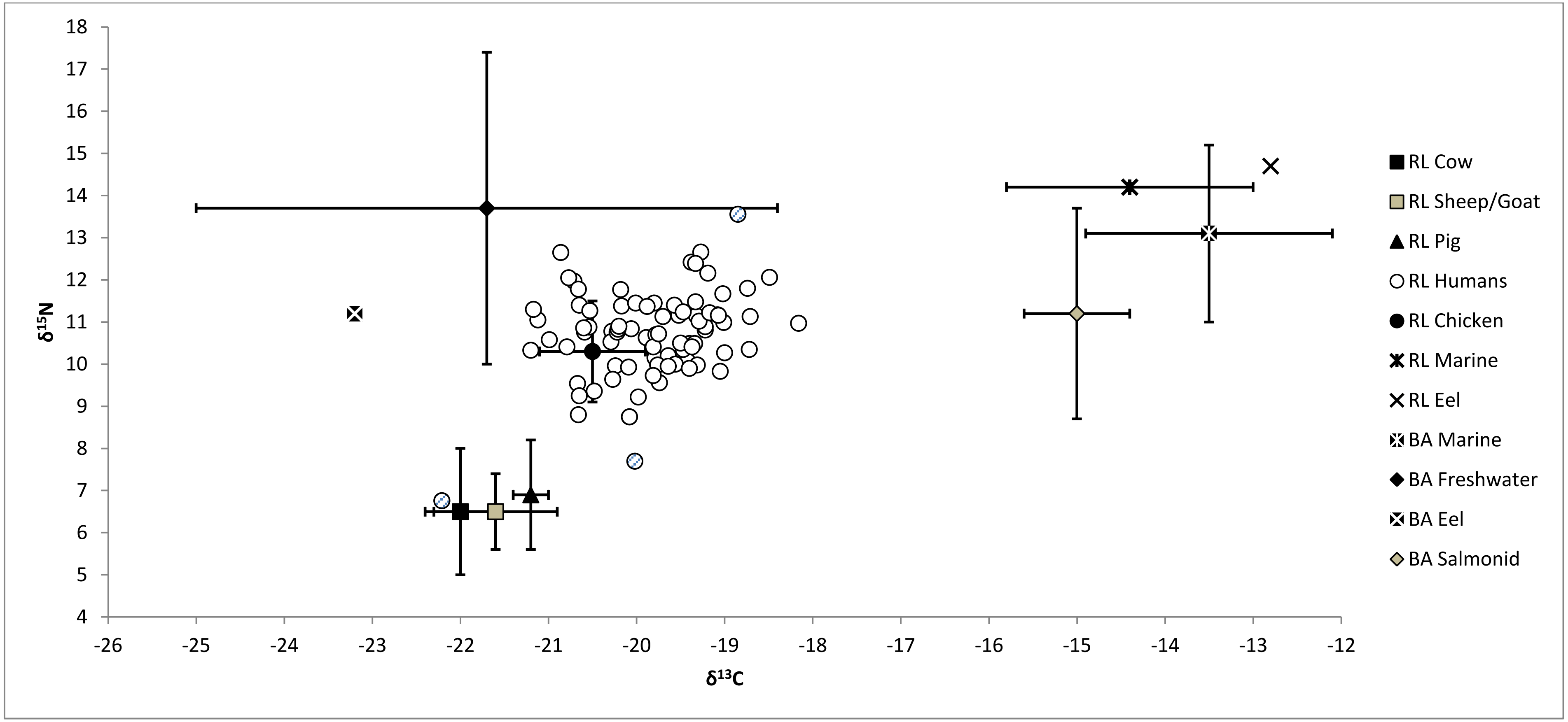


Figure 7.3: δ^{13}C and δ^{15}N ratios for the Roman London sample, plotted against mean δ^{13}C and δ^{15}N ratios for faunal samples from Roman London (RL) and other British archaeological sites (BA). Those circles with diagonal stripes represent individuals considered statistical outliers.

In the remaining sample, many of the individuals from Roman London appear to plot within the range of the omnivorous chickens, suggesting a probable mixed diet of both plant and terrestrial herbivore protein. Indeed, even the lowest level of Δ^{15}N-enrichment observed (1.2‰) suggests that almost everyone in Roman London had access to some form of dietary terrestrial animal protein. However the average Δ^{15}N-enrichment over the terrestrial herbivore mean (4.2‰, range 1.2-7.1‰) is above what would be expected for a single trophic level shift, suggesting dietary protein was almost exclusively derived from terrestrial animals. From what is already known regarding diet in Roman London (see Section 4.4) this seems unlikely, confirming the inclusion of moderate amounts of other Δ^{15}N-enriched foodstuffs into the diet.

Often potential sources of additional Δ^{15}N-enrichment tend to come from the consumption of omnivorous species known to have been present, i.e. pig and chicken. However, as the pig samples from Roman London have a herbivorous isotopic signature, it is unlikely that the high level of enrichment observed amongst the humans can be attributed to the consumption of pork, even if the highest pig δ^{15}N values are utilised. Conversely, the consumption of isotopically enriched chicken and their eggs could explain some of the Δ^{15}N-enrichment observed. However, the consumption of chicken by such a large proportion of the sample is problematic within Roman London as it is mostly associated with high-status dwellings and religious/funerary rites, with chicken representing only a very small part of the archaeozoological record (see Section 4.4). Furthermore, in order to achieve some of the most enriched results observed in the sample, a substantial amount of dietary protein would have had to have come from chickens, which does not seem feasible considering the small numbers of chicken bones recovered from the town. While the daily consumption of eggs may be more plausible, the low protein yield from a consumption of two eggs a day (c. 8.6g from two 33g eggs (USDA 01123)) would probably have had only a minor effect on overall isotopic values (Cummings 2008: 194). The consumption of chicken and/or eggs would also not explain the highest δ^{13}C values observed in the sample (maximum of -18.2‰), nor the highly enriched Δ^{15}N values associated with low levels of Δ^{13}C enrichment above the terrestrial herbivore mean (e.g.MSL87 [578] - Δ^{13}C = 0.6‰, Δ^{15}N = 4.8‰) (Hedges and Reynard 2007). Therefore, other Δ^{15}N-enriched foodstuffs must have been incorporated into the diets of some individuals (Hedges and Reynard 2007)

Perhaps a better explanation for the Δ^{15}N-enrichment observed at Roman London could be the consumption of fish. For at least those individuals with δ^{13}C values above -19.5‰ (i.e. 2‰ above the terrestrial herbivore mean, and 1‰ above that of the mean chicken δ^{13}C), the inclusion of marine fish in the diet is a likely cause of the isotopic enrichment observed. Utilising a strictly linear mixing model (Mays 1997), the individual with the highest $\delta^{13}C$ value, REW92 [204], could have obtained as much as 25-30% of their dietary protein from marine fish, although it is unlikely to be quite this high. Alternatively, those individuals, such as MSL87 [578], who have high $\delta^{15}N$ values associated with low $\Delta^{13}C$ enrichment over the herbivore mean, appear to have been consuming freshwater fish instead. A combination of both freshwater and marine fish could be hypothesised for those individuals with high $\delta^{15}N$ and middling $\delta^{13}C$ values, with the high marine and low freshwater $\delta^{13}C$ values effectively averaging out human $\delta^{13}C$ values.

Overall, the dietary protein intake of Roman London appears to have been largely based on a mixed diet of terrestrial plant and herbivorous animal protein with minor incorporations of marine and/or freshwater fish and possibly some chicken and/or egg. While the complex scrambling of multiple isotopically different foodstuffs makes it difficult to determine exact proportions of foodstuffs, the range of isotopic values observed ($\delta^{13}C$ = 4‰, $\delta^{15}N$ = 6.8‰) suggests a great deal of dietary variation at the site.

7.3 Stable Isotope Results by Age

The aim of this section was to identify how age affected the dietary intake of the subadults of Roman London. The first section will address infant feeding practices evident within the population. Following this, comparisons will be drawn between subadult and adult diets, and for subadult age categories. Lastly, $\delta^{15}N$ and $\delta^{13}C$ by specific age were examined within the subadult age group to identify any possible correlation between age and isotopic signature. In order to avoid the enrichment of $\delta^{13}C$ and $\delta^{15}N$ associated with breastfeeding affecting the identification of possible dietary differences, subadults below the age of four were excluded for all analyses, except those regarding infant feeding practices.

7.3.1 Infant Feeding Practices – Breastfeeding and Weaning

The $\delta^{15}N$ and $\delta^{13}C$ values of the subadults of Roman London are plotted against age in Figures 7.4 and 7.5, respectively. The mean adult female values are indicated on the graphs by a solid line, with one standard deviation either side represented by dashed lines.

From Figure 7.4, it is evident that the $\delta^{15}N$ values of subadults aged two years and under ($\bar{x}$ = 12.7 ± 0.8‰) are significantly elevated above the adult female mean ($\bar{x}$ =10.8 ± 1.6‰) (U = 35, p = 0.0005). The highest $\delta^{15}N$ values observed are amongst those subadults aged one year or

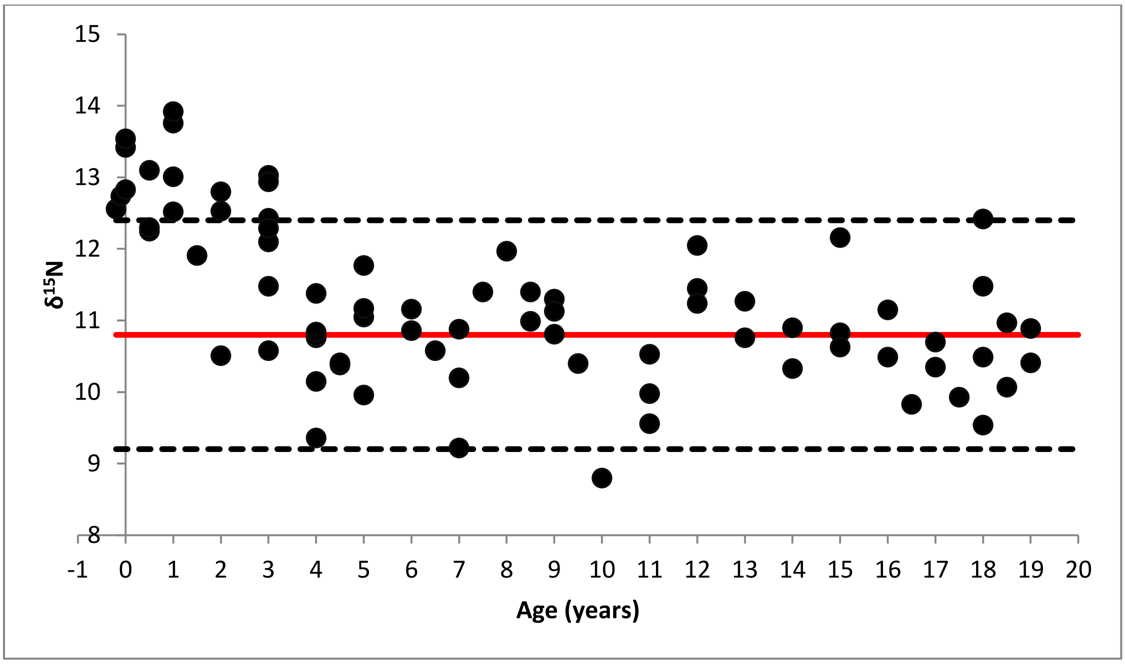


Figure 7.4: Scatter plot of the δ^{15}N values for the subadults of Roman London plotted against midpoint age values. The solid line represents the adult female mean, dashed lines represent 1 standard deviation from the mean

less ($\bar{x}$ = 13.0 ± 0.6‰), with an average enrichment of 2.2‰ above the adult female mean. This level of enrichment is consistent with the expected 2-3‰ trophic level shift observed with breastfeeding, confirming breastfeeding was consistently practiced within Roman London. Despite the inclusion of two preterm and three full term individuals, no initial rise in δ^{15}N values from the adult female mean is observed. As the δ^{15}N values of an exclusively breastfed infant is dependent on that of its mother, it is expected that the level of variation amongst suckling infants would reflect that of the adult female population. However, the range of δ^{15}N values for those expected to have to the largest contribution of breast milk within their diet (i.e. those one year and under) is 3.5 times smaller (1.7‰) than that of the adult females (5.9‰).

The complete cessation of breastfeeding, as indicated by a return to the mean adult female δ^{15}N value, appears to have varied within the population. While the δ^{15}N values of some two and three year olds are close to or fall below the adult female mean, others of the same age have δ^{15}N values suggesting breast milk was still a large part of dietary protein. While no dramatic decline in δ^{15}N values is observed, the largest decrease in δ^{15}N values occurs between the three and four year olds (three years $\bar{x}$ = 12.1‰, four years $\bar{x}$ = 10.6‰). By four years of age, all children appear to have been fully weaned, with δ^{15}N falling close to or below the adult female mean. Following this weaning process, the δ^{15}N values of all subadults remain within one standard deviation of the adult mean, with the exception of one 10 year old (WES89 781).

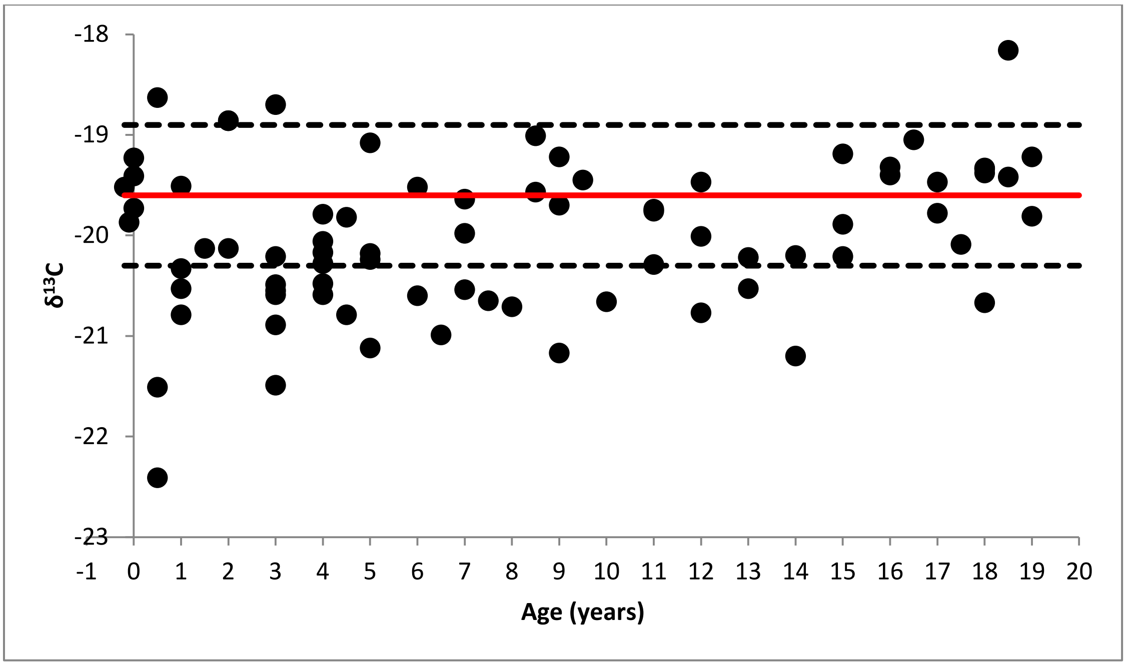


Figure 7.5: Scatter plot of the $\delta^{13}C$ values for the subadults of Roman London plotted against midpoint age values. The solid line represents the adult female mean, dashed lines represent 1 standard deviation from the mean

In contrast to the $\delta^{15}N$ results, few subadults exhibit the expected trophic level shift in $\delta^{13}C$ values associated with breastfeeding (Figure 7.5). From birth to six months, many of the subadults sampled have $\delta^{13}C$ ratios similar to or slightly elevated above the adult female mean ($\delta^{13}C = -19.6$), with only one infant (HOO88 869) with the expected 1‰ level of enrichment. After six months, the $\delta^{13}C$ of all but three individuals fall below the adult female mean until the age of 5 years, when a greater variability of $\delta^{13}C$ values either side of the adult female mean is observed. This depletion in $\delta^{13}C$ values between 6 months and 5 years when compared to the adult female population proved to be statistically significant (U = 104, p = 0.02). Studies of modern mother-infant pairings have identified that $\delta^{13}C$ values are more sensitive to the incorporation of supplementary foods into infant diets (Fuller *et al.* 2006b). Therefore, the significant decline in $\delta^{13}C$ values after six months indicates it was probably around this age that additional food was introduced into the diets of infants at Roman London, with the weaning diet consisting predominantly of a higher proportion of terrestrial food sources than that consumed in later childhood (as at Redfern *et al.* 2012). After five years, no statistically significant difference is observed between the subadult and adult female population (U = 286.5, p = 0.19).

7.3.2 Subadult and adult comparison

Figure 7.6 plots the δ^{15}N and δ^{13}C values by subadult and adult age category, with summary statistics given in Table 7.4.

When compared, the mean δ^{15}N and δ^{13}C values of the subadults and adults are relatively close, being within the normal variation of 1‰ observed between individuals eating the same diet. Despite this, a clear difference is observed in the distribution of the overall isotopic data.

The greatest difference appears to be within the δ^{13}C results, with adults overall appearing on average to be consistently more enriched over the herbivore mean (average 2.2‰) than the subadults (average 1.8‰), who are more equally distributed across the range of δ^{13}C values.

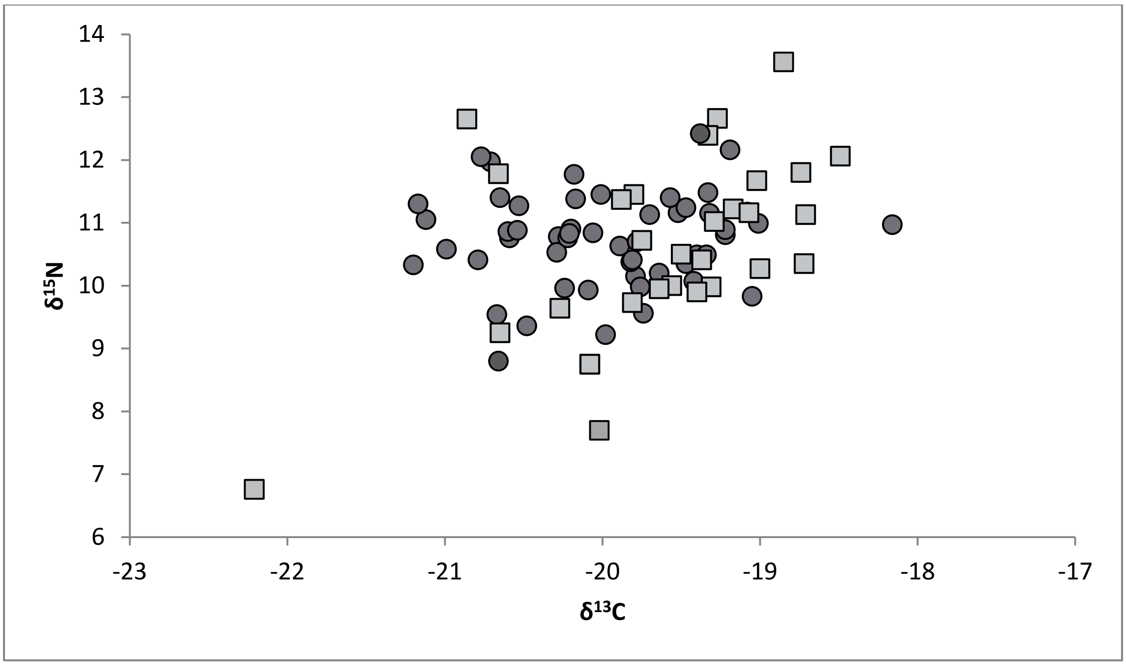


Figure 7.6: Scatter plot of δ^{15}N and δ^{13}C values of the Roman London sample by subadult (circles) and adults (squares) age categories.

Age Category	N	δ^{13}C (‰)				δ^{15}N (‰)			
		Min.	Max.	Mean ± 1σ	Median	Min.	Max.	Mean ± 1σ	Median
Subadult	54	-21.2	-18.2	-20.0 ± 0.6	-19.9	8.8	12.4	10.7 ± 0.7	10.8
Adult	30	-22.2	-18.5	-19.6 ± 0.8	-19.5	6.8	13.6	10.6 ± 1.5	10.6

Table 7.4: Summary statistics for the δ^{15}N and δ^{13}C values of the Roman London sample by subadult and adult age category

This difference in $\delta^{13}C$ between age categories was statistically significant ($n = 84$, $U = 533$, $p \leq 0.01$), even with the removal of statistical outliers. This difference in $\delta^{13}C$ results between subadults and adults could be explained by the preferential consumption of marine fish resources by adults, with the inclusion of freshwater fish in the diet appearing to be more of a feature of subadult diet. No statistically significant difference is observed between the $\delta^{15}N$ values of subadults and adults, both having an average enrichment of around 4‰ over the herbivore mean. However, despite a considerable overlap, a much greater range in $\delta^{15}N$ is apparent amongst the adult age group, perhaps reflecting a greater variation of the amount of animal protein within the adult diet.

Another noticeable difference between the subadult and adult age groups appears to be the greater correlation between carbon and nitrogen results amongst the adult sample. While almost no correlation is observed between $\delta^{15}N$ and $\delta^{13}C$ for the subadults ($n = 54$, $r = 0.079$, $p = 0.571$), a moderate positive correlation is apparent for the adult age group, although this was not quite statistically significant ($n = 29$, $r = 0.338$, $p = 0.073$). One possible reason for this could have been a greater stratification of adult diet, correlated with increasing proportions of marine fish and/or possibly chicken. Another possible explanation is that the inclusion of

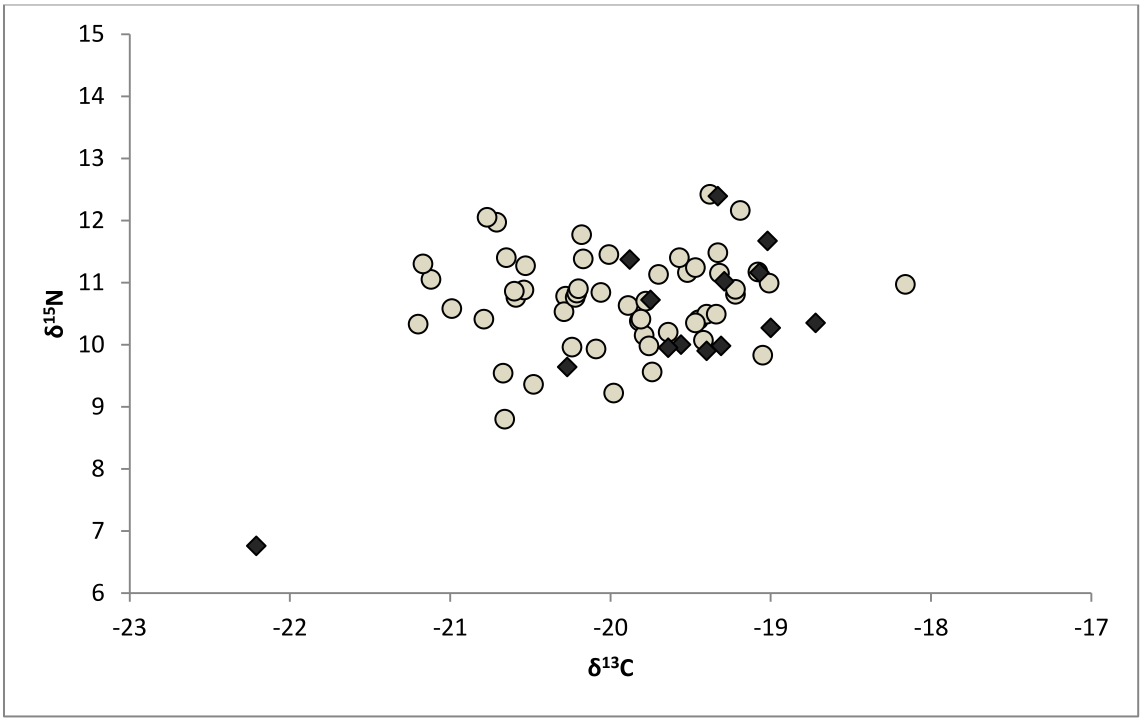


Figure 7.7: Scatter plot comparing the $\delta^{15}N$ and $\delta^{13}C$ values of the Roman London subadults (grey circles) and adult males (black diamonds)

freshwater fish in the diet of some subadults instead of marine fish may have reduced any potential positive correlation.

A further comparison of the subadult isotopic values to adult biological sex identified a significant difference in the δ^{13}C values between adult males and subadults ($U = 160.5$, $p \leq 0.01$), with adult males tending to be more consistently enriched (Figure 7.7). This difference may be attributed to the apparent absence of freshwater fish in the adult male diet. No statistically significant difference was observed for δ^{15}N results ($U = 306.5$, $p = 0.4854$), although the lowest adult male δ^{15}N values are slightly elevated above those of the lowest subadults. No statistically significant difference was observed between subadult and adult females for both δ^{15}N and δ^{13}C, although it is apparent that the adult female δ^{15}N range (5.9‰) is much greater than that observed both amongst the subadults (3.6‰) and adult males (2.8‰ excluding LTU03 10) (Figure 7.8). A comparison of the adult female and male isotope results also shows that while the positive correlation between δ^{13}C and δ^{15}N observed in the adult population is readily apparent amongst the adult females, it is not so within the adult male results. This suggests that the dietary variation for adult females in Roman London appears to have been greater than that of the adult males. Indeed, the two adults who appear to have some input of freshwater fish in the diet (SRP98 [5919] and WES89 [504]) are both females.

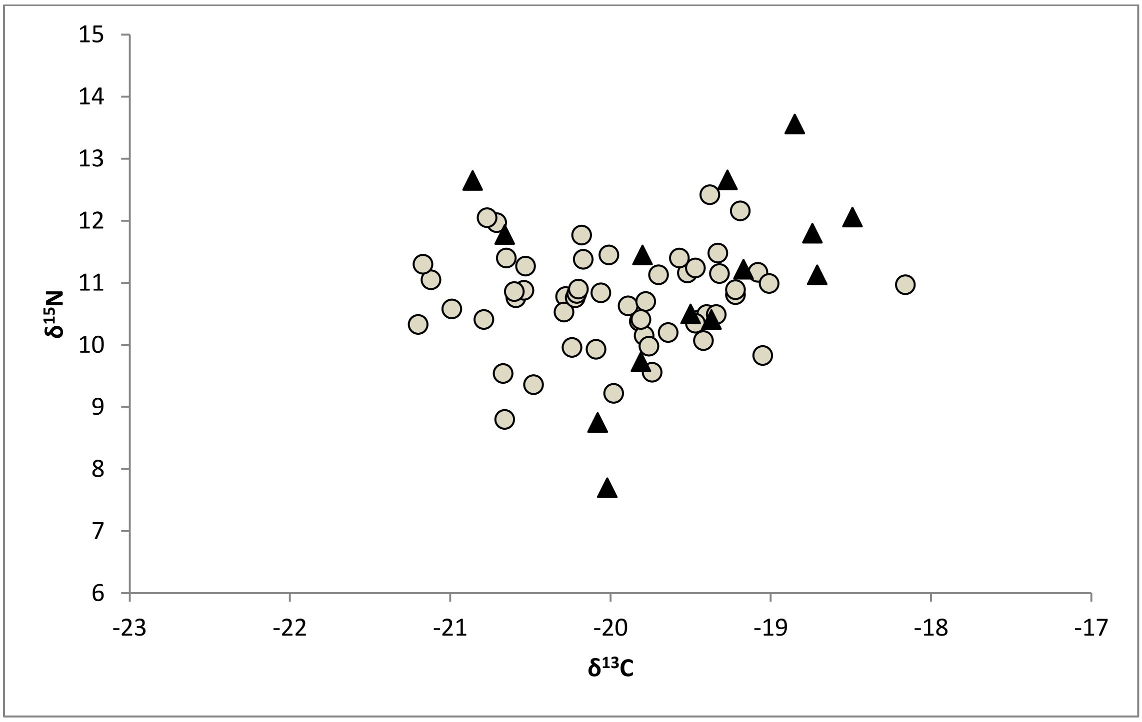


Figure 7.8: Scatter plot comparing the δ^{15}N and δ^{13}C values of the Roman London subadults (grey circles) and adult females (black triangles)

7.3.3 Subadult age categories

Figure 7.9 plots the δ^{15}N and δ^{13}C values by subadult age category, with summary statistics given in Table 7.5.

While the variation in mean δ^{15}N and δ^{13}C values observed between subadult age categories are very small, an increasing pattern of enrichment for both the mean δ^{13}C and Δ^{13}C above the herbivore mean (four = 1.6‰, five = 1.9‰, and six = 2.3‰) is observed with increasing age. While this relationship proved to be statistically significant (Kruskal-Wallis = 8.3, p = 0.01576), further analysis within the subadult age categories identified this statistically significant difference only occurs between age category four and six (4 and 5 – U = 164, p = 0.1204; 5 and 6 – U = 90, p = 0.1403; 4 and 6 – U= 36, p = 0.003428). The similarity in the mean of δ^{15}N values (Kruskal-Wallis = 1.276, p = 0.5284), and the lack of difference in the average Δ^{15}N enrichment between the subadult age categories (four = 4.1‰, five = 4.3‰, six = 4.2‰), suggests the differences in carbon are not the result of variation in animal protein consumption but are more likely the result of the more consistent incorporation of minor portions of marine instead of freshwater foodstuffs into the diet of the older subadults. While depleted δ^{13}C values in conjunction with enriched δ^{15}N are observed in age categories four and five, they are absent by age category six.

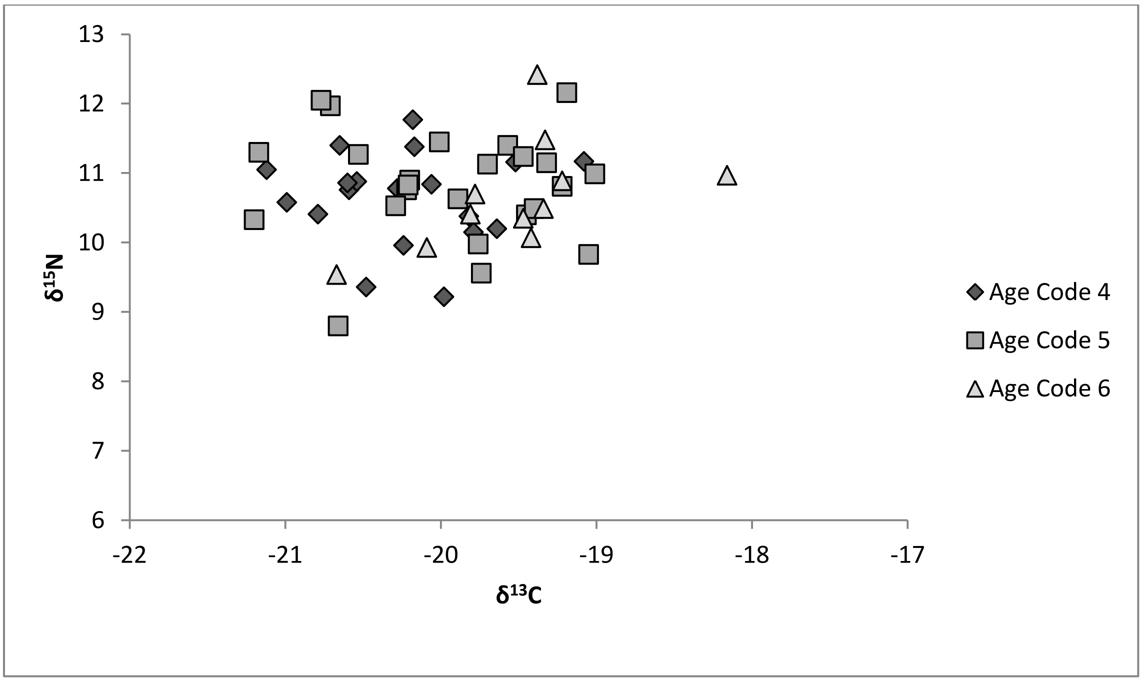


Figure 7.9: Scatter plot comparing the δ^{15}N and δ^{13}C values of the Roman London subadults by subadult age categories

Age Category	N	$\delta^{13}C$ (‰)				$\delta^{15}N$ (‰)			
		Min.	Max.	Mean ± 1σ	Median	Min.	Max.	Mean ± 1σ	Median
4	19	-21.1	-19.1	-20.2 ± 0.5	-20.2	9.2	11.8	10.6 ± 0.7	10.8
5	24	-21.2	-19.0	-19.9 ± 0.7	-19.8	8.8	12.2	10.8 ± 0.8	10.9
6	11	-20.7	-18.2	-19.5 ± 0.8	-19.4	9.5	12.4	10.7 ± 0.8	10.5

Table 7.5: Summary statistics for the $\delta^{15}N$ and $\delta^{13}C$ values of the Roman London sample by subadult and adult age category

From Figure 7.9, it is apparent that there is a greater spread of values across the isotopic ranges in age categories four and five, whilst the $\delta^{13}C$ and $\delta^{15}N$ values of age category 6 appear more strongly correlated, more closely resembling the pattern observed in the overall adult diet. This difference in the pattern of $\delta^{13}C$ enrichment between the youngest and oldest age categories may be a reflection of the adoption of an adult diet. This is further supported by statistical comparisons of adult $\delta^{13}C$ values. Whilst the $\delta^{13}C$ results from age category 4 and 5 are both significantly different from their adult counterparts (4 - U = 126, p = 0.001144; 5 – U = 248, p = 0.05225), no statistical difference is observed for age category 6 (U = 159, p = 0.8714).

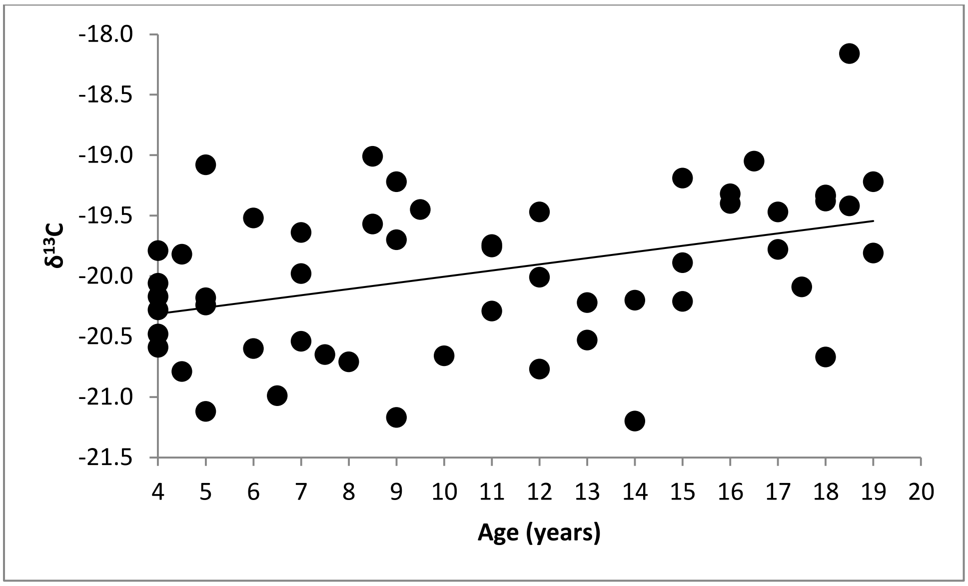


Figure 7.10: Scatter plot of the $\delta^{13}C$ values of the Roman London subadults by age in years with line of best fit

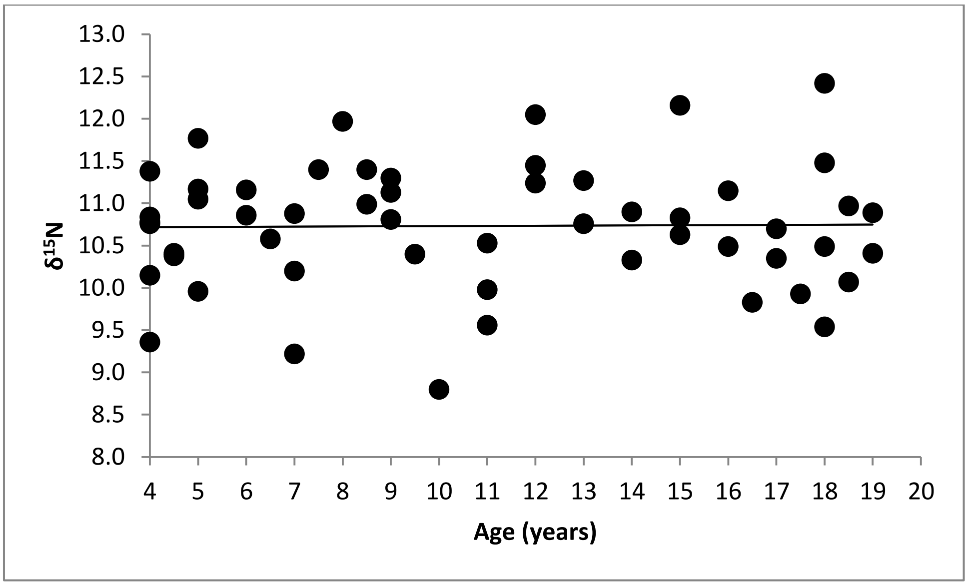


Figure 7.11: Scatter plot of the $\delta^{15}N$ values of the Roman London subadults by age in years with line of best fit

7.3.4 Age in years

The subadult isotopic ratios were further tested to identify any possible correlation between $\delta^{15}N$ and $\delta^{13}C$ values and age.

For $\delta^{13}C$, a significant positive correlation ($r = 0.408$, $r^2 = 0.166$, $p \leq 0.01$) was observed with age, although the strength of this correlation was weak, with less than 20% of variation in carbon isotope values being explained by age (Figure 7.10). Furthermore, the overall increase from 4 to 19 years is less than 1‰, within the natural variation seen between individuals consuming the same diet. However, this enrichment in $\delta^{13}C$ with increasing age agrees with previous results that saw increasing $\delta^{13}C$ between subadult age categories, perhaps reflecting increasing marine alongside decreasing freshwater contributions with increasing age. By contrast, there was an almost complete absence of correlation between $\delta^{15}N$ and age ($r = 0.006$, $r^2 = 0.0002$, $p = 0.967$), suggesting the amount of animal protein consumed was not affected by age (Figure 7.11).

7.3.5 Summary

- Children within Roman London would have been breastfed, with supplementary foods included in the diet from around the age of six months. Cessation of breastfeeding would have occurred by the time the child turned four years.

- Comparisons of subadult and adult diet suggest that while marine and/or freshwater resources were consumed by some of the subadult population, adults predominantly favoured marine fish.
- Within subadult age categories, subadults appear to have gradually adopted adult diet, with most subadults eating an adult diet by the time they were 17-20 years old.
- While no correlation in $\delta^{15}N$ results is observed with age, a significant positive correlation is observed for $\delta^{13}C$ with age.

7.4 Stable Isotope Results by Time Period

This section presents the results of the stable isotope data by time period. The aim of this section was to identify if, and how, diet changed over the course of the Roman occupation of London. The data are first presented for the overall population and then for the subadult population in order to allow comparisons of potential subadult relationships to those of the population as a whole. Following this, in order to identify possible trends within time periods, comparisons are drawn between subadults and adults in both the early and late periods. For all comparisons, those subadults under the age of four years were excluded to ensure that any potential relationships were not obscured by any enrichment associated with breastfeeding.

7.4.1 Total Population

Figure 7.12 shows the $\delta^{15}N$ and $\delta^{13}C$ values of the Roman London sample by time period, with summary statistics given in Table 7.6. Of the 84 successfully obtained samples, one individual could not be assigned to a time period and therefore was removed from subsequent analyses.

A comparison of the isotopic results from the early and late Roman period shows comparable mean $\delta^{15}N$ and $\delta^{13}C$ values, with no statistically significant difference for either $\delta^{15}N$ ($U = 744.5$, $p = 0.9306$) or $\delta^{13}C$ ($U = 579.5$, $p = 0.09225$) between the two groups. Despite this, Figure 7.12 shows that those individuals from the early time period tend to have more consistently enriched isotopic values, particularly regarding their $\delta^{13}C$ results. With the exception of one individuals located at the far left of the group, those from the early time period show enrichment in their $\Delta^{13}C$ values of at least 1.5‰ above the herbivore mean, up to a maximum of 3.1‰. Combined with the associated average enrichment in $\Delta^{15}N$ (4.3‰) also observed within the group, the isotopic results suggest the inclusion of $\delta^{13}C$ and $\delta^{15}N$-enriched

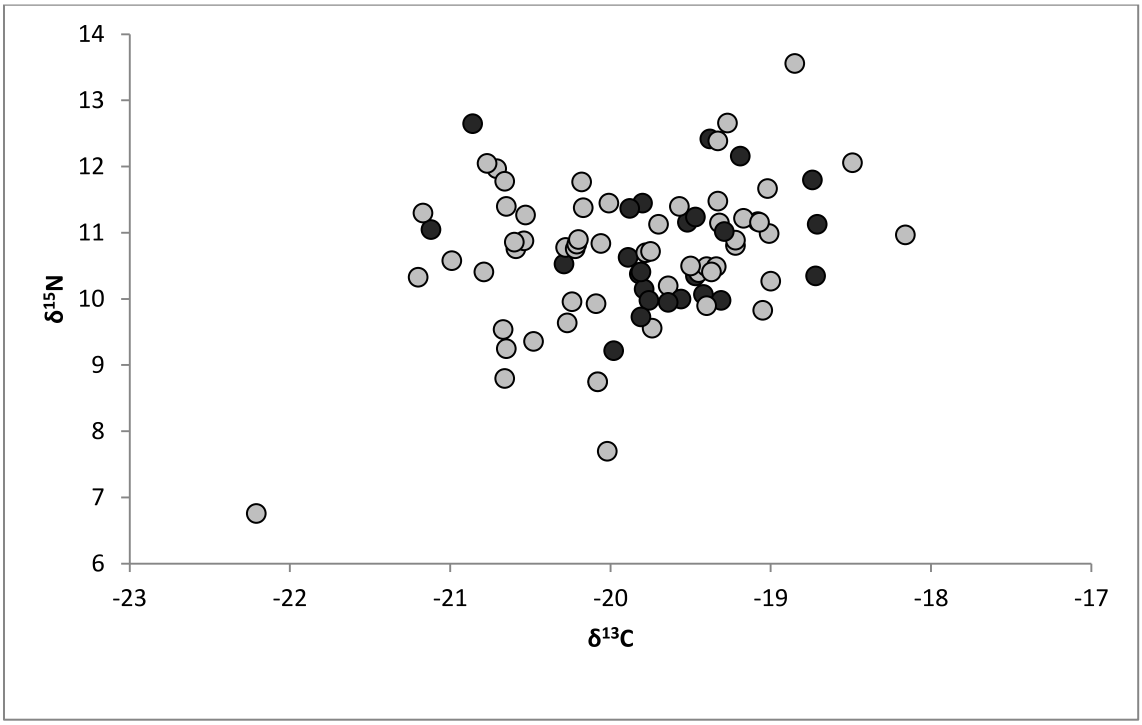


Figure 7.12: Scatter plot of δ^{15}N and δ^{13}C values of the Roman London sample by early (solid black circles) and late (grey circles) time periods

Time Period	N	δ^{13}C (‰)				δ^{15}N (‰)			
		Min.	Max.	Mean ± 1σ	Median	Min.	Max.	Mean ± 1σ	Median
Early	26	-21.1	-18.7	-19.6 ± 0.6	-19.6	9.2	12.7	10.8 ± 0.9	10.6
Late	57	-22.2	-18.2	-19.9 ± 0.8	-20.1	6.8	13.6	10.7 ± 1.2	10.8

Table 7.6: Summary statistics for the δ^{15}N and δ^{13}C values of the Roman London sample by presence and absence of burial container

foodstuffs, such as marine fish, in the diets of some individuals in addition to that derived from terrestrial herbivores. The two identified exceptions to this pattern (SRP98 [5919] and MSL87 [1707]) have more depleted δ^{13}C values in associated with enriched δ^{15}N, suggesting some of their protein may have come from freshwater resources instead.

Within the later period, although individual data points are consistent with those found within the early period, there appears to be a greater dispersal of isotopic values over the entire range, suggesting a potentially greater diversity of diet within the population in the later period. Furthermore, the inclusion of freshwater resources appears to have been more common in the later period, with more individuals showing high δ^{15}N enrichment alongside depleted δ^{13}C.

7.4.2 Subadult Population

Figure 7.13 shows the δ^{15}N and δ^{13}C values of the Roman London subadults by time period, with summary statistics given in Table 7.7.

A comparison of the early and late subadult stable isotope results reveals the same pattern observed in the overall population (Section 7.4.1). While the average δ^{15}N values for both groups are identical (10.7‰) with no significant difference observed (U = 261, p = 0.6421), those subadults from the early time period tend to have slightly more enriched δ^{13}C values (average enrichment – early = 2.1‰; late = 1.7‰), although this proved to be not statistically significant (U = 189, p = 0.05885). Again, from Figure 7.13, subadults from the early time period tend to have more consistently enriched stable isotope values, particularly regarding

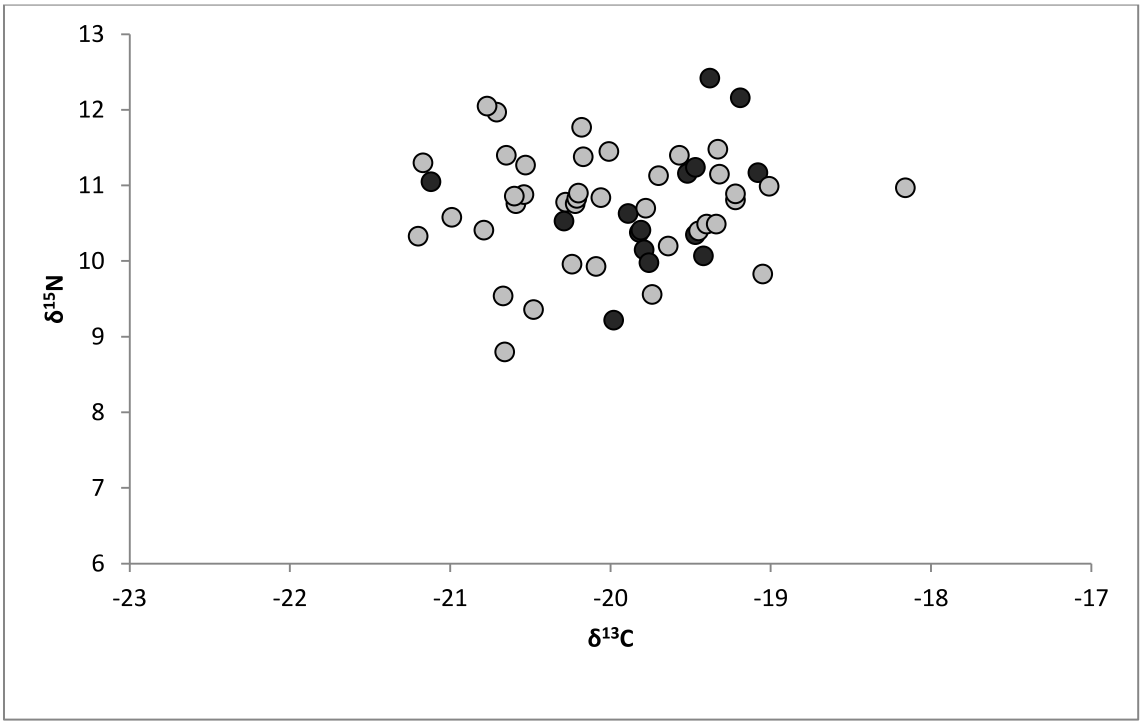


Figure 7.13: Scatter plot of δ^{15}N and δ^{13}C values of the Roman London subadults by early (solid black circles) and late (grey circles) time periods

Time Period	N	δ^{13}C (‰)				δ^{15}N (‰)			
		Min.	Max.	Mean ± 1σ	Median	Min.	Max.	Mean ± 1σ	Median
Early	15	-21.1	-19.1	-19.7 ± 0.5	-19.8	9.2	12.4	10.7 ± 0.8	10.5
Late	38	-21.2	-18.2	-20.1 ± 0.7	-20.2	8.8	12.1	10.7 ± 0.7	10.8

Table 7.7: Summary statistics for the δ^{15}N and δ^{13}C values of the Roman London subadults by presence and absence of burial container

their δ^{13}C values, with the δ^{13}C values of the subadults from the late period being more equally distributed across the entire range. Furthermore, the isotopic signature associated with freshwater fish consumption (i.e. depleted δ^{13}C values with high δ^{15}N) is much more common amongst subadults in the late period, with only one subadult from the early period exhibiting such values (MSL87 [1707]).

7.4.3 Subadult and adult comparison

(i) Early

Figure 7.14 shows the δ^{15}N and δ^{13}C values of early Roman Londoners by subadult and adult age groups, with summary statistics given in Table 7.8.

Overall, the mean δ^{15}N and δ^{13}C values of both subadults and adults within the early period are very similar, albeit with the adults tending to be slightly more enriched (subadult Δ^{13}C = 2.1‰, Δ^{15}N = 4.2‰; adult Δ^{13}C = 2.3‰, Δ^{15}N = 4.4‰). No statistically significant difference is observed between the early subadults and adults for either δ^{15}N (U = 82, p =1) or δ^{13}C (U = 61.5, p = 0.2872). From Figure 7.14, it is apparent that there appears to be no significant difference between the diets of subadults and adults in this period, which is contrary to the overall subadult and adult comparisons (see Section 7.3.2). Few individuals (n=2) have high δ^{15}N values associated with more depleted δ^{13}C values, suggesting the consumption of freshwater fish was less common for both adults and subadults in the early period.

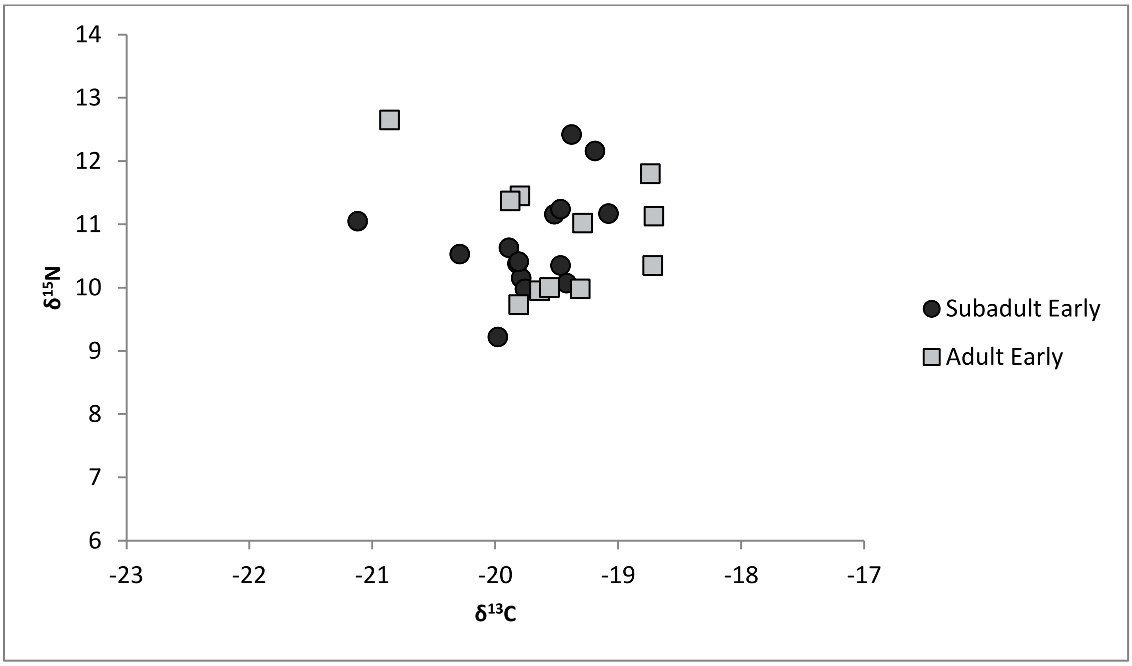


Figure 7.14: Scatter plot of δ^{15}N and δ^{13}C values of the early Roman Londoners by subadult (solid black circles) and adult (grey squares) age categories

Early Time Period	N	$\delta^{13}C$ (‰)				$\delta^{15}N$ (‰)			
		Min.	Max.	Mean ± 1σ	Median	Min.	Max.	Mean ± 1σ	Median
Subadult	15	-21.1	-19.1	-19.7 ± 0.5	-19.8	9.2	12.4	10.7 ± 0.8	10.5
Adult	11	-20.9	-18.7	-19.5 ± 0.6	-19.6	9.7	12.7	10.9 ± 0.9	11.0

Table 7.8: Summary statistics for the $\delta^{15}N$ and $\delta^{13}C$ values of the early Roman Londoners by subadult and adult age categories

(ii) Late

Figure 7.15 shows the $\delta^{15}N$ and $\delta^{13}C$ values of late Roman Londoners by subadult and adult age groups, with summary statistics given in Table 7.9.

A comparison of the mean values for the subadults and adults shows both groups have similar mean $\delta^{15}N$ and $\delta^{13}C$ values. However, unlike the early period (see 7.4.3 (i)), a difference in the overall distribution of the isotope results is apparent between the subadult and adult age categories (see Figure 7.15). Within the subadult group, $\delta^{13}C$ values appear to be evenly distributed across the full isotopic range, reflecting the inclusion of both marine (i.e. high $\delta^{15}N$ and $\delta^{13}C$) and freshwater fish (high $\delta^{15}N$, low $\delta^{13}C$) at either end of the spectrum. However, within the adult age category, only one individual (WES89 504) has isotopic results suggestive of freshwater fish consumption. Furthermore, while little correlation is observed between $\delta^{15}N$ and $\delta^{13}C$ values amongst subadults ($r = 0.025$, $p = 0.884$), a significant positive correlation is observed between adults ($r = 0.587$, $p= 0.01$), mirroring that seen for overall comparisons of subadult and adult results (see 7.3.2). This positive correlation can be attributed to: a lack of freshwater fish consumption in the adult diet, and a much greater range of $\delta^{15}N$ values.

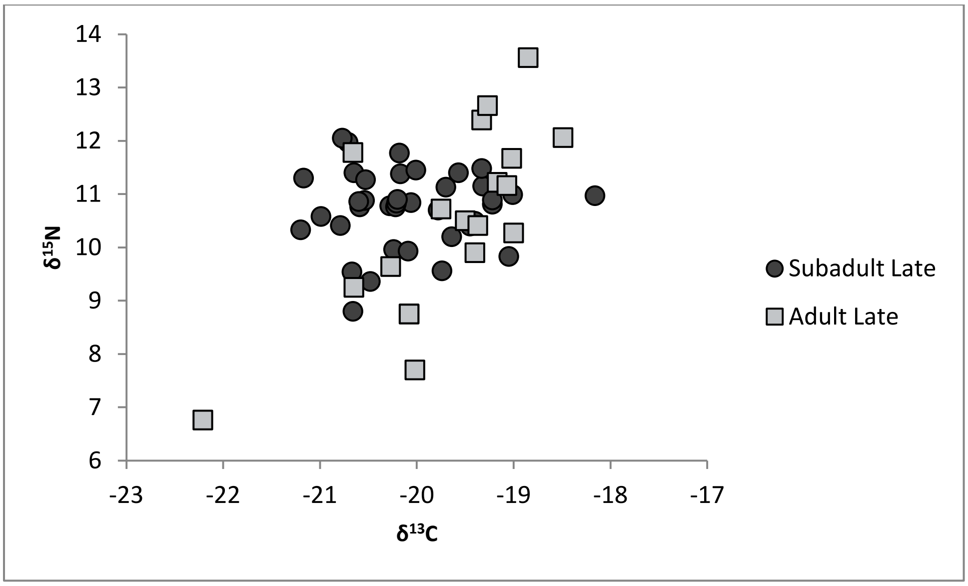


Figure 7.15: Scatter plot of $\delta^{15}N$ and $\delta^{13}C$ values of the early Roman Londoners by subadult (solid black circles) and adult (grey squares) age categories

Late Time Period	N	δ^{13}C (‰)				δ^{15}N (‰)			
		Min.	Max.	Mean ± 1σ	Median	Min.	Max.	Mean ± 1σ	Median
Subadult	38	-21.2	-18.2	-20.1 ± 0.7	-20.2	8.8	12.1	10.7 ± 0.7	10.8
Adult	19	-22.2	-18.5	-19.7 ± 0.9	-19.4	6.8	13.6	10.5 ± 1.7	10.5

Table 7.9: Summary statistics for the δ^{15}N and δ^{13}C values of the early Roman Londoners by subadult and adult age categories

7.4.4 Summary

- Comparisons of overall diet by time period shows that those individuals from the early period tend to have more consistently enriched isotopic values than those from the late period. Where enrichment was observed, foodstuffs with high δ^{15}N and δ^{13}C isotopic values (i.e. marine) were favoured in the early period, whilst both foodstuffs with δ^{15}N and δ^{13}C, and high δ^{15}N and low δ^{13}C values (i.e. freshwater fish), were utilised in the late period
- A comparison of early and late period subadults demonstrated the same pattern observed in the population overall
- Within the early period, no significant difference was observed between subadult and adult isotopic results. Where significant enrichment was observed, foodstuffs with high δ^{15}N and δ^{13}C isotopic values (i.e. marine) were favoured, with few individuals having isotopic signatures suggestive of freshwater fish consumption.
- Within the late period, a significant difference was observed between the overall distribution of subadult and adult isotopic results. For subadults, freshwater and marine fish were possible sources of isotopic enrichment, whilst adults appear to have favoured only marine foodstuffs. Furthermore, while no correlation was observed between subadult δ^{15}N and δ^{13}C values, a significant correlation was observed between adult δ^{15}N and δ^{13}C values.

7.5 Stable Isotope Results by Burial Status

This section presents the results of the stable isotope data by burial status. The aim of this section was to identify whether differences in burial status, as determined by the presence and type of burial container, were reflected within dietary practices. Comparisons will first be made for overall presence and absence of evidence for a burial container, followed by analysis of special burial container types. The data are first presented for the entire population and for the subadult population, allowing comparisons of potential subadult relationships to the population as a whole. Within both sets of data, those under four years were excluded to ensure that any potential relationships were not obscured by any enrichment caused by breastfeeding.

7.5.1 Burial Container Presence and Absence

(i) Total Population

Figure 7.16 shows the δ^{15}N and δ^{13}C values of the Roman London sample by presence and absence of burial container, with summary statistics given in Table 7.10.

A comparison of the δ^{15}N values of those individuals with evidence for a burial container with those without shows that those individuals without evidence of a burial container tended to have slightly higher δ^{15}N values. Furthermore, even with the removal of the outlier LTU03 [10], the range of δ^{15}N values for those individuals without a coffin (5.9‰) is 2.3‰ greater than that of those with a coffin (3.6‰). However, this difference proved to be not quite statistically significant (U = 642.5, p = 0.06904). Regarding the δ^{13}C values, no statistically significant difference was observed between groups (U = 820, p = 0.8475), with both having a similar range (with the exclusion of LTU03 [10] – present = 3‰, absent 2.7‰) and mean δ^{13}C ratio (see Table 7.10).

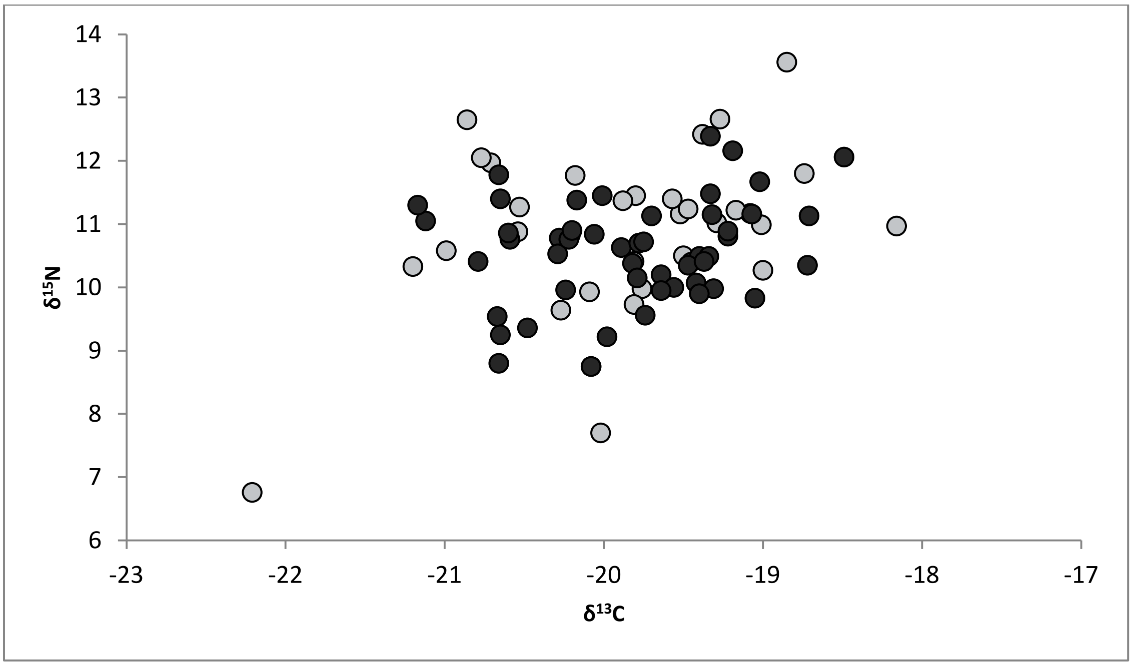


Figure 7.16: Scatter plot of δ^{15}N and δ^{13}C values of the Roman London sample by presence (solid black circles) and absence (grey circles) of burial container

Burial Container	N	$\delta^{13}C$ (‰)				$\delta^{15}N$ (‰)			
		Min.	Max.	Mean ± 1σ	Median	Min.	Max.	Mean ± 1σ	Median
Present	51	-21.2	-18.5	-19.8 ± 0.6	-19.8	8.8	12.4	10.6 ± 0.8	10.6
Absent	33	-22.2	-18.2	-19.9 ± 0.8	-19.8	6.8	13.6	10.9 ± 1.4	11.0

Table 7.10: Summary statistics for the $\delta^{15}N$ and $\delta^{13}C$ values of the Roman London sample by presence and absence of burial container

(ii) Subadults

Figure 7.17 shows the $\delta^{15}N$ and $\delta^{13}C$ values of the subadult population by presence and absence of burial container, with summary statistics given in Table 7.11.

A comparison of the mean isotopic values for subadults with and without evidence for a burial container shows those individuals without burial containers tend to have slightly more enriched $\delta^{15}N$ and $\delta^{13}C$ values. As in the overall population, only the difference between $\delta^{15}N$ values proved to be statistically significant ($\delta^{15}N$ – U = 199, p = 0.02233; $\delta^{13}C$ – U = 319.5, p = 0.9415).

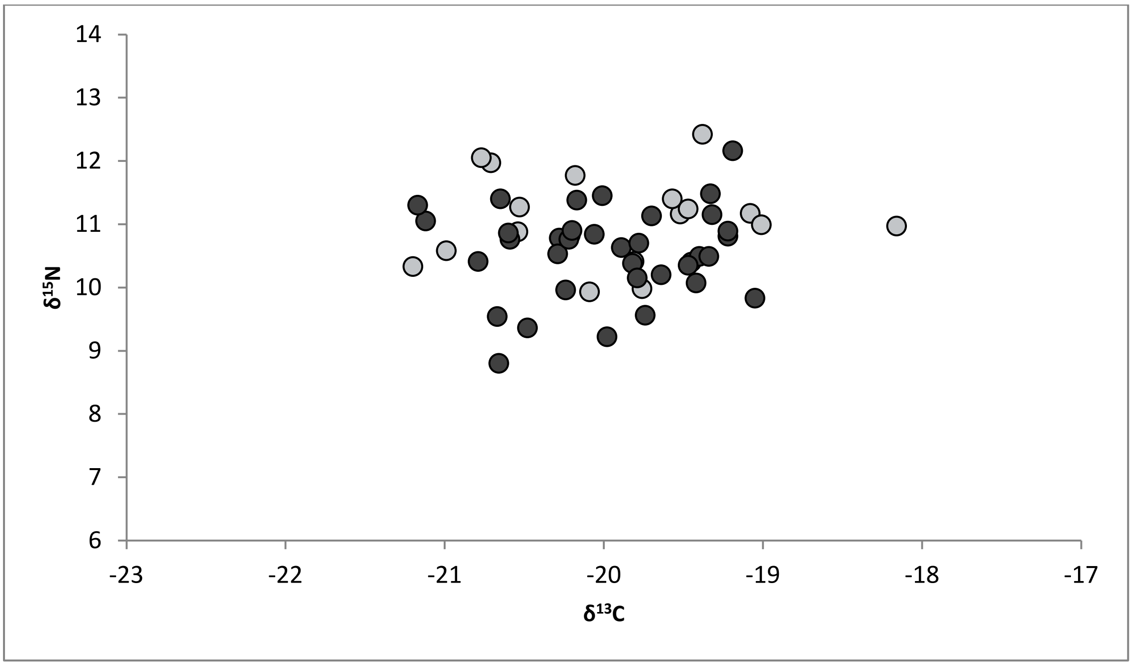


Figure 7.17: Scatter plot of $\delta^{15}N$ and $\delta^{13}C$ values of the Roman London subadults by presence (solid black circles) and absence (grey circles) of burial container

Burial Container	N	δ^{13}C (‰)				δ^{15}N (‰)			
		Min.	Max.	Mean ± 1σ	Median	Min.	Max.	Mean ± 1σ	Median
Present	36	-21.2	-19.1	-20.0 ± 0.6	-19.9	8.8	12.2	10.6 ± 0.7	10.7
Absent	18	-21.2	-18.2	-19.9 ± 0.8	-20.0	9.9	12.4	11.1 ± 0.7	11.1

Table 7.11: Summary statistics for the δ^{15}N and δ^{13}C values of the Roman London subadults by presence and absence of burial container

7.5.2 Special Burial Types

(i) Subadult Population

Amongst the successful subadult samples, only one subadult had a burial container type other than that of wooden coffin. This subadult (GDV96 56) was a 15 year-old individual buried within a stone-lined cist outside one of the walled cemeteries at the Great Dover Street site (see Figures 5.1 and 7.18). While the δ^{13}C and δ^{15}N values of this individual (-19.2‰ and 12.2‰ respectively) are not isotopically distinct, they are amongst the most enriched of all the subadult samples over the age of four years (Figure 7.19). The enrichment in both δ^{13}C and δ^{15}N over the herbivore mean (2.6‰ and 5.7‰) suggests this individual may have had a diet that contained ample terrestrial animal protein as well as small amounts of marine protein. While it is possible that this individual's diet may be a reflection of higher status, another possibility for the enrichment of this individual's δ^{13}C and δ^{15}N could be the early date of the burial (mid-second century AD). As discussed in Section 7.4.2, subadults from the early period of Roman London (AD43-250) tend to have slightly higher enrichment of their δ^{13}C values.

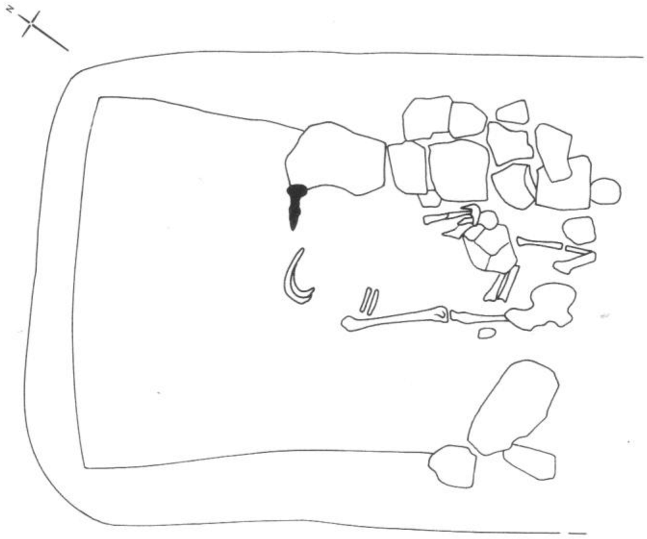


Figure 7.18: Plan of GDV96 56, a 15yr old individual within a stone-lined cist. The burial was subsequently robbed and was subject to post-medieval intrusion that resulted in the loss of the lower half of the burial (Mackinder 2000: 40)

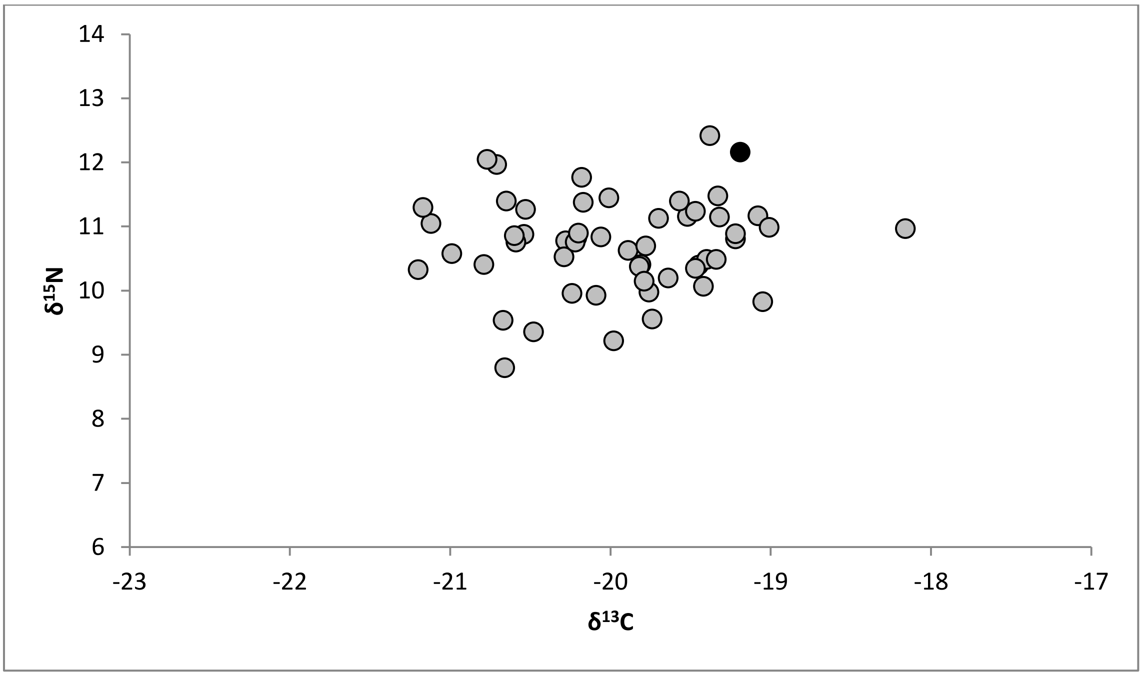


Figure 7.19: Scatter plot of δ^{15}N and δ^{13}C values of subadult special burial types (solid black circle) compared to the remaining Roman London subadults (grey circles)

(ii) Adult Population

Amongst the successful adult samples, three individuals had burial container types that differed from the more prevalent wooden coffins.

MSL87 [2034] was a young adult male dated to the early Roman period (AD 120-200). Although not buried within a coffin, this individual was buried prone with ragstones placed on his back (Figure 7.20). This burial practice was interpreted as a method of containment by the original excavators, though whether this was the intention of the burial practice is uncertain. Despite this unusual burial practice, the δ^{15}N and δ^{13}C values of this individual (10.0‰ and -19.3‰ respectively) were not noticeably different from those of the other adult burials (Figure 7.22). However, a slightly lower enrichment over the herbivore mean of this individual's δ^{15}N value (3.5‰) is observed when compared to the adult average (4.1‰).

The remaining two individuals, also adult males, date to the late Roman period (AD250 – 410), both having burial containers associated with potentially higher status individuals. While no photograph or plan of HOO88 [981]'s burial was published, the container type given by the excavators was that of a tile cist. The use of tile in the construction of burial containers is a particular Roman introduction, associated with strong Mediterranean influences (Philpott 1991: 66-7). MSL87 [720] was buried within a lead coffin 2.43 metres in length and 0.33-0.41m width. The lid of the coffin was particularly well-decorated with a bead and reel and pectin shell motif (Figure 7.21). From Figure 7.22, it is apparent that while these two individuals both have $\delta^{15}N$ and $\delta^{13}C$ values above the adult mean (HOO88 [981] - $\delta^{15}N$ = 11.2‰, $\delta^{13}C$ = -19.1‰; MSL87 [720] - $\delta^{15}N$ = 11.7‰, $\delta^{13}C$ = -19.0‰), they are not the most enriched adults within the sample.

Figure 7.20: Prone burial of young adult male (MSL87 2034) with ragstones placed on the back of the body in order to contain it (Barber and Bowsher 2000: 323)

Figure 7.21: Supine burial of young adult male (MSL87 720) buried within a lead coffin (Barber and Bowsher 2000: 328)

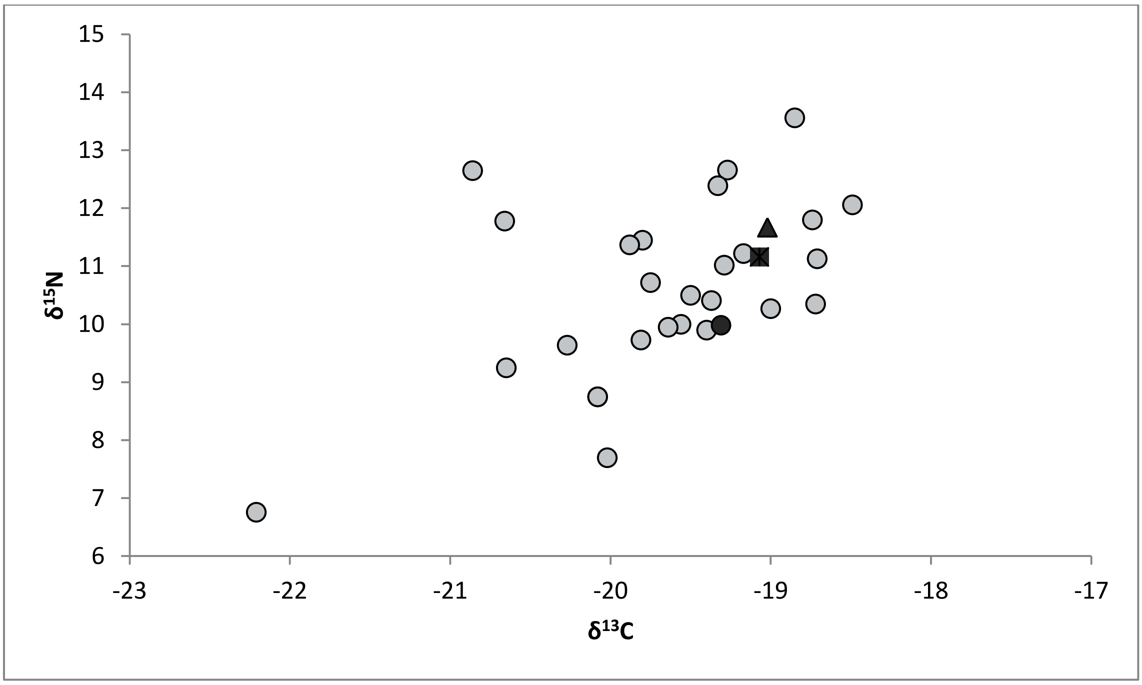


Figure 7.22: Scatter plot of $\delta^{15}N$ and $\delta^{13}C$ values of adult special burial types (solid markers) compared to the remaining Roman London adults (grey circles). Black circle – ragstone, square – tile cist, triangle – lead coffin

7.5.3 Summary

- Both within the total population and amongst subadults, those individuals without evidence for burial containers have slightly higher $\delta^{15}N$ values than those with burial containers. However, this difference albeit statistically significant, for both the total population and subadults, is small, with considerable overlap in isotopic values between groups.
- An analysis of special burial types shows that while both subadults and adults appear with these special burial types and they are amongst the most $\delta^{15}N$ and $\delta^{13}C$ enriched individuals, they are not isotopically distinct.

7.6 Pathology

This final section presents the results of the stable isotope data by pathology. The aim of this section was to identify if the occurrence of the pathologies within the population were associated with dietary differences. Comparisons will first be made for overall pathology, followed by analysis of each individual stress marker addressed within the study. The only exception to this was vitamin C deficiency, as it was not possible to sample any skeleton with this pathology present. For each of the pathological conditions considered, data are first presented for the entire population and then for the subadult population. Presenting the data in this way allows any potential relationships within the subadult age category to be compared to the population as a whole. Within both sets of data, those under four years where excluded to ensure that any potential relationships were not obscured by any enrichment caused by breastfeeding.

7.6.1 Individuals with and without pathology

(i) Total Population

Figure 7.23 plots the δ^{15}N and δ^{13}C data of the sample population by presence and absence of pathology. This comparison shows a considerable overlap in the isotope ratios of both those with and without pathology, with both groups having similar mean δ^{15}N and δ^{13}C values (see Table 7.12). While a larger range of δ^{15}N values is observed for those individuals without evidence of pathology, when LTU03 10 is removed, the range of δ^{15}N values for both groups are very similar. No statistically significant difference was observed between the group medians for either δ^{15}N (U = 733, p = 0.4146) or δ^{13}C (U = 681, p = 0.196). Furthermore, when individual outliers were removed, almost no correlation between the δ^{15}N and δ^{13}C values of either group was observed.

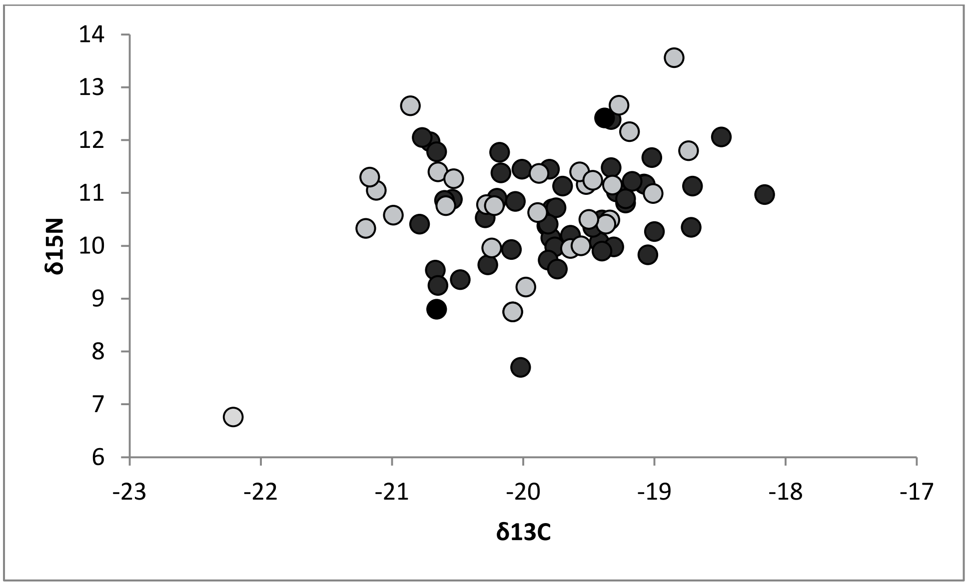


Figure 7.23: Scatter plot of δ^{15}N and δ^{13}C values of the Roman London sample by presence (solid black circles) and absence (grey circles) of pathology.

Pathology	N	δ^{13}C (‰)				δ^{15}N (‰)			
		Min.	Max.	Mean ± 1σ	Median	Min.	Max.	Mean ± 1σ	Median
Present	53	-20.8	-18.2	-19.7 ± 0.6	-19.8	7.7	12.4	10.7 ± 0.9	10.7
Absent	31	-22.2	-18.7	-20.0 ± 0.8	-19.9	6.8	13.6	10.8 ± 1.3	10.8

Table 7.12: Summary statistics for the δ^{15}N and δ^{13}C values of the Roman London sample by presence and absence of pathology

(ii) Subadult Population

Figure 7.24 plots the δ^{15}N and δ^{13}C data of the subadult population by presence and absence of pathology. A comparison of values within this group shows a similar relationship to that observed within the overall population, with both those with and without evidence of pathology having similar mean δ^{15}N and δ^{13}C values (see Table 7.13). No statistically significant difference was observed between those subadults with and without evidence of pathology for either δ^{15}N (U = 262.5, p = 0.208) or δ^{13}C (U = 274.5, p = 0.2976).

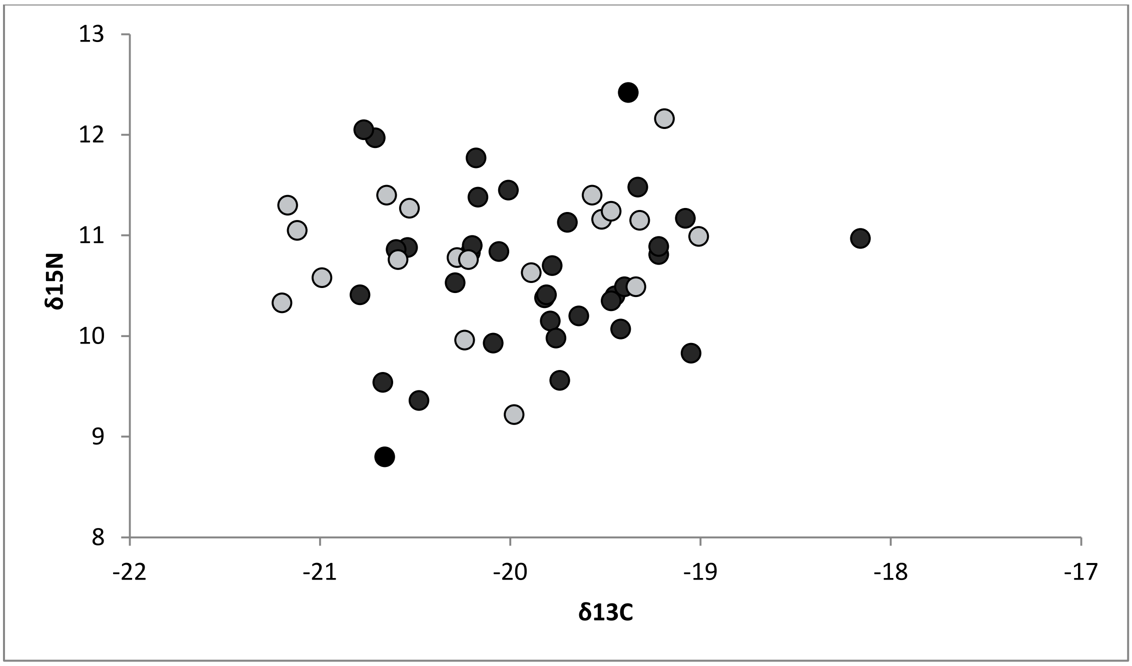


Figure 7.24: Scatter plot of δ^{15}N and δ^{13}C values of the Roman London subadults by presence (solid black circles) and absence (grey circles) of pathology.

Pathology	N	δ^{13}C (‰)				δ^{15}N (‰)			
		Min.	Max.	Mean ± 1σ	Median	Min.	Max.	Mean ± 1σ	Median
Present	35	-20.8	-18.2	-19.9 ± 0.6	-19.8	8.8	12.4	10.7 ± 0.8	10.7
Absent	19	-21.2	-19.0	-20.1 ± 0.7	-20.2	9.2	12.2	10.9 ± 0.6	11.0

Table 7.13: Summary statistics for the δ^{15}N and δ^{13}C values of the Roman London subadults by presence and absence of pathology

7.6.2 *Cribra orbitalia*

(i) Total Population

Figure 7.25 plots the δ^{15}N and δ^{13}C values of the Roman London sample by presence and absence of *cribra orbitalia* and summary statistics are given in Table 7.14. Of the 84 successful samples attained, 54 individuals had at least one orbit present. Of these, 30 individuals were observed to have *cribra orbitalia* in at least one orbit.

While the range of both δ^{15}N and δ^{13}C is slightly larger for those individuals without *cribra orbitalia*, the mean δ^{15}N and δ^{13}C for both those with and without *cribra orbitalia* are the same. Statistical comparisons identified no statistically significant difference between those with and without *cribra orbitalia* for both δ^{15}N (U = 348, p = 0.8413) and δ^{13}C (U = 351.5, p = 0.8892).

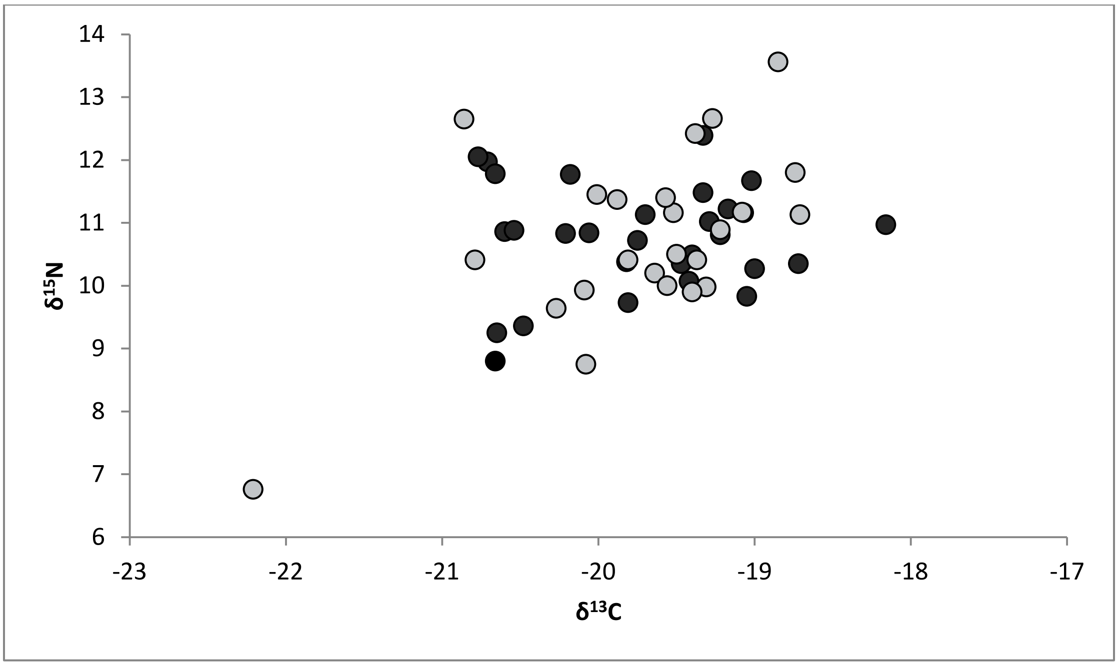


Figure 7.25: Scatter plot of δ^{15}N and δ^{13}C values of the Roman London sample by presence (solid black circles) and absence (grey circles) of *cribra orbitalia*.

Cribra orbitalia	N	δ^{13}C (‰)				δ^{15}N (‰)			
		Min.	Max.	Mean ± 1σ	Median	Min.	Max.	Mean ± 1σ	Median
Present	30	-20.8	-18.2	-19.7 ± 0.7	-19.6	8.8	12.4	10.8 ± 0.9	10.8
Absent	24	-22.2	-18.7	-19.7 ± 0.8	-19.6	6.8	13.6	10.8 ± 1.4	10.7

Table 7.14: Summary statistics for the δ^{15}N and δ^{13}C values of the Roman London sample by presence and absence of *cribra orbitalia*

(ii) Subadult Population

Figure 7.26 plots the δ^{15}N and δ^{13}C values of the subadult population by presence and absence of *cribra orbitalia,* with summary statistics given in Table 7.15. Of the 54 subadults that were successfully sampled, 29 individuals had at least one orbit present. Of these 29 individuals, 19 had *cribra orbitalia* present.

A comparison of the isotopic results for those subadults with and without *cribra orbitalia* shows that those without *cribra orbitalia* had slightly more enriched and narrower ranges of δ^{15}N and δ^{13}C values when compared to those with *cribra orbitalia*. However, in both instances these differences are less than 1‰ and no significant difference is observed between groups for either δ^{15}N (U = 52, p = 0.8195) and δ^{13}C (U = 49.5, p = 0.6826).

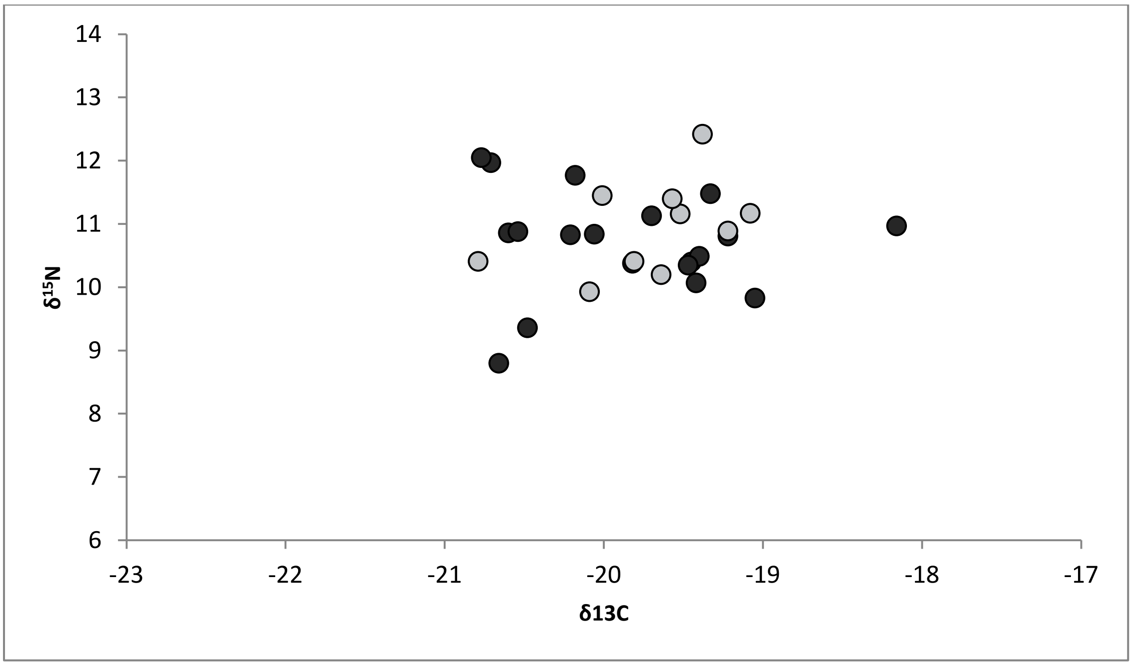


Figure 7.26: Scatter plot of δ^{15}N and δ^{13}C values of the Roman London subadults by presence (solid black circles) and absence (grey circles) of *cribra orbitalia*

Cribra orbitalia	N	δ^{13}C (‰)				δ^{15}N (‰)			
		Min.	Max.	Mean ± 1σ	Median	Min.	Max.	Mean ± 1σ	Median
Present	19	-20.8	-18.2	-19.9 ± 0.7	-19.8	8.8	12.1	10.7 ± 0.8	10.8
Absent	10	-20.8	-19.1	-19.7 ± 0.5	-19.6	9.9	12.4	11.0 ± 0.7	11.1

Table 7.15: Summary statistics for the δ^{15}N and δ^{13}C values of the Roman London subadults by presence and absence of *cribra orbitalia*

7.6.3 Enamel Hypoplasia

(i) Total Population

Figure 7.27 plots the δ^{15}N and δ^{13}C values of the Roman London by presence and absence of enamel hypoplasia. Among those successfully sampled, 71 individuals had at least one tooth present. Enamel hypoplasia was observed in 46 of these individuals.

Despite considerable overlap between groups, the δ^{13}C values of those with enamel hypoplasia tend to be slightly more enriched than those without (Table 7.16). This difference was statistically significant (U = 412, p = 0.01049). No significant difference was observed in the δ^{15}N values between groups (U = 552.5, p = 0.7909).

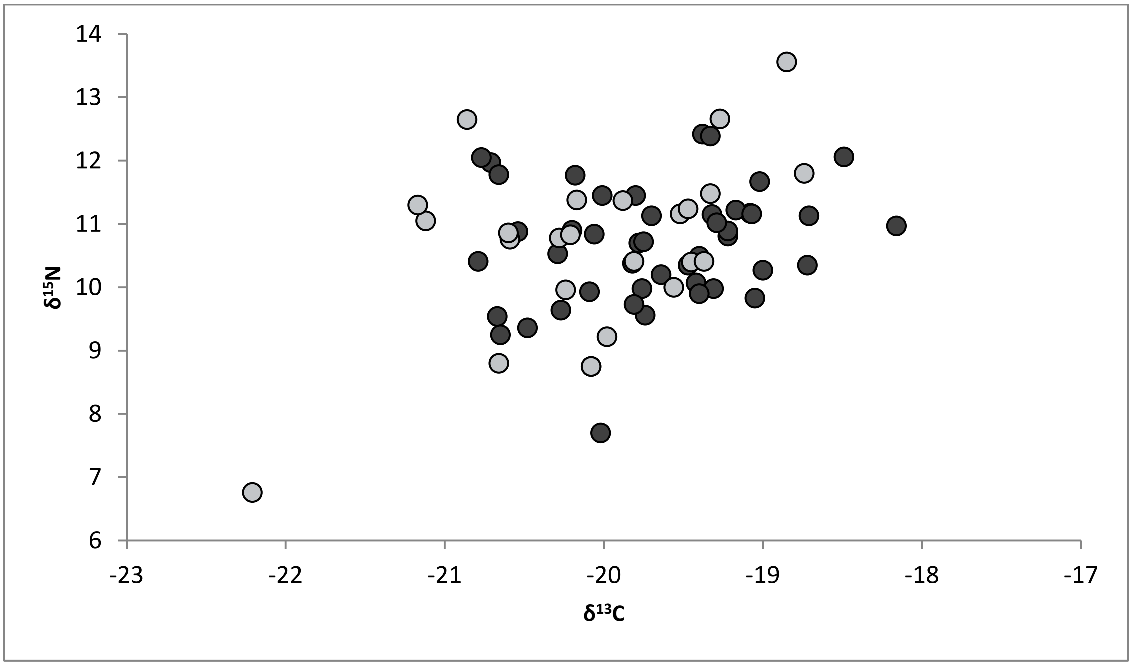


Figure 7.27: Scatter plot of δ^{15}N and δ^{13}C values of the Roman London sample by presence (solid black circles) and absence (grey circles) of enamel hypoplasia

Enamel Hypoplasia	N	δ^{13}C (‰)				δ^{15}N (‰)			
		Min.	Max.	Mean ± 1σ	Median	Min.	Max.	Mean ± 1σ	Median
Present	46	20.8	-18.2	-19.7 ± 0.7	-19.7	7.7	12.4	10.7 ± 0.9	10.8
Absent	25	-22.2	18.7	-20.1 ± 0.8	-20.1	6.8	13.6	10.7 ± 1.4	10.8

Table 7.16: Summary statistics for the δ^{15}N and δ^{13}C values of the Roman London sample by presence and absence of enamel hypoplasia

(ii) Subadult Population

Figure 7.28 plots the $\delta^{15}N$ and $\delta^{13}C$ of the subadult population by presence and absence of enamel hypoplasia, with summary statistics given in Table 7.17. Of the 54 subadults successfully sampled, 43 had at least one tooth present. Of these subadults, 28 individuals were observed to have enamel hypoplasia.

As within the total population, those subadults with enamel hypoplasia have slightly enriched $\delta^{13}C$ values compared to those without. However, this was not significant within the subadult population (U = 144.5, p – 0.09692). Again, no difference was observed in the $\delta^{15}N$ values of those with and without enamel hypoplasia (U = 199, p = 0.7885).

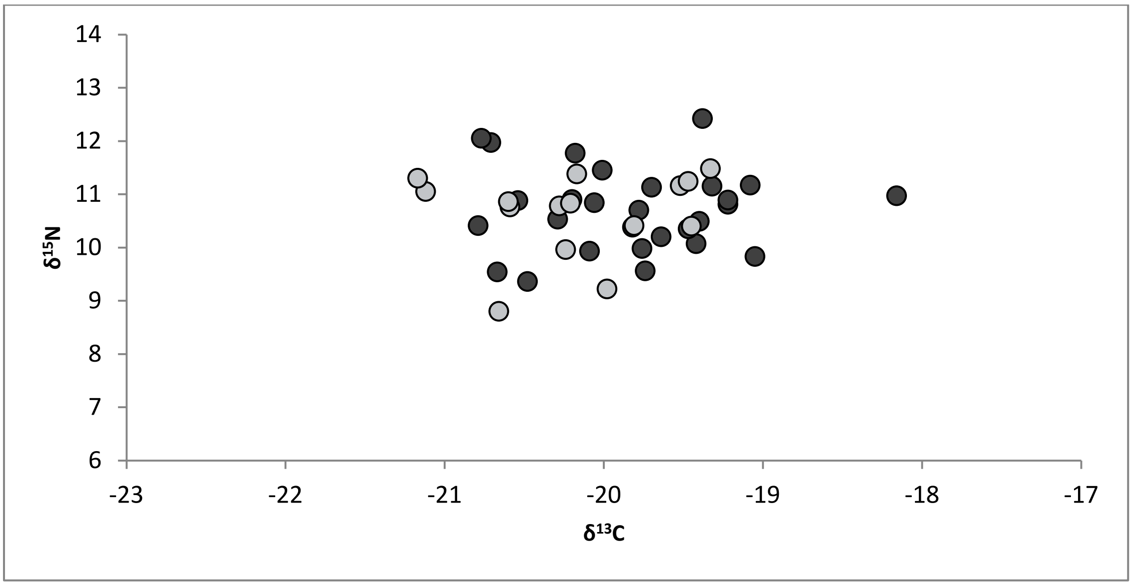


Figure 7.28: Scatter plot of $\delta^{15}N$ and $\delta^{13}C$ values of the Roman London subadults by presence (solid black circles) and absence (grey circles) of enamel hypoplasia

Enamel Hypoplasia	N	$\delta^{13}C$ (‰)				$\delta^{15}N$ (‰)			
		Min.	Max.	Mean ± 1σ	Median	Min.	Max.	Mean ± 1σ	Median
Present	28	-20.8	-18.2	-19.8 ± 0.6	-19.8	9.4	12.4	10.7 ± 0.8	10.8
Absent	15	-19.3	-21.2	-20.2 ± 0.6	-20.2	8.8	11.5	10.7 ± 0.8	10.8

Table 7.17: Summary statistics for the $\delta^{15}N$ and $\delta^{13}C$ values of the Roman London subadults by presence and absence of enamel hypoplasia

7.6.4 Porotic Hyperostosis

(i) Total Population

Figure 7.29 plots the $\delta^{15}N$ and $\delta^{13}C$ values of the Roman London sample by presence and absence of porotic hyperostosis, with summary statistics given in Table 7.18. Of the 84 individuals successfully sampled, 69 had at least one bone from the cranial vault present that could be examine for the presence of porotic hyperostosis. Of these, only one person had the lesion present. A comparison of their isotopic results to the remaining sample shows their $\delta^{15}N$ and $\delta^{13}C$ values are identical to the mean $\delta^{15}N$ and $\delta^{13}C$ of those without porotic hyperostosis, plotting at the centre of the graph. As only one data point represented those with porotic hyperostosis, it was not possible to test for statistical significance.

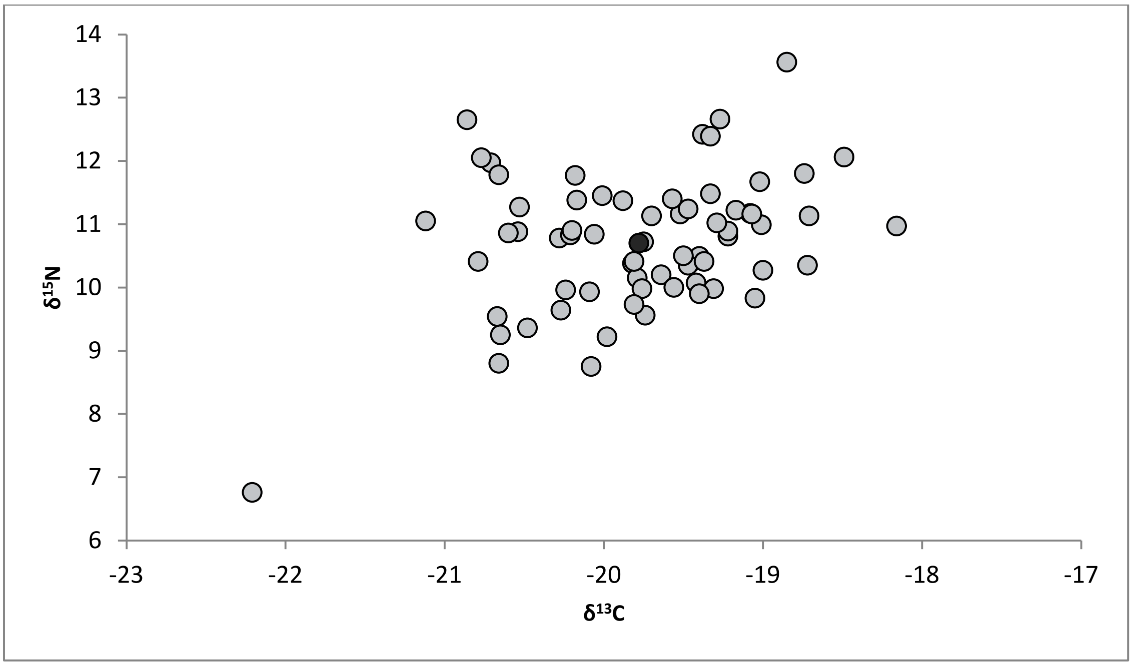


Figure 7.29: Scatter plot of $\delta^{15}N$ and $\delta^{13}C$ values of the Roman London sample by presence (solid black circles) and absence (grey circles) of porotic hyperostosis

Porotic Hyperostosis	N	$\delta^{13}C$ (‰)				$\delta^{15}N$ (‰)			
		Min.	Max.	Mean ± 1σ	Median	Min.	Max.	Mean ± 1σ	Median
Present	1	-	-	-19.8	-	-	-	10.7	-
Absent	68	-22.2	-18.2	-19.8 ± 0.7	-19.7	6.8	13.6	10.7 ± 1.1	10.8

Table 7.18: Summary statistics for the $\delta^{15}N$ and $\delta^{13}C$ values of the Roman London sample by presence and absence of porotic hyperostosis

(ii) Subadult Population

Figure 7.30 plots the δ^{15}N and δ^{13}C values of the subadult population by presence and absence of porotic hyperostosis, with summary statistics given in Table 7.19. Of the 54 subadult sample, 43 had at least one bone from the cranial vault present that could be examined for porotic hyperostosis. Of these, only one subadult had the lesion present.

As within the total population, the subadult with porotic hyperostosis had almost identical δ^{15}N and δ^{13}C values to the average δ^{15}N and δ^{13}C of the remaining subadults amongst whom the lesion was not present. The small number of subadults affected meant it was not possible to test this relationship statistically.

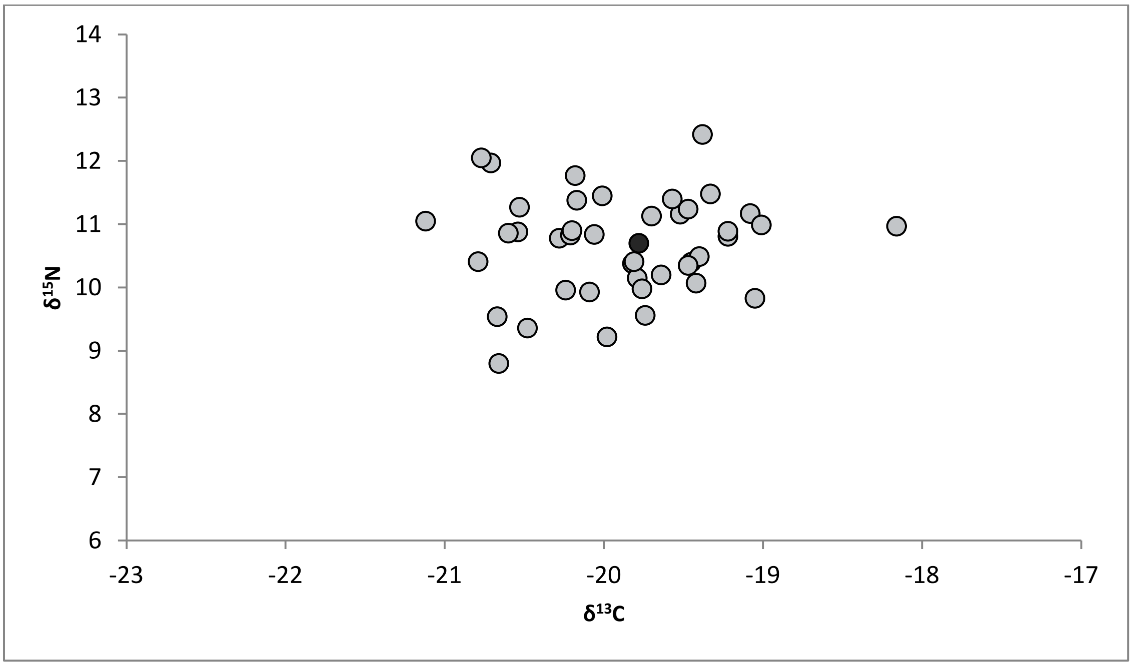


Figure 7.30: Scatter plot of δ^{15}N and δ^{13}C values of the Roman London subadults by presence (solid black circles) and absence (grey circles) of porotic hyperostosis

Porotic Hyperostosis	N	δ^{13}C (‰)				δ^{15}N (‰)			
		Min.	Max.	Mean ± 1σ	Median	Min.	Max.	Mean ± 1σ	Median
Present	1	-	-	-19.8	-	-	-	10.7	-
Absent	42	-21.1	-18.2	-19.9 ± 0.6	-19.8	8.8	12.4	10.7 ± 0.8	10.8

Table 7.19: Summary statistics for the δ^{15}N and δ^{13}C values of the Roman London subadults by presence and absence of porotic hyperostosis

7.6.5 Non-specific Infection

(i) Total Population

Figure 7.31 gives the $\delta^{15}N$ and $\delta^{13}C$ values for the Roman London sample by presence and absence of evidence for non-specific infection, with summary statistics presented in Table 7.20.

A comparison of those with and without non-specific infection shows no differentiation in the isotopic values between the two groups, with both having similar mean $\delta^{15}N$ and $\delta^{13}C$. No statistically significant difference was observed between those with and without evidence for non-specific infection for both $\delta^{15}N$ (U = 618.5, p = 0.149) and $\delta^{13}C$ (U = 691, p = 0.4543).

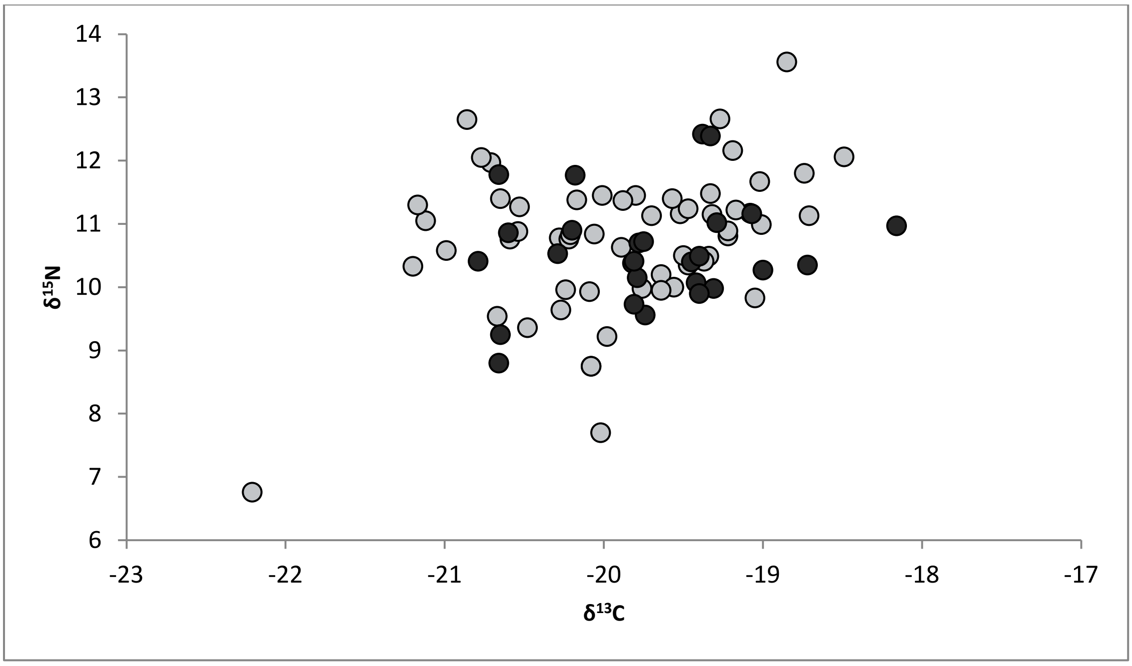


Figure 7.31: Scatter plot of $\delta^{15}N$ and $\delta^{13}C$ values of the Roman London sample by presence (solid black circles) and absence (grey circles) of non-specific infection

Non-specific Infection	N	$\delta^{13}C$ (‰)				$\delta^{15}N$ (‰)			
		Min.	Max.	Mean ± 1σ	Median	Min.	Max.	Mean ± 1σ	Median
Present	27	-20.8	-18.2	-19.7 ± 0.6	-19.8	8.8	12.4	10.6 ± 0.8	10.4
Absent	57	-22.2	-18.5	-19.9 ± 0.7	-19.9	6.8	13.6	10.8 ± 1.2	10.9

Table 7.20: Summary statistics for the $\delta^{15}N$ and $\delta^{13}C$ values of the Roman London sample by presence and absence of non-specific infection

(ii) Subadult Population

Figure 7.32 plots the δ^{15}N and δ^{13}C values of the subadult population by presence and absence of evidence for non-specific infection.

As in the total population, there is a very close similarity between the mean δ^{15}N and δ^{13}C values of those subadults with and without evidence of non-specific infection (see Table 7.21). While the range of values for both δ^{15}N and δ^{13}C is narrower for those without evidence of non-specific infection, no significant difference was observed between the groups for either δ^{15}N (U = 225.5, p = 0.1395) and δ^{13}C (U = 280, p = 0.6562).

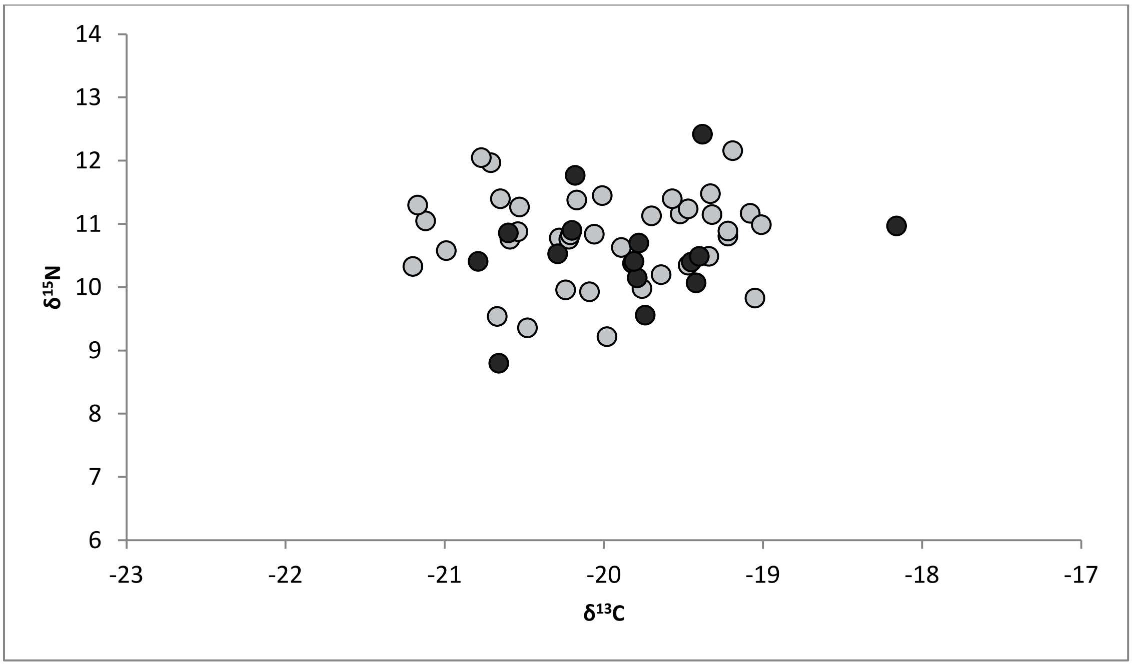


Figure 7.32: Scatter plot of δ^{15}N and δ^{13}C values of the Roman London subadults by presence (solid black circles) and absence (grey circles) of non-specific infection

Non-specific Infection	N	δ^{13}C (‰)				δ^{15}N (‰)			
		Min.	Max.	Mean ± 1σ	Median	Min.	Max.	Mean ± 1σ	Median
Present	16	-20.8	-18.2	-19.8 ± 0.6	-19.8	8.8	12.4	10.6 ± 0.8	10.5
Absent	38	-21.2	-19.0	-20.0 ± 0.7	-20.0	9.2	12.2	10.8 ± 0.7	10.9

Table 7.21: Summary statistics for the δ^{15}N and δ^{13}C values of the Roman London subadults by presence and absence of non-specific infection

7.6.6 Vitamin D Deficiency

(i) Total Population

Figure 7.33 plots the $\delta^{15}N$ and $\delta^{13}C$ values for those with and without evidence for vitamin D deficiency present, with summary statistics given in Table 7.22.

The variation in $\delta^{15}N$ and $\delta^{13}C$ values between groups is small, although those with vitamin D deficiency have slightly higher average $\delta^{15}N$ values compared to those without. The numbers of individuals affected were too small to allow for statistical comparisons.

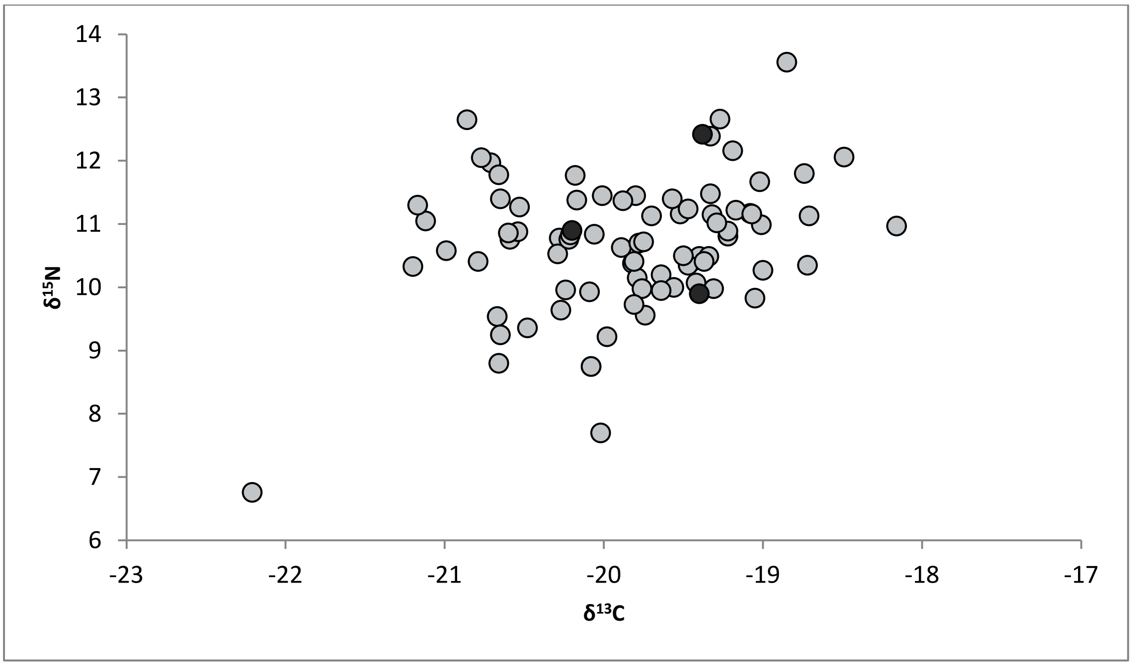


Figure 7.33: Scatter plot of $\delta^{15}N$ and $\delta^{13}C$ values of the Roman London sample by presence (solid black circles) and absence (grey circles) of vitamin D deficiency

Vitamin D Deficiency	N	$\delta^{13}C$ (‰)				$\delta^{15}N$ (‰)			
		Min.	Max.	Mean ± 1σ	Median	Min.	Max.	Mean ± 1σ	Median
Present	3	-20.2	-19.4	-19.7 ± 0.5	-19.4	9.9	12.4	11.1 ± 1.3	10.9
Absent	81	-22.2	-18.2	-19.8 ± 0.7	-19.8	6.8	13.6	10.7 ± 1.1	10.8

Table 7.22: Summary statistics for the $\delta^{15}N$ and $\delta^{13}C$ values of the Roman London sample by presence and absence of vitamin D deficiency

(ii) Subadult Population

Figure 7.34 plots the $\delta^{15}N$ and $\delta^{13}C$ values for subadults with and without evidence for vitamin D deficiency present and summary statistics are given in Table 7.23.

While there is no clear separation between the two groups, the mean $\delta^{15}N$ value (11.7‰) for the two subadults with evidence for vitamin D deficiency are more enriched than those without (10.7‰). Unfortunately, the numbers of individuals affected were too small to allow statistical comparisons.

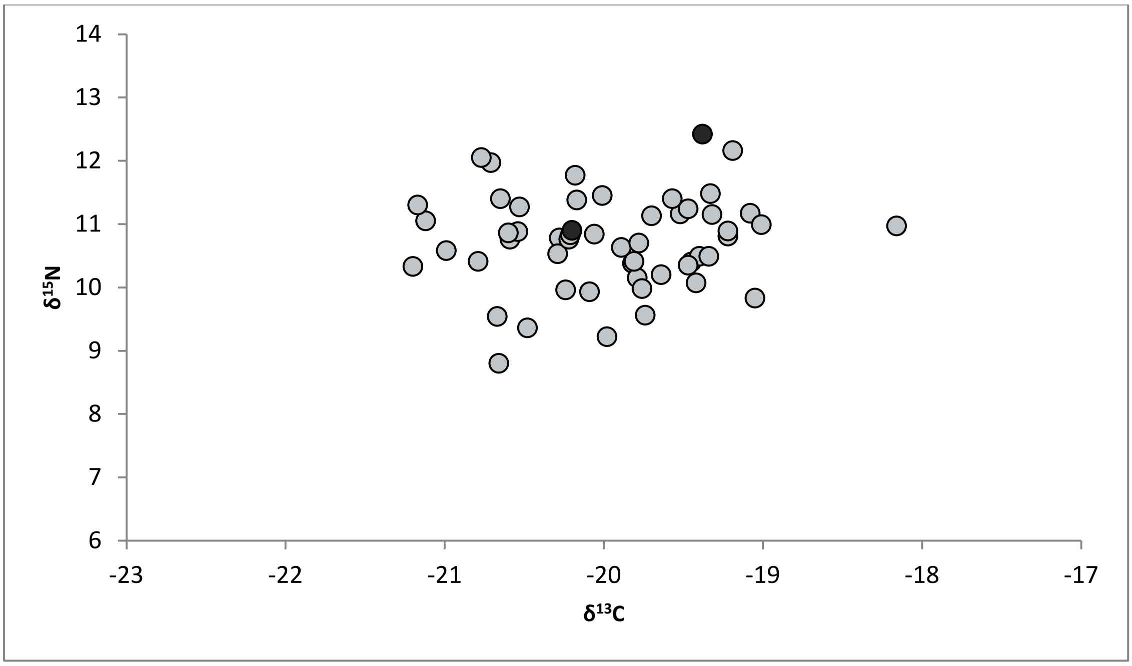


Figure 7.34: Scatter plot of $\delta^{15}N$ and $\delta^{13}C$ values of the Roman London subadults by presence (solid black circles) and absence (grey circles) of vitamin D deficiency

Vitamin D Deficiency	N	$\delta^{13}C$ (‰)				$\delta^{15}N$ (‰)			
		Min.	Max.	Mean ± 1σ	Median	Min.	Max.	Mean ± 1σ	Median
Present	2	-20.2	-19.4	-19.8 ± 0.6	-19.8	10.9	12.4	11.7 ± 1.1	11.7
Absent	52	-21.2	-18.2	-20.0 ± 0.7	-19.9	8.8	12.2	10.7 ± 0.7	10.8

Table 7.23: Summary statistics for the $\delta^{15}N$ and $\delta^{13}C$ values of the Roman London subadults by presence and absence of vitamin D deficiency

7.6.7 Summary

- Comparisons of the $\delta^{15}N$ and $\delta^{13}C$ values for individuals with and without pathology showed no significant difference for total pathology or individual stress indicators. The only exception observed was for $\delta^{13}C$ values and enamel hypoplasia.
- Comparisons of the $\delta^{15}N$ and $\delta^{13}C$ values for subadults with and without pathology showed no significant difference for total pathology or individual stress indicators.

Chapter 8: Discussion

This chapter will integrate the results from the isotopic, funerary and osteological data at Roman London and contextualise and compare the evidence with sites elsewhere in Roman Britain and the wider Roman Empire. The chapter is divided into four main sections. The first seeks to examine the palaeodemographic profile of Roman London and to elucidate and interpret any patterns in the burial record in terms of the representation of different age groups. The second section is the largest and discusses the prevalence of skeletal health stress indicators recorded, and interprets them in relation to living conditions and diet in Roman London. The changing prevalence of these pathological changes will then be discussed further with reference to different life course stages. The isotopic evidence for diet at Roman London will also be interpreted in relation to the archaeological and palaeopathological data, as well as being compared to that observed at other Roman period sites. The third section discusses the temporal trends in the palaeopathological data and dietary intake between the earlier and later periods and whether these mirror the fluctuating fortunes of Roman London. The final section explores the relationship between health, diet and social status, using burial containers as a proxy for status.

8.1 Palaeodemography

8.1.1. Subadult and Adult Representation

Studies of Roman palaeodemography have argued that approximately 33% of the total population would have been under the age of 15 years (Parkin 2003: 36-56; Laes 2011: 28). However, children up to the age of fifteen represent only 22.5% of the total Roman London sample. Furthermore, adults, that form the largest proportion of the Roman population, outnumber subadults under the age of fifteen years by 3.1:1. This result was not unexpected as archaeological populations are rarely representative of the living population from which they are derived, with most displaying unequal subadult to adult ratios (Waldron 1994: 20ff, Chamberlain 2006: 89-92; Saunders 2008: 118f). A comparison of the percentage of subadults and adults from a selection of Romano-British urban sites (Figure 8.1) demonstrates that the under-representation of subadults at Roman London is broadly similar to that found in contemporaneous urban populations in Roman Britain. Of all the sites, the percentage of subadults at Roman London is amongst the highest observed, being much greater than that seen at other sites of comparable legal status, namely Gloucester, York, and Colchester.

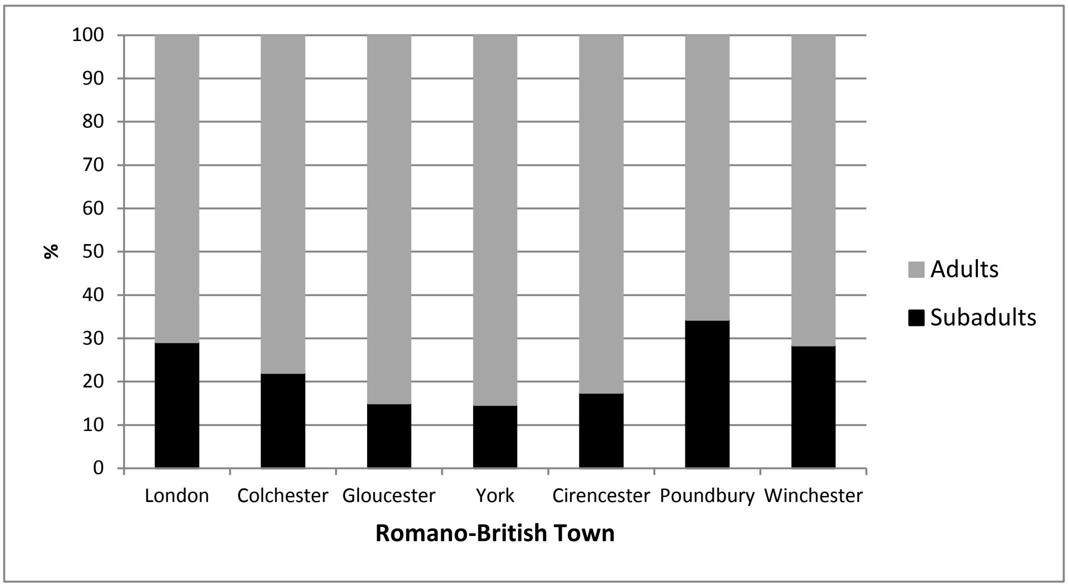


Figure 8.1: Percentage representation of subadults (≤18 years) and adults at a selection of large Romano-British urban settlements (London – this study; Colchester – Pinter-Bellows 1993; Gloucester - Márquez- Grant and Loe 2008; York – Peck 2009; Cirencester – Wells 1982; Poundbury – Molleson 1993; Winchester – Clarke 1979 and Clough and Boyle 2010)

Several factors are implicated in the differential representation of subadults and adults within the Romano-British and Roman London cemetery populations available for analysis. Firstly, in order for an individual to be recovered they must first be afforded a burial, something that is governed by cultural practices and norms. For example, the differential burial treatment of perinates and infants in the Roman world in well known both historically and archaeologically, with these youngest members of the community often being deliberately placed within domestic rather than formal cemetery spaces (see Section 8.3.1 for further discussion). A second factor to be considered is the role of preservation and taphonomy. The underrepresentation of subadults within archaeological populations is often attributed to the greater susceptibility of their skeletal elements to post-depositional diagenesis, due to both their smaller size and lower mineral density (Walker *et al.* 1988; Guy *et al.* 1997; Bello *et al.* 2006; Buckberry 2000) (see Chapter 2 for further discussion). The truncation and post-burial disturbance of graves by later medieval and modern activity, a particular problem in Roman London, is a further potential cause of lost skeletal remains, with the smaller elements of subadults being more susceptible to removal than the larger bones of adults (Morton and Lord 2002: 156; Chamberlain 2006: 89; Roberts 2009: 59). This problem may be further exacerbated by the use of shallower graves for subadult burials, although excavations within the eastern cemetery of Roman London found no clear relationship between age-at-death and the depth of graves in the majority of burial plots (Barber and Bowsher 2000: 83)

The last factor to be considered is recovery bias. Due to the limitations of excavations within a densely packed modern city such as London, full excavation of entire cemeteries is unfortunately not possible. Therefore, if specific areas were designated for subadult burial, a failure to uncover them may account for their underrepresentation within the overall population. The clustering of infant remains in particular is a feature that has been observed at other Romano-British urban and rural sites, becoming more frequent in the later period (Cocks 1921; Scott 1999; Pearce 2001). Even when excavations are conducted, the smaller, less diagnostic elements of young subadults may not be recognised or missed by excavators, particularly if sieving of the grave contents was not undertaken (Guy *et al.* 1997; Saunders 2008: 120; Stodder 2008: 77). In London, many of the excavations within the Roman cemeteries took place in the 1980s and early 1990s, prior to the routine implementation of these excavation techniques. The retention of human remains for analysis may also introduce a further element of bias within the burial population at London. For example, at one of the West Tenter Street sites (WTN84) a total of 113 individuals were identified, and at least twenty-four were subadults (Waldron 1986). However, due to the reburial of the majority of the skeletons, only four skeletons (including one subadult) were available for analysis as part of this study. Many skeletons may have also been lost across the long history of development within the city of London. High status burials in stone and lead coffins appear to have been of particular interest in the Victorian period, with anecdotal evidence that at least some of the uncovered lead coffins were recycled into cigar boxes after the disposal of their contents (Shepherd 1998). While many of these high status burials may have belonged to adults, it is probable that at least some would have contained subadults.

8.1.2 Subadult Age Categories

The demographic profile of subadults within the Roman London sample displays a pattern contrary to that expected. Estimations of mortality rates in the past, based on those derived from modern pre-industrialised populations, identify that the highest mortality risk tends to occur in the youngest age categories, with mortality rates decreasing to their lowest between the ages of ten to fifteen years (Rousham and Humphrey 2002; Chamberlain 2006: 25). As a result, the subadult demographic profile for a Roman population is expected to resemble the first half of a U-shaped profile (Waldron 2007: 35). However, the reverse is seen at Roman London, with the lowest mortality rates being observed within the preterm and full term age categories, increasing to a peak mortality rate in the juvenile age category (Figure 6.1). This pattern is not unique to Roman London, with most of the large Romano-British urban centres of equivalent *colonia* status also displaying a similar demographic profile (Figure 8.2).

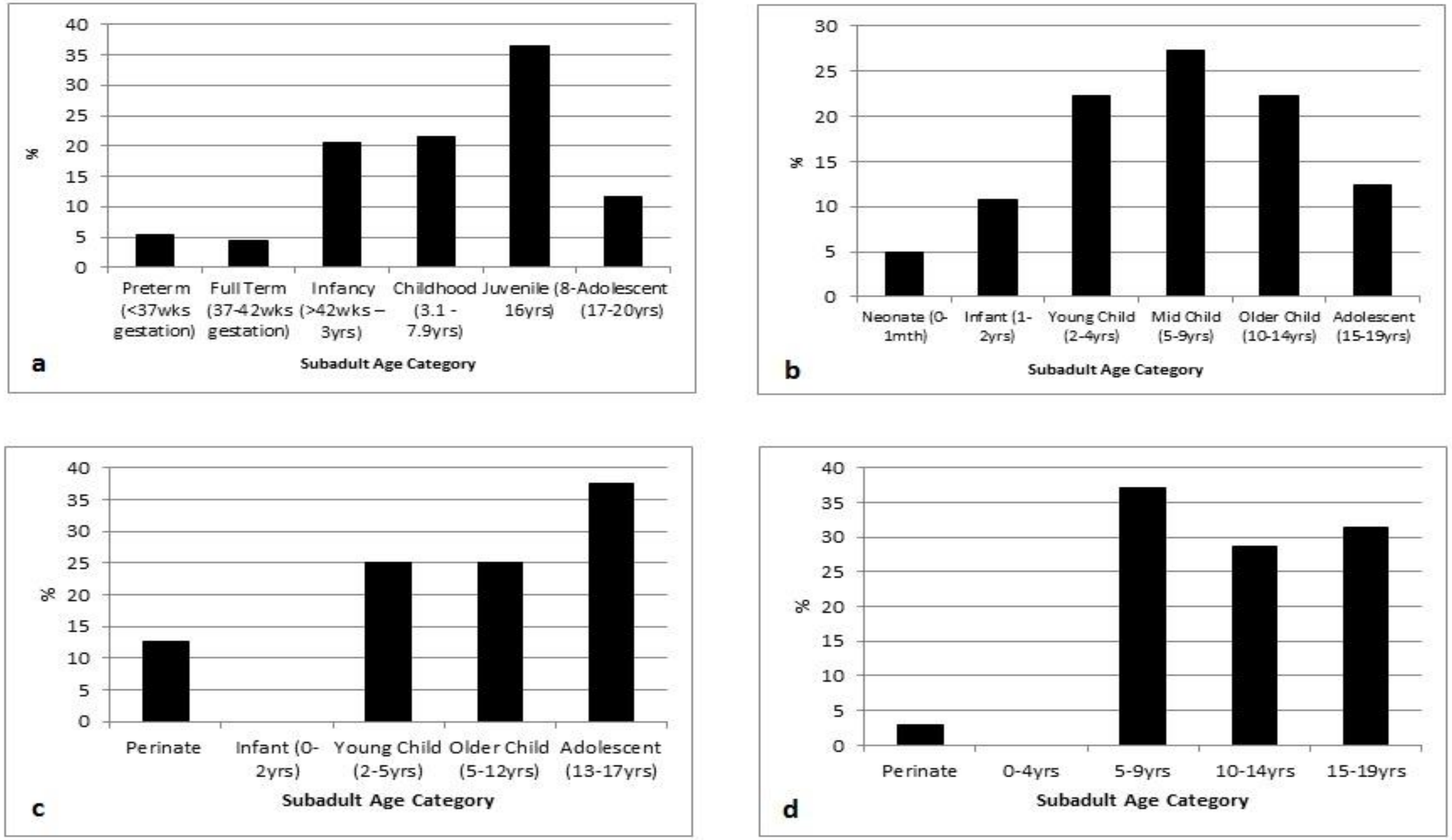


Figure8. 2: Demographic Profiles of Romano-British Settlements as a percentage of the total subadult population: a) Roman London (this study); b) Butt Road, Colchester (Pinter-Bellows 1993); c) London Road, Gloucester (Márquez-Grant and Loe 2008) d) Trentholme Drive, York (Peck 2009).

The main explanation for this reversed pattern appears to be the underrepresentation of infants, namely those aged less than one year at death. Within the Roman period, it is estimated that infant mortality rates would have been in the region of 20-40% (Parkin 1992: 84; Rawson 2003: 104), yet at Roman London infants below the age of one year make up just 4.1% of the total population. However, the underrepresentation of infants within Roman formal cemeteries is not uncommon, with the percentage of infants uncovered at other large Romano-British urban cemeteries being comparable to that seen in London (Figure 8.3). Notable differences are observed at some *civitas* capitals, such as Poundbury and Winchester, though these are still well below that expected. A similar pattern is also observed at Roman cemetery sites on the continent, with infants generally tending to make up less than 10% of the burial population in Italy, Gaul and Germany (Figure 8.3) (Pearce 2001: 32-36; Carroll 2011: 104-105).

The cause of infant underrepresentation within Roman cemeteries is often associated with the differential treatment of infants in burial, particularly with the utilisation of domestic intramural spaces for those under the age of six months (Struck 1993; Scott 1999; Gowland 2001; Pearce 2001; Moore 2009; Gowland *et al.* 2014). Indeed, 29.2% of the preterm and full term subadults within the sample were recovered from contexts within the town. The choice to bury infants within domestic spaces has been linked to a variety of reasons such as exclusion from formal burial rites due to incomplete membership of the community, ritual notions of fertility and rebirth, and the recognition of the domestic sphere as encompassing the social world of the infant (Watts 1989; Mays 1993; 91997; Moore 2009; Gowland *et al.* 2014). At a number of sites in Roman Britain and on the continent, the clustering of infant remains has been observed, both within formal cemeteries and at sites possibly designated as communal infant burial grounds. For example, at Oram's Arbour in Winchester, 65.2% of the total burials belonged to subadults under the age of one year (Pearce 2001: 135). If such practices were also followed at Roman London, it is possible these areas are yet to have been uncovered. However, the recovery of 84.4% of all subadults under the age of one year from the formal cemeteries surrounding Roman London suggests the town's infants were not universally excluded from normal burial rites. As such, the practice of burying infants within intramural contexts cannot solely be responsible for the large underrepresentation of infants within the sample.

Another social practice that has been implicated is infanticide. The likelihood of infanticide being practiced within Roman Britain has been fiercely debated within the osteological literature. The main proponent for infanticide in Roman Britain has been Mays (1993), who identifies a peak in deaths at 38-40 weeks gestation at a range of Romano-British cemeteries and settlements as

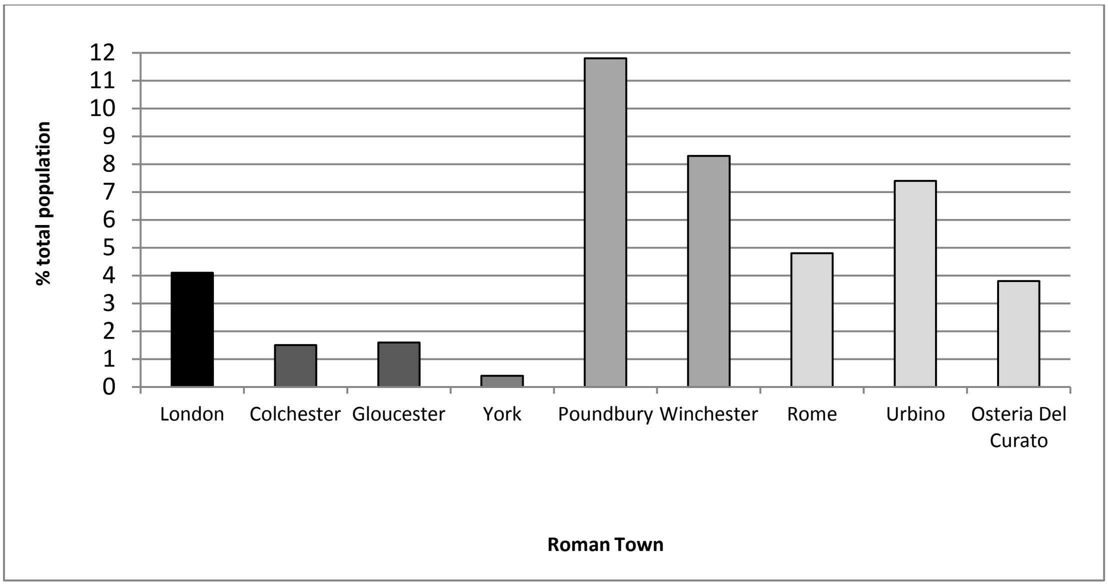


Figure 8.3: Comparison of infant population (one year and under) as a percentage of total population at several Roman cemeteries. Romano- British *colonia* – Colchester (Pinter-Bellows 1993), Gloucester,(Márquez-Grant and Loe 2008) and York (Peck 2009); Romano-British *civitas capitals* – Poundbury (Molleson 1993) and Winchester (Clough and Boyle 2010); and Roman Italian sites – Rome (average compiled by Gowland and Redfern 2010), Urbino (Paine *et al.* 2009) and Osteria Del Curato (Egidi *et al. 2003*)

evidence for its practice. An examination of age-at-death in the preterm and full term age categories identifies a similar peak in deaths at 38-40 weeks at Roman London (see Figure 6.1b). However, such a peak in neonatal mortality is now generally accepted to be the result of age mimicry, with the peak at 38-40 weeks reflecting the sample used to create foetal age standards (Gowland and Chamberlain 2002; Gowland *et al.,* 2014). There is no osteological evidence for infanticide in the cemeteries of Roman London. A more likely alternative explanation is preservation bias.

Subadults in the remaining age categories represent 5-10% of the total population, which is comparable with that seen in previous studies of Romano-British populations (Gowland 2002). While the peak in mortality observed within the juvenile age category may be an artefact of poor preservation in the younger age categories, it may also represent an increase in mortality risk at this age. Within Roman society, the age of seven years is recognised as an important social transition within the life course, when the child leaves the vulnerable stage of *infans* (infancy) and for the first time is bestowed with an engendered identity (Rawson 2003: 134-145; Laes 2011: 84-100). The increased mortality risk observed in this age group may then be the result of the increased freedoms afforded to these individuals. For example, it is within this age category that subadults tended to begin their apprenticeships and enter the world of work although, for many, work would have begun at an earlier age in the home (Bradley 1985; 1991; Krause 2011: 629; Laes

2011: 148-155). These greater freedoms and activities outside of the domestic sphere may have in turn exposed juveniles to greater mortality risks. The subsequent fall in the adolescent age category may be the result of decreased mortality and morbidity risks in this age category. However, it seems probable that the decline in this age category reflects the difficulty in separating the 17-20 year olds from the larger 18-25 year age category in to which the individuals were originally recorded for the WORD database. An examination of the results for childhood health may help to further elucidate some of the palaeodemographic patterns and this will be explored further in the next section.

8.2 Childhood Health and Diet in Roman London

8.2.1 Health

This section will focus on the skeletal indicators of poor health and interpret prevalence rates in relation to the living environment, diet and childcare practices across the subadult life course. The overall pathology rates will be discussed, followed by a brief discussion of the prevalence of each skeletal indicator of stress. This will be followed by a discussion of the range of skeletal stress indicators expressed in each subadult age category.

(i) Subadult and Adult Comparisons

(a) Total pathology

Within the Roman London sample, 51.3% of individuals had evidence for at least one of the stress indicators analysed within this study, suggesting that the population overall was exposed to high levels of physiological stress. Subadults had a slightly higher prevalence of overall stress indicators (54.4%) than adults (50.0%), though this was not statistically significant. The higher rates of overall stress indicators within the subadult compared to adult population were expected due to the greater susceptibility of the growing skeleton to stress and disease (Saunders and Barrans 1999: 184; Lewis 2007: 12; Saunders 2008: 117). In a study of global disease burden, 36% of the total instances of disease and injury were found to affect children below the age of fifteen years (WHO 2008: 42). This rate increases to 39% in low and middle income countries, while falling to almost zero in high income countries (WHO 2008: 49). Further to this, the higher rates of pathological lesions observed in subadults also reflects the fact that the stress indicators chosen for this study relate to the growth period (i.e. *cribra orbitalia*, porotic hyperostosis, and enamel hypoplasia), or have a peak onset during development (i.e. vitamin C and D deficiencies).The lower rates in adults may also be a reflection of the remodelling of lesions once the causative stressor had been overcome. The one exception to this is enamel hypoplasia, as enamel does not remodel over time (although teeth, of course, may wear down), perhaps explaining the higher prevalence rate of this stress indicator in the Roman London adults.

While the presence of stress indicators provides evidence for the impact of a population’s living environment on the community’s total stress burden, the implications of their expression for mortality has been debated. Originally, it was believed that those individuals with stress indicators would have been exposed to the greatest mortality risks, making them more susceptible to future stress and ultimately resulting in them entering the mortality record at an earlier age (Goodman *et al.* 1988). However, this assumption was challenged by Wood *et al.* (1992), as an individual would require an immune system strong enough to withstand the causative stressor long enough for an osseous response to be produced, termed the “osteological paradox” (see Section 2.2.2). Therefore, in order to determine the overall impact of stress indicators on subadult mortality in Roman London, the mean age-at-death of individuals with and without stress indicators were compared. Such comparisons revealed that, for overall stress indicator prevalence and individual stress indicators, those subadults with stress indicators tended to live slightly longer than those without. This result supports the osteological paradox, suggesting that while these subadults were disadvantaged enough to be exposed to “stress”, their immune systems were sufficiently strong enough to withstand the stressor for long enough for it to be expressed in the developing bones and teeth (Wood *et al.* 1992). This is further supported by the significant increase in overall stress indicator prevalence with increasing subadult age, suggesting those subadults who lived to an older age were more robust (i.e. less frail) than those subadults who died within early childhood. However, it is important to note that the subadults in the Roman London sample are ultimately “non-survivors”. Therefore, high rates of stress indicators amongst them does not indicate a greater ability to recovery and adapt to stress when compared to adults, as these individuals ultimately failed to survive into adulthood (see DeWitte and Stojanowski 2015 for further discussion). As such, determinations of mortality risk in individuals with stress indicators amongst these subadults are unlikely to be a true reflection of the living subadult population from which they are derived (Wood *et al.* 1992: 346).

In addition to slightly higher overall stress indicator prevalence rates, subadults were also found to have higher prevalence rates than adults for four of the six individual stress indicators analysed, namely *cribra orbitalia*, non-specific infection, and vitamin C and D deficiencies. In order to explore the implications of these patterns, further consideration will now be given to each of the individual stress markers in turn. Following this will be a brief discussion of the prevalence of different pathological lesions by subadult age category.

(b) *Cribra orbitalia* and Porotic Hyperostosis

The prevalence rate of *cribra orbitalia* in individuals buried in Roman London was high, affecting 46.6% of individuals with at least one orbit present. The significantly higher prevalence rates of *cribra orbitalia* within the subadult population (59.2% compared to 40.7%) conforms to expected epidemiological patterns as *cribra orbitalia* is thought to only actively occur during childhood (Stuart-Macadam 1985: 393-397; Walker *et al.* 2009: 111). This is thought to be due to the redistribution of sites of red blood cell production (erythropoiesis) in the skeleton with increasing age. After the age of four years, the red haematopoietic marrow in the cranium is increasingly replaced by non-haematopoietic yellow marrow, with the main sites of erythropoiesis in adults being relocated to the axial skeleton (Stuart-Macadam 1985: 394; Halvorsen and Bechensteen 2002; Gordon 2005: 2; Higgs and Wood 2005: 13-14; Howard and Hamilton 2013: 2-4). As such, the presence of inactive marrow in the adult cranium makes potential bone alteration less likely, as sufficient space is available for necessary haematopoietic marrow expansion (Stuart-Macadam 1985: 394; Walker *et al.* 2009: 111). The identification of *cribra orbitalia* in adults then is thought to be a reflection of previous childhood anaemia, with prevalence rates lowered by the remodelling of the lesions over time (Stuart-Macadam 1985: 393-397; Walker *et al.* 2009: 111). Sullivan (2005: 253, 266) has questioned the assertion that *cribra orbitalia* only occurs actively in childhood, identifying active adult cases in adults at Medieval York. However, the identification of stages of healing was not possible using data available from WORD. The prevalence rate of porotic hyperostosis in the sample was overall very low (3.8%), but this is not unusual in skeletal populations from temperate Europe (Larsen 1997: 31; Roberts and Manchester 2005: 230). Interestingly, an opposing prevalence pattern between subadults and adults is observed for porotic hyperostosis, with adults having higher prevalence rates (4.2%) than subadults (2.9%), although this difference was not statistically significant.

While there is general consensus that *cribra orbitalia* and porotic hyperostosis occur as a consequence of anaemia, the potential aetiological factors responsible continue to be the subject of debate (Stuart-Macadam 1992; Grauer 1993; Wapler *et al.* 2004; Sullivan 2005; Walker *et al.*, 2009; Oxenham and Cavill 2010; Rothschild 2012). A consideration of the potential aetiology of these lesions in Roman London is given below.

As genetic anaemias are not traditionally endemic within northern European populations (Modell *et al.* 2007: 39-40), their contribution to the prevalence rates of *cribra orbitalia* and porotic hyperostosis in archaeological populations from this region is considered to be low (Stuart-Macadam 1989a: 218). However, a recent re-examination of the Roman subadult population of Poundbury has implicated the genetic anaemia thalassaemia as a potential cause for the increased levels of *cribra orbitalia* and porotic hyperostosis observed in this population (Lewis 2012). Thalassaemia is caused by genetic mutations of haemoglobin chains, resulting in a decrease in the overall haemoglobin content of red blood cells (see Bunn and Nathan 2010 for further discussion). While ß-thalassaemia minor is usually asymptomatic and occurs without skeletal changes, more severe forms of the condition (ß-thalasseamia major and ß-thalasseamia intermedia) can result in skeletal manifestations (Lagia *et al.* 2006: 272). These skeletal lesions, caused by marrow hypertrophy, include: porotic hyperostosis, expansion of the maxilla and intra-orbital space, widening of the ribs, osteopenia, increased porosity and cortical thinning of the long bones, metaphyseal flask deformities, premature epiphyseal fusion, and enlargement of the phalanges (Aufderheide and Rodríguez-Martín 1998: 347; Ortner 2003: 364-367; Lagia *et al.* 2006; Lewis 2012). As the treatment of thalassaemia requires regular blood transfusions (Borgna-Pignatti 2007), it is unlikely those individuals with ß-thalasseamia major in the past would have survived beyond infancy (Ortner 2003: 365). Therefore, those cases identified in past populations probably represent the less severe forms of the condition (Ortner 2003: 365; Lagia *et al.* 2006:272).

Thalassaemia affects populations genetically derived from the Mediterranean basin, South East Asia, Northern Africa and the Indian subcontinent (Angastiniotis and Modell 1998; Weatherall and Clegg 2001). Therefore, its appearance in a population in Roman Britain is attributed to the migration of individuals whose genetic origin is from these regions (Lewis 2012: 691). As stable isotope analyses of the geographic origins of a small number of Roman Londoners have identified individuals originating from regions within the Mediterranean (Montgomery *et al.* 2010; Shaw 2013; Millard *et al.* in prep), it is possible that some people within the town may have been predisposed to this genetic anaemia. Despite this, a diagnosis of thalassaemia has yet to be recorded within Roman London. Furthermore, the prevalence rates of porotic hyperostosis, which is often reported in diagnosed skeletal casestudies of thalassaemia (Ortner 2003: 365; Lagia *et al.* 2006: 273-274; Lewis 2012: 688-690) is considerably lower in Roman London (3.8%) than at Poundbury (31%) (Lewis 2012: 686). However, absence of evidence for thalassaemia in Roman London cannot be considered as evidence for its absence, particularly as more detailed diagnostic criteria have only become more readily known in the last ten years (Lagia *et al.* 2006; Lewis 2012:

685). Unfortunately, the data available from WORD was insufficient to allow further reanalysis of the sample for potential cases of thalassaemia. It is therefore at present impossible to determine the extent to which this genetic anaemia may have contributed to the prevalence rates of *cribra orbitalia* and porotic hyperostosis observed at Roman London.

Unlike genetic anaemia, acquired anaemias comprise a more significant global disease burden (Allen and Casterline-Sabel 2001: 8; Milman 2011: 370; Miller 2013), with epidemiological patterns comparable to the prevalence rates of *cribra orbitalia* and porotic hyperostosis seen in archaeological populations (Stuart-Macadam and Kent 1992; Kent *et al.* 1994; Grauer 1993; Stuart-Macadam 1998; Sullivan 2005). While consensus over the most likely acquired anaemia responsible for the development of *cribra orbitalia* and porotic hyperostosis has yet to be achieved, acquired iron deficiency anaemia and megaloblastic anaemia, due to vitamin B9 and/or B12 deficiencies, have both been implicated (Stuart-Macadam 1992; 1998; Grauer 1993; Sullivan 2005; Walker *et al.*, 2009; Oxenham and Cavill 2010; Rothschild 2012; but see Wapler *et al.* 2004). Regardless, the same risk factors are observed in the development of both of these forms of anaemia, potentially allowing both of them to co-occur in the same individual (Stabler and Allen 2004; though see McIlvaine 2013 for potential issues). Foremost of these risk factors is malnutrition, caused by either inadequate dietary intake or malabsorption due to gastrointestinal infections, chronic disease and/or parasitic infection (Allen and Casterline-Sabel 2001; Fischer Walker and Black 2007; Long *et al.* 2007; Weiss and Goodnough 2005; Ramakrishnan and Semba 2008: 468-7; Balarajan *et al.* 2011: 2126-2130; deGusta 2012; Ngui *et al.* 2012). High pathogen load due to bacterial and/or viral infections has also been identified as a risk factor in the development of iron deficiency anaemia (Weinberg 1992).

Regarding dietary intake, animal products provide the best source of both iron and B12, with leafy green vegetables providing B9 vitamins (Baxter 2007: 299-300, 308; Watanabe 2007). Modern populations that restrict consumption of these products, such as people who are practicing vegans, are more prone to developing iron and B12 deficiency anaemias (Sanders *et al.* 1978; Dyer *et al.* 1982; Ambroszkiewicz *et al.* 2006; Killip *et al.* 2007: 673). Archaeological evidence suggests that all of these food items were available within the town (see Section 4.4). Isotopic analyses conducted as part of this study also confirm that all but one individual had access to some form of terrestrial animal products within their diet (see Section 8.2.2). Based on these findings it appears that the diet of Roman Londoners would have been sufficient to avoid dietary deficiencies of these macronutrients. However, neither isotopic nor archaeological evidence can identify potential periods of food shortages that may have led to the development of potential deficiencies, nor can they provide information regarding the nutritional quality of the diet itself.

Even when dietary intake of iron and B12/B9 are sufficient, gastrointestinal infections and diarrhoea may prevent the adequate absorption of both nutrients in the intestinal tract (Fischer Walker and Black 2005; Long *et al.* 2007). Overcrowding, poor hygiene, and water contamination are seen as the leading predisposing factors for the transmission of gastrointestinal infections in the developing world, accounting for 94% of all cases of diarrhoeal disease globally (O'Ryan *et al.* 2006; Prüss-Űstün and Corvalán 2006: 9; Batchelor and Conway 2008: 219). Environmental analyses of domestic spaces within four large towns in Roman Britain (i.e. York, Lincolnshire, Gloucester, and Colchester) have identified that towns during the Roman period would have been cleaner than their medieval counterparts (Dobney *et al.* 1999). Within Roman London, there appears to have been an emphasis on the removal of waste from the town, with evidence suggesting the state provision and maintenance of a drainage system (Maloney 1990; Williams 2003; Goodman *et al.* 2011: 413; Rogers 2013: 220-221). However, in the majority of cases this took the form of open sewers and drains that ran along the front and back of properties, emptying into the town's rivers (Rowsome 2000: 30-35; Williams 2003; Goodman *et al.* 2011: 413). Effluence from the towns' many industries would have also run into these drains and the town's rivers (*Ibid*). Recent excavations at No.1 the Poultry have identified an absence of cesspits, suggesting these drains, alongside the use of other methods, such as night soiling and dumping in landfill sites, would have formed the main modes of rubbish disposal (Goodman *et al.* 2011: 413).

These waste provisions appear to have been inadequate to prevent contamination, with environmental samples identifying the presence of human and animal faecal matter in domestic spaces (Davis and Smith 2011: 412). These open sewers would also have attracted insects and vermin that carry further health problems, with the remains of black rats and fleas being found within the town (Davis and Smith 2011: 412; Pipe 2011a; 2011b). The keeping of animals within the town would have also contributed to accumulating waste deposits (Scobie 1986; Davis and Smith 2011: 412; Taylor 2015: 74-75). Wacher (2002: 75) has questioned the cleanliness of the streets of Romano-British towns more generally, arguing that they would have been covered in mud, rotting rubbish, and dung. The direct frontage of houses onto these streets would have further facilitated the transmission of contaminants into the living space (Redfern and Roberts 2005: 121). Without modern knowledge of disease transmission, these living conditions would have undoubtedly led to contamination of food preparation and domestic spaces (Jackson 1988: 53; Capasso 2007; Taylor 2015). Under such poor hygiene conditions, contamination of the water supplies with faecal matter and microbial pathogens was also likely, as the wells that formed the main water sources for inhabitants were placed in close proximity to drains and sewers (Williams 2003; Blair *et al.* 2006). This contamination would have allowed water-borne pathogens implicated in diarrhoeal diseases, such as cryptosporiasis, *Escherichia Coli*, cholera, dysentery, and typhoid, to spread amongst the population more easily (Bosch 1998; Ashbolt 2004; Eisenberg *et al.* 2013).

As with gastrointestinal diseases, the potential spread of parasites in Roman London would have also been aided by the contamination caused by these living conditions (Williams 2003; Naish *et al.* 2004; Pedersen *et al.* 2005; 651-2; Hotez *et al.* 2008; Hall and Kenward 2015). Gastrointestinal parasitic infections have also been implicated in the development of malabsorption of both iron and vitamin B9 and B12, either by reducing the bioavailability of these macronutrients or interfering with their absorption (Cordingley and Crawford 1986; Hielt *et al.*1992; Olivares *et al.* 2002; Vuylsteke *et al.* 2004; Barnett *et al.* 2007; Ngui *et al.* 2012; Rodríguez-Guardado 2013). Though palaeoparasitic investigations have yet to be published for Roman London, studies of cesspit deposits and coprolites from other Roman towns have identified a range of parasites, such as whipworm, roundworm and tapeworm, present within the gastrointestinal tracts of Romano-British urban dwellers (Addyman 1989; Jones 1993: 197-8; Dobney *et al.* 1999; Murphy 2007; Hall and Kenward 2015: 100-103). Freshwater fish parasites, such as *Diphyllobothrium latum*, that deplete B12 and, less commonly iron, may also have been found within the subadult population, considering their increased consumption of this food resource (see Section 8.2.2) (Hutchinson *et al.* 1997; Sullivan 2005: 255; Stanciu *et al.* 2009).While the effects of parasites on relatively healthy individuals with sufficient dietary intake will be minimal, chronic infestations can lead to anaemic conditions and exacerbate the condition in those individuals already malnourished and/or weakened by gastrointestinal infections (Paerregaard *et al.* 1990).

Identifying to what extent both dietary deficiencies and malabsorption contributed to high prevalence rates of *cribra orbitalia* is complex, with most studies citing a synergistic relationship between both as the most likely explanation (e.g. Stuart-Macadam 1991; Grauer 1993; Sullivan 2005; Walker *et al.* 2009; deGusta 2012). As discussed above, both causative factors are likely to have been present within Roman London. The higher prevalence rates of *cribra orbitalia* in subadults could be explained by the greater nutritional demands of the growing skeleton and the increased susceptibility of subadults to diarrhoeal diseases, which are a leading cause of death for those under five years in the developing world (O’Ryan 2005; Baxter 2007: 286-287; WHO 2008: 14; Qazi *et al.* 2015: S23). While some may have died prior to the development of skeletal lesions, the high prevalence rate of *cribra orbitalia* suggests many subadults were able to survive acute and chronic episodes of diarrhoeal diseases for at least a sufficient period to allow skeletal evidence to be recorded. Cultural practices, such as the weaning process followed by a population, have also been implicated in the high prevalence of *cribra orbitalia* in young subadults, and will be discussed further in Section 8.2.1 (ii) (b). The post-weaning diet at Roman London was also seen to be more restricted than that consumed by its adults (Section 8.2.2), thereby increasing their risk of developing dietary deficiencies.

In addition to these risk factors, population migration has been suggested as another factor that could explain the high prevalence of *cribra orbitalia* recorded at Roman London. In a previous study of stress indicators in the town, Gowland and Redfern (2010: 30) identified a high prevalence rate of *cribra orbitalia* (56%) that was anomalous when compared to other Romano-British towns (average 0.3-12.5%). Instead, the prevalence rates observed were more analogous with those seen in Roman Italy, where high prevalence rates of over 50% are often recorded due to adverse living conditions and endemic malaria (see Gowland and Garnsey 2010). They therefore suggest that the movement of individuals from areas where these lesions are more prevalent could have increased the overall prevalence rates at Roman London. This was further supported by the higher prevalence rate of *cribra orbitalia* in their adult sample, as it is thought to be an indicator of childhood stress (see above). Gowland and Redfern (2010: 33-34) explain this pattern as a reflection of adults who came to Britain after spending their childhood in areas where *cribra orbitalia* is more prevalent, such as in the Mediterranean region. A high prevalence of *cribra orbitalia* was also observed within the thesis study sample. Furthermore, while significantly higher prevalence rates are recorded for the subadult population, a peak in early childhood is not observed as might be expected, with prevalence rates remaining similarly high in all age categories including adults.

Roman London was original established as a migrant community and archaeological evidence suggests migrants were likely to have continued to make up a part of the population throughout its occupation (see Section 4.1 for discussion). Two small stable isotope investigations have also identified at least seven migrants from Roman London, three of whom came from Rome and the Mediterranean basin and two individuals who appear to have originated from the Germanic region (Montgomery *et al.* 2010; Shaw 2013). The other two individuals appear to have been internal migrants, with one individual appearing to originate from Scotland (Shaw 2013). Preliminary investigations have also identified African migrants within the town (Millard *in prep*). Studies of migrant health have demonstrated that discrepancies in disease prevalence rates between home and host locations can result in migrants increasing overall incidence rates (Gushulak and MacPherson 2006; Knobler *et al.* 2006; MacPherson *et al.*2009). Conversely, migrants to Roman London themselves may have been more susceptible to developing pathological conditions, particularly if they had not been previously exposed to them (Knobler *et al.* 2006). Furthermore, the process of migration itself may also have increased the physiological and psychological stress experienced by migrants, particularly if they were subject to adverse socio-economic circumstances (Ben-Sira 1997; 50-54; Al-Baldawi 2002; Malmusi *et al.* 2010). Indeed, a pilot study of migrant health in Roman Britain found significantly higher rates of stress indicators amongst migrants compared to those identified as native inhabitants (Redfern *et al.* 2015: 116).

However, while migration is a risk factor that should be considered, identifying the extent to which it affected prevalence rates of *cribra orbitalia,* porotic hyperostosis, and the other pathological conditions examined within this study is difficult. While small numbers of stable isotope studies have identified the presence of migrants within Roman Britain (Evans *et al.* 2006; Eckardt *et al.* 2009; Leach *et al.* 2009; Chenery *et al.* 2010; Müldner *et al.* 2011; Cheung *et al.* 2012; reviewed by Eckardt *et al.* 2014), this handful of individuals are insufficient to quantify and examine the true picture of migration within the province. A similar paucity of stable isotope evidence is also observed from Roman populations elsewhere (e.g. Prowse *et al.* 2007; Kilgrove 2010; Prowse *et al*. 2010; Loesch *et al* .2014), making it difficult to assess where and how people were moving across the Empire. As such, identifying the true impact of migration on population health at Roman London is not possible. In order to remedy this, extensive stable isotope analyses are required, both within Britain and the rest of the Empire, something Gowland and Redfern (2010) highlight as essential.

(c) Dental Enamel Hypoplasia

The overall CPR of dental enamel hypoplasia was high, with more than half of the individuals within the sample being affected (57.6%). Such a high frequency of enamel hypoplasia indicates individuals within Roman London were subject to high levels of systemic physiological and/or psychological stress during the period of growth delineated by dental crown development (i.e. < 13 years) (Regezi *et al.* 2000: 151; Ortner 2003: 595; Hillson 2014: 201-204). As an individual must recover in order for a defect to be observed, the presence of an enamel hypoplasia denotes a period of acute non-lethal stress (Goodman and Martin 2002: 27; Kessler 2013: 571). However, determining the most likely aetiologies for the high prevalence rate of enamel hypoplasia within the Roman London sample is complicated by the potential 100 factors implicated in their formation, including: diet, infectious disease, psychological stress and trauma (Cutress and Suckling 1982) (see Section 2.2.3 (ii)).

Malnutrition is regarded as a key causal factor for the development of enamel hypoplasia, due to the increased susceptibility of malnourished individuals to acute infectious disease (Scrimshaw 2003; Moynihan 2009: 84; Schuurs 2012: 60-63; Hillson 2014: 193-194). Archaeological evidence for food provisions within the town suggests a sufficiently wide variety of food items were available to ensure adequate dietary intake (see Section 4.4), whilst isotopic investigations conducted as part of this study confirm the heterogeneous nature of the Roman London diet and the consumption of meat and/or animal products by all individuals (see Section 8.2.2). However, this evidence cannot provide information regarding the nutritional quality of the food eaten or short-term fluctuations in food provisions. Indeed, the presence of metabolic diseases within the sample, indicated by *cribra orbitalia* and vitamin C deficiency, suggests food provision was not adequate for all individuals. The link between gastrointestinal infections and malnourishment within the town has been previously discussed, with archaeological and environmental evidence supporting findings of the likely bacterial contamination of food preparation areas and water supplies (see Section 8.2.1 (i) (b)). In addition to increasing the susceptibility of individuals to further bacterial and viral infections that may disturb enamel development, gastrointestinal infections themselves are also considered to be a likely aetiology for defect formation (King *et al.* 2005: 554; Moynihan 2009: 84; Seow 2015: 8-9). Other types of infectious diseases, caused by these adverse living conditions and the introduction of new pathogens through increased population migration, may also be implicated in the high prevalence rate of enamel hypoplasia seen in the Roman London sample (see Section 8.2.1 (i) (d).

A comparison of the crude prevalence rate of enamel hypoplasia by age group presents a contrasting pattern to that observed with the other stress indicators examined within the study, with adults having a higher prevalence rate (60.2%), than their subadult counterparts (52.0%). An increase in enamel hypoplasia prevalence is also observed across successive subadult age categories. This positive correlation between enamel hypoplasia presence and increasing age seemingly supports the osteological paradox, with those people with evidence of this stress indicator having better immune systems that allowed them to withstand periods of acute stress and ultimately survive to an older age (Wood *et al.* 1992). This is further supported by the much higher mean age-at-death identified for those subadults with evidence of at least one enamel defect compared to those without any (see Table 6.23). An alternative explanation that has been posited for this age-related pattern in prevalence rates is increased population mobility. As has been previously discussed for *cribra orbitalia,* Gowland and Redfern (2010) argue the prevalence rate of enamel hypoplasia within the town may have been increased by the movement of people to Roman London from areas where the prevalence rate of this lesion is particularly high. For example, prevalence rates of over 40% are often recorded in populations from Roman Italy, where the impact of systemic infections, such as malaria, and poor living conditions in overcrowded towns are considered contributory causal factors (Manzi *et al.* 1999; Salvadei *et al.* 2001; Egidi *et al.* 2003; Cucina *et al.* 2006; Belcastro *et al.* 2007; Paine *et al.* 2009). Again, isotopic investigations have identified migrants from this area in Roman London (Montgomery *et al.* 2010; Shaw 2013), and a preliminary study has identified higher rates of this stress indicator in known migrants within Roman Britain (Redfern *et al.* 2015: 116). However, based on the available evidence, the extent to which migration is responsible for the high prevalence rate of enamel hypoplasia seen in the study sample is impossible to determine at present.

(d) Non-specific Infection

Potential evidence for non-specific infection in Roman London was observed in 22.1% of individuals, with similar CPRs being observed for subadults (23.8%) and adults (21.4%). As is observed in other archaeological populations, the tibia was the most commonly affected skeletal element, both within the population overall (TPR = 12.8%) and within different age categories (see Figures 6.9 and 6.10). Of those individuals with tibial involvement, 49.2% were affected bilaterally, which is more commonly seen in systemic infectious conditions (Roberts 2000: 148). Periosteal lesions were by far the most commonly observed pathological change (CPR 21.1%, n = 205), occurring in 95.8% of all affected individuals. The association of periosteal lesions with non-specific infection in skeletal populations is complicated by the multiple aetiologies that have been implicated in their formation, including: trauma, metabolic disease, neoplastic disease, circulatory disorders and skeletal dysplasia (Aufderheide and Rodríguez-Martín 1998: 179; Resnick 2002: 2418; Ortner 2003: 84, 563; Burgener 2006: 131; Brickley and Ives 2008: 56f; Vigorita 2008: 298; Schultz 2012: 261-262; Weston 2012). In an examination of periosteal lesions, Weston (2008; 2009) found there were no aetiologically specific macroscopic or histological features that would allow the differentiation of these multiple causal factors. Therefore, it is possible that the pattern of periosteal lesions observed at Roman London may not be wholly related to infectious processes. However, in a re-evaluation of Weston's (2008; 2009; 2012) critiques, Klaus (2014: 296) maintains when differential diagnosis has ruled out more obvious potential causes of periosteal lesions through careful consideration of lesion morphology and skeletal distribution, non-specific infection remains a viable causative factor. Larsen (2015: 88) also argues that the concomitant risk factors observed in the development of periosteal lesions in archaeological populations, namely: increased population density, increased social contact between communities, poor living conditions, and malnutrition, still makes these lesions an important stress indicator.

After the Roman conquest of Britain, the process of urbanisation that followed would have resulted in the greater aggregation of people in urban centres. The population at Roman London was estimated to be approximately 10,000 by the time of the Boudiccan revolt in AD 60/1, reaching a peak of 25,000-35,000 by the second century AD (Swain and Williams 2008: 39). While this population level is below that seen in the large Mediterranean Roman towns and later medieval and post medieval towns, the accumulation of individuals would have provided a permanent reservoir to sustain pathogens and enabled their spread (Roberts and Manchester 2005: 173; Redfern and Gowland 2012: 123; Larsen 2015: 89). Roman London’s population was also considered to have been heterogeneous, with individuals being drawn to the town from across Britain and the wider empire (Millett 1996; Holder 2007; Montgomery *et al.* 2010; Shaw 2013). Social contact would have also been aided by the increase in trade between provinces, as evidenced by the number of imports observed within the town (Milne 1985: 103-126; Cowan and Wardle 2009; Davis 2011a; Hill and Rowsome 2011: 402-403). This movement of people would have allowed new pathogens and disease vectors to be more easily spread. For example, the remains of a black rat, thought to have been introduced to Britain during this time, were identified at No.1 the Poultry (ONE94) (Rowsome 2000: 34; Pipe 2011a; 2011b).

Within the town, excavations at No.1 the Poultry have provided evidence regarding the densely packed nature of domestic buildings, with houses being closely grouped into grid blocks, divided by narrow alley ways (Perring 2002: 55; Hill and Rowsome 2011). The most common form of housing would have been simple timber structures consisting of a parallel arrangement of rooms (strip buildings), each approximately 2.5-4m^2, with commercial activities located at the front of the property, and domestic activities to the rear, though variations in the number of rooms are observed (Perring 1991: 52; Drummond *et al.* 2002: 36; Perring 2002: 56; Watson with Heard 2006: 39, 72-73; Cowan *et al.* 2009: 86-90; Hill and Rowsome 2011). The average occupancy of each dwelling is thought to have been in the region of 6-12 individuals (Swain and Williams 2008: 38), though if some of the properties provided single room occupancy to families/renters, as has been suggested for some of the dwellings near the forum-basilica (Perring 2002: 193), this number could be higher. While an increase in dwelling size and a movement towards the use of stone is seen in the later period, a continuity in the use of small timber building types for the majority of the population is seen into the fourth century AD (Bluer *et al.* 2006: 69; Goodman *et al.* 2011: 416; Hill and Rowsome 2011: 363, 451). An increase in population density and crowded living conditions has been linked to increased prevalence rates of periosteal lesions, largely due to the provision of inadequate sanitation and the unhygienic living conditions it creates (Roberts 2000: 147; Oxeham *et al.* 2005; Šlaus 2008; Nriagu *et al.* 2010: 358; Gayer 2012: 86-87; Larsen 2015: 88-94). As in previous sections, archaeological and environmental evidence from within the town has identified the presence of faecal material and waste within domestic spaces, and the likely contamination of the town's water supplies by the presence of open sewers/drains and industrial waste (see Section 8.2.1 (i) (b). The keeping of animals within close proximity to dwellings would have also contributed to sanitation issues and potentially introduced zoonoses into the population (Barnes 2005: 137-155; Davis and Smith 2011: 412; Suresh *et al.* 2012; Ulijaszek *et al.* 2012: 177; Taylor 2015: 74-75). Without knowledge of modes of disease transmission, it is likely that these unhygienic living conditions would have exposed many individuals within the town to infection, while greater proximity between individuals would have facilitated the easier spread of pathogens (Lawrence 2002: 404; Roberts and Roberts 2005: 122; Nriagu *et al.* 2010: 358; Gayer 2012: 86-87). The dual purpose use of buildings for commercial and domestic purposes may explain the similar prevalence rates of periosteal lesions that are observed in subadults and adults, as both groups would have been exposed to similar levels of causal stressors. The overcrowded nature of these living conditions and participation in small scale craft and industrial activities may also have increased incidences of trauma, another potential aetiology in the development of periosteal lesions (Grauer 1993; Weston 2012: 501-502)

Another factor that must be considered in the prevalence of infectious disease within the town is dietary intake. Malnutrition is observed to have a synergistic relationship with infection, decreasing a person's immunocompetence and their ability to sustain and fight an infection (Scrimshaw and SanGiovanni 1997; Scrimshaw 2003; Shetty 2010: 1-2; Ulijaszek *et al.* 2012: 177-206). As previously discussed, archaeological and stable isotope evidence suggests the foodstuffs available within the town should have been sufficient to ensure adequate nutrition. However, the identification of vitamin C deficiency and high levels of *cribra orbitalia* within the sample suggests not all individuals would have been well-nourished. Evidence of enamel hypoplasia also suggests the population would have been subject to acute episodes of physiological and/or psychological stress that may have also left them immunologically weaker. The combination of malnutrition and poor living conditions may then be responsible for the prevalence rate of periosteal lesions seen in Roman London. Despite this, many of these stress indicators, including periosteal lesions, require a degree of healing in order for them to be observed (Wood *et al.* 1992). As such, the individuals within the sample with evidence of periosteal lesions would have had a sufficiently strong immune system to sustain a chronic infection (Roberts 2000: 145; Ortner 2008: 196).

The prevalence rate of periosteal lesions is one of a number of indicators that have been used to determine population frailty, with previous studies linking periosteal lesions to elevated mortality risk (DeWitte and Brown 2008; DeWitte 2010; Redfern and DeWitte 2011). This pattern of decreased longevity is not universally observed (see DeWitte 2014). For example, Grauer (1993) identified a positive correlation between periosteal lesion prevalence and increasing age, which she attributed to the accumulation of non-lethal conditions over time. When mean-age-at death amongst the subadult population of the sample is examined, those individuals with evidence of non-specific infection appear to have lived to a slightly older age than those without (Table 6.23). However, while this seemingly supports the osteological paradox, DeWitte (2014) has stressed the importance of considering the age distribution of a population when interpreting periosteal lesion expression. Indeed within the Roman London sample, subadults are slightly more affected than adults, with the highest prevalence rates being observed in the infancy age category. The higher prevalence rate of these lesions within one of the youngest age categories suggests a greater frailty amongst the subadults within the sample (DeWitte and Stojanowski 2015). However, it is acknowledged that the higher prevalence rate in the infancy age category may have been inflated by the misidentification of woven bone caused by normal physiological growth with that of a pathological aetiology (Shopfner 1966; Mann and Murphy 1990; Ribot and Roberts 1996; Lewis 2004; Weston 2012).

(e) Sinusitis and Rib Lesions

Respiratory infections are responsible for 6% of the annual global burden of disease and are a leading cause of death in the under five year age category (Kumar *et al.* 2005: 1; Liu *et al.* 2015). Within the clinical literature, distinctions are made between those infections that occur within the upper respiratory tract (i.e. nose, sinus and throat), such as sinusitis, tonsillitis and laryngitis, and those that affect the lower respiratory tract (i.e. the lungs and airways), such as pneumonia, bronchitis, tuberculosis and brucellosis (Niederman 2010: 1-4). Despite their prevalence, evidence for respiratory infections will only be observed osteologically when these inflammatory conditions are chronic (i.e. longstanding) (Roberts 2007: 795; Ortner 2008: 194). Sinusitis is the most common infection of the upper respiratory tract seen within archaeological populations, with inflammation of the mucous membranes of the sinuses stimulating new bone formation and/or resportive pitting/porosity of the sinus cavity floor and walls (Boocock *et al.* 1995; Merrett and Pfeiffer 2000; Roberts 2007). However, sinusitis may also occur independently of infection, as exposure to environmental particulates (e.g. smoke, chemical fumes, bioaerosols) may also irritate the mucous membrane and stimulate an inflammatory response. Lower respiratory tract infections that cause inflammation of the lungs and/or pleura are identified by porosity and/or new bone formation on the visceral rib surfaces (Roberts *et al.* 1994: 181; Roberts 2000: 151).

Within the Roman London sample, 3.5% of individuals (n = 34) had evidence of sinusitis, with maxillary sinusitis accounting for the majority of cases (91.2%). The prevalence rate of maxillary sinusitis (3.2%) was double that previously reported for the Roman period by Roberts and Cox (2003: 113) (1.8%), though this lower prevalence rate may be the result of a lack of recording of this pathology prior to the 1990s. It was not possible to determine what proportion of sinuses were available for inspection in the sample, or if an endoscope was consistently utilised to inspect completely preserved sinuses. Therefore, the prevalence rates of sinusitis in the sample studied here may be underrepresented. Indeed, in a study that examined maxillary sinusitis in a smaller Roman London subset (n= 88), Bernosky (2010: 144) reported a much higher TPR of 31.8%. Periosteal lesions were also observed on the visceral surfaces of the ribs of 3.2% of individuals within the thesis sample. Again this is higher than that reported by Roberts and Cox (2003: 113). When TPRs are considered, the 5.2% reported here is well below that given by Bernosky (2010:173) for her Roman London subset (17.3%). However, this difference may be a factor of the small size of the subset, drawn from only two of the four Roman London cemeteries.

Indoor air pollution caused by the burning of solid biomass fuels within poorly ventilated properties has been identified as a major risk factor in the development of respiratory problems (Ezzati and Kammen 2001; Bruce *et al.* 2002; WHO 2007: 1; Janjua *et al.* 2012). These biomass fuels, such as wood, dung, and animal and vegetable fats, tend to produce large amounts of smoke particulates and toxic substances that can penetrate the respiratory system and cause irritation within the lungs and sinuses (Fullerton *et al.* 2008; Perez-Padilla *et al.* 2010: 1081). In Roman London, these sources of fuel would have been burnt within open hearths and portable heating sources, such as braziers, as the main source of heating and lighting for the majority of the population (Eckardt 2011: 181; Hill and Rowsome 2011: 294). The use of thatch or slatted roofs without chimneys, and the small room sizes (c. 2.5-4m^2) of the timber structures that were home to the majority of Roman London's inhabitants (Wacher 2000: 72; Perring 2002; Goodman *et al.* 2011), would have prevented adequate ventilation, resulting in a smoky atmosphere and the concentration of particulates within buildings (Roberts and Lewis 2002: 187). Bioaerosols, such as pollen, viruses and fungi, are also health hazards implicated in respiratory infections, which would have been increased by the poor living conditions and population density described in previous sections (Perez-Padilla *et al.* 2010: 1080; Colbeck and Nasir 2010: 49-59). The use of buildings materials, such as wattle-and-daub, and compacted earth and clay flooring would have increased dust particulates within the air, while the keeping of animals within close proximity to the home may have introduced further allergens (Cardoso *et al.* 2013; Reperant *et al.* 2013: 62). The roadside location of many of the properties would have allowed further particulates and bioaerosols from the street to have been more easily introduced into homes (Redfern and Roberts 2005: 121). Damp was also likely to have been a problem within the properties of Roman London, exposing inhabitants to mould spores (Brimblecombe 1987: 5; WHO 2009; Fisk *et al.* 2010). Those inhabitants of more elaborate housing that utilised hypocaust heating systems and better building materials (e.g. stone, tile, and *opus signinum*) may have been less exposed to these particular risks. However, ventilation would have been impaired by the use of stone walls, tiled roofs, and window glass, sealing in and trapping any potential particulates. The use of such building materials for housing, rather than the less well sealed timber properties inhabited by the majority of the Roman London population, may explain the higher prevalence rate of rib periosteal lesions seen at Herculaneum (11.6%), despite the use of similar lighting and heating sources at both towns (Capasso 2000).

As well as domestic sources of indoor air pollution, the economic activities identified within the town, such as metalworking, pottery and glass firing, tanning, and baking (see Section 4.2), would have all produced particulate pollution as well as releasing toxic substances that would have caused further respiratory irritation (Brimblecombe 1987: 6; Wacher 2000: 94-95; Roberts and Lewis 2002: 187; Roberts and Cox 2004: 249; Yu *et al.* 2007: 144; Palmer and Coggan 2013). Tuberculosis, identified skeletally in three individuals within the town, may have also increased the prevalence rate of rib periosteal lesions within the sample. However, despite their association with the disease, rib periosteal lesions cannot be considered pathognomonic of tuberculosis (Molto 1990; Roberts *et al.* 1994; 1998; Roberts 1999).

Within modern epidemiological studies, women and children are found to be most at risk of contracting respiratory infections caused by indoor pollution due to the greater length of time they spend indoors (Bruce *et al.* 2002: 7; Fullerton *et al.* 2008). Within the Roman London sample, subadults were found to have only a slightly higher CPR of rib periosteal lesions (5.6%) than adults (5.0%), with seven of the ten affected subadults being over the age of ten years. For sinusitis, the adults within the sample had a significantly higher overall CPR (4.4%) than the subadults (1.4%). A potential explanation for this difference to expected patterns may be the greater frailty of the young subadults within the sample, who may have succumbed during the acute phase of the infection before skeletal lesions could form. However, the lower prevalence rate of sinusitis within the subadult age category could be a factor of the greater difficulty in recording the pathology in subadults with undeveloped maxillary antra (i.e. < 6 years) (Lewis 2007: 137). By biological sex, over two-thirds of these lesions in adults (70.0% of sinusitis cases, and 66.7% of rib periosteal lesions) were found in the male population, also contradicting modern studies. These findings suggest males were either preferentially exposed to causal risk factors, perhaps through their greater participation in industrial activities than females, or were more able to sustain a chronic respiratory infection. Employment in industrial occupations has also been suggested by Lewis *et al.* (1995) as a potential contributory factor for the high frequency of sinusitis observed in males from medieval York. However, these interpretations are cautiously made in regards to sinusitis in the thesis sample, as the higher prevalence in males may be the result of a greater availability of sinuses for inspection.

(f) Specific Infections- Tuberculosis

Evidence regarding specific infection in Roman London is limited to only three individuals with tuberculosis (0.3%). There was no evidence of any other specific infection, although diseases such as the bacterial infection leprosy and the viral infection of poliomyelitis have been recorded elsewhere in Roman Britain (Roberts and Cox 2003: 120, 127; Bonsall 2013: 275). This low prevalence rate is consistent with the prevalence rates previously identified for tuberculosis in Roman Britain (0.5%) (Roberts and Cox 2003: 120), with only eighteen confirmed diagnoses being published for the period to date (Roberts and Buikstra 2003: 134; Lewis 2011). Further potential cases of tuberculosis have been suggested on the basis of the presence of rib lesions (Lewis 2011: 15), though as previously discussed, rib lesions cannot be considered pathognomonic of tuberculosis (Roberts *et al.* 1998: 60). The low prevalence rate of tuberculosis in Romano-British samples is expected to be an underrepresentation of the total disease prevalence within the population, as only 3-5% of individuals affected will develop skeletal lesions (Jaffe 1972: 953; Resnick and Niwayama 1995: 2462; Roberts and Buikstra 2003: 89), with most individuals dying prior to their formation.

Of the three individuals affected, two were subadults aged four and seven years respectively. Modern investigations of disease epidemiology have identified subadults as being much more likely to develop tuberculosis following infection (infants=43%; 1-5 years = 24%; adolescents 15%)

than adults (5-10%) (Walls and Shingadia 2004: 14; Roberts and Buikstra 2003: 48). Therefore, its diagnosis within the subadult population is expected to reflect a small section of the much larger proportion of adults with or likely to develop the infection (Walls and Shingadia 2004:13). The small numbers of subadults diagnosed with tuberculosis in the Roman London sample is again likely to be an underrepresentation of the true prevalence of the disease. This is because subadults, particularly those under nutritional and physiological stress, are more susceptible to infectious diseases (Lunn 1991; Scrimshaw and SanGiovanni 1997; Scrimshaw 2003), with many probably dying prior to the development of lesions. Cases of tuberculosis in subadults may also be missed due to the more subtle nature of the skeletal lesions themselves (Lewis 2011: 20). The ages of the two subadults affected, somewhat reflects a period of peak onset identified in clinical studies of tuberculosis (i.e. < 5 years) (Donald and Clifton 2010: 1852), but the number of individuals affected within the sample are too small to draw conclusions regarding palaeoepidemiological patterns of the disease in Roman London.

Despite its low prevalence, the identification of tuberculosis within the Roman London population suggests that suitable conditions were present within the town to sustain the pathogen and its transmission. Though the causes of tuberculosis are many and complex, poverty is a risk factor for the development of tuberculosis, due to its association with increased population density, malnutrition, and poor sanitation (Spence *et al.* 1993; Bhatti *et al.* 1995; Elender *et al.* 1998; Oxlade and Murray 2012).

High population densities and overcrowded conditions have been linked to increased prevalence rates of tuberculosis, due to the increased possibility for droplet transmission (Chen 1988; Bhatti *et al.* 1995; Cohen 1989: 47; Clark *et al.* 2002; Roberts and Buikstra 2003: 122; Klaus 2010). The population density in Roman London would have been considerably lower than that observed in modern populations, reaching approximately 20-30,000 people at its peak, with this level only being maintained in the mid-second century AD (Swain and Williams 2008: 39). However, a population of just 180-440 people has been identified as sufficient to allow a host-pathogen relationship to develop (McGrath 1988; Roberts and Buikstra 2003: 119). Further to this, the small rooms and closeness of narrow strip buildings to each other in Roman London, particularly in the early period (Perring 2002: 55-60; 117-118; Goodman *et al.* 2011), would have ensured people within the town would have lived within close proximity and had sufficient social contact to allow the spread of the infection.

Malnutrition, either through poor dietary intake or malabsorption, is known to have an adverse effect on immunity and increase risk to infectious diseases such as tuberculosis (Scrimshaw and

SanGiovanni 1997; Cegielski and McMurray 2004; Wilbur *et al.* 2008). As previously discussed, dietary deficiency, poor sanitation, contaminated water supplies and unhygienic living conditions within Roman London are potentially implicated in the high levels of *cribra orbitalia* and non-specific infection seen within the sample population (see above). As such, exposure to these poor living conditions and their potential health consequences may have also resulted in a weakened immune system and increased susceptibility to tuberculosis for some individuals. Indoor air pollution has also been identified as a risk factor for the development of tuberculosis (Bruce *et al.* 2000; Lin *et al.* 2007; Sumpter and Chandramohan 2013). The primary cause of this association is that pollutants and smoke particles impair the normal clearance of the tracheobronchial mucosal surface, and depress the pulmonary macrophages that normally prevent pathogens from reaching the alveoli (Lin *et al.* 2007: e20). As previously discussed, the same risk factors identified in these studies, i.e. the indoor burning of fuels, industrial pollutants, and poor ventilation within houses, would also have been present within Roman London (see above).

Another disease vector to be considered is the transmission of tuberculosis (M. *bovis*) from infected animals, meat and dairy products (Michel 2015: 894). The stable isotope analyses conducted as part of this study have identified animal products were a feature of the diets of all but one of the individuals examined (see Section 8.2.2). Therefore, it is possible that if these sources of food were contaminated, tuberculosis could have been passed from the animal to the human population (Ayele *et al.* 2004). Living in close proximity to animals, and the presence of occupations that involved working with animals and/or animal products, such as butchery or bone working, within Roman London may have also left its inhabitants exposed to M. *bovis* strains of tuberculosis (Cosivi *et al.* 1998: 64-66; Cowan and Wardle 2009: 111; Davis and Smith 2011: 412; Pipe 2011a; Michel 2015: 896-899). Unfortunately, identifying if animals at Roman London did comprise a significant reservoir for tuberculosis is currently not possible, as few studies of animal bones record palaeopathological findings (Roberts 2011: 270). Ancient DNA sequencing does provide a potential avenue for further exploration of the possibility of different modes of transmission, with recent studies identifying the present of tuberculosis in Roman individuals elsewhere (Muller *et al.* 2014).

In addition to the accumulation of populations within towns, increased communication, trade and movement of individuals during the Roman period would have further aided in the spread of tuberculosis. Studies of historical texts identify tuberculosis, or *phthisis,* as a common problem in Mediterranean communities, perhaps due to the large population densities and poor sanitation of large towns, such as Rome (Meinecke 1927; Sallares 1991: 236-237; Thomas 2006; Bynum 2012:

1-23; Eddy 2015). Though tuberculosis was already present in Britain from at least as early as the Iron Age (Mays and Taylor 2003; Taylor *et al.* 2005), the movement of people from these areas of potentially high prevalence, as evidenced by stable isotope analyses, may have contributed to further disease transmission (Roberts and Buikstra 2003: 6; Gushulak and MacPherson 2006; Lune 2007: 80-82; Migliori 2007; MacPherson *et al.*2009). However, these interpretations can only be cautiously made as identifying disease prevalence from historical records is complicated by incomplete descriptions and potential conflation with other conditions (Aufderheide and Rodríguez-Martín 1998: 125).

(g) Metabolic Disease – Vitamin D and C Deficiencies

The crude prevalence rate of vitamin deficiencies in Roman London appears to be low, affecting only 2.3% (n = 22) of the population. This figure is slightly higher than the 0.8% prevalence rate previously reported for Romano-British populations (Roberts and Cox 2003: 143). However, this increase in the prevalence rate of vitamin deficiencies is expected, as the data collected and recorded in WORD has benefited from improvements in diagnostic criteria for the identification of vitamin C and vitamin D deficiencies over the last fifteen years (e.g. Ortner and Ericksen 1997; Ortner *et al.* 1999; 2001; Brickley *et al.* 2005; 2007; 2009; Brickley and Ives 2006; 2008; Mays *et al.* 2006). However, the diagnoses of metabolic disease can be confounded by the presence of co-morbidities. Malnutrition, either through dietary deficiency or malabsorption due to gastrointestinal infections and/or high parasite loads, is implicated as a factor in the development of both metabolic diseases (Ortner and Mays 1998: 45; Buckley 2000: 499; Ortner 2003: 385ff; Fain 2005; Bikle 2007). As the skeletal lesions of both vitamin D and vitamin C deficiencies share some similarities, it may be difficult to determine which metabolic disease a person suffered from (Ortner and Mays 1998: 45; Ortner 2003: 82; Brickley and Ives 2008: 69-71; Lewis 2010: 408). The possibility of multiple deficiency diseases in the same person must also be considered (Barlow 1883; Follis *et al.* 1940; Ortner *et al.* 2001: 349; Pimentel 2003). The synergistic relationship between malnutrition and infection may further complicate diagnoses (Scrimshaw and SanGiovanni 1997), as periosteal lesions can occur in vitamin C, vitamin D and infectious disease (Brickley and Ives 2008: 69). These complications underline the need for careful examination and differential diagnosis (Ortner 1991).

By age, higher prevalence rates of metabolic disease were identified amongst the subadults (6.0%) than in the adult age category (0.7%). The higher prevalence rate of metabolic diseases in subadults may be a reflection of the greater expression of the associated skeletal lesions within the growing skeleton, making them more readily identifiable (Ortner *et al.* 1999; Ortner 2003: 393-401; Brickley and Ives 2008: 90-91; Van der Merwe *et al.* 2010). Further to this, the remodelling of lesions in adulthood must also be considered as a potential cause for their lower prevalence in this age group.

(h) Vitamin D Deficiency

Within the sample population, the CPR of vitamin D deficiencies was 2.1% (n=20). Whilst more synonymous with the industrialised communities of the post-medieval period, bowing deformities associated with rickets were identified as a problem affecting subadults within the Roman medical texts of Soranus (*Gynecology* II.44.113). The main aetiological factor in the development of vitamin D deficiency is inadequate sunlight exposure (ultraviolet radiation) (Holick 2007). The amount of ultraviolet radiation an individual is exposed to is known to vary by latitude, with northern latitudes receiving low enough concentrations of ultraviolet radiation in winter months to result in seasonal vitamin D deficiency (Chapuy and Meunier 1997; Huotari and Herzig 2008). In Britain, ultraviolet radiation is insufficient for vitamin D production between October and March (Holick and Adams 1998: 128; Shaw and Pal 2002: 148), leaving inhabitants of Britain exposed to potential vitamin D deficiency. While for most individuals this may represent just a seasonal deficiency, migrants with dark skin that move to Britain and other northern latitudes will be more affected by insufficient sunlight levels due to their biological need for longer ultraviolet exposure (Meyer *et al.* 2004; Holick 2005: 2742S; Roy *et al.* 2007). Isotopic investigations have identified individuals that moved from the Mediterranean and northern Africa to both Roman London and other towns in Roman Britain (Chenery *et al.* 2010; Eckardt *et al.* 2010; Montgomery *et al.* 2010; Shaw 2013; Millard *et al.* in prep). However, as previously discussed, the extent to which population migration contributed to the pattern of vitamin D deficiency at Roman London is difficult to determine based on the small numbers of isotopic investigations that have been conducted to date.

In addition to low winter ultraviolet levels, sunlight exposure may have been further limited by the living and working conditions experienced within the town. As discussed above, the houses and workshops of many of the inhabitants of Roman London are likely to have consisted of small rooms with small high-set windows (Perring 2002: 55-60, 117-118; Goodman *et al.* 2011: 425-6), allowing limited sunlight penetration. Therefore, those individuals confined to these spaces for long periods of time, for example through occupational activities, would have been more at risk of developing vitamin D deficiencies. Indeed, Bradley (1991) identified Roman working contracts that required the employee to work from dawn until dusk. Subadults, particularly those who were suffering from illness, may also have been restricted indoors under parental supervision, also exposing them to vitamin D deficiencies. Pollution levels have also been considered a potential cause of reduced sunlight exposure in industrialised post-medieval populations (Mays 2008b: 220-221), as airborne pollutants and smog have been shown to reduce the penetration of ultraviolet radiation and increase vitamin D deficiency in modern populations (Agarwal *et al.* 2002; Hosseinpanah *et al.* 2010; Kurylowicz 2010). Whilst industrial activities identified in Roman London, such as metal smelting (Hammer 2003; Henig 2008; Dungworth and Bowstead Stallybrass 2011; Wardle 2011a), and domestic fuel combustion would have produced airborne pollution (Bruce *et al.* 2000; Smith *et al.* 2000), the concentrations would have been unlikely to have reached those seen in industrial post-medieval cities.

A lesser contributory aetiological factor that should also be considered is diet, contributing to approximately 10% of total vitamin D intake (Holick 2003: 300; Holick 2007: 267; Kurylowicz 2011). Dietary sources of vitamin D include: dairy, fish and eggs (Holick 2006: 2065), all of which were part of the Roman London diet (see Section 8.2.2). While dietary sources may have been ample in the town, gastrointestinal infections and parasitic infestations, already identified as a potential risk factor for health in Roman London, may have also inhibited absorption of calcium from the gut (Bikle 2007; Pappa *et al*. 2008).

The CPR of vitamin D deficiency was highest amongst the subadults of Roman London (5.3%). This CPR is marginally higher than the highest CPR previously reported from a Roman subadult population (i.e. Poundbury - 4.8%) (Lewis 2010: 410). Cultural factors have been implicated in the higher prevalence of vitamin D deficiency in subadults in the Roman period (Redfern and Roberts 2005; Redfern 2007; Lewis 2010; Redfern *et al.* 2015). The process of swaddling in the Roman period is well attested to in historical texts (e.g. Soranus *Gynecology* II.45.114) and archaeological evidence (Dasen 2009: 101-2; Baker 2010: 161; Derks 2014; Graham 2014). Within modern populations, the use of swaddling has been identified as a risk factor for the development of vitamin D deficiency, as the coverings used reduce the skin's sunlight exposure (Yurdakok *et al.* 1990: 874; Styne 2004: 121; Holick 2007: 267). Without direct evidence, it is at present unknown if swaddling was practiced within Roman London, as the extent to which child-rearing practices in Roman Britain were influenced by these historical texts is unknown. However, the presence of migrants within the town, as attested to by stable isotope analysis (Montgomery *et al.* 2010; Shaw 2013; Millard *et al.* in prep), suggests these sort of practices could have been introduced from other parts of the empire and continued by migrant mothers (Redfern *et al.* 2015: 116). Another factor that may have increased the prevalence rate of vitamin D deficiency in children could have been the confinement of “sick” subadults to indoor spaces, reducing their sunlight exposure (Garnsey 2004: 248). As such, the fewer cases of vitamin D deficiency observed within adults may then be a reflection of the fact that those who survived into adulthood were somewhat “healthier” children and therefore less likely to have been confined indoors, reducing their risk of developing a deficiency (Ortner and Mays 1998: 54).

(j) Vitamin C Deficiency

The CPR of vitamin C deficiency in the sample population is low, being observed in only 2 individuals (0.2%). Within both modern and bioarchaeological investigations, scurvy has been most readily identified within malnourished populations (Hampl *et al.* 2001; Levine *et al* 2006) and those exposed to famine (Geber and Murphy 2012) or periods of seasonal/occupational shortages of fresh food (Maat 1982; 2004; Van de Merwe *et al.* 2010). Environmental evidence from archaeozoological and archaeobotanical remains from Roman London suggests that the food items available, such as indigenous and exotic fruit and vegetables, would have been sufficient to provide the levels of vitamin C required to avoid deficiency (Cool 2006: 121f; Cowan and Wardle 2009: 101-2, 115; Davis 2011a: 403-404; Davis 2011b: 410). However, neither environmental nor isotopic analyses can provide evidence regarding access to these food items by all members of the community, nor do they allow the identification of temporary and seasonal fluctuations in food availability which may have led to periodic deficiency. Garnsey (1999: 43-61) argues that undernutrition would have been endemic within the Roman world, with access to food being markedly affected by seasonal fluctuations. These periodic shortages of fresh food would have been particularly adverse to the health of people in urban centres like Roman London, where food access was heavily reliant on market availability, rather than production of their own food (Garnsey 1999: 25; Alcock 2006; Cool 2006: 27-8). As vitamin C is sensitive to heat (Fain 2005: 124), cooking methods practiced by Roman Londoners, such as boiling and roasting over open fires (Cool 2006: 37-55), could have further reduced the vitamin content of their diet (Fafunso and Bassir 1976).

For many individuals, these periodic deficiencies may have only resulted in the development of subclinical signs that leave no traces on the skeleton (Maat 2004; Levine *et al.* 2006: 50; Brickley and Ives 2008: 53-54). Therefore, it is likely that the low prevalence rate of vitamin C deficiency in the sample is an underrepresentation of the TPR of scurvy in the population. The observed prevalence rates may also be reduced by the remodelling of scorbutic lesions following the reintroduction of vitamin C into the diet (Brickley and Ives 2008: 48). Another factor that should be considered in the underrepresentation of scurvy in the skeletal population is its synergistic relationship with infection. As vitamin C plays a fundamental role in immune function, its deficiency has been linked to a potential increase in susceptibility to infection (Bartley *et al.* 1953; Scrimshaw and SanGiovanni 1997: 469S; Jacob and Sotoudeh 2002; Brickley and Ives 2008: 47). Gastrointestinal and chronic diseases may also further exacerbate this situation, by preventing the absorption of ingested vitamin C (Scrimshaw and SanGiovanni 1997: 465S; Buckley 2000: 499). It is therefore possibly that many individuals, particularly more vulnerable subadults, would have died of acute infections before the manifestation of skeletal lesions occurred (Brickley and Ives 2008: 55-6).

The age of the two individuals diagnosed with a vitamin C deficiency within the population, i.e. subadults both aged less than one year at time of death, is consistent with the identification of the peak age of onset at 8-11 months (Fain 2005: 126; Brickley and Ives 2006: 163). That no incidences of vitamin C deficiency were recorded in the adult sample from Roman London may be a reflection of the difficulty in diagnosing the condition in adults, due to the more subtle and non-specific expression of many of the scorbutic lesions seen in this age group (for further discussion see Maat 1982; Brickley and Ives 2008: 61-62; Van de Merwe *et al.* 2010). As breast milk provides an ample source of vitamin C for infant needs (Ahmed *et al.* 2004), vitamin C deficiency is expected to be low in infants that are still being breastfed (Jelliffe and Jelliffe 1978). Therefore, the identification of vitamin C deficiency in infants is linked to the absence of breastfeeding or early weaning onto foods low in vitamin C (Stuart-Macadam 1989a: 202-205; Rajakumar 2001; Lewis 2010: 413). This potential cause of vitamin C deficiency is less likely for Roman London as stable isotope investigations conducted as part of this study have identified that all of the infants examined were consistently breastfed, with the weaning process taking place over an extended period, with complete cessation at around three years of age (see Section 8.2.2). However, as it was not possible to take samples from these two subadults for isotopic analyses, it cannot be ruled out.

A more likely aetiology may be malabsorption of vitamin C due to gastrointestinal infections. The introduction of supplementary foods and liquids into the diet, which appears to have taken place at around six months in Roman London (see Section 8.2.2), is a precarious time for infant health as it potentially exposes them to new pathogens (Katzenberg *et al.* 1996; McDade and Worthman 1998; WHO 2008). Therefore, if the foodstuffs introduced to the diet were contaminated, the concomitant weaning diarrhoeal diseases may have inhibited vitamin C absorption (Buckley 2000:

499). Poor maternal health may also be a factor in the development of vitamin C deficiency, as the vitamin C content of the breast milk of mothers deficient in vitamin C will be reduced (Fain 2005).

Lewis (2010: 415) also considers the low vitamin C content of weaning foods, such as flour-based pap, as another potential source of the high levels of scurvy within the Roman population at Poundbury (4.6%), as well as exposure to gastrointestinal diseases through contaminated food and water introduced at weaning. While it is not possible to identify the nutritional quality of food through stable isotope analysis, this study has identified a weaning and post-weaning diet that was more restricted and isotopically depleted than that eaten by the adult population (see Section 8.2.2). Therefore, it is possible that this more restricted diet may have reduced the subadult access to vitamin C rich foods, though it is unfortunately not possible to confirm this based on this evidence only.

(ii) Subadult Age Categories

In order to address the changing nature of health over the subadult life course in Roman London, this section examines the pattern of pathological lesions observed within the subadult age categories

(a) Preterm (<37 weeks gestation) and Full Term (37-42 weeks gestation)

Globally, 2.6 million stillbirths are recorded annually, with four million newborns dying within the first four weeks of life (Lawn *et al.* 2006: 891; Jehan *et al.* 2009: 130; Samarasekera and Horton 2014: 107). Within the Roman London sample, 1.3% of individuals died at less than 37 weeks gestation, and a further 1.1% died between 37-42 gestational weeks. Mortality risks in this age group can either be attributed to endogenous or exogenous factors, depending on whether the individual survived birth (Saunders *et al.* 1995). Endogenous factors implicated in stillbirths include: poor maternal health, infection, prolonged labour, pre-eclampsia, and congenital defects, many of which leave no trace on the skeleton (Barnes 1994:5; Wutzler and Sauerbrei 1999; Goldenberg and Thompson 2003; Fretts 2005; Nagahawatte and Goldenberg 2008; McClure *et al.* 2009; Lawn *et al.* 2011). Exogenous risk factors following the birth of a child arise due to the exposure of an immature immune system to the external environment, with preterm birth, low birth weight, and severe infections (i.e. tetanus, sepsis and gastrointestinal diarrhoeal infections) producing the highest mortality risks (Ashworth 1998; Scott and Duncan 1999; Stoll *et al.* 2002; Jones *et al.* 2003; Bacak *et al.* 2005; Bryce *et al.* 2005; Lawn *et al.* 2006; Ngoc *et al.* 2006; WHO

2008: 15; Jehan *et al.* 2009). These risks increase dramatically in developing countries due to unsanitary living conditions, contaminated water, and a lack of medical care, with 99% of all neonatal deaths occurring in low-income and middle income countries (Rousham and Humphrey 2002: 126-127; Lawn *et al.* 2006: 891). Identifying the impact of these different risk factors in archaeological populations is difficult, as it is often hard to determine whether an individual was born alive from skeletal remains. One method that can be utilised is to identify the presence of a neonatal line developed within the deciduous dentition by birth trauma, indicating a live birth (Scheuer and Black 2000: 162; Hillson 2014: 100). Unfortunately, this information was not recorded in WORD for the Roman London sample.

An alternative crude estimation of the effects of endogenous versus exogenous mortality factors is to compare the number of deaths occurring at 38-40 weeks gestation to those at 41-48 weeks gestation (Saunders 1992; Lewis 2002: 122). From Figure 6.1b, it is apparent that slightly more subadults died at 38-40 weeks (n = 8) than at 41-49 weeks (n=5), suggesting neonatal deaths due to endogenous factors tended to outweigh those arising from exogenous ones. This is contrary to the expected pattern, as the effects of poor living conditions have tended to result in post-neonatal deaths exceeding pre-natal deaths in past urban populations (Landers 1990; Saunders 1992; Vögele 1994; Lewis 2002: 170). As previously discussed, the higher peak of subadults at 38-40 weeks could be a factor of the age standards used, which tend to bias foetal age determination towards this age category (Gowland and Chamberlain 2002). However, the higher percentage of preterm to full term individuals buried at sites in Roman London, despite these ageing biases, lends further weight to the increased endogenous risk of neonatal deaths, although the obvious underrepresentation of individuals from these age categories and the very small sample size from Roman London may obscure real patterns.

Without the medical intervention available today, many of the endogenous risk factors highlighted above would be fatal to both mother and child (Todman 2008). The birth process, in particular, was notoriously dangerous in the Roman period, with the death of the mother and child being a very real prospect (French 1986; Jackson 1988; Todman 2008; Dasen 2011). The vast number of Roman prayers, votives, and amulets, as well as the number of deities dedicated to the protection of mother and child, are testament to the recognition of this danger (Dasen 2003; 2004; 2009; 2011). While Roman medical texts suggest some medical interventions for obstructed births were known and attempted at this time (Soranus *Gynecology* Book II), they would have been dangerous to the mother (Jackson 1988). Evidence of one such practice, embryotomy, has been identified at Poundbury (Molleson and Cox 1998) and Hambledon Villa (Mays *et al.* 2014), suggesting such medical expertise was available in Roman Britain, though its implementation would have been fatal for at least the foetus.

Further skeletal evidence for death during pregnancy or childbirth is rare, though a small number of double burials of adult females and foetal remains within Roman cemeteries have been discovered. (see Carroll 2011; 2014 for reviews). One instance of a potential mother-infant burial has been identified within the Roman London sample. At Great Dover Street, a preterm subadult (GDV96 [347]), aged at 28 gestational weeks, was found buried at the foot of a young adult female (GDV96 [325]) (Figure 8.14) (Mackinder 2000: 32). However, in none of these cases were the foetal remains discovered within the pelvic cavity or birth canal. Without a direct association, the connection between the remains is uncertain, as neonates and infants are also known to have been placed within the graves of seemingly unrelated adults (e.g. Farwell and Molleson 1993: 151).

Evidence of stress indicators within these age categories is low, with only three individuals being affected. *Cribra orbitalia* was identified in one preterm subadult aged at 32 gestational weeks (HOO88 [843]) and one full term subadult aged at 40 gestational weeks (LTU03 [170]). The presence of *cribra orbitalia* at such a young age implicates poor maternal health and nutrition, with maternal vitamin B12 and B9 deficiencies both resulting in low foetal stores of these vitamins (Molloy *et al.* 2008; Fekete *et al.* 2010; Blackburn 2013: 227; Sande *et al.* 2013). However, foetal iron deficiency appears to only occur in severe cases of maternal deficiency, as sufficient foetal iron levels have been recorded in iron-deficient mothers (Dallman *et al.* 1980; Wadsworth 1992; Lewis 2007: 113). Periosteal lesions were found in two full term individuals aged at 40 gestational weeks (LTU03 [170] and KWS94 [3985]). In both cases, new bone formation was observed on the endocranial surfaces of multiple cranial bones. As previously discussed, the identification of non-specific infection in very young individuals is complicated by the presence of woven fibre bone deposited as part of the normal growth process (Shopfner 1966; Ribot and Roberts 1996; Lewis 2004). In a study of endocranial lesion aetiology, Lewis (2004: 94) found diffuse new bone formation across multiple cranial bones in preterm and full term subadults was most likely due to rapid growth. However, she also notes that intra-cranial haemorrhage, caused by mineral deficiency and birth trauma, can cause endocranial lesions within this age group (Lewis 2004: 94). Based on the available information, it is not possible to determine which of these causes was most likely, although the identification of *cribra orbitalia* in LTU03 [170] suggests at least one of these subadults was nutritionally deficient.

(b) Infancy (>42 weeks gestation to three years)

The prevalence rate of stress indicators within the infancy age category is high, with more than half of all individuals having osseous evidence of at least one of the recorded pathologies. Traditionally, high frequencies of stress indicators in this age group are attributed to weaning stress, with the type of feeding strategies employed by a community influencing the overall health of their infants (Dettwyler 1995). A detailed discussion of infant feeding practices in Roman London is presented below (see Section 8.2.2 (ii) (a)), but a brief consideration of the health implications of these practices will be provided here.

The choice of whether to breastfeed an infant is a significant determinant in infant health outcomes. Breast milk contains the optimum level of vitamins, minerals, and nutrients required for the first six months of growth, with their arrangement ensuring maximum bioavailability and the most efficient absorption possible (Laurence and Laurence 2011: 215; 2013: 112; Brown *et al.* 2014: 172-173; Gaimard 2014: 54; Koreti and Prasad 2014: 1634). Breast milk also contains a variety of immunological components derived from the mother, including leukocytes, antibodies and antimicrobial factors, which boost the infant's immune system and provide passive immunity from common infections as well as non-infectious illnesses, such as asthma (Sachdev and Choudhury 1994: 418; Laurence and Laurence 2011: 216; Gaimard 2014: 54). An absence of breastfeeding and the use of nutritionally inadequate alternatives have been identified as major risk factors for infant morbidity and mortality (Katzenberg *et al.* 1996; McDade and Worthman 1998; Kramer and Kakuma 2004: 63; WHO 2002: 56; Doherty 2011: 181; Gaimard 2014: 54). For example, the use of goat and cow's milk as a substitute for breast milk has been linked to the development of megaloblastic and iron deficiency anaemia, due to the low bioavailability of iron and B vitamins within it (Oliveira and Osório 2005; Basnet *et al.* 2010; Ziegler 2011; Carmell *et al.* 2015: 333). Cow's milk is also known to cause gastrointestinal bleeding and diarrhoea in infants, further inhibiting the absorption of nutrients (Oliveira and Osório 2005; Ziegler 2011). The rapid growth experience during this early period will exacerbate these nutritional deficits in infants, with those born prematurely or at a low birth weight being particularly vulnerable (Ryan 1997: 38; Allen 2005: 1207S-1208S; Carmell *et al.* 2015: 332). Within developing countries where living conditions and hygiene are poor, the likely contamination of alternative and supplementary food and drink will increase these risks dramatically, with infants being exposed to bacterial and parasitic infections that may overwhelm their immature immune systems (Katzenberg *et al.* 1996: 180; McDade and Worthman 1998; Reddy and Lakshmamma 2008: 30).

The adoption of Roman feeding practices has been linked to adverse infant health in bioarchaeological investigations. For example, Fairgrieve and Molto (2000) suggest the early introduction of goat's milk, as advised by Soranus (*Gynecology* II. XI [xxxi]), into the diet of infants at the Dakhleh Oasis, Egypt, may have been responsible for the identification of *cribra orbitalia* at six months of age. A significant proportion of the infants buried in Roman London were also affected by *cribra orbitalia* (55.2%), and in some individuals these lesions developed before the age of six months. However, the use of alternatives to breast milk appears to be an unlikely cause of these lesions, as the isotopic evidence suggests the infants of Roman London were breastfed, though it is not possible to rule out the use of additional food sources alongside breast milk. An alternative explanation could be poor maternal health, as infants of healthy mothers will amass sufficient stores of macronutrients *in utero* to prevent deficiencies developing before the age of six months (Saarinen 1978; Allen 2005: 1207S). Maternal malnourishment will also reduce the macronutrient content of breast milk, increasing the likelihood of developing iron and vitamin B deficiency anaemia in those with already low foetal stores (Allen 2005: 1208S). Poor maternal health and breast milk macronutrient content may also be implicated in the development of vitamin C deficiency in two infants in the sample aged less than a year old (see Section 8.2.1 (i) (i)) (Allen 2005: 1280S; Donovan 2008: 348).

Another Roman infant feeding practice that has received particular attention in the consideration of infant health is the practice of denying colostrum (Fildes 1986; Holman 1998; Garnsey 1991: 58-59; Garnsey 1998: 270; Harlow and Laurence 2002: 41; Prowse *et al.* 2008: 305; Lewis 2010: 413; Gowland and Redfern 2012: 125). Colostrum is a viscous substance that is produce in the first few days post-partum. In addition to having a high carbohydrate and protein content, colostrum also contains high levels of antibodies and immunological factors that activate the infant's immune system (Jelliffe and Jelliffe 1978; Ley 2000: 17-24; Uruakpa *et al.* 2002; Brink 2013: 74). These antibodies line the infant intestine and help prevent harmful microorganisms from enteric diseases, such as salmonella and *Escherichia coli*, from developing (Hoshower 1994; Ley 2000: 17-24; Lewis 2007: 99). In addition to this, colostrum stimulates peristalsis and encourages the infant's first bowel movement, which aids in the removal of meconium and excess blood cells in the intestine, preventing jaundice (Stuart-Macadam 1995: 8; Brink 2013: 75). Therefore, the exclusion of colostrum could have potential life limiting consequences for infants. Within some societies colostrum is seen to be an unfavourable and poisonous substance for babies (Stuart-Macadam 1995: 9). The evidence for the denial of colostrum in the Roman period is derived predominately from Soranus, who considered it to be *'unwholesome, being thick, too caseous, and therefore hard to digest, raw, and not prepared to perfection*' (*Gynecology* II. 18[87]). If colostrum was denied to the infants at Roman London, it may have been a contributory factor for the high level of stress indicators observed within this age category (Garnsey 1991: 59). However, the extent to which this practice was followed in Roman London is unknown (see section 2.3.3 (v) for discussion) and no evidence for it has been identified in Roman Britain to date.

After six months of age, supplementary food is required to ensure infants continue to receive adequate nutrition (Sachdev 1994: 105; Desal 2000: 378; Liamputtong 2007: 16). The isotopic analyses conducted as part of this study suggest supplementary food was introduced into the infant diet at about this age in Roman London. As discussed above, the introduction of supplementary food and drink is a particularly hazardous milestone, often referred to as the 'weanling's dilemma' (Jelliffe and Jelliffe 1978; Katzenberg *et al.* 1996: 180; King and Ulijaszek 2000; Lewis 2007: 100). The poor hygiene and water contamination observed in Roman London would have increased the infant's exposure to parasitic and gastrointestinal infections and, as a consequence, malnutrition. The use of nutritionally poor weaning foods, such as flour-based gruels and pap, could also contribute to malnutrition deficiencies, such as *cribra orbitalia* and scurvy (Katzenberg *et al.* 1996: 182; Onofiok and Nnanyelugo 1998; Lartey 2008; Lewis 2010: 413). The isotopic analyses conducted for this study suggest that the supplementary food used at Roman London was largely C_3 plant-based, with the overall diet of subadults appearing to be more restricted than that of the adults. While it is difficult to determine the nutritional quality of the weaning food used through isotopic analyses, the restricted nature of the diet might have meant subadults did not have access to a wide range of foods. The combination of malnutrition and gastrointestinal infections may have also been a contributory factor to the peak in vitamin D deficiencies observed in this age category, reducing the amount of calcium absorption taking place within the intestine. However, as a lack of sunlight exposure is considered the most common aetiology (Holick 2007), cultural practices like swaddling must also be considered (see Section 8.2.1 (i) (h) for further discussion).

The synergistic relationship between malnutrition and infection (Scrimshaw and SanGiovanni 1997; Scrimshaw 2003) could be responsible for the peak in periosteal lesions observed in this age category (31.4%), as well as exposure to poor living conditions. However, it is acknowledged that this figure may be inflated by an inability to distinguish between woven bone with an infectious aetiology and that due to growth in the youngest of these individuals (Ribot and Roberts 1996; Lewis 2000; Weston 2012: 498). Acute respiratory and bacterial infections that leave no trace on the skeleton are the leading cause of death for the under fives in developing countries (United Nations Children's Fund *et al.* 2014: 1). The prolonged period of breastfeeding into the third year and the gradual weaning process observed at Roman London may have afforded some of these infants a degree of continued passive immunity (Brown 2008: 412), making it possible for them to sustain a chronic infection long enough for a skeletal response to be recorded. The prevalence of stress indicators within the group testifies to the ability of some of the infants to withstand the onslaughts of poor health prior to death (Wood *et al.* 1992). However, as non-survivors, the acute and chronic stress experienced within this age group may have left them particularly vulnerable to these fatal infections.

(c) Childhood (3.1 to 7.9 years)

Following infancy, a slight decline in the overall prevalence of stress indicators is observed in the childhood age category, with large declines also being observed for porotic hyperostosis, non-specific infection, and both vitamin deficiencies. These results complement the findings of decreased mortality and morbidity risks reported in population studies and Roman model life tables (Parkin 1992; Saller 1994: 22; Bogin 1999; Rousham and Humphrey 2002). Factors responsible for this decline include: increased cognitive awareness and self sufficiency due to the completion of 95% of total brain growth during this age period; increased immunocompetance from the age of two years, with full maturity by six to eight years; the greater ability to process food due to the eruption of the permanent dentition (commencing at approximately 5-5-6 years); and the decline in nutritional requirements for growth and maintenance to less than 50% of total energy needs (Dettwyler 1995: 56; Bogin 1998: 21-22; Bogin 1999; Rousham and Humphrey 2002: 124; Ochet 2009: 28; Crews and Bogin 2010: 126, 132; Sommer 2011: 343; Scanlon and Saunders 2015: 363). An additional cultural factor that may be responsible for the lower morbidity risk observed in this age category could also have been their social status. While the cessation of breastfeeding would have allowed these subadults greater freedom and independence from their caregivers (Rawson 2003: 139; Redfern 2007: 191), they would still have been regarded as vulnerable *infants* until the age of seven years, with protection and food still predominantly being provided by their carers (Harlow and Laurence 2002: 42-52). This perceived vulnerability associated within their social status may have afforded them greater cultural buffering from potential causative stressors than in later subadult age categories.

However, the subadults within the childhood age category still represent “non-survivors” who died before attaining adulthood, suggesting they were still exposed to high mortality risks. Despite any cultural buffering that they may have been afforded, these subadults would have ultimately been exposed to the same unsanitary living conditions as those from other age categories. Indeed, the childhood age group was the only subadult category in which tuberculosis was identified, though the number of individuals affected are incredibly small (n=2). Isotopic analysis also suggests that post-weaning dietary intake in this age category was not significantly different to the supplementary food used during weaning, nor did it differ isotopically from that seen in the later juvenile category (see Section 8.2.2). Therefore, an alternative explanation for the decline in these stress indicators may be that these individuals represent those unable to sustain a chronic condition long enough for an osseous response to be recorded, as suggested by the osteological paradox (Wood *et al.* 1992). The high prevalence of *cribra orbitalia* and enamel hypoplasia in this age group confirms that these individuals were exposed to both acute and chronic stress prior to this age, perhaps resulting in a more compromised immune system. A lack of any decline in subadult representation for this age category provides further corroborating evidence of sustained mortality risk.

(d) Juveniles (8.0 to 16.9 years)

Within the juvenile age category, there is an increase in both overall pathology and individual stress indicators. However, with the exception of enamel hypoplasia, the prevalence rate of individual stress indicators remains below the peak seen in the infancy age category. The only stress indicator where a decline was observed was *cribra orbitalia.* The increase in the prevalence rates of stress indicators for juveniles also corresponds with a peak in the percentage of subadults observed within this age category.

A possible factor for the increase in morbidity seen at this age could be employment. Documentary evidence for child labour in the Roman world, mostly derived from Roman Egypt, identifies the age of twelve or thirteen as the most likely age for when boys outside of elite families would begin apprenticeships, though it could begin as early as seven years (Bradley 1985; 1991: 107-116; Saller 2011: 125; 2012: 76; Huebner 2013: 77). Girls appear to have been less likely to undertake formal apprenticeships outside the home, although they would have had domestic chores and may have operated as assistants to their parents (Bradley 1985; Laes 2011: 190; Saller 2011: 127; Holleran 2013: 315; Huebner 2013: 77). Regional variations across the empire are of course to be expected, with the age at which children were sent to work largely being governed by the financial requirements of the family (Holleran 2011: 168;2012: 30; Saller 2012: 75-76). Amongst the lower classes, it is likely that children would have been obliged to work as soon as they were considered able to do so, with increasing responsibilities and domestic chores beginning observed from around seven years (Wiedemann 1989: 153-155; Rawson 2003:

139; Caldwell 2004: 4; Krause 2011: 629). For slave children, work would have commenced after the age of 5 years (Laes 2011: 165; Caldwell 2015: 123). Evidence for the age at which children would have been expected to work is not available for Roman London, yet the increased physical and mental capabilities of subadults in this age category makes it likely that some form of employment could have been undertaken (Bogin 1998: 21-22). The age of eight years also coincides with a recognised transition point in the Roman life course, where subadults were no longer considered vulnerable *infans* and were imbued with an engendered identity for the first time (Laurence 2000; Gowland 2001: 158-160; Harlow and Laurence 2002: 36; Rawson 2003: 141; Laurence and Trifiló 2012: 28). This potentially offers a logical point for an increase in responsibilities associated with the transition to adulthood, such as employment.

The types of occupation undertaken by juveniles would have been numerous and varied. At Roman London, this could have included, amongst others: construction; industrial activities such as metal, glass, textile and leather working; or service-based industries, such as dock working, butchery and grain processing (Milne 1985: 61-62; Greene 1986; Perring 1991; Hammer 2003; Seally and Drummond-Murray 2005; Henig 2008; Cowan and Wardle 2009: 91-118; Shepherd and Wardle 2009; Dungworth and Stallybrass 2011; Pipe 2011a; Wardle 2011a; Scheidel 2012) (see Chapter 4 for further discussion of economic activities present in the town). Many of these occupations would have been hazardous to health, exposing them to toxic environments, chemicals and smoke, as well as increasing their risk of injury (Roberts and Cox 2003: 144-145; 2004: 249; Mattingly 2011: 197-199). True prevalence rates of rib periostitis are considerably higher in this age category than that seen in the adult population or any of the other subadult categories (see Figure 6.11), suggesting that the initial exposure to smoky working conditions, toxic chemicals and fumes, if present, could have made them particularly susceptible to pulmonary infection (see Section 8.2.1 (i)(e)). As it is not possible to reliably determine biological sex in immature skeletons, differential exposure of males and females to these hazards could not be assessed.

While adults would have been similarly exposed to these dangers, the developmental characteristics of subadults make them particularly vulnerable to these kinds of occupational hazards. For example, multiple factors, including their higher metabolic rate, the higher overall percentage of water content within their organs, and their greater body surface area in relation to weight, make subadults more susceptible to the absorption of chemicals, dust and vapours (GOHNET 2005). Rapid growth, such as that seen with the onset of puberty, also makes them more susceptible to toxic hazards and carcinogenic exposure (GOHNET 2005). These toxins can have devastating effects on the developing subadult endocrine system, resulting in severe immunological deficits (GOHNET 2005). The malnutrition and the physiological stress observed within this age category, as denoted by the high prevalence rates of enamel hypoplasia and *cribra orbitalia*, could have exacerbated these detrimental effects. Therefore, a combination of these factors may be responsible for the increased prevalence of periosteal lesions observed within this age category, being second only to that observed in infancy. The long working hours associated with apprenticeships, dictated in some contracts as lasting from sunrise to sunset, could also explain the slight rise in vitamin D deficiency in this age group (Laes 2011:192). However, due to the small sample size, and lack of information regarding whether the vitamin D deficiency was active at the time of the individual's death, this cannot be confirmed.

If the increased in morbidity in this age category is associated with the start of employment, it is interesting that it probably coincides with a change in care provision. Prior to this, the needs of the child would be met solely within the home. However, once employment began, elements of care within the working environment, such as protection, would have to be either shared by the employer or the subadult alone (Bradley 1991: 107-116). If the child was expected to reside outside the home, as evidenced by some apprenticeship contracts, the care of the child would fall completely within the hands of the master (Bradley 1991: 107-116; Laes 2011: 192; Hueber 2013: 76). While it is difficult to know the extent to which these practices were followed in Roman London, it appears the greater independence of the child may have had an adverse effect on subadult health, particularly if the protections given by employers fell short of that given by the family.

(e) Adolescents (17.0 to 19.0 years)

Of all the subadult age categories, the highest rates of "total pathology" were observed within the adolescent age group, with 82.8% of individuals having evidence of at least one of the studied pathologies. Prevalence rates of enamel hypoplasia (76.9%), *cribra orbitalia* (63.2%), and porotic hyperostosis (12.0%) also peaked within the adolescent age category, being well above those seen in any of the other subadult age categories or the adult population. The higher prevalence rates of stress indicators within this age category could be the result of the lower representation of this age category of subadults, but it also appears to reflect the osteological paradox, with those subadults with stress indicators having stronger immune systems that allowed them to withstand acute and chronic infections, thereby living to an older age (Wood *et al.* 1992).

An alternative explanation for these high prevalence rates may be increased mobility within this age group. As previously discussed, Gowland and Redfern (2010) attributed high prevalence rates of enamel hypoplasia (31%) and *cribra orbitalia* (56%) within a smaller sample from Roman London to increased mobility from areas within the empire where prevalence rates tend to be much higher than those recorded in Roman Britain, such as in the Mediterranean region. For example, prevalence rates of about 60% for cribra orbitalia and above 40% for enamel hypoplasia are commonly reported for Roman Italian populations (Manzi *et al.* 1999; Salvadei *et al.* 2001; Egidi *et al.* 2003; Facchini *et al.* 2004; Cucina *et al.* 2006; Belcastro *et al.* 2007; Paine *et al.* 2009). During the Roman period, social conventions prevented men from holding office until the age of 25 years and until that age they were still considered *adolescentes*, and conceptualised as still being prone to irrational tendencies and impetuousness (Eyben 1993; Harlow and Laurence 2002: 72-78; Laes and Strubbe 2014: 42-48). Despite this, they were able to join the army from 18 years, which would have resulted in increased opportunities for mobility around the empire (Eyben 1993; Erdkamp 2007; Giles 2012). In addition to the Roman army, it is likely that others of this age would have also worked/sought their fortune across the empire as part of the merchant community. It is therefore possible that the particularly elevated prevalence rates for this age group are because these individuals represent migrants from areas of the Empire with comparable rates, as suggested by Gowland and Redfern (2010). A summary of strontium, lead and oxygen isotope analyses conducted for the Roman period provides further evidence for mobility within this age category, with young male migrants being a frequent finding (Eckardt *et al.* 2014: 541). However, these studies also identified older male, female, and child migrants within the province too (Eckardt *et al.* 2014: 541). Of the small number of individuals identified as migrants from Roman London, five of the individuals were adults and two were much younger subadults (Montgomery *et al.* 2010; Shaw 2013: 93-94). However, these findings reflect the small number of individuals that have been analysed to date from Roman London and the absence of the adolescent age category from these studies. In order to remedy this absence of data, additional isotopic investigations are required.

Evidence for periosteal new bone formation remained at a similar level to that seen in the previous age category, suggesting the detrimental effects of increased personal mobility and occupation-based exposure identified in the previous age category remained a continued risk to health in this age group. That the diversity of skeletal elements affected was greatest in this age category suggests that the increasing responsibilities that came with increasing age added to the stress burden experienced by these adolescents.

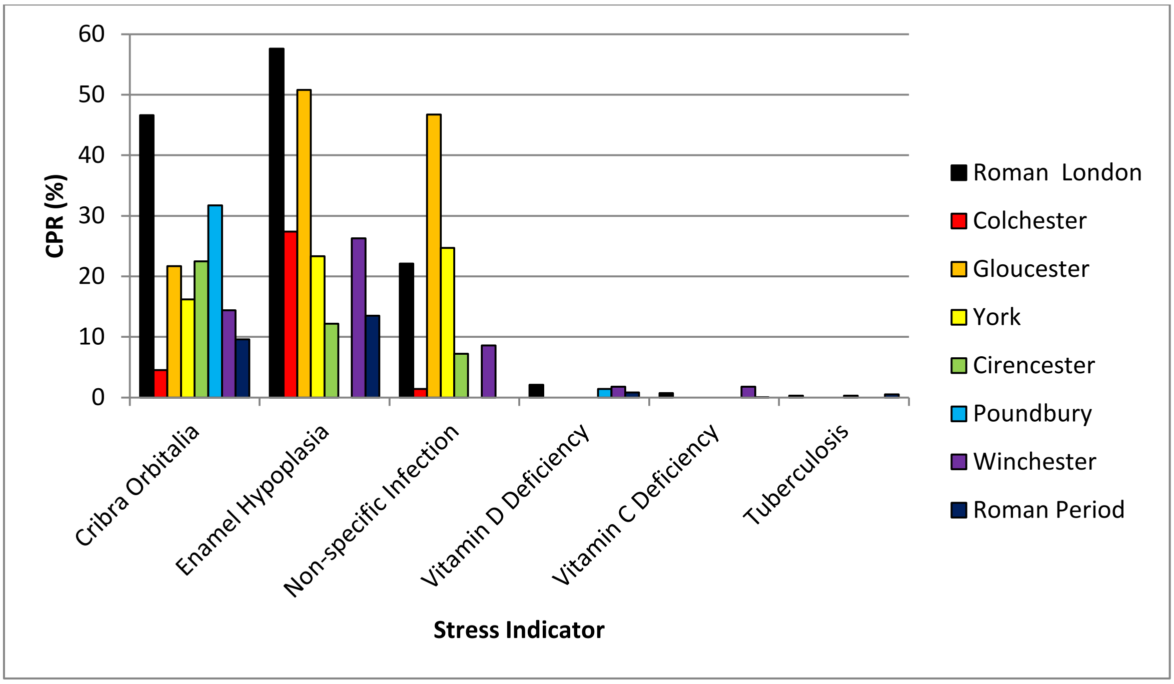
(iii) Inter-site comparisons

This section provides a brief comparison of the stress indicator data from Roman London with other Romano-British urban sites to situate the results of the thesis within the wider archaeological context (Figure 8.4). It is acknowledged that comparability between populations is confounded by differences in preservation, particularly when CPRs are used (Dutour *et al.* 2003; Waldron 2007: 59ff). Further complications are also introduced by the use of different recording techniques, age categories, and potential inter-observer error (Ortner 1991; Miller *et al.* 1996; Jacobi and Danforth 2002; Ritzman *et al.* 2008; Jackes 2011). Therefore, only broad comparisons will be made between health in the different cemetery populations overall and subadults, without further subdividing the data into smaller age groups. Where possible, the most up-to-date analyses were utilised. For example, the Trentholme Drive data for the York population was taken from Peck (2009), rather than the original analysis by Warwick (1968). As a consequence of these limitations, all conclusions drawn here are tentatively made.

Overall, the prevalence rates of stress indicators observed in the total sample from Roman London tend to be amongst the highest observed. *Cribra orbitalia* and enamel hypoplasia in particular are markedly higher in the Roman London sample than any other cemetery sample. This higher prevalence rate of these stress indicators could be due to the reassessment of all the skeletal remains by the WORD project. For example, a previous estimation of stress indicators in the Eastern cemetery gave substantially lower prevalence rates of “probably less than 5%” for *cribra orbitalia* and “around 10%” for enamel hypoplasia (Conheeney 2000: 285). However, even at those sites where recent re-evaluation has been undertaken (e.g. York, Poundbury, and a sample from Colchester (Jenny 2011)), the prevalence rates of these stress indicators are lower than that seen in the Roman London sample. While higher prevalence rates of *cribra orbitalia* and enamel hypoplasia have been linked to differences in breastfeeding and weaning practices, it seems unlikely that infant feeding practices are responsible for the differences observed between the urban centres as isotopic evidence indicates similarities in these practices within Roman Britain (see Section 8.2.2 (ii) (b)).

Another potential explanation for higher rates of these lesions that has been previously discussed is population mobility, with migrants moving to Roman London from areas where these childhood

a)



b)

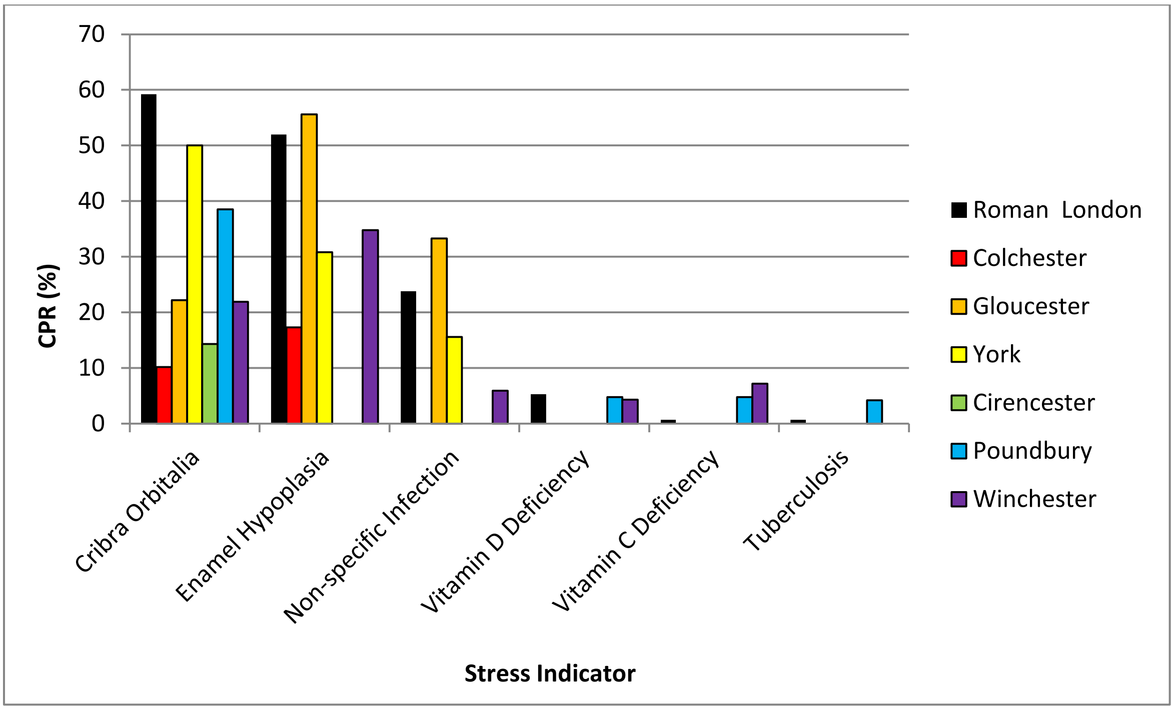
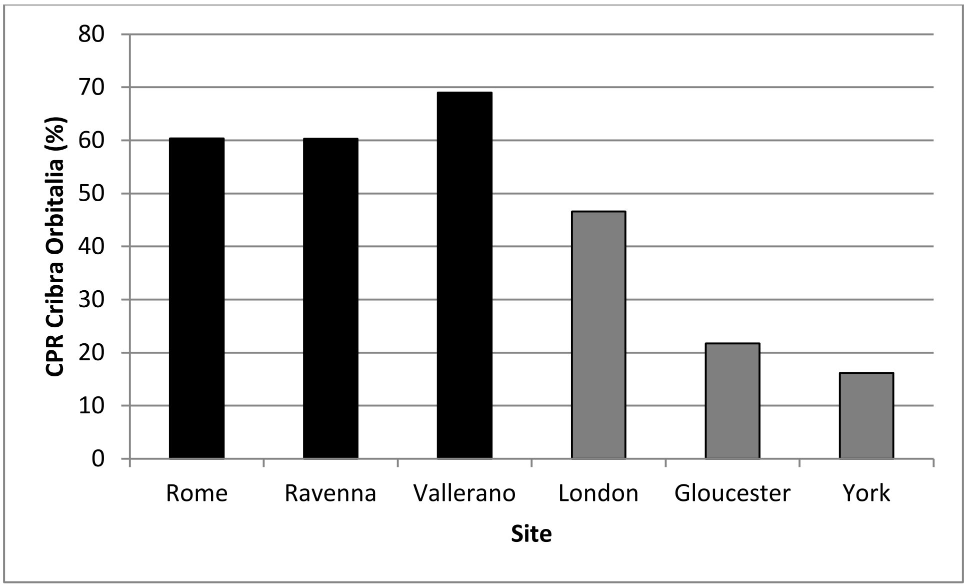


Figure 8.4: Comparison of the prevalence of stress indicators at large Romano-British towns. Roman London for a)total population; and b) subadult population. Roman London (this study); Colchester (Pinter-Bellows 1993); Gloucester (Márquez-Grant and Loe 2008); York (Peck 2009); Cirencester (Wells 1982); Poundbury (Lewis 2010; 2011) and Winchester (Clarke 1979 and Clough and Boyle 2010).

stress markers are traditionally higher (Gowland and Redfern 2010). This is further supported by the closer comparability of the Roman London subadult *cribra orbitalia* and enamel hypoplasia prevalence rates to other large urban centres at York and Gloucester respectively (Figure 8.4b).

However, the extent to which population mobility can explain the higher prevalence rates observed at Roman London is uncertain, as migrants have also been identified at York and Gloucester, as well as other Romano-British towns (Evans *et al.* 2006; Eckardt *et al.* 2009; Leach *et al.* 2009; Chenery *et al.* 2010; Müldner *et al.* 2011; Cheung *et al.* 2012; reviewed by Eckardt *et al.* 2014). As such, migration may have also been a potential factor in stress indicator prevalence at these towns. Based on the currently available isotope evidence, it is not possible to determine the extent of population mobility at these different urban centres. However, the highest prevalence rates of these lesions are observed at Gloucester, London, and York, which were all *coloniae* within the early period, with London and York becoming provincial capitals following subsequent reorganisations of the province in the second, third, and fourth centuries AD (Wacher 1995: 79-179; Jones 2008). The lower legal status of *civitas* capital was held by Cirencester, Dorchester (Poundbury), and Winchester, which all show lower prevalence rates of *cribra orbitalia* and enamel hypoplasia (Mattingly 2006: 268-269). As such, the higher legal status of London, Gloucester, and York could have resulted in increased population mobility into these centres. However, the cemeteries considered here are predominately dated to the third and fourth centuries AD, during which time these differences in legal status would have been much less important (Loseby 2000). Furthermore, isotopic and archaeological evidence suggests high levels of population mobility were also observed in these smaller towns (Eckardt *et al.* 2014), with estimates suggesting up to 34% of the population buried in the Lankhills cemetery, Winchester, may have been “foreigners” (Eckardt 2010: 121).

A more likely contributory factor in the high prevalence rate of *cribra orbitalia* and enamel hypoplasia at London, Gloucester, and York may be the increased population density and poorer living conditions observed at these larger towns. Indeed, the highest prevalence rates of non-specific infection are observed within these three towns (Figure 8.4a,b). Environmental analyses of these sites have demonstrated that while sanitation in these Roman towns was better than their medieval counterparts, evidence for rubbish dumps, faecal material and other waste is present within the towns, as well as the presence of pests, such as fleas, lice, and rats (Addyman 1989; Dobney *et al.* 1999; Williams 2003; Davis and Smith 2011; Hall and Kenwood 2015; Taylor 2015). The importance of these factors over legal status is supported by the much lower prevalence rates of stress indicators observed at the colonia at Colchester. Again, the report from a)



b)

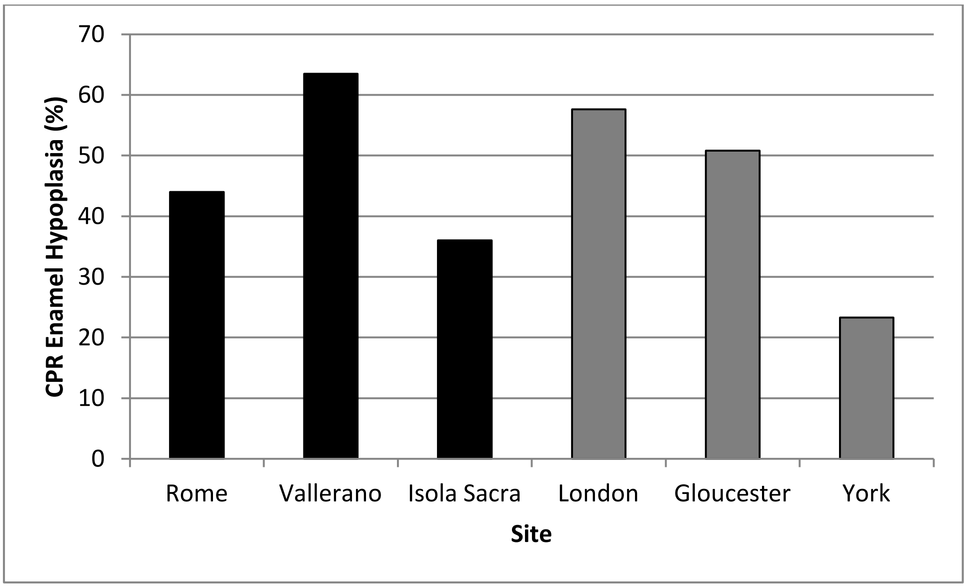


Figure 8.5: Comparison of the true prevalence rates of a) *cribra orbitalia* and b) enamel hypoplasia at a selection of Roman Italian (black) and Romano-British settlements (after Gowland and Redfern 2010). Italian data taken from Gowland and Redfern (2010); London (this study); Gloucester (Márquez-Grant and Loe 2008); York (Peck 2009).

Colchester (Pinter-Bellows 1993) was completed several decades ago and this could be a reason for the low prevalence rates. However, a subsample of this collection was recently reanalysed by Jenny (2011) and she identified similar prevalence rates. Jenny (2011: 257) argues that the better living conditions within Colchester could be a significant factor in the lower prevalence rates of stress indicators within this population, identifying cleaner water supplies within the town and the provision of good farming land that buffered against food shortages as being particularly important. In the later period, Gloucester, York, and London also held more significant positions within the provincial road and communication network than Colchester (Mattingly 2006: 264). As such, the greater volume of movement through these towns may have preferentially exposed them to higher levels of pathogens.

In contrast, higher prevalence rates of specific infection (i.e. tuberculosis) and metabolic disease are observed in the smaller sized towns of Dorchester (Poundbury) and Winchester. However, both of these cemeteries have been the subject of recent reinvestigations, with the former in particular being the focus of a number of subadult health investigations (Lewis 2004; 2007' 2010; 2011; 2012; Redfern 2007; Redfern and DeWitte 2011a; 2011b; Clough and Boyle 2010). That the prevalence rate of vitamin D deficiency in Roman London is comparable to these sites is a testament to the re-examination of the subadult population of Roman London by Dr. Rebecca Redfern. Therefore, it is suggested the higher rates of specific infection and vitamin deficiency seen at these sites is a factor of this reinvestigation, rather than a representation of actual differences in cultural and environmental causal factors that has been previously suggested (Lewis 2010). However, in order to confirm this, additional analyses of the skeletal remains of Roman Britain is needed.

Comparisons were also drawn with Roman Italian sites to identify if the prevalence rates at Roman London were comparable to those reported at the heart of the Empire (Figure 8.5). Due to differences in the way skeletal data are recorded and published from Italian sites, comparisons could only be drawn for *cribra orbitalia* and enamel hypoplasia. As the Italian reports use different age bands to denote subadults and adults, i.e. in some reports subadults are considered to be those thirteen years and under, comparisons are drawn between overall cemetery populations. However, as *cribra orbitalia* and enamel hypoplasia represent childhood stress, these comparisons should provide a good indicator of differences in childhood stress in different areas of the empire.

Traditionally, high rates of *cribra orbitalia* and enamel hypoplasia have been identified within Roman populations in Italy (Manzi, *et al.* 1999; Salvadei *et al.* 2001; Facchini *et al.* 2004; Cucina *et al.* 2006; Paine *et al.* 2009; Gowland and Garsney 2010). While the role of poor living conditions within urban centres has been cited as a contributory factor to this pattern, the same high rates are also observed from Roman Italian rural centres, such as Vallerano (Cucina *et al.* 2006). Another potential causal stressor that may have been responsible for these high prevalence rates in Roman Italy is malaria, as well as congenital anaemia in the case of *cribra orbitalia* (Salvadei *et al.* 2001; Facchini *et al.* 2004; Cucina *et al.* 2006; Gowland and Redfern 2010; Gowland and Garsney 2010). From Figure 8.5a, it is apparent that while the prevalence rate of *cribra orbitalia* in

Roman London is lower than that seen in Roman Italian sites, it is much higher than the other Romano-British towns. In the case of enamel hypoplasia, the prevalence rates observed at both London and Gloucester are amongst the highest. While the living conditions in these Romano-British towns would have been poor and unhygienic, it is unlikely they would have been as polluted as the considerably larger Italian sites (Redfern *et al.* 2015: 116; see Scobie 1986 for review of living conditions in Rome). Therefore, as previously discussed, the high prevalence rates of these stress indicators may be influence by population mobility (Gowland and Redfern 2010), though its extent still remains to be determined. The process of migration itself may have also been an additional source of physiological and psychological stress, particularly as the migrants were likely to have experienced a decline in socioeconomic circumstances (Ben-Sira 1997; 50-54; Al-Baldawi 2002; Malmusi *et al.* 2010).

8.2.2 Diet

(i) Overall Diet in Roman London and Inter-Site Comparisons

The stable isotope data showed that the overall dietary protein intake of Roman Londoners appears to have been largely terrestrial-based, with the regular consumption of terrestrial animal protein observed for almost all individuals. These results contradict traditional assumptions of an almost vegetarian diet amongst the majority of peasants and the urban poor that has been derived from literary descriptions of diet (Sippel 1988: 47-48; Garnsey 2004: 226-256; Wilkins and Hill 2006: 56-57; Grimm 2007: 86), instead supporting more recent findings of greater meat (and/or dairy) consumption within Roman Britain than expected (Cummings 2009). Studies of meat consumption patterns in the Roman world have identified differences between provinces in the types of meat favoured, with pork being favoured in Roman Italy by high status individuals, and high cattle consumption being connected to a “militarisation” of the diet (King 1984; 1999). Within the western provinces, including Roman Britain, the preferential selection of beef over mutton is seen as a particular marker of dietary change associated with Roman influence (King 1984; Hawkes 1999: 91; Cool 2006: 80). Within the archaeozoological record of Roman London, cattle are the most represented of the three species, followed by pig, with sheep/goat being found in the lowest quantities (Bluer *et al.* 2006; Cowan and Wardle 2009; Pipe 2011b; 2011c). Unfortunately, as no significant difference was observed between the isotopic ratios of the cattle, sheep/goat, and pigs at the site, it was not possible to determine the importance of each of these to the Roman London diet isotopically.

The level of variability observed in the $\delta^{13}C$ and $\delta^{15}N$ values suggest a great deal of heterogeneity in the range of foodstuffs available to the inhabitants of Roman London. For some of the individuals sampled, the level of enrichment observed suggests the inclusion of additional isotopically enriched food items, with small contributions of chicken, marine and freshwater fish all being likely candidates. The consumption of fish, particularly marine species, is particularly interesting due to its apparent absence in pre-conquest populations in Britain (Dobney and Ervynck 2006; Locker 2007; Müldner 2013).

The diet eaten in Roman London on the whole appears to be consistent with other contemporaneous Romano-British large urban centres, such as Gloucester (*Glevum*), York (Eburacum) and Cirencester (*Corinium Dobunnorum*) (Müldner and Richards 2007; Cummings 2008; Chenery *et al.* 2010; Cheung *et al.* 2012). At all of these sites a similar pattern of isotopic enrichment is observed, with a predominantly terrestrial diet that included significant proportions of terrestrial animal protein and minor contributions of both marine and/or freshwater fish. Heterogeneity within the isotopic values is also observed at each of these sites, with individuals consuming a range of isotopically different diets. Figure 8.6 presents a comparison of average stable isotope values from available Romano-British settlements. In order to ensure comparability between sites, the values are presented as an average of human to terrestrial herbivore diet spacing ($\Delta_{\text{human-herbivore}}$). Figure 8.6 shows that the highest levels of both $\Delta^{13}C$ and $\Delta^{15}N$ enrichment are consistently observed in these large urban centres. One exception to this appears to have been Poundbury, the cemetery of the civitas capital of *Durnovaria*, which has slightly lower $\Delta^{13}C$ and $\Delta^{15}N$ enrichment than the other large urban centres (Richards *et al.* 1998). One possible explanation for this could be the inclusion of members from the surrounding rural population within the cemetery (Molleson 1993).

Regardless, the results tended to group with the small towns and Roman Dorset values (comprising urban and rural sites from the same area as Poundbury), characterised by lower overall $\Delta^{15}N$ and $\Delta^{13}C$ enrichment than the large urban centres. This apparent difference in the average isotopic values between the small and large urban settlements of Roman Britain may be a reflection of the increased adoption of Roman cultural practices at the larger urban centres, such as the consumption of fish, being more widely reflected within their diet. Alternatively, it could reflect access to a wider variety of foodstuffs in these large markets

Within Romano-British rural sites, the overall trend appears to be a similar level of nitrogen enrichment to the large towns with a smaller corresponding enrichment in carbon. Of all the Romano-British settlement types, it is the rural settlements that have the lowest $\Delta^{13}C$ values.

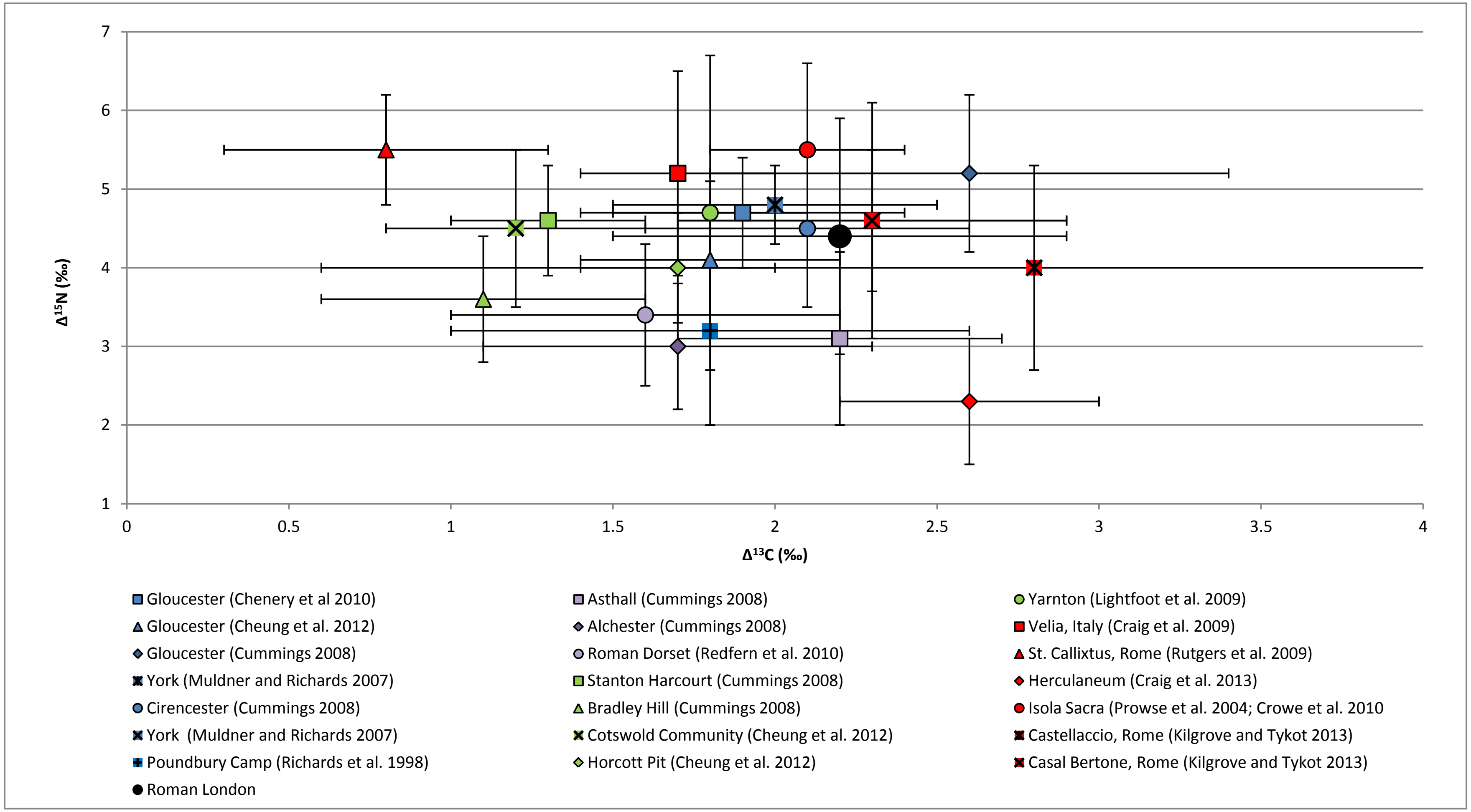


Figure 8.6: **Comparison of the average carbon and nitrogen stable isotope values from Roman settlements in Britain and Italy. To ensure comparability, results are given as deviation from the terrestrial herbivore (cow and sheep/goat) mean (($\Delta_{\text{human-herbivore}}$ (‰)). For the Poundbury Camp, terrestrial herbivore values were obtained from Redfern *et al.* 2010). Symbols represent as follows: blue = Romano-British large urban centre, purple = Romano-British small town, green = Romano-British rural settlement, red = Roman Italian site**

Within each of the rural site studies, the authors note the apparent absence of marine fish within the diets of the vast majority of the population, something viewed as indicative of a more traditional diet (Cummings 2008; Lightfoot *et al.* 2009; Cheung *et al.* 2012). However, this pattern is not universal, and the level of human-herbivore diet spacing at Yarnton is very close to that of some of the large urban centres. However, it is noted within the study that similar high levels of enrichment are observed within the Iron Age populations at the site (Lightfoot *et al.* 2009). One possibility could be freshwater fish consumption at Yarnton, which has a riverine location, although this was ruled out by the authors.

Comparisons were also drawn between Roman London and sites from Roman Italy. The closest comparability observed is with the site of Casal Bertone, a cemetery located just outside the walls of Rome (Killgrove and Tykot 2013). As at Roman London, the dietary protein intake here appears to have been predominantly derived from C_3 terrestrial foods with minor contributions of marine and/or freshwater fish. A comparable level of intra-population variability is observed within both populations (Casal Bertone ±1 σ- $\Delta^{13}C = 0.6$, $\Delta^{15}N = 1.5$; Roman London ±1 σ- $\Delta^{13}C = 0.8$, $\Delta^{15}N = 1.5$), suggesting similar levels of heterogeneity at each site. Such comparability with a population at the heart of the empire is striking and seemingly supports archaeozoological and environmental evidence for the influence of Roman cultural practices on the diet of the inhabitants of Roman London (Cowan and Wardle 2009: 101; Cowan *et al.* 2009: 113-117; Hill and Rowsome 2011: 410-411). Perhaps this is not surprising when considering the proposed migrant merchant population thought to have established the settlement, bringing with them pre-existing dietary preferences that are apparent from the settlement's origin (see Section 4.5.1). In addition, its position as an important harbour and provincial capital would also have allowed the inhabitants of Roman London access to a greater variety of foodstuffs which were, at least isotopically, similar to those in Rome.

However, it is important to note that the isotopic values observed at Casal Bertone differ to those found at other sites surrounding Rome and the rest of Roman Italy. For example, Castellacio Europarco is a cemetery located within the suburbs of Rome, yet the dietary intake at this site differs significantly (Killgrove and Tykot 2013). The isotopic values of the Castellacio Europarco population is characterised by a higher level of carbon enrichment alongside lower nitrogen levels (see Figure 8.6), explained by the greater reliance on millet within this possibly more agrarian population (*Ibid*). A different diet is also observed in Romans buried at the Christian catacombs of St. Callixtus, located along the Appian Way (Rutgers *et al.*2009). Here, the consumption of freshwater fish, rather than marine, has resulted in low carbon and high nitrogen isotopic enrichment. A different pattern of consumption from that of Casal Bertone and Roman London is also observed at the sites of Isola Sacra, cited as the "typical" Roman diet in previous isotopic comparisons, and Velia (Prowse *et al.* 2004; Craig *et al.*2009). At these sites high $\delta^{13}C$ and $\delta^{15}N$ values have been attributed to increased marine protein consumption in these coastal populations. The $\Delta^{15}N$ values are much higher at these sites than at Roman London, although the $\Delta^{13}C$ is lower than that seen at both Roman London and Casal Bertone. As Isola Sacra and Velia served coastal harbour towns it is perhaps not surprising that increased access to marine food resources is observed, and Prowse *et al.* (2004) stress that their location makes them atypical and not necessarily representative of the average Roman diet. Such large differences in the isotopic composition of sites in Roman Italy highlight the difficulty in identifying potential "Roman" influence on dietary practices elsewhere in the empire. Previous studies of Roman diet have already identified a great divergence in diet at different types of settlements within the Empire, and these results show that there was no "typical" Roman diet (King 1984; 1999; Cool 2006: 243; Wilkins and Hill 2006: 22f; van der Veen 2008; van der Veen *et al.* 2008; Cheung *et al.* 2012).

(ii) Subadult Diet in Roman London

(a) Infant Feeding Practices

The stable isotope results of this study confirm breastfeeding was practiced within Roman London consistently, with all subadults aged two years and under exhibiting significant enrichment comparable to a trophic level shift in their $\delta^{15}N$ values. The tight clustering of $\delta^{15}N$ values amongst the ≤1yr age group was of particular interest as we would expect the $\delta^{15}N$ values of an exclusively breastfed infant to reflect that of the females from which they would have been suckling. However, the level of variation seen in the ≤1yr age group was over four times smaller than that of the adult female population at one standard deviation. These results suggest that the diet of breastfeeding women at the settlement may have been much more conservative than the overall adult diet. As the infants in this study are drawn from across all of the town's cemeteries (i.e. northern, eastern, western, and southern), covering both time periods, it is possible that a special breastfeeding diet may have been a recognised practice, unaffected by the changing diversity of the town's population. Unfortunately, due to the long turnover rate of bone collagen in adults, it is not possible to detect such short-term changes in dietary practices, making it impossible to confirm this hypothesis. An alternative explanation could be age-related variation in the female diet, with young women of child-bearing age consuming a more restricted diet than older females. Although such age-related variation is known to have occurred within the documentary record (Garnsey 1999: 101; Harlow and Laurence 2002: 57; Rawson 2003: 126; Alberici and Harlow 2007; Caldwell 2015: 79-104) and has been observed in other Roman populations (Prowse *et al.* 2005), no significant difference was observed between the adult age groups in the female population at Roman London for either $\delta^{15}N$ (Kruskal-Wallis p=0.5608) or $\delta^{13}C$ (Kruskal-Wallis p = 0.3091).

Determining a precise weaning age through stable isotope analysis is complicated by uncertainty regarding the time needed for detectable isotopic changes in diet to be incorporated into bone collagen (Millard 2000). However, the steady decline in $\delta^{15}N$ values from a peak level of enrichment at one year suggests that the overall weaning process at Roman London occurred gradually, with breast milk still making up a significant portion of dietary protein into the third year of life. The absence of any detectable breast milk in $\delta^{15}N$ by the age of four years indicates that this age may have been a culturally recognised endpoint for the cessation of breastfeeding in this population. The age of four years has been previously identified as a possible time of social transition in Roman Britain, signified by an increase in the number of grave good inclusions between four to seven years at the Lankhills cemetery in Winchester (Gowland 2001: 158-160). That this age coincides with the cessation of breastfeeding and weaning in Roman London suggests that the completion of the weaning process was an important marker in the subadult life course, not only for health reasons but also for their social identity.

While a breastfeeding pattern is observed in terms of the $\delta^{15}N$ values, few of the subadults exhibit the expected corresponding 1‰ enrichment in their $\delta^{13}C$ values. However, isotopic studies of modern infants have identified that $\delta^{13}C$ ratios are more susceptible to the incorporation of supplementary foods into the diet (Fuller *et al.* 2006b). While the number of subadults in the youngest age categories in this study is small, the significant decline in the $\delta^{13}C$ values after six months indicates that it was probably around this age that supplementary foods were introduced into the diet. This is corroborated by the decline in the contribution of breast milk to overall dietary intake from one year, indicated within the $\delta^{15}N$, with breast milk being increasingly replaced as the main source of protein until the age of four years. As the $\delta^{13}C$ values of subadults between the ages of six months to five years were significantly depleted compared to those of the older subadults and adult population, the weaning diet utilised in Roman London would have consisted of higher proportions of terrestrial food items, such as C_3 cereal grains (i.e. wheat and barley) with relatively little, if any, marine fish. A similar depletion in $\delta^{13}C$ values was also recorded in modern infants who had been weaned onto a diet of mostly rice and oatmeal (Fuller *et al.* 2006b).

When the overall pattern of infant feeding practices adopted in Roman London is considered, it appears to be consistent with the prescriptions detailed by Soranus in *Gynecology* and Galen in *Hygiene*, with a cereal-based weaning diet being introduced during the sixth month and a gradual cessation of breastfeeding that extended into the third year (see Chapter 2). However, the ambiguous nature of the weaning timetables derived from these sources, as outlined in Chapter 2, means that it is perhaps not surprising that the infant feeding practices in Roman London were consistent with their teachings: any age between two and four years could be considered consistent with the historical documents.

In addition to this ambiguity, the use of fixed chronological age points as a basis for comparison with the historical documents should also be questioned. The weaning timetable detailed above is by no means exclusive to the prescriptions of Galen and Soranus. In a survey of 113 non-industrialised modern populations, Sellen (2001) found that five to six months was the most common age for the introduction of supplementary foods. Six months also marks a turning point in biological development, with many infants developing the ability and desire to start self-feeding at this age (Carruth and Skinner 2002, Carruth *et al.* 2004). In another study of traditional societies, Dettwyler (1995) identified the practice of gradual weaning over an extended period was a common occurrence, most often taking place between the ages of two and five years. Based on these findings, it would be possible to find societies completely unconnected to the Roman Empire whose infant feeding practices could be interpreted as being consistent with the historical texts. Therefore, while this does not negate the influence of Soranus and Galen, an apparent conformity to them may not necessarily be a reliable indicator of the extent of their influence in Roman London.

(b) Infant Feeding Practices - Inter-site and temporal comparisons

Few isotopic studies of infant feeding practices in the Roman period have been conducted. The three most prominent are based on skeletons from: Queenford Farm, a Romano-British fourth to fifth century AD rural settlement in Oxfordshire (Fuller *et al.* 2006a), the Dakleh Oasis, Egypt, dating to AD 250-450 (Dupras *et al.* 2001), and Isola Sacra, a first to third century AD necropolis associated with the harbour at Portus, Italy (Prowse *et al.* 2008). Each of these studies have claimed a parity with the weaning timetables outlined in Soranus and Galen, although there is an overall lack of agreement as to whether the patterns at each of these sites are comparable to each other (see Chapter 2 for further discussion). Considering the issues discussed above regarding the problems of using simple start and end dates to interpret comparability, performing direct comparisons of the isotopic data at each site is a more

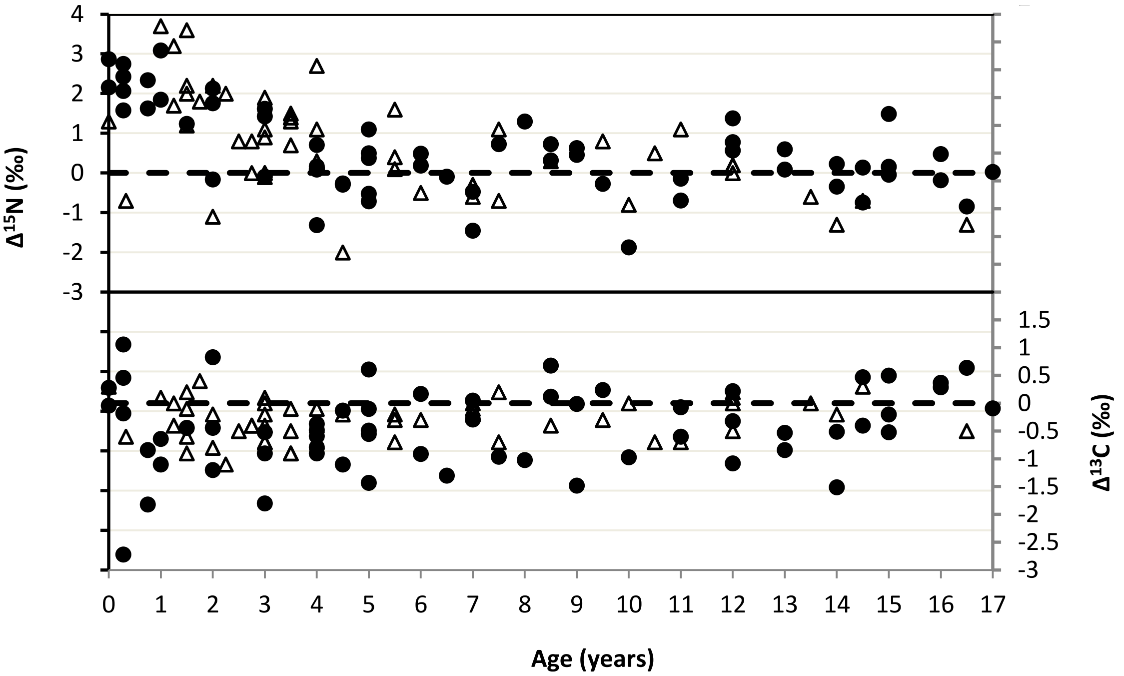


Figure 8.7: Comparison of the subadult isotopic values at Roman London (black circles) and Queenford Farm (open triangles) (Fuller *et al.* 2006a). All isotopic values plotted as deviation from the adult mean (expressed as a dashed line).

informative method to determine how the infant feeding practices may have varied at settlements throughout the empire. Direct comparisons will be drawn here with two of the published isotopic studies – Queenford Farm and Isola Sacra. It was not possible to include the Dakleh Oasis site as the individual isotopic results were not provided in the original publication (Dupras *et al.* 2001). In order to ensure comparability, the isotopic results from each site are plotted according to the deviation from the site's adult female mean (Δ‰) (Figure 8.7 and 8.8).

Figure 8.7 plots the data from the two Romano-British sites, Roman London and Queenford Farm. As in Roman London, the δ^{15}N values at Queenford Farm confirm breastfeeding was undertaken, with both settlements having a similar overall average enrichment, peaking at 1.5 years. Similarities were also observed regarding weaning, with a gradual decline in δ^{15}N values at both sites indicating that weaning took place over an extended period, with the age for complete cessation of breastfeeding being approximately three to four years at both sites. The lack of individuals at Queenford Farm in the 0-1.5 year age range means that it is not possible to ascertain when supplementary foods were introduced into the diet here. Despite this, a significant depletion in δ^{13}C values is also seen with supplementary feeding at Queenford Farm. A similar depletion in δ^{13}C values was also apparent with weaning in a smaller study of subadults from Roman Dorset (Redfern *et al.* 2012). It is therefore proposed here that a

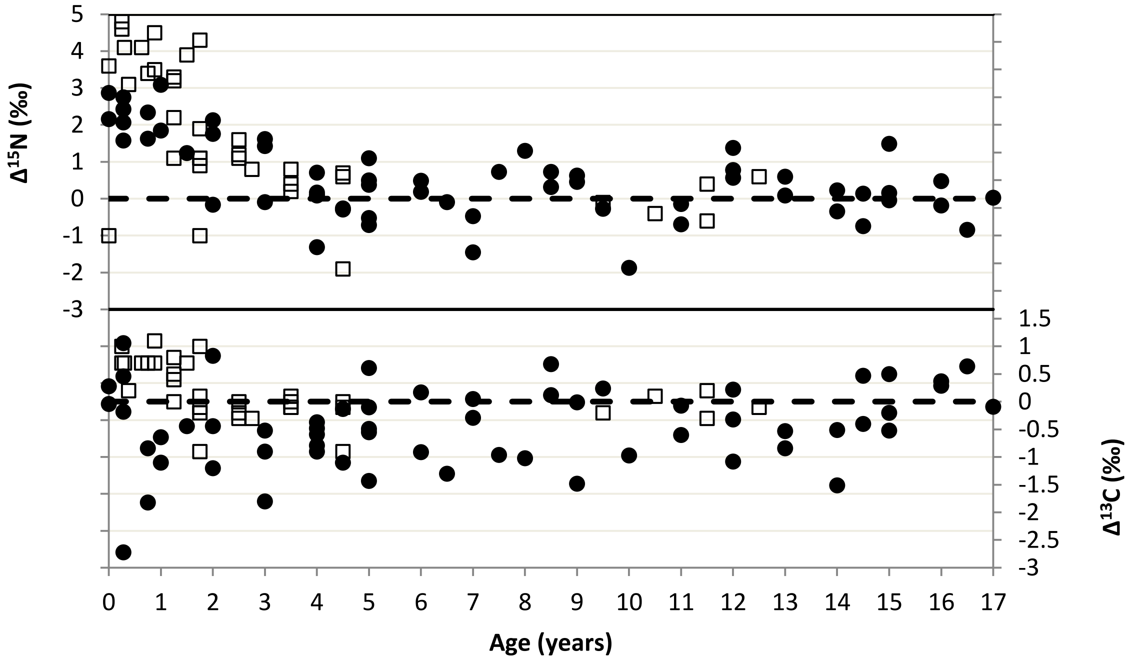


Figure 8.8: Comparison of the subadult isotopic values at Roman London (black circles) and Isola Sacra (open squares) (Prowse *et al.* 2008). All isotopic values are plotted as deviations from the adult female mean (expressed as a dashed line)

special weaning diet, higher in cereal grain and lower in marine foods than the rest of the population, was recognised throughout Roman Britain.

The overall degree of similarity in the infant feeding regimens being practiced in these two Romano-British settlements was largely unexpected, considering the vast difference in their social and economic characteristics and the greater degree of population mobility seen in Roman London. As such, it seems likely that a widely disseminated and accepted oral knowledge of infant feeding practices had developed within the province at this time, with women, whether as mothers, wet-nurses, or midwives, being pivotal in its distribution.

While close comparability in infant feeding practices was observed within Roman Britain, stark differences were observed between those in Roman London and in Roman Italy (Figure 8.8). While breastfeeding was practiced at both sites, the level of average $\Delta^{15}N$ enrichment seen in breastfed children at Isola Sacra is twice that seen in Roman London. A pregnancy and breastfeeding diet with a high marine content is suggested as the explanation for this high $\Delta^{15}N$ enrichment (Prowse *et al.* 2008), something not seen at any of the Romano-British sites. The enrichment of $\Delta^{13}C$ values until after the first year of life at Isola Sacra also suggests that the period of exclusive breastfeeding was much longer here than in Roman Britain. As such, the period of supplementary feeding at Isola Sacra would have been much shorter than that seen in Roman Britain, with the rapid decline in $\delta^{15}N$ values after 1.5yrs suggesting it took place over one year, with a complete cessation of all breastfeeding by 2.5yrs. The minimal depletion in the $\Delta^{13}C$ values below the adult female mean suggests that no special weaning diet given to children at the site, with subadults being fed a diet isotopically similar to that of the adult females. Overall, it appears that the pattern of infant feeding practices in Roman Britain differed markedly from that seen in the Italian population, favouring the conclusion of a contrasting pattern of weaning practices across the empire put forward by Prowse *et al.* (2008). This finding is further supported by a recent investigation of a population from Rome, amongst whom breastfeeding appears to have continued into the second year (Killgrove and Tykot 2012).

The results of these comparisons seemingly confirm that childcare practices across the empire were indeed subject to considerable regional heterogeneity. Yet, such contrasting patterns do not negate the influence of Roman culture, and its medical teachings, in Roman Britain completely. Figure 8.9 provides a comparison of published weaning timetables for six archaeological periods in England. From this, we can see that the pattern of infant feeding practices identified for Roman Britain was markedly different to that seen at the Iron Age site of Wetwang Slack, East Yorkshire (4th to 2nd C B.C.) (Jay *et al.* 2008). At this site, the $\delta^{15}N$ values of infants lacked the expected trophic level shift above the adult female mean, suggesting unusually restricted breastfeeding took place, with significant amounts of animal milk and plant-based supplementary foods being used almost from the beginning (Jay *et al.* 2008). The age at which complete cessation of breastfeeding occurred was also much sooner at the Iron Age site, with subadults assuming a diet similar isotopically to that of the adult females by the age of 2.5yrs (Jay *et al.* 2008). Following the Roman period, Anglo-Saxon practices appear to have favoured a more extended period of exclusive breastfeeding, although the weaning period was much shorter, lasting approximately half a year (Haydock *et al.* 2013). This meant that complete cessation of breastfeeding occurred much earlier in these populations, again at around 2.5yrs. A decrease in both the age when supplementary foods were introduced and the overall weaning period would be a continuing pattern in the following medieval and post-medieval periods (Haydock *et al.* 2013).

This marked difference in feeding practices seen in Roman Britain compared to other time periods has previously been attributed to the increasing influence of Soranus in the province (Fuller *et al.* 2006a). However, if these medical texts were solely governing infant feeding practices at Roman Britain it might be expected that some comparability with Roman Italian sites would be present (Prowse *et al.* 2008). However, the reverse is seen. The Roman occupation of Britain would have undoubtedly exposed indigenous

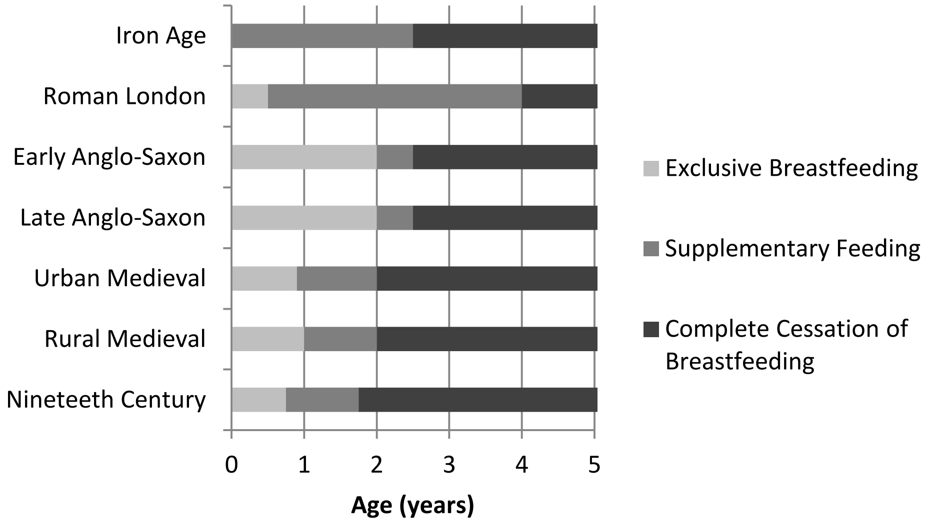


Figure 8.9: Comparison of infant feeding practices across six different archaeological time periods in England (after Haydock *et al.* 2013): Iron Age (Jays *et al.* 2008); Roman London (this study); early Anglo-Saxon (Privat *et al.* 2002); late Anglo-Saxon (Haydock *et al.* 2013); Urban Medieval (Burt 2013); Rural Medieval (Mays *et al.* 2002) and nineteenth century (Nitsch *et al.* 2011; Beaumont *et al.* 2013a)

populations to a number of different political, social and economic changes that would have affected childcare practices, including breastfeeding and weaning timetables. Therefore, while medical texts and Roman medicine may have been influential, the regional adoption of, and adaption to, a variety these different social, cultural and economic processes appears to have resulted in a breastfeeding and weaning timetable that was distinctly Romano-British, showing neither continuity from the Iron Age nor comparability with contemporary Mediterranean communities.

(c) Post-weaning Subadult Diet

Few historical or archaeological investigations into the nature of subadult diet from the period of post-weaning to adulthood have been undertaken within the Roman period (Booth 1991; Bradley 1998; Sigismund-Nielsen 1998; Dunbabin and Slater 2011). The study of Roman subadult diet has also been largely neglected by stable isotope analyses, beyond infant feeding practices (see above), with subadults either being “lumped” in with adult data or being excluded altogether. However, the two studies that have focused on post-weaning subadult dietary differences in Roman populations have reported contrasting results regarding the nature of age-related changes (Prowse *et al.* 2005; Redfern *et al.* 2012) (see chapter 2). Therefore, one of the aims of this study was to identify if, and how, subadult diet in Roman

London differed from that of their adult contemporaries, and how diet change over the subadult life course.

Examination of overall diet in Roman London identified no significant difference between the $\delta^{13}C$ and $\delta^{15}N$ values of subadults and adults, with both having similar overall mean isotopic values. These findings and the large overlap in isotopic values between the two age groups suggest that children and adults in Roman London had access to isotopically similar food items. However, the overall distribution of isotopic values identified clear differences in the pattern of consumption between the two age groups.

The most striking of these differences is the inclusion of freshwater fish in the subadult diet and its apparent absence in that of the adults. Within the Roman world, freshwater fish was regarded as a low status food item, with its price being fixed at half, or even a third, that of its equivalent marine species (Diocletian *Edict of Diocletian* V.1-5) (Rutgers *et al*. 2009: 1132). Its consumption has not only been linked to the poorer sections of society in historical records, but also in isotopic studies of less wealthy sections of society in Roman Italy itself (Rutgers *et al.* 2009). Therefore, the recognition of freshwater fish as a food item deemed acceptable for children but not adults, particularly adult males, is extremely interesting. The patriarchal nature of Roman society afforded adult males a higher social and legal standing to that of their female and subadult counterparts (Bradley 1991; Harlow 1998: 55; Dixon 2001; Grubbs 2002; Johnston 2004: 30). Such differences permeated all aspects of Roman life, Roman dining practices that denied females and children full participation and the “right to recline” (Booth 1991; Bradley 1998; Sigismund Nelson 1998; Dunbain and Slater 2011). Instead, their lower hierarchical position was reinforced by positioning them in noticeably inferior seated positions below, beside or even behind the couches of the adult males (*Ibid*). The higher social status of males was also likely to have given them preferential access to food (Garnsey 1999: 6). It is perhaps then not surprising that significant differences were observed between the subadult and adult males in Roman London, with the higher social standing of adult males affording them preferential access to high status food items, such as marine fish. As a result, the utilisation of freshwater fish within the subadult diet may be seen as a marker of their lower social position, not only within the family but society at large. The fact that the only evidence of consumption of freshwater fish observed in adults was found in two females, and no significant difference was observed between subadults and adult females, seemingly strengthens this hypothesis.

It is important to note that not all subadults appear to have consumed freshwater fish, with some displaying levels of $\delta^{13}C$ and $\delta^{15}N$ enrichment consistent with the preferential consumption of marine resources. In some cases, the level of enrichment observed in subadults equalled that of some of the more enriched adult males. The consumption of freshwater fish by subadults in Roman London then was by no means universal. In his discussion of food distribution, Garnsey (1999) identified that in times of limited resources those members considered of most importance for the family's survival would receive the greater share of the available resources. If so, it may also follow that in times of plenty, children may also have had greater access to luxury food items, particularly in more affluent households. As a result, the pattern of consumption amongst subadults is also likely to have been governed by the economic status of their families (see Section 8.3.3).

Another noticeable difference in consumption observed between subadults and adults at Roman London was the greater variability and stratification of the adult isotopic values. When biological sex was considered, the majority of the variation and stratification observed occurred within the adult females, with a positive correlation observed in their isotopic values suggesting that their access to high status food items, namely that of marine fish, may have been related to status. This is the opposite of the pattern seen in the adult males, where all individuals appear to have had at least some marine fish. Based on these findings, it appears that the adult female diet at Roman London, like that of the subadults, may have been more dependent on status than that of the adult males. Indeed, within a patriarchical society, such as that of the Roman Empire, the status of females would have been largely dependent on that of her family and later her husband (Shaw 1987; Harlow and Laurence 2002; D'Ambra 2007). Greater variability in δ^{13}C and δ^{15}N values has also been observed in adult female populations at other Romano-British sites, such as Poundbury (Richards *et al.* 1998) and Queenford Farm (Fuller *et al.* 2006a), with adult females tending to have lower average δ^{15}N values.

Another potential explanation for the greater variation seen in the isotopic values of the adult population at Roman London may be higher levels of mobility in this section of the population. From Figures 7.4 and 7.5, it is apparent that almost all of the δ^{15}N and δ^{13}C values of the subadults at Roman London, post-weaning, fall either within one standard deviation of the adult female mean, or are more significantly depleted below it. As the isotopic signature in adult bone collagen represents an average dietary intake of between five to fifteen years (Hedges *et al.* 2007), the large variability in the adult population may be a reflection of dietary intake prior to their arrival at Roman London. Greater mobility in the adult population is supported by limited isotopic data, which show the presence of migrants from the Mediterranean region in Roman London (Montgomery *et al.* 2010; Shaw 2013; Millard *in prep*). However, as much of the variability in dietary intake in the adult population is attributed to females, it would mean that the greatest mobility occurred amongst women. As yet, the number of adult individuals analysed both within this study, and those looking at population mobility in Roman London, is too small to determine if such patterns existed.

As clear differences in dietary intake were observed between subadults and adults, it was important to determine how and when the transition to an adult dietary pattern occurred. Comparisons by subadult age categories identified that, following weaning, dietary intake was significantly different to that of the adult population in the childhood and juvenile age categories. However, no statistically significant difference was observed between these age categories for either δ^{13}C or δ^{15}N. Whilst some individuals from both the childhood and juvenile categories do have isotopic values on a par with those seen in later age categories, the inclusion of freshwater fish is unique to these earlier age groups. The similarity in dietary intake across the childhood and juvenile age categories suggests dietary intake of protein remained similar to that utilised in the post- weaning period (Section 8.2.2 (ii)) , being based largely on terrestrial animal and plant protein. This agrees with Galen's age-related dietary prescriptions for the retention of the post-weaning diet across the first two seven years of life (*Hygiene*).

It is only by the time the adolescent age category is reached that no statistically significant difference is observed in the adult population, suggesting that the transition to an adult diet was completed by this age. This is further supported by the apparent absence of freshwater fish consumption amongst adolescents and the positive correlation of their δ^{13}C and δ^{15}N values, which were both seen in the data from the adults. Interestingly, this positive correlation amongst the adolescents is most comparable to the pattern seen in the adult females despite the inclusion of both males and females within the subadult age category. This similarity in diet between adult females and older subadults was also seen at Isola Sacra (Prowse *et al.* 2005), suggesting a diet similar to that of the adult males was yet to be introduced. However, when the isotopic signatures of the adolescent group in Roman London are examined by biological sex, it is apparent that the patterns for each sex closely resemble that seen in their adult counterparts.

The attainment of an adult diet by the age of seventeen to nineteen years in Roman London agrees with historical and archaeological evidence for a change in social status at this time. For males, the removal of the bulla between the ages of fourteen and seventeen marked the transition to adulthood and assured full membership to Roman dining practices. It is important to note that the extent to which these male social transitions were adhered to in Roman London is unknown, particularly within the lower status sections of society. Instead, greater access to higher status food items at this age, such as marine fish, may instead reflect the increased economic contribution of an individual at this age to their family. While females would have largely been excluded from the aforementioned social practices, they too would have experienced a social transition at this age through marriage. Whilst marriage was known to have taken place from as young as twelve for girls from elite families in Rome, archaeological and epigraphic evidence suggests for the vast majority of females marriage would take place in their late teens or earlier twenties.

Examination of the isotopic values by year shows the only significant difference in the progression from subadult to adult diet occurred within the $\delta^{13}C$ values, with a pattern of increasing enrichment with age attributable to increased marine consumption alongside decreasing contributions of freshwater fish (Figure 7.10). That the increase in $\delta^{13}C$ from four to twenty years had a shallow gradient (r^2= 0.166) suggests the transition towards an adult diet would have occurred gradually, mirroring the gradual social progression towards adulthood that would have also been taking place across the same age period (Harlow and Laurence 2002).

(d) Post-weaning subadult diet – Inter-Site comparisons

A lack of stable isotope analyses of Roman subadult diet which includes the post-weaning period means that few data sets are available for inter-site comparisons. Despite this, it was possible to draw comparisons with the two sites where subadult diet has been explored, Roman Dorset (Redfern *et al.* 2012) and Isola Sacra, Italy. For Isola Sacra, data were taken from post-weaning subadults featured in Prowse *et al.* (2008), with additional data taken from Crowe *et al.* (2010). In order to allow comparisons, the data are presented in Figure 8.10 according to the deviation from the site's terrestrial herbivore mean ($\Delta_{\text{hum-herb}}$).

From this comparison, it appears that, while some individual values at each site were similar, the overall pattern of $\Delta^{15}N$ enrichment in Roman London falls in between that of Roman Dorset and Isola Sacra. This ordering of $\Delta^{15}N$ enrichment mirrors that seen for the overall population from these sites (Figure 8.6), demonstrating that dietary intake of the different subadult populations depended on the types of foods available to them at each site (see Section 8.10). Interestingly, the overall range of both $\Delta^{13}C$ and $\Delta^{15}N$ data seems to be much greater in Roman London ($\Delta^{13}C$ =3.0‰, $\Delta^{15}N$ = 3.6‰) than at either Roman Dorset ($\Delta^{13}C$ =1.0‰, $\Delta^{15}N$ = 2.9‰) or Isola Sacra ($\Delta^{13}C$ =1.8‰, $\Delta^{15}N$ = 2.9‰), suggesting that the diet of subadults at Roman London would have been much more varied.

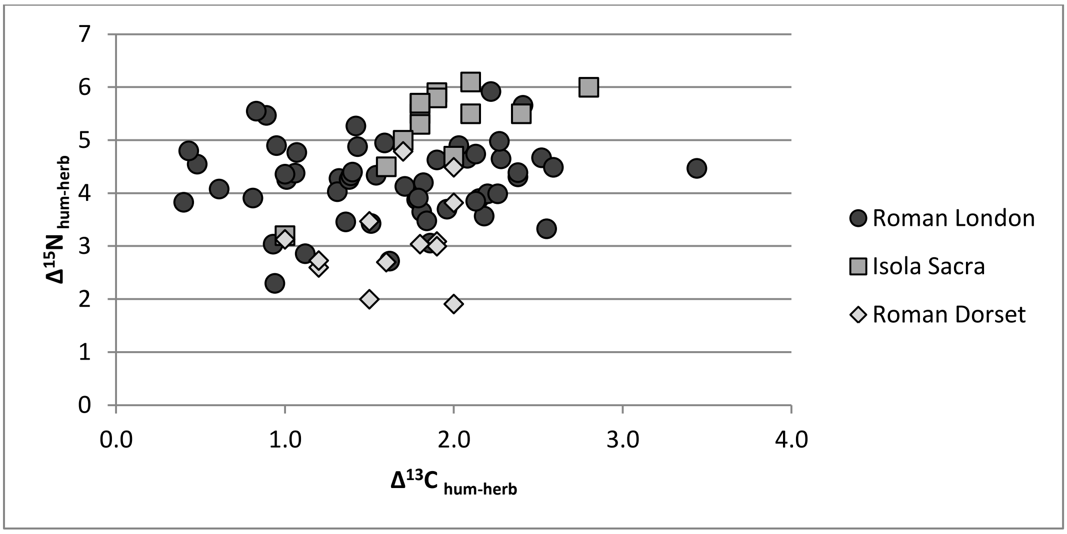


Figure 8.10: Comparison of subadult carbon and nitrogen values at Roman London to two other Roman Sites: Roman Dorset (Redfern *et al.* 2012); and Isola Sacra (Prowse *et al.* 2008; Crowe *et al.* 2010). To ensure comparability, all isotope ratios are presented as deviation from the site-specific adult mean.

The most likely reason for this greater variation in Roman London is the incorporation of both freshwater and marine fish into the diets of subadults, whereas marine resources were the only enriched foodstuffs favoured at Roman Dorset (Redfern *et al.* 2012) and Isola Sacra (Prowse *et al.* 2005). However, the absence of freshwater fish at Isola Sacra and Roman Dorset may be again a reflection of food acquisition at the sites rather than a difference in the types of foods considered acceptable for children. For example, the abundance of marine fish at Isola Sacra, a coastal town, would have made it unnecessary to utilise the more inferior freshwater fish varieties (Prowse *et al.* 2005). Within the Roman Dorset dataset, some of the sites selected were rural settlements, amongst whom fish consumption was known to have been much lower (see Section 8.2.2 (i)).

As the differences in subadult diet discussed above appear to be more of a reflection of access to food items available at each of the sites, further comparisons were undertaken to examine how subadult diet varied in relation to adult diet at each of the sites. Figure 8.11 presents the isotopic values of subadults by age. A further study was added to the aforementioned datasets, namely that of Queenford Farm, where data were taken for post-weaning subadults from Fuller *et al.* (2006a). Queensford Mill was excluded from previous comparisons as no faunal data were available from the site. In order to allow comparability, the results are again presented by deviation from the adult mean for each population. All subadults with evidence of enrichment associated with breastfeeding were excluded.

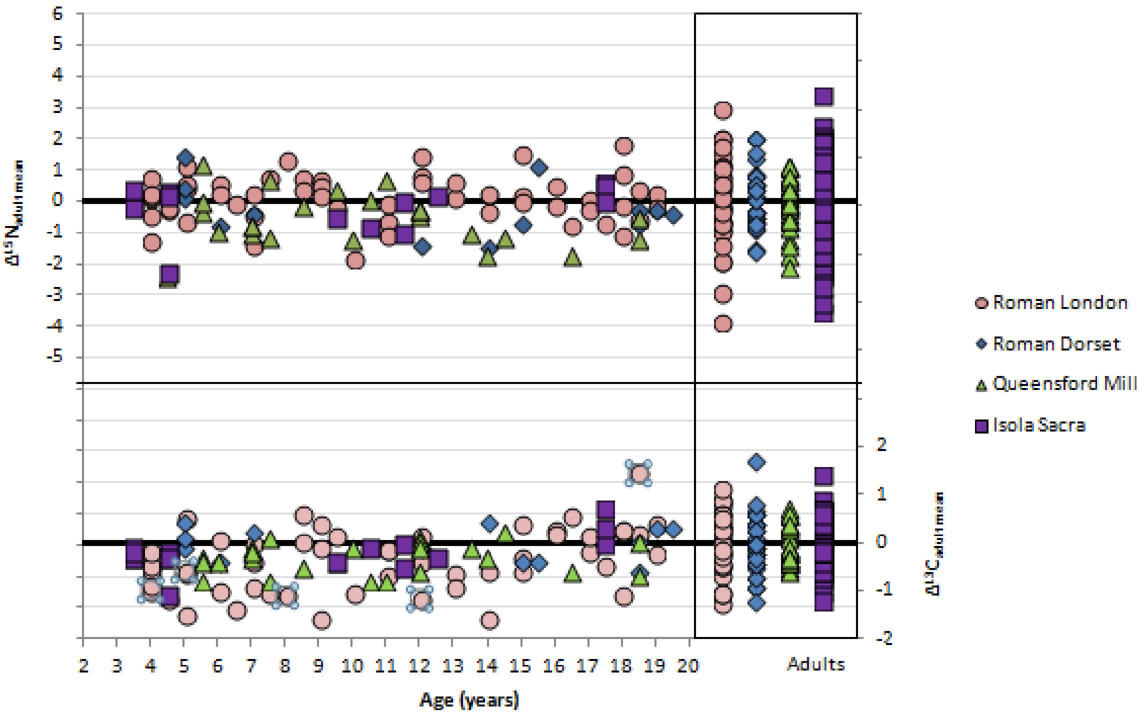


Figure 8.11: Comparison of the subadult and adult stable isotope values from various Roman populations: Roman London (this study); Roman Dorset (Redfern *et al.* 2012); Queenford Mill (Fuller *et al.* 2006a); and Isola Sacra (Prowse *et al.* 2008; Crowe *et al.* 2012). All isotope values plotted as deviation from the site specific adult mean (marked by a solid black line).

Within the δ^{15}N values, a similar pattern of decreased variability amongst subadults is observed when compared to the population's adult range in all populations, with most individuals falling either within one standard deviation above the adult mean or below it. The lowest variation is seen in the Roman Italian population of Isola Sacra, with most subadults tending to have δ^{15}N values close to the adult mean despite the large variation observed at the site. Subadults from the Romano-British sites also have δ^{15}N values that tend to remain close to or below the adult mean, although the subadult δ^{15}N ranges tend to encompass a much greater extent of the adult range. It is only for Roman London, that subadult δ^{15}N values tend to fall above one standard deviation of the adult mean, with the highest values occurring at eighteen years.

For the δ^{13}C values, a consistent pattern of depletion in subadult values below the adult mean is seen at all four sites. The greatest depletions below the adult values are observed at the Romano-British sites of Roman London and Queenford Farm, with the δ^{13}C values at Roman Dorset and Isola Sacra remaining closer to the adult mean. A noticeable increase in the δ^{13}C values is observed for all of the Romano-British samples from the age of fourteen years, suggesting that the retention of a diet akin to that used in the weaning period until this age was seen across Roman Britain. It is not until the eighteenth year that the same pattern is seen in the Roman Italian population; however, the absence of subadults in this population between the ages of thirteen to seventeen years may also be the cause of this pattern.

Overall, the subadult isotopic values at all four sites shows a similar pattern of lower variation when compared to their adult population, suggesting that access to dietary food items tended to be more restricted for subadults at most Roman sites. Within the Romano-British populations, it appears that the same pattern of a post-weaning restricted diet based predominantly on terrestrial plants and herbivore protein was retained until the age of fourteen as in Roman London. Despite this, the greatest level of variation around the adult mean is seen for Roman London, reflecting the greater variation of dietary food items available at this site. At Isola Sacra, the adult-like weaning diet identified in Section 8.2.2 (ii) (b) appears to have been consistently followed from the point of weaning, albeit with less overall variation than that seen amongst their adult counterparts. This difference between the Roman Italian and British sites further supports the existence of regional variation in childcare strategies.

(e) Subadult Health and Diet

Today, a good diet is recognised as a significant factor in the determination of good health and the susceptibility of an individual to stress and disease (Goodman *et al.* 1988). However, the impact of poor nutrition on mortality and morbidity is known to be most deleterious during growth, potentially having permanent ramifications on future health and development (Pan American Health Organisation *et al.* 1998; Black *et al.* 2008; Weisstaub *et al.* 2008; papers within Gilman *et al.* 2013). Undernutrition is also implicated as the underlying cause of 30-50% of deaths in those under the age of five years in low and middle income countries (Lutter *et al.* 2013; United Nations Children's Fund *et al.* 2014: 1). The importance of good nutrition and a well balanced diet was also recognised in the Roman world. One of the fundamental cornerstones of ancient medicine was prevention, and good hygiene was considered essential to ensuring this (Jackson 1988; Van der Eijk 2011: 26; Baker 2013: 126-132). Unlike today, the ancient notion of hygiene not only entailed careful maintenance and grooming of the body, but also encompassed exercise regimes and a healthy diet (Mazzini 1999; Grant 2000: 6-7; King 2001: 18; Israelowich 2015: 119). Food in the ancient world also played a further role in medicine itself, forming a key aspect of treatment (Jackson 1988; Grant 2000: 6-7; Nutton 2004: 246; Cool 2006: 32-33; Wilkins and Hall 2006: 213-244). Therefore, in order to examine the impact of dietary intake on health in Roman London, comparisons were drawn between the δ^{13}C and δ^{15}N values of those individuals with and without stress indicators.

It was initially believed that those individuals with stress indicators may have a marked difference in dietary intake to those without, due to their ability to survive acute stress episodes and sustain chronic infections long enough to ensure stress markers were recorded within the skeleton (Wood *et al.* 1992). These differences may have been recognised as an increased enrichment of δ^{15}N, associated with greater consumption of animal meat, or increased enrichment of δ^{13}C, associated with greater access to higher status food items such as marine fish (Richards *et al.*1998; Müldner 2013). However, examination of the δ^{13}C and δ^{15}N values for those with and without evidence of any stress markers identified no significant difference in dietary intake. The same lack of association between dietary intake and the presence of stress markers was also identified in another study of Romano-British populations by Cummings (2008: 202). While this lack of any significant difference may suggest that dietary intake was not one of the multiple potential contributory factors for the expression of stress indicators within the Roman London sample, a number of limitations regarding the nature of the isotopic evidence utilised are recognised.

Firstly, the lack of any significant relationship between dietary intake and the presence of stress indicators highlights the complex and multifactorial nature of the stress indicators examined (Goodman 1993). Therefore, in order to determine the role of dietary intake on health, it may be more beneficial to utilise other indicators more closely associated with poor nutrition in subadults such as growth trajectories or cortical bone thickness (Halcrow and Tayles 2011). Indeed, the only diseases that had a link to dietary intake in Cumming's (2008: 207) study were gout and DISH, both associated with high status consumption (Rogers and Waldron 2001; Jankauskas 2003; Roberts and Manchester 2005: 161-162; Saag and Choi 2006). Secondly, the δ^{13}C and δ^{15}N values detected within bone collagen only allow the identification of broad dietary patterns, such as the identification of marine consumption, the extent of animal protein within the diet, or the utilisation of C_4 crops like maize (Katzenberg 2008). As such, it cannot provide us with information regarding the nutritional "quality" of the food items consumed, something that is essential to our understanding of disease and stress indicator prevalence. For example, the consumption of C_3 fruit and vegetables would be largely isotopically indistinguishable from that of C_3 cereal crops, such as wheat or barley. Furthermore, the values obtained from bone collagen reflect a bulk average signal that even in subadults encompasses several years (Katzenberg 2008). Therefore, seasonal or periodic food shortages that may have had a dramatic impact on health would not be detectable in the bulk δ^{13}C and δ^{15}N values.

Thirdly, whilst the presence of stress indicators may identify potential differences within the health of the subadults at Roman London, essentially all of the subadults in the sample are "non-survivors" who failed to reach adulthood (Wood *et al.* 1992; Saunders and Hoppa 1993; Lewis 2007: 185). Therefore, it is likely that the diet of many of the individuals may have been compromised regardless of the presence or absence of stress indicators. As such, the dietary intake of these subadults may not be an adequate reflection of those subadults that survived into adulthood (Wood *et al.* 1992). A possible method that could be utilised to address this issue is the serial sampling of dentine from the children and adults of Roman London. As tooth formation occurs in a predictable age sequence that does not remodel over time, the δ^{13}C and δ^{15}N signatures obtained from dental tissues provide an accurate reflection of childhood values for those individuals who did survive into adulthood (see Beaumont *et al.* 2013a for further details regarding methodology). The application of this technique has been successfully undertaken across a number of different sites to identify incremental changes in dietary intake, including charting the changes that occur during the great Irish famine (Beaumont *et al* 2013a; b). The serial sampling of dental tissues was beyond the scope of this investigation, but it does provide a potentially fruitful avenue for future research.

8.2.3 Summary of Key Findings

- The overall level of health stress in Roman London was high and can possibly be attributed to poor living conditions and population mobility
- Subadults at Roman London had slightly higher rates of health stress than adults, although this was expected as the growth period is particularly vulnerable. The conditions analysed represent childhood stress and often are more easily diagnosed in subadults
- Comparisons of health stress across the subadult life course identified patterns correlated with social age transitions such as weaning and occupation
- Comparison of health stress in Roman London and other Romano-British towns showed higher prevalence rates at the large urban centres of London, Gloucester, and York, with London tending to be amongst the highest. Comparison to Roman Italian sites demonstrated higher rates of *cribra orbitalia* and enamel hypoplasia in Roman London may be influenced by population mobility from these Mediterranean areas of the Empire
- Dietary intake in Roman London was comparable to that of other large urban Romano-British centres.

- Age-related differences were observed in dietary intake between adults and subadults, namely the incorporation of freshwater fish into the subadult diet. Comparisons of dietary intake across the subadult life course identified a gradual transition towards the adult diet, with subadults assuming an adult diet by the adolescent age category.
- Comparison of the subadult pattern in Roman London to other Roman populations demonstrated that the greatest variation in subadult diet was in Roman London, with the least variation at the Roman Italian site of Isola Sacra.
- Isotopic evidence showed that the infant feeding practices in Roman London were comparable to those seen at other Romano-British sites, but markedly different to that seen in Roman Italy.

8.3 Temporal Trends in Demography, Health and Diet in Roman London

This section seeks to examine trends between the early and later periods of the occupation of Roman London. The burials are divided into two broad periods, the early period dating from AD43-250 and the later period AD250-410. These divisions are somewhat crude but, due to the difficulties in phasing the cemetery sites, they provide a useful, if somewhat arbitrary, means of comparing the earlier and later phases of Roman London's occupation.

8.3.1 Palaeodemography

Analysis of the population distribution of Roman London indicates that 60% of the overall skeletal population dates to the later period. This result is expected considering the transition of the dominant burial practice from cremation in the early period to that of inhumation in the later period (Philpott 1991: 53; Barber and Hall 2000: 103). Another factor in the predominance of late period burials could also have been the expansion of the town during the later period, which encompassed those sites that would previously have been extra-mural cemeteries, resulting in disturbance of early period burials (Rowsome 2008; Wallace 2014: 53-55). Limitations regarding our ability to precisely date many of Roman London's burials, due to a lack of radiocarbon dates, or datable grave goods, may also have a significant role (Barber and Bowsher 2000: 8-12; Mackinder 2000: 22; Watson 2003: 15).The 967 burials available for analysis in this thesis represent just a small proportion of the overall 10,000 burials that have been excavated within London. They are also an even smaller fraction of the likely original number of burials from a town estimated to have had a lifetime population of approximately one million individuals (Barber and Hall 2000: 112). Therefore, it is not possible to make assertions regarding fluctuations in population levels between time periods based on the results obtained in the study.

Interestingly, whilst the adult to subadult ratio between the early and late period remains almost identical, a significant difference is observed in the representation of the individual subadult age categories. This difference can be attributed to the 10.8% decline in the number of preterm and full term subadults observed between time periods. A 2.9% decline is also observed in the infant age category. Perhaps the largest contributory factor to this is the absence of subadults from intramural contexts in the late period. Of the seven preterm and full term infants recovered from within the town, four are securely dated to the earliest period of occupation (AD50-70) (Pre-construct Archaeology 2009: 10), whilst the remaining three (KWS 94) are also thought to date to the late first century AD (Barber and Bowsher 2000: 312). Regardless of this, preterm and full term infants are also less apparent in the formal extramural cemetery areas.

One possible reason for this reduction in the representation of the youngest members of the community could have been a change in burial traditions, with fetal and neonatal remains being increasingly excluded from burial in the domestic spaces and cemeteries they had once been afforded. However, the late Roman period is generally characterised by a pattern of increasing visibility of neonate and infant burials, both within villas and towns, and the formal cemeteries that surround them (Philpott 1991; Scott 1999; Pearce 2001). It is also during the fourth century when the appearance of communal infant burial areas, such as Barton Court Farm Villa, are seen (Miles 1984), and the clustering of neonate and infant remains in formal cemeteries, such as Poundbury, Winchester, and Colchester (Scott 1999; Pearce 2001). During this time, neonates and infants were also increasingly being associated with the ritual and votive realm (Scott 1999). Whilst regional variation is observed within this general phenomenon, it seems unlikely that funerary practices at Roman London would differ so significantly to that of the rest of the province. The continued presence of at least some preterm and full term subadults within the formal cemeteries provides some supporting evidence.

A more likely explanation for the contrasting pattern in Roman London may then be preservation bias. As previously acknowledged (see Section 8.1), discussions of the nature of late Roman London are hampered by the greater truncation and disturbance of the town’s third and fourth century occupation layers. Due to the greater susceptibility of the small elements of neonatal and infant remains to physical disturbance, this disruption may have been responsible for the lack of their recovery from intramural contexts in the late Roman period (Walker *et al.* 1988; Guy *et al.* 1997; Bello *et al.* 2006; Buckberry 2000). If communal infant burial areas, or at least the clustering of neonate and infant burials, were used to some extent within late Roman London's cemeteries, it is possible that these areas have yet to be found and excavated. Indeed, the discovery of the four preterm and neonatal burials clustered together at Drapers Garden (DGT06) and three at Regis House (KWS94) suggests that this practice was not unknown, at least within the town in the early period.

8.3.2 Impact of the Roman Conquest

One of the key aims of this study was to identify how the health and dietary intake of subadults of Roman London, as well as the overall population, changed over the course of its 400 year habitation. Undoubtedly, the Roman conquest and subsequent occupation of Britain would have had substantial social and economic impacts on the lifestyles of the native population (Mattingly 2006). The development of urbanisation would also have certainly had environmental consequences for the living conditions of the inhabitants of the new towns (Maloney 1990; Milne 1995; Dobney *et al.* 1999; Hill and Rowsome 2011). Previous palaeopathological investigations have identified significant increases in the level of stress indicators between the Iron Age and Roman periods, suggesting that the overall effect of the Roman conquest was deleterious to health (Redfern 2005; 2007; Roberts and Cox 2003; Peck 2009; Redfern and DeWitte 2011a). Stable isotope analyses have also detected changes in dietary intake following the Roman conquest (Richards *et al.*1998; Redfern *et al.* 2010; Redfern *et al.* 2012; Müldner 2013). However, due to the nature of Romano-British cemetery populations, most of these studies are biased towards inhumations from the third and fourth centuries AD, making it difficult to assess what kind of impact the invasion initially had on the health and diet of the indigenous population. Therefore, the presence of burials dating from this early period in Roman London provides a unique opportunity to discuss questions regarding the nature of health and diet in the aftermath of the conquest of Roman Britain. However, it should be noted that direct comparisons between Iron Age and Roman London are not possible because London did not exist prior to Roman occupation.

Figure 8. 12 presents the results of a comparison of stress indicator crude prevalence rates between various Iron Age populations in England to those seen for Roman London. As discussed in 8.2.1. (iii), drawing comparisons between populations is complicated by

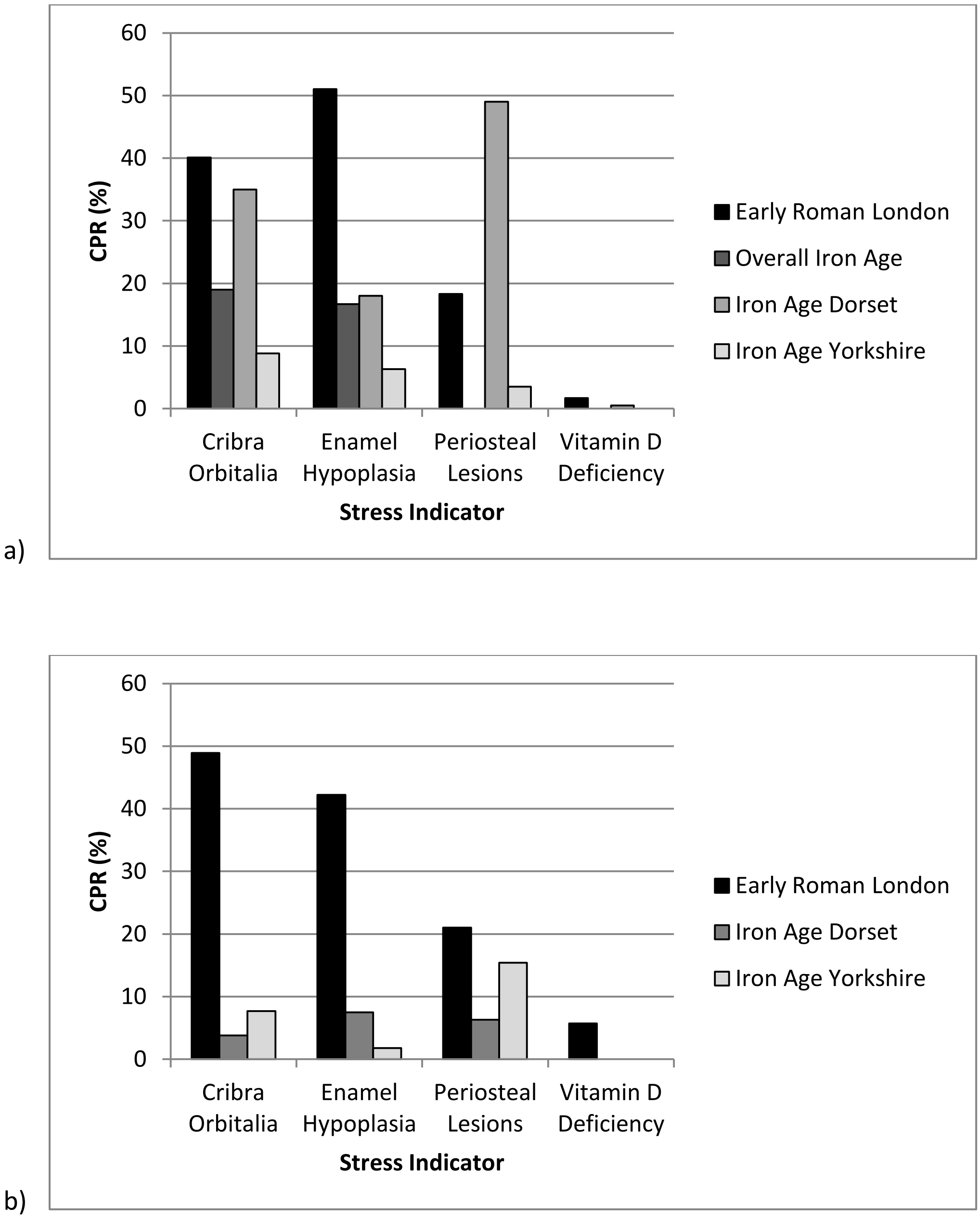


Figure 8.12: Comparison of stress indicator prevalence from early Roman London (AD43-250) to various Iron Age sites for a) total population, and b) subadult population. Early Roman London (this study); Overall Iron Age (Roberts and Cox 2003); Iron Age Dorset (Redfern 2005; 2007); Iron Age Yorkshire (Peck 2009).

differential preservation and disparity in recording techniques used by investigators. Therefore, all conclusions here are tentatively made.

When the prevalence of stress indicators from Iron Age cemeteries are compared to the results from early Roman London it confirms the pattern of increasing stress identified in previous palaeopathological studies. In the overall population from the earlier period of Roman London, *cribra orbitalia* and enamel hypoplasia are particularly high. The only stress indicator for which the reverse is true is the level of non-specific infection in the Iron Age Dorset population. However, this may be due to the small sample size available within this study (Redfern 2005; 2007). For subadults, all stress indicators examined demonstrated a higher prevalence in the early period of Roman London when compared to Iron Age sites. These increases have been attributed both to the adoption of urbanisation and its associated poor living conditions, and the increased level of psycho-social stresses associated with subjugation by an incoming power (Redfern 2005; 2007; Redfern and DeWitte 2011a). Another factor to be considered is the increase in stress associated with population mobility, both in terms of the bringing of, and exposure to, new pathogens, and the potential decline in socio-economic status experienced by transient populations (Ben-Sira 1997; 50-54; Al-Baldawi 2002; Malmusi *et al.* 2010; Redfern and DeWitte 2011a; 2011b; Redfern *et al.* 2015: 116). As Roman London was established by a migrant mercantile community, this may have been an important factor in the levels of stress seen in its early population.

The conquest of Roman Britain has been associated with a change in dietary intake (Cool 2006; Redfern *et al.* 2010; 2012; Müldner 2013). While archaeozoological and environmental evidence for diet in Roman towns have highlighted the increased availability/expansion of a more diverse range of foodstuffs (Willcox 1978; Cool 2006; Locker 2007; Van der Veen 2008; Davis 2011a; 2011b), within stable isotopic investigations there is a notable increase in the consumption of marine resources observed (Richards *et al.*1998; Redfern *et al.* 2010; Redfern *et al.* 2012; Müldner 2013). The stable isotope results from Roman London also demonstrate dietary changes introduced by the Roman conquest. Figure 8.13 compares the stable isotope results of a number of Iron Age populations in Britain with those of early Roman London. In order to ensure comparability, the results are presented as deviations from the sites' herbivore mean. As few subadult values were available, comparisons were drawn between the overall populations.

From Figure 8.13, it is apparent that while the level of nitrogen enrichment in both the Iron Age populations and early Roman London is similar, the enrichment observed in the early Roman London population is much greater. This suggests that while Iron Age and Roman populations were both consuming terrestrial animal protein, only the Roman population of London was consuming carbon-enriched foodstuffs, namely marine fish. This difference is comparable to those reported in other isotopic investigations of temporal changes in dietary intake in Britain, with increased marine consumption being seen as characteristic of the transition from the Iron Age to Roman period (Richards *et al.*1998; Redfern *et al.* 2010; Redfern *et al.* 2012; Müldner 2013). However, it is notable that higher levels of carbon enrichment were observed in the earlier period of Roman London, suggesting that the biggest

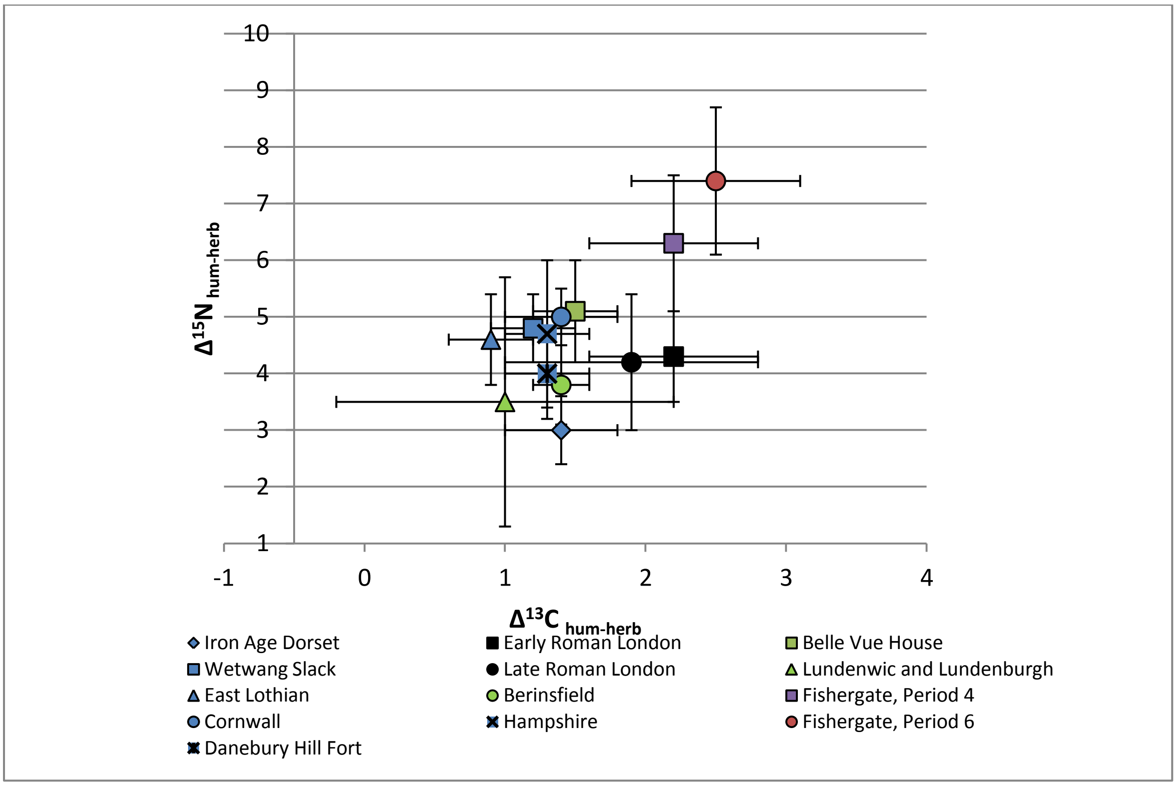


Figure 8. 13: Comparison of δ^{13}C and δ15N isotope results from Iron Age, Roman and Medieval populations. Blue symbols represent Iron Age populations – Iron Age Dorset (Redfern *et al.* 2010; 2012), Wetwang Slack, East Yorkshire (Jay and Richards 2006), East Lothian (Jay and Richards 2007); Cornwall (Jay and Richards 2007); Danebury Hill Fort (Stevens *et al.* 2010); Hampshire (Jay and Richards 2007). Black symbols represent Roman London (this study). Green symbols represent Anglo-Saxon populations – Berinsfield, Oxfordshire (Privat *et al.* 2002); Bell Vue House, York (Müldner and Richards 2007); Lundenwic and Lundenburgh, London (Johnson 2012). Purple and pink symbols represent medieval populations from York (Müldner and Richards 2007)

changes in diet in Roman London were observed early on (see Section 8.3.3 for further discussion of temporal trends with Roman London). Another difference apparent between the Iron Age populations and Roman London is the greater level of variability within the isotopic data for Roman London. This difference highlights the greater accessibility of the inhabitants of Roman London to a wider range of dietary food items than indigenous Iron Age populations (Cool 2006).

In order to identify how dietary intake changed following the collapse of Roman occupation in London, comparisons were also drawn between diet in late Roman London and populations from the subsequent Anglo-Saxon and Medieval periods (Figure 8.13). Interestingly, the Δ^{13}C and Δ^{15}N of the three Anglo-Saxon populations is much more akin to that from the Iron Age, suggesting that dietary intake following the Roman period reverted to a more traditional diet that lacked marine fish consumption. Privat *et al.* (2002) identified that freshwater fish gained a more prominent place in the diet of the Anglo Saxon population at Berinsfield, Oxfordshire. There is a notable difference in diet between Anglo-Saxon London (Lundenwic) and Roman

London, with the apparent absence of marine fish in the period following the collapse of the Roman Empire. It is not until the early medieval period (Fishergate York, Period 4) that significant consumption of marine foods is reflected in the $\delta^{13}C$ values, although the higher $\delta^{15}N$ enrichment observed in both the early and late medieval period (Fishergate York, Period 5) indicates that the level of marine consumption at this site was much greater than that at late Roman London.

8.3.3 Temporal Trends within Roman London

The data from Roman London provides a unique opportunity for examining changing health over the period of occupation. Most studies that have discussed the changing fortunes of Roman London have focused on the physical archaeological evidence (Perring 1991; Marsden 1980; Marsden and West 1992; Milne 1995; Esmonde Cleary 2004; Cowan *et al.* 2009; Hill and Rowsome 2011; Rogers 2011), with few undertaking a diachronic analysis of skeletal remains. Little is known about the fluctuating health of the Romano-British population, nor how it may have changed throughout the course of the 400 years of Roman occupation. Health during this period has tended to be conceptualised as static and the "Roman experience" of health largely homogenous. The existence of burials throughout the entire lifespan of Roman London provides a unique opportunity to assess how living conditions and health may have changed throughout the Roman period. However, it should be borne in mind that it was only possible to use the crude division of the early and late period here due to the uncertain phasing of some of the cemeteries. Therefore, short-term fluctuations in health will be obscured, and only long-term mean prevalence rates will be identifiable (Waldron 2007: 34).

Initially, it was expected that health stress would decrease over the duration of the Roman occupation. The process of urbanisation was particularly rapid during the early period, and it was during this period that the population density was at its highest, reaching in excess of 20,000 people (Swain and Williams 2008: 39). Due to the rapidity of the growth experienced, it is likely that sanitation and hygiene may not have been able to keep pace, resulting in contamination of water supplies and domestic spaces (Maloney 1990; Wacher 2000; Williams 2003; Alirol *et al.* 2010; Davis and Smith 2011; Hall and Kenward 2015). The most common form of housing used at this time was small, densely packed, timber single roomed structures and strip buildings, which would have brought further issues of sanitation and enabled the easier spread of infection (Milne 1992: 73; Ottaway 1992: 57-60; Perring 2002; Redfern and Roberts 2005: 120-123; Davis and Smith 2011; Wallace 2014: 100-102). Population mobility was also expected to be highest during this early period as London was previously unoccupied and so, by definition, all of the early inhabitants were migrants, whether local to Britain or from abroad (Millett 1990: 89; 1996; Holder 2007; Pearce 2010; Wallace 2014: 19). Long distance trade through London's port was also at its peak during the early period, further facilitating the greater movement of people into the town (Milne 1985: 112; Green 1986: 43; Perring 1991: 50). This increased movement of people would have doubtless brought with it the attendant risks of increased stress, socioeconomic deprivation, and the transmission of new pathogens (Ben-Sira 1997; 50-54; Al-Baldawi 2002; Knobler *et al.* 2006; MacPherson *et al.*2009; Malmusi *et al.* 2010). The negative psychological aspects of the initial conflict and dramatic consequences of occupation that came with the conquest may also have had a deleterious physiological impact on early settlers (reviewed by Jennings 2010: 10-44).

The palaeopathological results of this investigation, however, provided evidence to the contrary, with significant increases in stress indicators between the early and later phases. This increase was observed for the population as a whole as well as for adults and subadults, when analysed separately. There are a number of potential reasons for this. Firstly, while there was conflict during the earlier period of occupation, instability continued, particularly during the 3rd and 4th centuries (Reece 1981; 1992; Faulkner 2000; Esmonde Cleary 2004). The late third century was a period of crisis for the Roman Empire with civil wars, barbarian incursions, hyper-inflation and near collapse of the currency (Blockley 1980; Reece 1992; Fulford 2004; Drinkwater 2005; Mattingly 2006: 225-238). During the mid-fourth century, Roman London was looted after attacks by Saxons and Picts (amongst others) and coin hoards dating from the 3rd and 4th centuries also testify to conflict and economic uncertainty (Blockley 1980; Marsden 1980: 10; Perring 1991: 124-131; Pre-Construct Archaeology 2009: 56-65). Imports and long distance trade declined and luxury commodities became less readily available (Milne 1985; Perring 1991: 85; Esmonde Cleary 2004: 23; Cowan and Wardle 2009: 25-33; Hill and Rowsome 2011: 445, 450). These periods of economic uncertainty may have compromised food supplies and inflation may have driven up the cost of some food items beyond the means of some the town's residents. However, the increase in tributary modes of taxation payment from the third century AD, may have allowed some buffering for some centres of tax collection such as Roman London (Esmonde Cleary 2004: 420).

The late period was also the era that saw the decline and eventual collapse of Roman London. The nature and pace of the decline of Roman London has been the subject of much debate. Archaeological evidence appears to suggest the decline in the fortunes of the town began as early as the late second century AD, with the population level apparently falling by up to two-thirds (Marsden 1980; Perring 1991; Marsden and West 1992; Reece 1992; Faulkner 2000). However, it has been suggested that this apparent decline may simply be an artefact of poor preservation (Yule 1990; Esmonde Cleary 2004; Witschel 2004; Rogers 2011). Much of the debate has focused on the deposition of “dark earth” layers, traditionally thought to represent the end of Roman occupation, as it was believed that there were few structures or features within it (Perring 1991: 78-81; Yule 1995). However, evidence of building structures from other late Roman towns, such as the timber buildings raised on stone pads observed at Silchester, have proved to be more ephemeral and less archaeologically visible (Clarke and Fulford 2002: 163). As dark earth tended to be removed during excavation to gain access to the earlier Roman layers until recently, evidence for this kind of occupation may have been lost and population levels underestimated (Rogers 2011: 10). Truncation and post-deposition reworking of the late Roman layers may have also contributed to this underestimation of population density, as, in areas of good preservation, evidence suggests continuation of occupation into the fourth century (e.g. Cowan *et al* 2009: 166-170; Hill and Rowsome 2011). Indeed, Roman London continued to remain an important settlement within the province, being the provincial capital of *Britannia Superior* in the third century AD, and becoming the seat of the *Vicarus* and the location of a provincial mint and treasury in the fourth century AD (Perring 1991: 112; Wacher 1995: 84; Hassall 1996: 25; Esmonde Cleary 2004: 66; Southern 2004: 393). Due to the aforementioned issues, determination of population levels in the later period is extremely difficult, although Swain and Williams (2008: 39) suggest the population would have been around 20,000 at the beginning of the time period. If population density remained at a significant level, associated risk factors, such as poor sanitation and increased transmission of pathogens, may still have remained present within the town. Stable isotope investigations of population mobility have also identified the continued presence of migrants within the province and Roman London itself in the later period, though it is not possible to estimate the extent of migration based on the current available evidence (Evans *et al.* 2006; Eckardt *et al.* 2009; Leach *et al.* 2009; Chenery *et al.* 2010; Montgomery *et al.* 2010; Müldner *et al.* 2011; Cheung *et al.* 2012; Shaw 2013; reviewed by Eckardt *et al.* 2014).

Living conditions appear to have remained similar to the previous period, with timber structures continuing to be used for housing for the majority of the population despite the increase in the appearance of larger stone town houses from the third century AD (Perring 1991: 100-104; Perring 2002: 44; Bluer *et al.* 2006: 69; Goodman *et al.* 2011: 416). Maintenance of the roads and drainage infrastructure also appears to have continued until at the least the end of the fourth century AD, after which sanitation issues may have become more problematic (Rowsome 2008; 2011). The movement away from the use of large public wells, to smaller private wells and other means of water collection is also noted from the mid-second century (Blair *et al.* 2006). If these smaller wells were placed in close proximity to properties and were not sufficiently maintained, it is possible that water contamination became increasingly more problematic in the later period. The continued use of Roman London's rivers and watercourses as a means of drainage over the course of the occupation would have also increased water pollution levels (Maloney 1990: 124-5; Williams 2003). With increasing abandonment of the town's buildings by the mid-fourth century AD, the dilapidation of the settlement may also have caused increased stress and health issues for those individuals who remained.

The results of the palaeopathological investigation of Roman London provide contrasting results to those from Colchester which provides the only other study of temporal trends within a single settlement across the Roman period. An examination of the prevalence of stress indicators and metabolic disease at Colchester, another prominent large Roman urban centre, yielded no significant difference between time periods (Jenny 2011). However, the overall levels are much lower than those observed for Roman London (see Section 8.2.1 (iii)). Therefore, the environmental and cultural buffers afforded to individuals at Colchester may have also sheltered them from the changes in the third and fourth centuries that were so detrimental to health in London. (Jenny 2011). Conversely, if the lack of stress indicators and metabolic disease in Colchester is instead a reflection of the population's inability to recover from stressors, the political, socio-economic, and environmental changes in both periods had similar effects on overall population health.

The lack of any significant change between subadult and adult prevalence rates between time periods in the Roman London sample suggests no cultural buffering was afforded to the adult population, with both being equally effected by the increase in health stress experienced at this time. Full term subadults are the only age category where an overall decrease in prevalence is present, although the small number of individuals from this age group in the late period is the most likely explanation for such a difference.

Of all the subadult age categories, individuals in the infancy age category appear to have been most affected by the apparent increase in stressors of the late period in London, with prevalence rates doubling for almost all stress indicators in infancy. As previously discussed, the highest rates of frailty amongst subadults in pre-industrialised developing countries occur in the youngest members of the community, with morbidity and mortality rates remaining high until the fifth year of life (Rousham and Humphrey 2002: 124). It is therefore not surprising that the observed increase in stress between the early and late periods would have had the most profound effect on this age group. It is likely that the high prevalence rates of stress indicators in infants during this period are also reflecting maternal stress factors (see Section 8.2.1 (ii) (b)). The females in Roman London of reproductive age may have experienced a great deal of stress from a variety of physiological and psychological causes. As infant feeding practices practiced within a community are thought to be a major causative factor of increased morbidity and mortality in this age category, a detrimental change in breastfeeding and weaning timetables in Roman London could be a reason for the increase in infant stress indicator prevalence in the later period (Stuart-Macadam 1995; Katzenberg *et al.* 1996). However, no evidence for such changes was apparent in the δ^{13}C or δ^{15}N data, with breastfeeding and weaning timetables remaining consistent across the entire period of Roman occupation. While infant feeding practices may not have changed, decreases in the quality and range of food available may be responsible (see below). Further to this, supplementary food may not have been as nutritionally adequate, or perhaps was more likely to be contaminated due to increased pollution, exposing infants to greater health risks.

The most notable change in dietary intake between the early and late period in Roman London was the introduction of freshwater fish into the subadult diet. During the early period there is a closer comparability of diet between post-weaning subadults and adults, with no statistically significant differences observed. Any enrichment in diet that was observed came from marine resources. By contrast, in the late period it is more common for subadults to consume freshwater fish, which do not feature as part of the adult diet. There was also a statistically significant difference in the carbon isotope data between subadults and adults for the later period. This change to the incorporation of freshwater fish seen in the isotopic data coincides with a decrease in the variety of plant species and archaeozoological evidence within third and fourth century Roman London, and a decline in long distance trade from the third century AD (Milne 1985: 112; Cowan *et al.* 2009: 173; Davis 2011a: 403). This decline was in part due to the aforementioned turbulence in the empire. While the island nature of Britain would have sheltered it to some extent from raids and incursions seen on the continent, the effect on trade was still felt (Fulford 2004). A decrease in trade would have been more keenly felt in towns such as Roman London that relied on food being imported to the city, rather than providing food for themselves (Garnsey 1999: 2,32; Erdkamp 2005: 148; Alcock 2006: 231).

Therefore, the choice to utilise more freely available wild foods may be a reflection of these problems. During the later period, London was still an important place and it is possible that during this time there was a widening gulf between the rich and the poor in terms of access to a variety of foodstuffs. The local elite would still have expectations of high status food items. The greater dispersal of values in the late period may therefore be a reflection of greater status differentiation between the poor and wealthy. While in the early period there would have been some differentiation between the rich and the poor in terms of food, pressures in the later period would have made it more difficult for the poor, forcing them to exploit more locally available resources such as freshwater fish to supplement the diet. This is a pattern that has also been observed at the Roman Italian Christian catacombs of St. Callixtus, where the lower socio-economic status of those buried there was reflected in their greater consumption of freshwater fish (Rutgers *et al.* 2009). It was the children that appear to have borne the brunt of this in Roman London, as it was predominantly their diet that was supplemented, whilst adults continued to consume marine resources.

The choice to exploit freshwater fish, particularly for subadults, may be one of the reasons an increase in the levels of pathology between time periods is seen. Subadults have the highest overall levels of pathologies in the late period (compared to vice versa in the early period). The River Thames, the main source in the later period for freshwater fish, was used as the main means of removing both industrial and domestic waste, including human waste, from the town. Exposure to contaminated fish and water supplies can result in diarrhoeal diseases, particularly in infants (O'Ryan 2005; Baxter 2007: 286-287; WHO 2008: 14; Qazi *et al.* 2015: S23). Galen noted that fish from the Tiber were noticeably smaller and bad for health (Rutgers *et al.* 2009) and, while the Thames is likely to have been less polluted than the Tiber, parallels can still be drawn.

8.3.4 Summary of Key Findings

- Results from the study support previous findings of a decline in health following the Roman conquest in Britain and the adoption of a Romanised diet, characterised by the consumption of marine fish
- Temporal trends within the town show that stress indicator prevalence increased in the later period, indicating a decline in health associated within increased disturbance in the Empire and declines in living standards. Diet also appears to have declined in quality, with the consumption of freshwater fish, although subadults appear to have been the most exposed to these changes

8.4 Status

Identifying aspects of identity, such as status, through the analysis of funerary remains is challenging. This is because funerary remains may not always directly reflect the social identity the deceased held in life, and may equally provide a subversive view (Pearce 2000; 2013; Garwood 2011: 268-270; Heilen 2012: 36-38; Fowler 2013). The criteria used to assess status within the archaeological record can also be hard to determine, as the way in which culturally determined aspects of identity interact within the burial environment may be unknown (Williams 2006: 37-38; Fowler 2013: 73-87). Within traditional processual interpretations of mortuary practices there has been a tendency to focus on financial investment and the items buried with the body when investigating status (e.g. Brown 1971; Binford 1971; 1972). However, the level of significance attached to grave goods as status indicators may not be universally observed in all societies and social importance cannot simply be “read” from these items (Hodder 1982; Parker Pearson 1982; 2003: 72-94; Shanks and Tilley 1982; Babić 2005; Garwood 2011: 268-270; Chapman 2013; Ekengren 2013). Instead, other facets of the burial ritual, such as burial type and location, or the attendant funerary services, such as sacrifices and feasts, may be considered far more important (Ucko 1969: 266-268; Ekengren 2013; Pearce 2013). The ephemeral nature of some of these practices may make it impossible to identify them archaeologically, and differential preservation of materials in the burial record may further exacerbate analyses (Williams 2006: 37-38; Cool 2011:296; Ekengren 2013).

Within Roman London, few burials were found to have grave goods included, and no clear pattern with regards to status has been observed (Hall 1996; Barber and Hall 2000). This pattern is similar to that observed elsewhere within the province (Philpott 1991; Quensel-von-Kalben 2000; Cool 2011: 309-312). In an analysis of mortuary remains, Hamlin (2007) found the burial container type to be a more fruitful means of identifying status differences within settlements, with those requiring greater financial investment representing high status (also Philpott and Reece 1993; Richards *et al.* 1998; Redfern *et al.* 2010). In the Roman London sample, 60% of individuals within the sample were found to be buried within some form of burial container. However, over 90% of these containers were simple wooden coffins and, for those without evidence of a burial container, it could simply be that they did not survive: absence of evidence is not evidence of absence. There are a few examples of lead or stone coffins known from Roman London, but the whereabouts of the skeletal material is unknown, or the coffins were discarded or misplaced during early archaeological excavations.

Comparisons of burial containers between subadults and adults show that children were more likely to have been buried in a container than adults. This, and the fact that they were included in the formal cemeteries, goes against the idea that children were excluded from normal burial rites or were not mourned (Scott 1999; Pearce 2001; Carroll 2011). A poignant example of the care afforded to children in death at Roman London is seen in the burials at Drapers Gardens of four perinatal infants carefully laid out in wooden coffins and buried next to each other (Pre-Construct Archaeology 2009: 10) (Figure 8.14). Another potential example of care is the burial of a perinate laid out at the foot of a young adult female at the Great Dover Street site (GDV96) (Figure 8.14). Subadults within this sample were also included in high status

Figure 8.14: Poignant child burials from Roman London: Left – Remains of a neonate from Drapers Garden, carefully laid within a small timber coffin (Pre-Construct Archaeology 2009: 10). Right – Burial of a neonate at the feet of a young adult female from Great Dover Street (Mackinder 2000: 32).

container types; for example, they were four times more likely to have been buried within a mausolea or tomb than adults. At Great Dover Street (GDV96) one of the sections of the walled cemetery was almost exclusively utilised for subadult burial (Mackinder 2000: 18-19). There were no subadults in lead or stone coffins in this sample, but this could be due to the lack of retention of skeletal remains in some instances. The use of tiles in burials differed between subadults and adults, with the former being laid out on top of the tiles, while the adults had a cist constructed from tiles. Philpott (1991: 67) argues that tiles are associated with migrants from the Mediterranean where they are more commonly used in capuchin-style burials. However, the numbers in the Roman London sample are too small to say anything conclusive.

Within the subadults, there is no difference in terms of the presence or absence of containers between the subadult age categories. The majority were buried with some form of container, with infants slightly more likely to have a container than other age groups, but this is not statistically significant. Further to this, no difference was found in terms of the type of burial container and subadult age category, with almost all in each age group being interred in wooden coffins. Based on the above evidence it appears that the use of burial containers in terms of differentiating social status in Roman London is problematic.

8.4.1 Palaeopathology

When correlating the evidence for health stress indicators with the funerary evidence for burial containers, those individuals with a container tended to have significantly higher prevalence rates of each of the stress indicators, with the exception of porotic hyperostosis, for which the numbers were very small. Subadults and adults, when analysed separately, both had higher rates of stress indicators with a burial container than without. The same pattern held true between the subadult age categories. One could argue that this pattern lends support to the osteological paradox in that those individuals with burial containers were more able to survive stress episodes (Wood *et al.* 1992). However, most of these burial containers identified at Roman London were wooden and not particularly indicative of high status.

When examining differences between health status and container type, those subadults buried within mausolea/tombs tend to have the highest, or amongst the highest, prevalence rates. Again, one could argue that this supports the osteological paradox (Wood *et al.* 1992), but the numbers of individuals are small and this may distort the figures.

8.4.2 The Role of Status in Dietary Intake in Roman London

In order for humans to survive, eating and drinking is essential. However, often, what and how we eat is socially and economically determined. The highly stratified nature of Roman society makes it unlikely that access to food would have been equal for all sections of the population, with poorer members being unable to afford significant quantities of luxury foods (Garnsey 1999; Corbier 1999; Wilkins and Hill 2006: 51-61). The presence of markets and collation of food into urban centres may have given poor sections of the population greater access to a wider variety of foodstuffs, though their inability to produce their own foods may have made them more susceptible to fluctuating food costs and shortages (Garnsey 1999: 2,32; Erdkamp 2005: 148; Alcock 2006: 231). While Roman literature provides insights into dietary intake and tastes of the elite and military (e.g. Davis 1971; King 1984; Dalby 2000; Dunbabin and Slater 2011), little is known about the kinds of diets eaten by the non-elite and poorer sections of Roman society (Garnsey 2004: 226; Grimm 2010: 355). From the documentary evidence that is available, it has been suggested that the diet of the vast majority of people in the Roman world would have been predominantly grain-based, with little access to meat (Sippel 1988: 47-48; Garnsey 1998: 226-252; 1999; Alcock 2006). However, as previously identified (Section 8.2.2 (ii)), diet differed widely across the empire and meat consumption, in Roman Britain at least, was much higher than previously thought (Cummings 2008; 2009). While archaeological evidence can provide us with possible information regarding food consumption patterns within a settlement, it does not allow the identification of what different social and economic groups were actually eating. As such, this makes stable isotope analysis unique in its ability to identify potential status-based differences in food consumption.

It is important to note that in order for status-based dietary differences to be observed using stable isotope analyses, the diets of different status groups must not only be significantly different, but also isotopically different. Unfortunately, it is not possible to identify differences in quality for isotopically similar food items, and therefore such status-based choices cannot be identified through stable isotope analysis. For example, clear differences are often alluded to in the descriptions of bread consumed by the elite and poor within Roman literature, with wealthy individuals being able to afford better milled and sifted flour for white wheat bread compared to the dark coarse bread eaten by the less well off (Cool 2006: 77; Wilkins and Hill 2006: 118; Shaw 2014: 85). However, such qualitative differences would be impossible to determine isotopically. Another known status-based difference was the preference of wheat to barley, with the latter considered to be of lower status, fit only for the consumption of animals (Erdkamp 2005: 48, 164; Purcell 2005: 4-8; Donahue 2015: 58-61). However, as both are C_3 grains, the preferential consumption of one over the other is isotopically indistinguishable. One crop that may reflect status that can be detected isotopically is that of millet, considered to be a low status food item compared to wheat in the Roman world (Dalby 2003: 218-219; Erdkamp 2013: 262; Donahue 2015: 61-62). As a C_4 plant, millet's different photosynthetic pathway gives the plant a more positive $\delta^{13}C$ value, making consumers of it more isotopically enriched than those who eat only C_3 plants. Whilst millet consumption has been shown to vary slightly with status in Rome (Killgrove and Tykot 2012), no evidence for millet consumption was identified within the Roman London sample and, to date, the only evidence for its presence in the town is a single carbonised grain (Willcox 1978).

While the elaborate and exotic dietary preferences of the Roman elite compared to that of "common people" has been well documented (Booth 1991; Sirks 1991; Bradley 1998; Sigismund-Nielsen 1998; Dalby 2000; Dunbabin and Slater 2011), the complex nature of Roman society, with its multiple levels of social status, makes it much more complicated and difficult to interpret Roman diet than through simple notions of rich versus poor (Woolf 1998:

168-171; Corbier 1999: 130; Garnsey 1999; van der Veen 2008; van der Veen *et al.* 2008; Grimm 2010). Within Roman society, status was not a binary opposition, it was much more complex, occurring at multiple levels (Garnsey 1970; Hope 2000; Mennen 2011: 6-10; Peachin 2011). Therefore, the separation of diet into poor and elite is complicated and difficult to interpret from the archaeological evidence. Even where differences between status groups in diet are observed, it does not necessarily follow that diets would be radically different isotopically. For example, greater access to fresh fruit and vegetables by elites would not be identifiable.

It is perhaps for the aforementioned reasons that the pattern at Roman London showed no correlation between status, as determined by container presence and absence, and dietary intake. Further to the above issues, and as mentioned previously, the identification of status-based differences within the burial record in Roman London is also complicated by the differential preservation of burial container types and the skeletons buried within them (see Section 8.3.1). The analysis of the relationship between status and diet in this study was further complicated because the destructive sampling of rare and high status burials is often prohibited. The poor preservation of collagen at Great Dover Street (GDV96) also made it impossible to compare dietary intake for those buried within the mausoleum/walled cemetery and those without. Therefore, results were only obtained for three individuals whose burial containers differed significantly from the more traditional wooden coffin. Even amongst these individuals, no significant difference between their diet and that of the overall population was observed, although both the adult buried within the lead coffin and the subadult in the tile cist do show carbon and nitrogen enrichment, probably due to the consumption of marine food items. The subadult in the tile burial is of particular interest as they did have one of the highest levels of carbon and nitrogen enrichment. Philpott (1991: 67) identifies the use of tile with migrants from the Mediterranean and, combined with the “Romanised” dietary pattern of increased marine consumption, it is possible that this individual or their family may have been new to London. However, with such a small sample, further work is needed to explore this avenue further.

The overall lack of status-based differences in Roman London appears contrary to that observed elsewhere in the province. In one of the first studies to examine isotopic variation within Roman populations, Richards *et al.* (1998) found that δ^{13}C and δ^{15}N enrichment in the diets of individuals with high status burials (i.e. mausolea and lead coffins) was so substantial that they formed a distinct and separate group. This significant enrichment was attributed to increased consumption of marine foods by this group. A similar relationship was also observed for high status burials in stone coffins at Roman Cirencester, although the level of enrichment was not high enough for the individuals to form a separate group (Cummings 2008: 205). The status-based differences observed in these studies were associated with the highest status burial containers, such as stone, lead and mausolea, which were unfortunately absent from this study sample. However, status-based dietary differences were observed between those buried with and without wooden coffins at the Lankhills cemetery, Winchester, with individuals buried within wooden coffins having significantly higher $\delta^{13}C$ values (Cummings 2008: 206). The pattern of increased marine food consumption is frequently associated with high status at Romano-British cemeteries, but not in Roman London, or the large urban settlements at York (Müldner and Richards 2007) and Gloucester (Cheung *et al.* 2012).

Similarly, few status-based isotopic dietary differences have been observed at Roman sites on the continent (Prowse *et al.* 2004; Craig *et al.* 2009; Crowe *et al.* 2010). Instead, the greatest difference regarding social status at the Roman Italian sites relates to sex-based differences in dietary intake, with males tending to have greater enrichment, particularly in their carbon values, compared to their female counterparts (Prowse *et al.* 2004; Craig *et al.* 2009; Crowe *et al.* 2010). Perhaps this is not surprising considering the patriarchical organisation of Roman society, with males holding a higher social status than that of females or children, giving them greater access to dietary resources (Allason-Jones 2005: 6, 41; Wilkins 2005: 42; Prowse 2011: 428; Larsen 2015: 330-332). While there were no status-related isotopic differences in terms of burial containers at Roman London, there were status differences that correlated with sex and life course stage (see Section 8.2.2). This highlights the fact that we cannot view status simply in terms of a linear hierarchical structure, but should consider the role of cross-cutting identities such as gender and age (Lucy 2005; Gowland 2006; Sofaer 2006; Pearce 2013).

8.4.3 Summary

- Evidence from this research shows that children in Roman London were not excluded from burial within the town's formal cemeteries, and were more likely to be given a burial in a coffin than their adult counterparts.

- Higher prevalence rates of stress indicators were observed in those individuals with a burial container present in both subadult and adult populations, supporting the osteological paradox (Wood *et al.* 1992). However, the vast majority of burial containers were wooden coffins, which are not considered of particularly high status. Few lead or stone coffins were included within the sample, although those children buried within mausolea did have high rates of stress indicators. Despite this, the number of high status coffins available for analysis from Roman London is too small to draw conclusions about status, and therefore other methods of determining status are needed.

- No status based differences were observed with diet in Roman London, although this confirms the patterns seen at other large Romano-British towns, and towns in Roman Italy. However, as dietary differences were associated with sex and age differences, the use of burial containers to determine status at Roman London appears problematic.

Chapter 9: Conclusion

This thesis has, for the first time, integrated the palaeopathological, isotopic and funerary evidence from the cemeteries of Roman London in order to investigate the health, well-being and social identities of the people who lived there. In particular it has focused on perceptions of childhood, childcare practices and the impact of these on the health of children in Roman London. The analysis has revealed a number of important patterns regarding regional infant feeding practices, maternal health and breastfeeding diets, childhood morbidity and mortality, health-related temporal trends, shifting dietary norms throughout the childhood period, and the social construction of childhood. These data have been compared to contemporary evidence from Roman Britain and Italy and have indicated that childhood was a heterogeneous experience, with childcare and perceptions of childhood subject to regional variability. Each of the original research questions outlined in the introduction are now addressed in turn.

9.1 Research questions

1) What is the age distribution of the subadult skeletal remains recovered from cemeteries in Roman London?

The age distribution of the subadult skeletal remains from Roman London follows the same patterns observed elsewhere in Roman Britain. Subadults generally are under-represented, but this follows the pattern observed at almost all Roman sites, and indeed archaeological sites of other periods. In this respect the age distribution of the subadults from Roman London is not anomalous in any way. The under-representation of subadults is likely to have arisen from a combination of factors including taphonomic processes, including truncation of features, recovery bias and possibly cultural factors. The latter in particular is implicated in the under-representation of infants. With an estimated infant mortality rate of 30% for the Roman period, one would expect a greater proportion to be present in the archaeological record. Older children (8-16 years) are more visible in the burial record and this may be due to greater mortality risk associated with changing responsibilities and identity throughout the life course.

2) What skeletal indicators of poor nutrition and living environment are evident in the skeletal remains of these children and how do these compare to the adults?

The prevalence rates of non-specific stress indicators are high in Roman London compared to other Romano-British sites, with just over half of all individuals exhibiting at least one of the studied stress indicators. The subadults exhibited a slightly higher prevalence of stress indicators when compared to the adults. However, this pattern is to be expected given that some of these stress indicators may form in childhood and then remodel into adulthood, with the exception of enamel hypoplasia. Subadults were found to have higher prevalence rates for four out of the six stress indicators analysed including *cribra orbitalia*, non-specific infection, vitamin D and vitamin C deficiencies. However, diagnosis of vitamin deficiencies in adult skeletal remains is more problematic than diagnosis during the growth period, and this may be responsible for the discrepancies observed. The high prevalence of stress indicators in the Roman London sample highlights the deleterious effect of urbanisation on population health. This has previously been identified in other studies, with poor hygiene, sanitation and overcrowding all being implicated. A further consideration in Roman London is the effect of population mobility on the prevalence of these stress indicators.

3) Are there age-related patterns in terms of the prevalence of skeletal indicators of poor health amongst subadults?

In pre-term and full-term infants endogenous factors appear to be responsible for mortality rates, assuming that the sample is representative of the living population, which is of course problematic. Health stress indicators are apparent even in perinatal infants and this indicates poor maternal health. Infants (0-3 years) have the highest rates of non-specific infection, vitamin deficiencies. The prevalence of *cribra orbitalia* is consistent throughout childhood, with no peaks at weaning age observed, in contrast to other sites in the Roman Empire. Approximately half of all infants had no stress indicators present and this may mean that they died of acute infections or gastro-intestinal problems associated with diarrheal diseases. Stress indicator prevalence in the older subadult age categories may be linked to occupation and exposure to a greater range of stressors. Enamel hypoplasia increases dramatically throughout the childhood period. Overall, children with stress indicators survive to slightly older ages than those without, which supports the osteological paradox, but the children are ultimately non-survivors. This subadult pattern is not consistent with the adult pattern observed at other sites where reduced longevity is associated with stress indicator presence (Goodman *et al.* 1988).

4) What is the diet, as indicated by isotopic evidence, of subadults in Roman London and how does this compare to adult diet?

The overall diet in Roman London was comparable to other Romano-British settlements, with almost all individuals having access to some terrestrial animal protein as well as isotopically enriched foods such as marine fish. When compared to the adults, the greatest difference in subadult diet was the inclusion of freshwater fish. This was regarded as a low status food item in the Roman world and possibly relates to the lower status of children when compared to adults. When biological sex of adults is considered, the diet of males is significantly different to that of children, with the only enrichment in dietary isotopes coming from marine resources. In females the isotopic values were much more varied, perhaps reflecting a greater influence in social status on their diet, and there was no statistically significant difference in diet between the females and the children.

5) What were the infant feeding practices evident in Roman London, and how do they compare to elsewhere in Roman Britain and the wider Empire?

The stable isotope data identified that breastfeeding was undertaken for all infants in the sample, with breast milk remaining part of the diet until three to four years of age. The introduction of supplementary food appears to have taken place at around six months of age and would have been predominantly cereal-based. The pattern observed in Roman London was comparable with other Romano-British sites, including the recognition of a likely specialised breastfeeding diet for the mothers. In contrast, the pattern from Roman Britain (including London) differed from that seen in Roman Italy where the duration of breastfeeding was much shorter and the cessation of breastfeeding occurred more abruptly. These findings demonstrate that child-rearing practices did not necessarily subscribe to a universal pattern across the Empire and instead were subject to great regional variability.

6) Were there health consequences of the particular infant feeding regime in Roman London as assessed through skeletal indicators?

There is no peak in non-specific indicators of health stress coincident with the timing of the introduction of supplementary foods. Non-specific infection was higher during the period of “transitional” feeding, but this was the only health stress indicator to increase in prevalence. At other sites a peak in *cribra orbitalia* has been observed to coincide with weaning, but this was not the case in Roman London. The period of extended breastfeeding may have afforded the infants of Roman London with greater passive immunity. Alternatively, and following the osteological paradox, it could be that the infants died of lethal acute diseases during this precarious time of life. Unfortunately, due to the ambiguous nature of many of the skeletal stress indicators for examining past health, interpretations could be equally valid in either direction.

7) What is the relationship between skeletal indicators of poor health and isotopic evidence for diet throughout childhood?

There was no relationship found between skeletal indicators of poor health and isotopic evidence for diet throughout the subadult period.

8) What was the initial impact of the Roman Conquest on childhood health and diet?

As in other studies, evidence from Roman London suggests that, following the Roman conquest, health deteriorated and there was an increase in skeletal stress indicators when compared to Iron Age populations. This may be due to a worsening in living conditions and diet, but may also be the consequence of an increase in psycho-social stressors. Societies which are more hierarchical tend to be those where such stressors are most acute. Increased population mobility during this period may also be a factor, with greater opportunity for the introduction and spread of new pathogens. After the Roman conquest there is a well-attested increase in marine consumption and this is supported by the results from Roman London.

9) Did childhood health and diet in Roman London mirror the fluctuating fortunes of the city throughout its four hundred year history?

In terms of the isotopic evidence for diet, there appears to be a decline in the quality of the subadult diet between the early and later periods, with childhood diet being supplemented by local exploitation of low status freshwater fish. Skeletal indicators of health stress also increase during the later period suggesting that the decline in the town’s fortunes is mirrored by the deteriorating health of the children. However, as mentioned previously, skeletal health stress indicators can be problematic to interpret in such a direct way. An alternative explanation could be that subadults from the later period were able to withstand chronic stressors for a longer period before succumbing.

10) Can we access perceptions of childhood through status-related burial practices and what role, if any, does status play in the health and diet of children?

Analysis of the burial practices from Roman London suggests that children were afforded funerary rites that were equivalent to those given to adults. Indeed children were more likely to have been buried within a coffin than their adult counterparts, nor were they excluded from high status burial types such as walled cemeteries, mausoleums, or lead coffins. Infants were more likely than any other subadult age group to be buried in a coffin. Rather than evidence for disregard or ambivalence, the funerary data suggests that infants and children were cared for in death and likely mourned. Further, more detailed, research on the association between funerary variables and age-at-death and sex from the cemeteries of Roman London is required in order to detect any other patterns that may be indicative of social identity. Subadults with burial containers had higher prevalence rates of all non-specific stress indicators with the exception of porotic hyperostosis. This pattern remains consistent into adulthood. However, making the link between these stress indicators and high status is problematic, given that the majority of these burial containers are modest wooden coffins. The numbers of burials within more ostentatiously wealthy graves are too few in number to be conclusive, although subadults afforded such burials also had numbers of stress indicators.

Likewise there is no particular link between social status and isotopic evidence of dietary intake, although those within high status burials tended to have isotopically enriched values associated with the consumption of marine fish. While little evidence of status differentiation in health and diet is associated with burial containers, there is a distinction in the status of the diet between adults and subadults. The latter are much more likely to consume lower status food items and there is a closer link between childhood and female diet than with male diet. By the adolescent age group individuals are eating an adult diet, suggesting that diet was socially constrained and dependent upon life course stage.

11) How does the evidence for childhood in Roman London compare to published data from contemporary sites from Roman Britain and the Roman Empire?

In terms of health, the evidence for skeletal indicators of stress from Roman London is substantially higher than many comparable urbanised Roman sites, with the exception of the nutritional deficiencies observed at Poundbury, Dorset. When London is compared to the Roman town of Colchester, which had comparable legal status, health in London appears to be much worse. There are a number of possible reasons for London having such high prevalences of stress indicators, including population mobility, the pollution of the water tables and rivers through industrial and domestic waste, and a reliance on imported foods, with little capacity for agricultural productivity.

There have been limited studies of child feeding practices in the Roman Empire. However, the isotope data from Roman London are comparable with results from Queensford Farm in Oxfordshire and Roman Dorset in terms of the weaning diet and the timetable for the cessation of breastfeeding. The Romano-British pattern of infant feeding practices differed from Roman Italy. At all Romano-British sites, subadult diet post-weaning tended to be more constrained than the adult diet and was predominantly terrestrial-based until the age of fourteen. Of all of the sites, the greatest variability in subadult diet, post-weaning, was observed in Roman London, which may be a reflection of the greater range of foodstuffs available due to its location. Interestingly, at the Italian port site of Isola Sacra, the subadults demonstrate a much more restricted diet than their adult counterparts suggesting that the post-weaning diet remained relatively homogenous in Roman Italy.

9.2 Limitations of the Data

While this thesis has identified a number of interesting findings regarding subadult health and diet in Roman London, a number of limitations regarding the nature of the data utilised are apparent. Firstly, the nature and constraints of the WORD database meant it was not always possible to obtain all of the information required. For example, while a *cribra orbitalia* score was given for all individuals affected, few entries identified whether the lesion was healed or active, making it difficult to determine the peak ages when subadults were most affected. In the case of non-specific infection, while periosteal new bone formation associated with trauma, diagnosed metabolic diseases, and specific infections could be easily separated out, the descriptions of periosteal lesions were limited, making further analysis of potential disease processes difficult.

Secondly, the data extracted from the WORD database for this thesis was compiled by multiple individuals, introducing potential unknown comparability issues into the skeletal data collection. While some of these issues are mitigated by the requirement that only trained osteologists, using standard manuals designed to ensure uniformity in data collection, may enter data onto the database, the use of data collected by others always carries this inherent risk.

Thirdly, in order to create a sample of sufficient size to address the aims of the thesis, it was necessary to bring together data from all four of Roman London's cemeteries. This larger sample allowed the investigation of subadult health and diet across Roman London and was sufficient in size to allow statistical analyses to be conducted. However, the use of this combined population has obscured potential differences between the cemeteries themselves. Furthermore, the imbalance in the representation of individuals from each cemetery, with the eastern and northern cemeteries making up a large proportion of the sample, may have masked potential relationships present in the smaller sites.

Finally, the subadults examined within this study represent "non-survivors", those children who failed to reach adulthood. As such, caution is necessary when inferring information regarding the health and diet of those children who survived into adulthood from this sample group.

9.3 Future Directions

In order to address some of the limitations of the thesis outlined above, further work is required to nuance the available data. This will require the collection of additional information that is not consistently recorded in the WORD database, particularly regarding the palaeopathological data. For example, identifying whether lesions appear to be healed or active at time of death may provide further valuable information regarding the ages at which subadults were most vulnerable to these different pathologies. Also, additional evidence regarding the nature of periosteal lesions, including their location and better descriptions (after Weston 2012) may allow a more in-depth investigation into the myriad types of disease processes that cause them.

Techniques of biomolecular analysis are developing rapidly and during the course of this research new methods of incremental serial sampling and analysis of dentine now allows a more nuanced approach to the study of subadult diet (Beaumont *et al.* 2013b). Such techniques allow longitudinal data to be obtained from individuals, providing a much greater resolution in the study of dietary change throughout the life course. The application of these techniques to the Roman London sample would potentially provide more information regarding the complex interaction between diet and health during the subadult period. In the future it may also be feasible to do large-scale studies of infectious diseases within the Roman London sample using next generation DNA and proteomic techniques. Such studies are currently too expensive to involve large sample sizes.

This study has shown the complex nature of the relationship between health and status. While no obvious patterns were attributed to burial container type, more detailed analysis of grave inclusions, body position, and cemetery layout may be more revealing. Further to this, an analysis of inter-cemetery differences provides another potential area of investigation. In order to fulfil the aims of the thesis, it was necessary to combine evidence from the four main Roman cemeteries of London. However, little work has been conducted to identify potential differences between the populations of the north, east, south and west cemeteries of Roman London. An examination of the individual cemeteries, including comparisons of the skeletal populations, burial rites, cemetery organisation, and status differences, may provide more evidence of the population composition of this Roman town. However, this would require detailed archival work as much of this evidence has yet to be published in sufficient detail.

Finally, population mobility has proven to be a key variable in terms of understanding and interpreting the patterns of health and diet in Roman London. While small-scale studies have been undertaken to examine the ethnic population composition, further extensive sampling is needed in order to gain a better understanding.

Chapter 10: Bibliography

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Appendices

Appendix 1 – List of Sites Included Within the Roman London Thesis Sample

Site Code	Site Name	Publication	Site Grid Reference
15SK80	Calvert Buildings	Cowan 1992	TQ32528011
ATC 97	Atlantic House	Watson 2003	TQ31538159
BAR 79	St.Bartholomew's Hospital	Bentley and Pritchard 1982	TQ3187081510
BAZ 05	Basinghall Street	Powers 2008	TQ32558148
BDC03	Broad Street	Powers 2011a	TQ33008165
BOS87	Spitalfields: Bishopsgate, Spital Square	Gibson 1988; Powers 2011a	TQ3341081870
COSE 84	Courage Brewery	Cowan 2003	TQ32478031
DGT06	Drapers Garden	Sayer 2012	TQ3283081400
ELD88	Liverpool House 15-17 Eldon Street	Potter 1989	TQ3298081650
ENS03	Finsbury Circus	Powers 2011a	TQ3294981664
FIB88	12-15 Finsbury Circus	Powers 2011a	TQ3288081680
GDV 96	Great Dover Street	Mackinder 2000	TQ32687946
GHT00	Blossom's Inn, 30 Gresham Street	Powers 2006a	TQ32418125
HAY 86	Haydon Street	Barber and Bowsher 2000	TQ33708105
HOO88	Hooper Street	Barber and Bowsher 2000	TQ34208100
HR77	Harper Row	Cowan *et al.* 2009	TQ32467930
KWS94	Regis House and Ridgeway House	No published report – historical information from database	TQ 32888074
LTU 03	Lant Street	Sayer 2006	TQ32257970
MNL88	65-73 Mansell Street	Barber and Bowsher 2000	TQ33838002
MRG95	Northgate House	Powers 2006b	TQ32728142
MSL87	Mansell Street	Barber and Bowsher 2000	TQ33808110
MST87	Mansell Street	Barber and Bowsher 2000	TQ33828115
NGT 00	Paternoster Square - Newgate Triangle	Watson with Heard 2006	TQ3198881304
OBL97	Britannia House	White 2002	TQ31738138
PNS 01	Paternoster Row	Watson and Heard 2006	TQ3207281228
REW 92	Red Cross Way	Drummond-Murray and Thompson 2002	TQ32458004
RIV 87	Riverplate House	Powers 2011b	TQ3283081700
RWG 94	Red Cross Way	Drummond-Murray and Thompson 2002	TQ32478011
SPT85	Central Foundation Girls School, Spital Square	Powers 2011b	TQ 3348 19
SRP 98	Spitalfields Market	Powers 2011b	TQ33488189
STE95	250 Bishopsgate	Powers 2011b	TQ33438180
STO86	Spitalfields	Green 1988; Powers 2011b	TQ3341081860
SWH 86	Snow Hill	Kelly 1988	TQ3174081480
TIY 07	Trinity Street	Langthorne 2011	TQ3245079400
TOB 95	The Trocette	Cowan *et al.* 2009	TQ33257931
UNE 03	Union Street	Walker 2010	TQ3244180000
WES 89	1-4 Giltspur Street	Department of Urban Archaeology 1990	TQ3181081530
WTE90	29 West Tenter Street	Barber and Bowsher 2000	TQ 3384 8108
WTN84	West Tenter Street	Barber and Bowsher 2000	TQ 3390 8101

Appendix 2 - Sample Composition by Site

Site Code	Total Population Indicated within Publication	Thesis Sample Population	Adults	Subadults
15SK80	13	6	5	1
ATC 97	19	19	15	4
BAR 79	19	15	9	6
BAZ 05	3	1	0	1
BDC03	24	24	17	7
BOS87	6	6	5	1
COSE 84	7	7	4	3
DGT06	5	5	1	4
ELD88	24	23	20	3
ENS03	72	68	53	15
FIB88	7	5	5	0
GDV 96	25	23	13	10
GHT00	2	2	1	1
HAY 86	14	12	10	2
HOO88	105	102	75	27
HR77	1	1	1	0
KWS94	3	3	0	3
LTU 03	89	54	29	25
MNL88	4	4	4	0
MRG95	1	1	0	1
MSL87	228	208	146	62
MST87	74	56	48	8
NGT 00	2	2	1	1
OBL97	3	2	2	0
PNS 01	6	5	2	3
REW 92	6	5	2	3
RIV 87	2	2	2	0
RWG 94	2	2	1	1
SPT85	3	2	2	0
SRP 98	130	127	85	42
STE95	2	2	2	0
STO86	5	5	1	4
SWH 86	2	2	1	1
TIY 07	44	44	38	6
TOB 95	2	2	2	0
UNE 03	1	1	0	1
WES 89	133	109	79	30
WTE90	9	6	2	4
WTN84	113	4	3	1
Total	1210	967	686	281

Appendix 3 – TPR of Non-Specific Infection

Table 1 – TPR of Non-Specific Infection for the Total Sample

Age Category	Non-Specific Infection		
	Number of Observable Elements	Affected	%
Endocranial*			
Subadult	203	20	9.9
Adult	409	24	5.9
Total	612	44	7.2
Ectocranial*			
Subadult	203	4	2.0
Adult	409	2	0.5
Total	612	6	1.0
Cranio-facial (maxillae and zygoma)*			
Subadult	154	3	1.9
Adult	325	1	0.3
Total	480	4	0.8
Mandible			
Subadult	171	6	3.5
Adult	366	1	0.3
Total	537	7	1.3
Scapula			
Subadult	219	3	1.4
Adult	564	2	0.4
Total	783	5	0.6
Clavicle			
Subadult	216	1	0.5
Adult	602	0	0
Total	818	1	0.1
Humerus			
Subadult	320	5	1.6
Adult	732	0	0
Total	1052	5	0.5
Radius			
Subadult	274	3	1.1
Adult	688	1	0.1
Total	962	4	0.4
Ulna			
Subadult	276	3	1.1
Adult	704	2	0.3
Total	980	5	0.5
Metacarpals			
Subadult	621	8	1.3
Adult	2246	1	0.04
Total	2867	9	0.3
Ribs*			
Subadult	178	10	5.6
Adult	421	21	5.0
Total	599	31	5.2

* = number of individuals within the sample with at least one of these elements present

Age Category	Non-Specific Infection		
	Number of Observable Elements	Affected	%
	Vertebrae – Thoracic*		
Subadult	164	1	0.6
Adult	375	0	0.0
Total	539	1	0.2
	Vertebrae - Lumbar		
Subadult	604	0	0.0
Adult	1531	4	0.3
Total	2135	4	0.2
	Sacral Vertebrae		
Subadult	383	0	0.0
Adult	969	1	0.1
Total	1352	1	0.1
	Ilium		
Subadult	274	2	0.7
Adult	687	1	0.1
Total	961	3	0.3
	Femur		
Subadult	368	22	6.0
Adult	849	29	3.4
Total	1217	51	4.2
	Tibia		
Subadult	304	50	16.4
Adult	811	151	18.6
Total	1115	201	18.0
	Fibula		
Subadult	253	13	5.1
Adult	714	45	6.3
Total	967	58	6.0
	Calcaneus		
Subadult	138	1	0.7
Adult	599	4	0.7
Total	737	5	0.7
	Metatarsals		
Subadult	579	7	1.2
Adult	2326	8	0.3
Total	2905	15	0.5
	Foot Phalanges		
Subadult	283	1	0.4
Adult	1277	0	0.0
Total	1560	1	0.1

* = number of individuals within the sample with at least one of these elements present

Table 2 - TPR of Non-specific Infection of the Long bones by Laterality

(a)Total Sample

Element	Side	Total Number of Observable Bones	Affected	TPR
Clavicle	Right	407	0	-
	Left	411	1	0.2
	Total	818	1	0.1
Humerus	Right	522	3	0.6
	Left	530	2	0.4
	Total	1052	5	0.5
Radius	Right	484	2	0.4
	Left	478	2	0.4
	Total	962	4	0.4
Ulna	Right	489	3	0.6
	Left	491	2	0.4
	Total	980	5	0.5
Femur	Right	602	23	3.8
	Left	615	28	4.6
	Total	1217	51	4.2
Tibia	Right	549	97	17.7
	Left	566	104	18.4
	Total	1115	201	18.0
Fibula	Right	484	28	5.8
	Left	483	30	6.2
	Total	967	58	6.0

(b) Subadults

Element	Side	Total Number of Observable Bones	Affected	TPR
Clavicle	Right	105	0	-
	Left	111	1	0.9
	Total	216	1	0.5
Humerus	Right	157	3	1.9
	Left	163	2	1.2
	Total	320	5	1.6
Radius	Right	134	2	1.5
	Left	140	1	0.7
	Total	274	3	1.1
Ulna	Right	133	2	1.5
	Left	143	1	0.7
	Total	276	3	1.1
Femur	Right	189	10	5.3
	Left	179	12	6.7
	Total	368	22	6.0
Tibia	Right	151	23	15.2
	Left	153	27	17.6
	Total	304	50	16.4
Fibula	Right	127	5	3.9
	Left	126	8	6.3
	Total	253	13	5.1

(c) Adults

Element	Side	Total Number of Observable Bones	Affected	TPR
Radius	Right	350	0	-
	Left	338	1	0.3
	Total	688	1	0.1
Ulna	Right	356	1	0.3
	Left	348	1	0.3
	Total	704	2	0.3
Femur	Right	413	13	3.1
	Left	436	16	3.7
	Total	849	29	3.4
Tibia	Right	398	74	18.6
	Left	413	77	18.6
	Total	811	151	18.6
Fibula	Right	357	23	6.4
	Left	357	22	6.2
	Total	714	45	6.3

Appendix 4: Roman London Human Bone Collagen Results

Subadults

Site Code and Skeletal Number	Age Category	Specific Age	Sex	Yield (%)	%C	δ^{13}C	Difference	%N	δ^{15}N	Difference	C:N
DGT06 4579	1	36 weeks gestation		3.8	44.6	-19.9	0.05	14.3	12.7	0.02	3.6
GDV96 347	1	28 weeks gestation		5.8	41.8	-19.5	0.03	15.0	12.6	0.04	3.3
LTU03 170	2	40 weeks gestation		3.1	44.6	-19.7	0.23	14.8	12.8	0.1	3.5
LTU03 86	3	46 weeks gestation		2.3	40.9	-19.2	0.03	14.0	13.4	0.55	3.4
SRP98 15400	3	0 years		10.2	44.8	-19.4	0.06	15.6	13.5	0.03	3.4
HOO88 832	3	0.5 years		7.4	44.5	-21.5	0.07	15.7	12.3	0.04	3.3
HOO88 869	3	0.5 years		3.4	43.7	-18.6	0.06	15.0	13.1	0.06	3.4
SRP98 15386	3	0.5 years		5.4	42.3	-22.4	0.02	15.1	12.3	0.04	3.3
HOO88 1350	3	1 year		4.9	44.0	-20.3	0.03	15.5	13.8	0.02	3.3
MSL87 1116	3	1 year		5.0	42.3	-20.8	0.08	14.5	12.5	0.06	3.4
PNS01 162	3	1 year		8.9	43.7	-20.5	0.01	15.9	13.0	0.01	3.2
STO86 73	3	1 year		5.7	41.5	-19.5	0.06	15.2	13.9	0.04	3.2
HOO88 854	3	1.5 years		14.1	42.4	-20.1	0.02	15.2	11.9	0.04	3.3
LTU03 91	3	2 years		8.6	42.4	-18.9	0.06	15.4	12.5	0.01	3.2
LTU03 375	3	2 years		2.6	42.4	-20.1	0.01	14.9	10.5	0.01	3.3
MSL87 227	3	2 years		5.3	44.4	-18.9	0.02	15.7	12.8	0.01	3.3
ATC97 375	3	3 years		3.8	43.8	-20.9	0.03	15.0	12.4	0.01	3.4
LTU03 93	3	3 years		5.8	41.7	-20.6	0.04	15.2	11.5	0.03	3.2
LTU03 397	3	3 years		4.0	42.0	-20.5	0.01	14.8	12.9	0.17	3.3
MSL87 194	3	3 years		2.2	43.7	-21.5	0.01	15.0	12.3	0.04	3.4
SRP98 3341	3	3 years		5.7	41.2	-18.7	0.11	15.3	13.0	0.09	3.1
SRP98 15644	3	3 years		4.6	47.1	-20.2	0.01	16.6	10.6	0.02	3.3
SRP98 15871	3	3 years		7.9	41.8	-20.6	0.03	14.7	12.1	0.01	3.3
GDV96 107	4	4 years		3.1	40.7	-19.8	0.03	13.9	10.2	0.03	3.4

MSL87 516	4	4 years		5.3	43.2	-20.3	0.02	14.4	10.8	0.02	3.5
MSL87 675	4	4 years		6.9	44.4	-20.2	0.04	16.0	11.4	0.02	3.2
MSL87 1700	4	4 years		1.1	43.8	-20.6	0.00	14.7	10.8	0.02	3.5
MSL87 1714	4	4 years		8.9	44.9	-20.1	0.03	16.5	10.8	0.03	3.2
WES89 429	4	4 years		1.4	43.4	-20.5	0.04	15.2	9.4	0.01	3.3
HOO88 1345	4	4.5 years		7.6	40.5	-19.8	0.01	14.5	10.4	0.04	3.3
MSL87 204	4	4.5 years		3.1	44.3	-20.8	0.01	15.5	10.4	0.03	3.3
ATC97 409	4	5 years		11.0	42.3	-19.1	0.06	15.2	11.2	0.02	3.3
BAR79 344	4	5 years		3.3	44.2	-20.2	0.09	16.0	11.8	0.03	3.2
MSL87 1707	4	5 years		4.1	43.8	-21.1	0.07	14.3	11.1	0.07	3.6
SRP98 23873	4	5 years		7.2	44.8	-20.2	0.04	15.2	10.0	0.02	3.4
BDC03 415	4	6 years		15.9	42.6	-19.5	0.01	15.5	11.2	0.01	3.2
WES89 1004	4	6 years		7.0	44.0	-20.6	0.18	14.6	10.9	0.01	3.5
SRP98 8990	4	6.5 years		6.8	42.6	-21.0	0.06	15.1	10.6	0.00	3.3
BAR79 180	4	7 years		3.3	45.5	-20.5	0.13	16.3	10.9	0.04	3.3
MSL87 377	4	7 years		10.5	41.5	-20.0	0.03	14.7	9.2	0.01	3.3
WES89 756	4	7 years		7.3	42.8	-19.6	0.03	15.0	10.2	0.07	3.3
REW92 227	4	7.5 years		5.3	43.9	-20.7	0.02	15.1	11.4	0.05	3.4
WES89 527	5	8 years		3.9	42.1	-20.7	0.03	14.8	12.0	0.04	3.3
TIY07 427	5	8.5 years		8.5	43.0	-19.6	0.06	14.9	11.4	0.07	3.4
TIY07 476	5	8.5 years		11.6	42.7	-19.0	0.01	15.4	11.0	0.01	3.2
HAY86 413	5	9 years		2.5	42.4	-19.2	0.05	14.9	10.8	0.03	3.3
MSL87 491	5	9 years		8.5	42.3	-19.7	0.07	15.0	11.1	0.04	3.3
MSL87 578	5	9 years		3.1	43.2	-21.2	0.12	14.6	11.3	0.02	3.4
SRP98 15345	5	9.5 years		9.9	42.5	-19.5	0.01	15.7	10.4	0.04	3.2
WES89 781	5	10 years		2.7	44.1	-20.7	0.01	15.0	8.8	0.08	3.4
MSL87 464	5	11 years		5.4	44.5	-20.3	0.07	15.6	10.5	0.05	3.3
MSL87 805	5	11 years		12.1	42.1	-19.8	0.01	15.4	10.0	0.04	3.2
WES89 460	5	11 years		8.1	42.2	-19.7	0.03	15.6	9.6	0.07	3.2
MSL87 505	5	12 years		6.3	42.4	-20.1	0.04	15.2	11.5	0.03	3.3
MSL87 922	5	12 years		5.6	43.1	-20.8	0.05	15.0	12.1	0.05	3.4

SRP98 5765	5	12 years		2.8	41.0	-19.5	0.09	14.4	11.2	0.04	3.3
WES89 228	5	13 years		6.5	43.5	-20.5	0.19	15.1	11.3	0.07	3.4
WES89 427	5	13 years		9.6	42.4	-20.2	0.03	14.9	10.8	0.11	3.3
BAR79 341	5	14 years		2.7	41.6	-21.2	0.01	13.9	10.3	0.03	3.5
LTU03 385	5	14 years	F	1.7		-20.2	0.25		10.9	0.15	3.3
BAR79 181	5	15 years		4.5	43.1	-20.2	0.04	15.1	10.8	0.1	3.3
GDV96 56	5	15 years		1.9	40.0	-19.2	0.05	14.3	12.2	0.25	3.3
SRP98 15438	5	15 years		11.0	42.4	-19.9	0.18	15.1	10.6	0.01	3.3
COSE84 1951	5	16 years		4.0	42.4	-19.4	0.03	14.7	10.5	0.03	3.4
MSL87 6	5	16 years		7.8	42.0	-19.3	0.04	14.7	11.2	0.12	3.3
ATC97 292	5	16.5 years		11.4	42.4	-19.1	0.04	15.4	9.8	0.02	3.2
MST87 114	6	17 years		3.6	41.7	-19.5	0.03	15.3	10.4	0.05	3.2
WES89 848	6	17 years		2.9	42.4	-19.8	0.05	15.0	10.7	0.04	3.3
TIY07 267	6	17.5 years		3.4	41.8	-20.1	0.07	14.2	9.9	0.01	3.4
BAR79 182	6	18 years	F	1.5	43.7	-20.7	0.08	14.7	9.5	0.03	3.5
LTU30 259	6	18 years	M	3.1	41.9	-19.4	0.09	14.6	12.4	0.08	3.4
MSL87 547	6	18 years	M	2.8	42.3	-19.3	0.07	14.5	10.5	0.06	3.4
SRP98 3662	6	18 years	F	10.2	42.0	-19.3	0.06	15.6	11.5	0.19	3.2
MSL87 753	6	18.5 years	M	5.9	42.2	-19.4	0.03	15.2	10.1	0.13	3.2
REW92 204	6	18.5 years	F	4.5	42.2	-18.2	0.05	14.9	11.0	0.01	3.3
SRP98 3251	6	19 years	M	2.4	42.1	-19.2	0.04	15.2	10.9	0.05	3.2
SRP98 5668	6	19 years	M	1.6	41.7	-19.8	0.00	14.6	10.4	0.16	3.3

Adults

Site Code and Skeletal Number	Age Category	Sex	Yield (%)	%C	δ^{13}C	Difference	%N	δ^{15}N	Difference	C:N
BDC03 400	7	F	8.1	43.0	-18.7	0.01	15.1	11.8	0.08	3.3
GDV96 325	7	F	9.9	42.3	-19.8	0.03	15.6	11.5	0.04	3.2
LTU03 10	7	?M	2.7	42.0	-22.2	0.06	14.1	6.8	0.04	3.5
LTU03 13	7	F	1.1		-19.5	0.10		10.5	0.06	2.9
LTU03 157	7	F	5.9		-20.0	0.05		7.7	0.14	2.9
MSL87 254	7	F	10.9	42.5	-18.5	0.03	15.6	12.1	0.08	3.2
MSL87 566	7	M	5.9	42.1	-19.8	0.51	14.8	10.7	0.17	3.3
MSL87 569	7	M	2.1	38.9	-19.3	0.06	13.7	12.4	0.15	3.3
MSL87 720	7	M	6.6	42.8	-19.0	0.01	15.2	11.7	0.01	3.3
MSL87 2034	7	M	5.2	42.4	-19.3	0.01	15.4	10.0	0.03	3.2
MST87 390	7	F	7.9	42.5	-20.1	0.04	15.1	8.8	0.00	3.3
SRP98 35553	7	M	6.8	42.0	-19.6	0.12	15.0	10.0	0.02	3.3
WES89 718	7	?M	4.3	41.0	-20.3	0.06	14.4	9.6	0.01	3.3
MSL87 39	8	F	9.9	42.1	-18.7	0.01	15.6	11.1	0.05	3.2
SRP98 23879	8	?M	7.2	42.6	-19.6	0.04	15.5	10.0	0.04	3.2
SRP98 34126	8	F	4.4	43.2	-19.4	0.01	15.2	10.4	0.03	3.3
TIY07 203	8	F	2.6	42.5	-19.3	0.02	14.9	12.7	0.00	3.3
WES89 504	8	F	2.5	43.4	-20.7	0.09	14.4	11.8	0.03	3.5
GDV96 70	9	?M	1.8	42.00	-19.3	0.04	15.1	11.0	0.02	3.2
MSL87 336	9	F	4.9	42.9	-20.7	0.01	14.7	9.3	0.07	3.4
MSL87 390	9	F	10.9	42.5	-20.1	0.04	15.1	8.8	0.05	3.3
MSL87 450	9	?M	9.4	42.3	-18.7	0.01	15.8	10.6	0.03	3.1
MSL87 606	9	?F	8.3	42.8	-19.8	0.00	15.2	9.7	0.02	3.3
SRP98 5919	9	?F	2.3	43.2	-20.9	0.05	14.1	12.7	0.00	3.6
SRP98 34273	9	M	1.7	41.2	-19.9	0.03	14.6	11.4	0.04	3.3

WES89 599	9	F	4.6	42.6	-19.2	0.01	15.3	11.2	0.02	3.3
LTU03 321	10	M	2.5		-19.4	0.05		9.9	0.09	3.0
HOO88 981	10	M	8.0	42.1	-19.1	0.02	15.7	11.2	0.07	3.1
MSL87 538	10	M	11.0	42.4	-19.0	0.02	15.5	10.3	0.03	3.2
SRP98 12147	10	F	14.1	42.7	-18.9	0.06	15.1	13.6	0.05	3.3

Excluded Samples

Site Code and Skeletal Number	Age Category	Specific Age	Sex	Yield (%)	%C	δ^{13}C	Difference	%N	δ^{15}N	Difference	C:N	Reason for Exclusion
SRP98 15615	3	0.3 years		0.0	-	-	-	-	-	-	-	No Collagen Yielded
GDV96 156	3	1.5 years		0.0	-	-	-	-	-	-	-	No Collagen Yielded
MSL87 1270	3	2 years		0.0	-	-	-	-	-	-	-	No Collagen Yielded
MSL87 1777	3	2.5 years		0.0	-	-	-	-	-	-	-	No Collagen Yielded
GDV96 281	3	3 years		0.8	-	-	-	-	-	-	-	Yield Too Low
STO86 2006	3	3 years		0.0	-	-	-	-	-	-	-	No Collagen Yielded
HOO88 549	4	4 years		0.0	-	-	-	-	-	-	-	No Collagen Yielded
MSL87 972	4	4 years		0.0	-	-	-	-	-	-	-	No Collagen Yielded
SRP98 15227	4	4 years		0.0	-	-	-	-	-	-	-	No Collagen Yielded
HOO88 676	4	6 years		0.0	-	-	-	-	-	-	-	No Collagen Yielded
GDV96 150	4	7 years		0.0	-	-	-	-	-	-	-	No Collagen Yielded
HOO88 531	4	7 years		0.0	-	-	-	-	-	-	-	No Collagen Yielded
LTU03 337	5	7 years		0.0	-	-	-	-	-	-	-	No Collagen Yielded
HOO88 1323	5	8.5 years		0.0	-	-	-	-	-	-	-	No Collagen Yielded
GDV96 123	5	9 years		0.0	-	-	-	-	-	-	-	No Collagen Yielded
LTU03 303	5	9 years		0.0	-	-	-	-	-	-	-	No Collagen Yielded
TIY07 164	5	9 years		0.0	-	-	-	-	-	-	-	No Collagen Yielded
SRP98 10883	5	10 years		5.2	42.1	-21.0	0.02	13.2	12.6	0.08	3.7	Abnormal C:N ratio
GDV96 251	5	12 years		0.0	-	-	-	-	-	-	-	No Collagen Yielded
ELD88 82	5	16 years		0.0	-	-	-	-	-	-	-	No Collagen Yielded

GDV96 126	5	16 years		0.0	-	-	-	-	-	-	-	No Collagen Yielded
SRP98 5815	5	16 years		0.0	-	-	-	-	-	-	-	No Collagen Yielded
ENS03 372	6	17 years		0.0	-	-	-	-	-	-	-	No Collagen Yielded
ELD88 108	7		M	0.0	-	-	-	-	-	-	-	No Collagen Yielded
ENS03 127	7		F	0.0	-	-	-	-	-	-	-	No Collagen Yielded
ENS03 321	7		?M	0.0	-	-	-	-	-	-	-	No Collagen Yielded
ENS03 356	7		M	0.0	-	-	-	-	-	-	-	No Collagen Yielded
GDV96 360	7		M	0.0	-	-	-	-	-	-	-	No Collagen Yielded
FIB88 110	9		?F	0.0	-	-	-	-	-	-	-	No Collagen Yielded
HOO88 1254	9		F	0.0	-	-	-	-	-	-	-	No Collagen Yielded
SRP98 34245	10		?M	0.0	-	-	-	-	-	-	-	No Collagen Yielded
TIY07 81	10		?M	0.0	-	-	-	-	-	-	-	No Collagen Yielded

Appendix 5: Roman London Animal Bone Collagen Results

Sample Number	Site Code and Context Number	Species	Yield (%)	%C	$\delta^{13}C$	Difference	%N	$\delta^{15}N$	Difference	C:N
C1	ONE94 3218	Cow	6.3	42.7	-22.3	0.01	15.0	7.3	0.03	3.3
C2	ONE94 11236	Cow	6.4	42.6	-21.4	0.06	15.4	6.2	0.13	3.2
C3	ONE94 11236	Cow	5.8	42.1	-21.8	0.03	15.1	6.5	0.29	3.3
C4	ONE94 3782	Cow	9.6	42.3	-22.5	0.01	15.4	4.1	0.07	3.2
C5	ONE94 3782	Cow	12.9	48.1	-21.9	0.01	16.5	8.2	0.03	3.4
S1	ONE94 11243	Sheep	2.4	41.4	-22.4	0.02	13.9	5.6	0.07	3.5
S2	ONE94 11243	Sheep	6.8	42.1	-20.8	0.02	15.3	6.0	0.03	3.2
S3	ONE94 3218	Sheep	9.3	42.4	-21.8	0.02	15.3	6.5	0.04	3.2
S4	ONE94 3782	Sheep	9.2	42.1	-21.4	0.01	15.2	7.7	0.18	3.2
P2	ONE94 6046	Pig	4.3	42.2	-21.1	0.07	15.0	7.3	0.02	3.3
P3	ONE94 3218	Pig	10.1	42.7	-21.0	0.02	15.4	7.9	0.08	3.2
P4	ONE94 7475	Pig	6.9	42.2	-21.3	0.02	15.0	4.9	0.04	3.3
P5	ONE94 7475	Pig	4.4	42.4	-21.5	0.04	15.0	7.3	0.01	3.3
CH1	ONE94 11243	Chicken	3.7	42.0	-21.6	0.03	14.2	9.3	0.07	3.5
CH2	MFI87 156	Chicken	13.1	42.5	-20.4	0.04	15.3	11.9	0.09	3.2
CH3	MFI87 156	Chicken	14.8	41.8	-19.9	0.02	15.4	10.7	0.04	3.2
CH4	MFI87 156	Chicken	10.7	42.8	-20.5	0.00	15.6	10.6	0.13	3.2
CH5	MFI87 156	Chicken	28.2	42.7	-20.2	0.00	15.6	8.9	0.06	3.2
F3	FER97 156	Conger Eel	2.9	42.5	-12.8	0.00	14.7	14.7	0.04	3.4
F5	MFI87 156	Cod	2.7	42.8	-15.4	0.04	14.6	14.3	0.02	3.4
F6	GYE92 15174	Fish - Marine	6.4	40.7	-13.4	0.05	14.5	14.1	0.08	3.3

Excluded samples

Sample Number	Site Code and Context Number	Species	Yield (%)	%C	$\delta^{13}C$	Difference	%N	$\delta^{15}N$	Difference	C:N	Reason for Exclusion
S5	ONE94 11215	Sheep	0.64	-	-	-	-	-	-	-	Collagen yield too low
P1	ONE94 11243	Pig	1.1	42.7	-22.8	0.02	13.6	7.5	0.06	3.7	Abnormal C:N ratio
F1	FER97 6060	Fish - Marine	-	-	-	-	-	-	-	-	No collagen yielded
F2	FER97 6874	Fish - Marine	2.5	40.4	-20.9	0.06	12.8	10.8	0.27	3.7	Abnormal C:N ratio
F4	MFI87 156	Fish – Cod	0.5	-	-	-	-	-	-	-	Collagen yield too low

Site Codes

ONE94 – No. 1 The Poultry – Domestic Contexts

MFI87 – Docklands Light Railway, Monument Street – Domestic Contexts

FER97 – Plantation House, Chesterfield House – Domestic Context

GYE92 – Guildhall Art Gallery, Guildhall Yard – Contents of well, domestic dump from presumed inn/mansion

Appendix 6: Database of Roman London Sample (DISC 1) – Available with paper copy/on request