The development and application of ambulatory monitor for measuring weight-bearing during fracture healing

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The Development and Application of an Ambulatory Monitor for Measuring Weight-Bearing during Fracture Healing

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I certify that all the material in this thesis which is not my own work has been identified and that no material is included for which a degree has previously been conferred upon me.

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Abstract

The aim of this study was to measure the weight-bearing during healing in a series of patients with tibial fractures, and to examine how this changed with time post-fracture. Weight-bearing indicates the force through the leg as a percentage of the total body weight. An ambulatory monitoring system was developed, comprising of the monitor and analysis software for a PC. The ambulatory monitor measures the force via pressure transducers attached to the load bearing areas on the underside of the foot to obtain the weight-bearing through the fractured leg. The software was developed in the C programming language by using a PC host executing a cross-compiler, the program then being down-loaded via the serial line to the monitor hardware for execution and testing. Once a basic monitor was operational, the clinical trials commenced, these being conducted at fracture clinic sessions at Middlesbrough General Hospital. Further development work occurred throughout the patient trials which led to increases in the accuracy and consistency of the results obtained.

Results were obtained from 37 patients with tibial fractures, and these all demonstrated that there was a non-linear increase in weight-bearing with time post-fracture. An increase in step duration relative to the step duration of the normal leg also occurred, indicating a gradual change in the gait pattern adopted, tending towards a normal gait pattern with time. A similar pattern was found with the stride length, this indicating a gradual change towards a more normal gait pattern with time. An increase in velocity of gait was also observed over the healing period, suggesting greater confidence in walking as healing progressed.

Such results lead to the hypothesis that a feedback mechanism operates which controls the weight-bearing applied to the fracture depending on the stiffness of the fracture. The clinical relevance of this work is to aid the clinician in fracture healing assessment enabling the prescription of more applicable treatment methods.

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1. Introduction and Biological Background

Fractures require a stable mechanical environment for healing, and so fractures in long bones are particularly problematic due to the larger moments and forces at the fracture site. Therefore to permit healing, the fracture is often stabilised by use of a fixation method.

Tibial fractures are especially prone to non-union or delayed union (Oni *et al.*, 1988), and so previous clinical practice was to stop the patient weight-bearing on the fractured leg until the healing process was well advanced. However due to increased understanding of the healing process, more recent clinical practice has been to encourage patients to partially weight-bear early to stimulate healing. The aim of this study was to monitor the weight-bearing over the fracture healing period.

In this chapter is discussed the biological aspects of bones, fracture healing and treatment, this leading to the various methods possible for weight-bearing measurement, and concluding with the chosen method.

1.1. Bone Function and Composition

Although the main purpose and function of individual bones may vary, in general each bone has three basic functions. The first is that when in combination to form a skeleton, the many different bones support the soft tissues and protect the internal organs from damage. They also provide for muscle, tendon and ligament attachments and by acting as levers and struts enable movement. Finally each bone stores various minerals and blood generating cells.

To be able to perform its first and second functions, bones are required to be strong. To minimise energy expenditure in movement, there is also a requirement for them to be as light as possible. The molecular and histological structures of bones are such as to satisfy both these requirements. Therefore the human skeleton, which constitutes less than 20% of the weight of the entire body, can endure high loads such as five times body weight on the bones of the knee joint when running. The equivalent skeletal framework made out of steel would weigh four to five times more than does the bony skeleton.

1.2. Bone Structure

1.2.1. General Structure

Examining bones at the gross level results in the discerning of two basic material structures: compact and spongy bone.

Compact bone, otherwise known as cortical bone, is solid, dense bone that is found in the walls of bone shafts and on external bone surfaces. Spongy, cancellous or trabecular bone has a more porous and lightweight honeycomb structure. It is found under protuberances where tendons attach, in vertebral bodies, at the ends of long bones such as the tibia and fibia, in short bones, and sandwiched between flat bones. The traberculae are arranged to withstand the stresses to which they are normally subjected, so that those lying along the lines of force are intersected by others acting as struts and ties (Gray, 1964). The benefit of spongy bone occurring at specific locations in a bone is that its weight is reduced due to its greater porosity. Figure 1.1 shows the difference in appearance between both types of bone, the example given being the proximal end of a tibia.

The porosity of spongy bone is greater than 70% which contrasts with that of cortical bone at 15% (Le Veau, 1992). As bone strength and stiffness varies inversely with increasing porosity, the mechanical properties of these two types of bone differ considerably. However the density and porosity of the bone do not alone dictate its mechanical characteristics, for these can vary as much as two orders of magnitude depending on its location and therefore use (Goldstein *et al.*, 1983). Wolff's law states that the physical characteristics of bone are matched to the routine structural demands placed upon it (Wolff, 1892). Therefore mechanical characteristic variations between bones exist due to a response or remodelling to different loading conditions existing across a bone according to Wolff's law (Mow *et al.,* 1991). This mechanism is explained in fuller detail later on in this chapter.

During life the outer surface of bones is covered with periosteum, with the inner surface being covered with endosteum. Both are osteogenic tissues meaning that they contain bone forming cells which are numerous and active during youth, but reduced in number and relatively inactive in adulthood. However they can be stimulated to deposit bone when the periosteum is traumatised due to a fracture.

1.2.2. Molecular Structure

Whatever the type of bone, its molecular structure is the same. Bone tissue is a composite material, 90% being made up of the large protein molecule collagen. Each molecule of collagen intertwines with others to form flexible, slightly elastic fibres which are then stiffened by a dense inorganic filling of hydroxyapatite, which is a form of calcium phosphate. This mineral gives bone its hardness and rigidity, and when removed by immersing in acid, the bone becomes a flexible rubber like structure. In contrast, when the collagen is removed from bone, for example by heating, it becomes extremely brittle and crumbles easily. Therefore the composition of these two materials result in a tissue that is strong and rigid.

1.2.3. Histological Structure

Histology is the study of tissues, usually at the microscopic level. Such studies of mammalian bone results in two distinct histological types, immature and mature bone. Immature bone, otherwise known as coarsely bundled or woven bone, develops first and its existence is usually temporary as it is replaced by mature bone. It has a higher proportion of osteocytes, which are bone cells, and is coarse and fibrous in microscopic appearance with bundles of collagen fibres arranged in a random pattern. Mature or lamellar bone tissue on the other hand has an organised structure due to the repeated addition of uniform lamellae to bone surfaces during appositional growth, this being apparent at two levels. The first is that the inner and outer bone surfaces are encircled by the inner and outer circumferential or primary lamellae, as shown by the second diagram of Figure 1.1. These lamellae's fibres are each oriented in a different direction as shown, so that the bone's strength is increased by being able to endure tensile and compressive forces in various directions. There are also the secondary lamellae which encircle the Haversian canal, each one's fibres again being oriented in a different direction than the next to increase strength.

Compact bone is too dense to be nourished by diffusion from surface blood vessels, therefore Haversian systems with their canals and canaliculi are present throughout the bone, as shown by Figure 1.1. The diagram on the right of this figure shows a cross section of an osteon or Haversian system, the lamellae indicated being called Haversian or secondary lamellae. An examination of each reveals a bed of parallel collagen fibres, with fibres in successive lamellae being oriented in different directions, again strengthening the structure. Through the Haversian canal there passes blood, nymph, and nerve fibres. Haversian canals run longitudinally within the bone, and are connected to each other by Volkmann's canals which are transversely oriented, not being surrounded by concentric secondary lamellae.

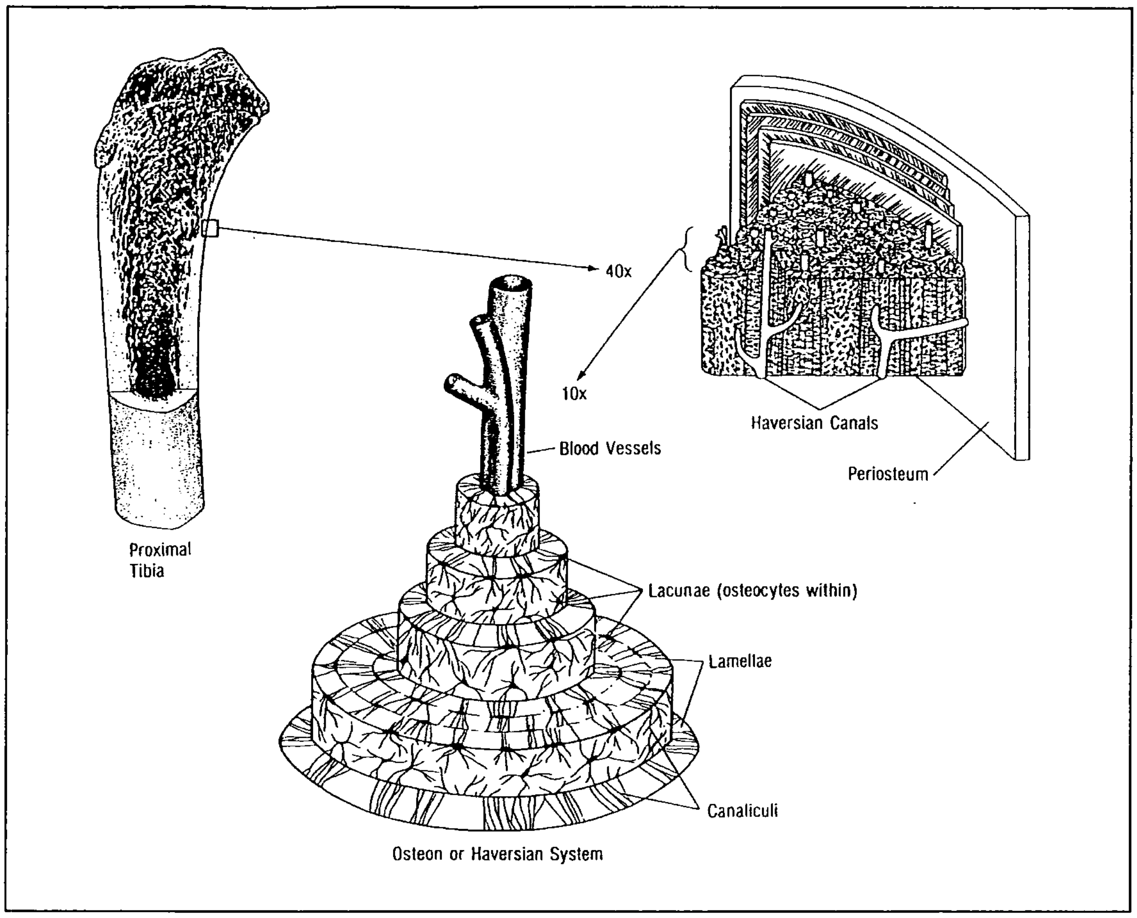


Figure 1.1 - Gross and microscopic structure of bone (White, 1991).

1.2.4. Bone Cells

There are three major types of bone cells involved in forming and maintaining bone tissue, called osteoblasts, osteocytes, and osteoclasts, as shown in Figure 1.2.

Osteoblasts are bone forming cells which produce many collagen molecules arranged in a matrix, this being called osteoid. Osteoblasts derive from osteoprogenitor cells which are present in the periosteum and also the blood vessels of the Haversian vascular system. A proliferation of these bone forming cells occurs at fracture sites as osteoprogenitor cells divide frequently in such areas.

Once the collagen is calcified, the osteoblast being surrounded by a bony matrix, it is called an osteocyte. Osteocytes' function changes from one of bone formation to one of bone regulation they resorb calcium or phosphate from the surrounding tissues in response to hormonal signals, this process being called osteolysis. The space where each is found is called a lacuna, with long dendritic arms, called canaliculae, acting as communication and nutritional channels.

Osteoclasts have the opposite function to osteoblasts in that they resorb rather than form bone tissue. These are found in hollow depressions in the bone tissue known as Howship's lacunae. At the surface of the cell are apatite crystals and collagen removed, the cell therefore moving through the bony tissue as it is resorbed.

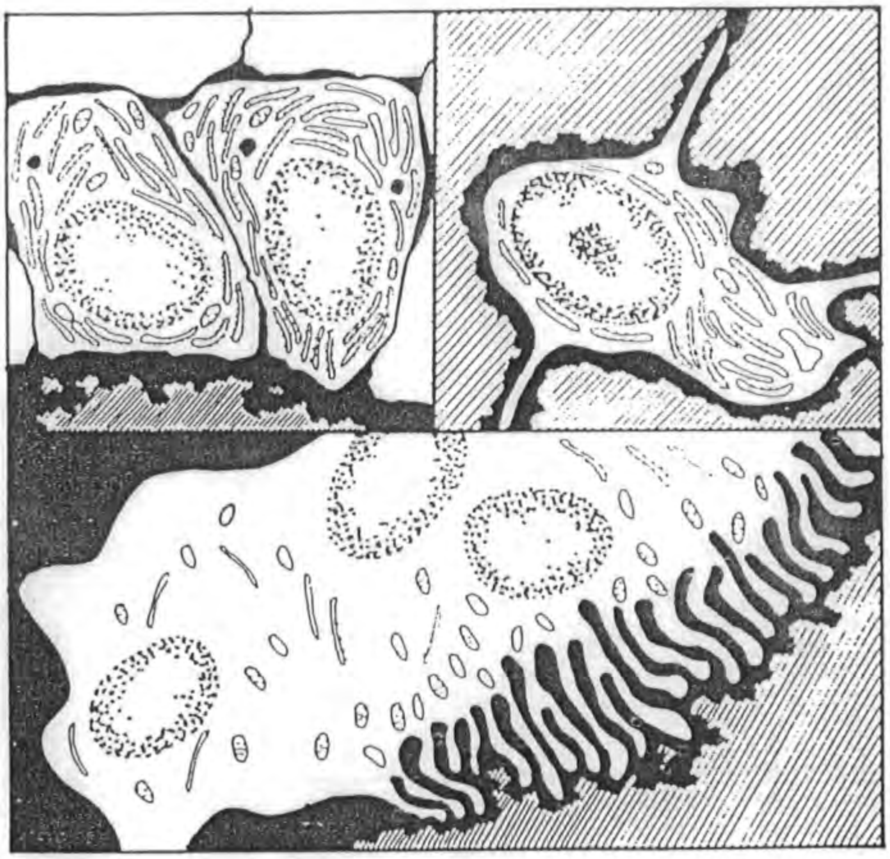


Figure 1.2 - Bone cells, with the diagonally shaded areas being bone. Osteoblasts are shown in the top left diagram. An osteocyte is shown in the top right diagram. Osteoclasts are large cells with many nuclei, part of one being shown in the bottom diagram. (Shipman et al., 1985).

1.3. Fracture Healing

Fracture healing can be divided into phases, with events described in one phase persisting into the next. This is shown by Figure 1.3 where the three basic phases occurring during fracture healing are displayed, with an approximation of the relative amounts of time for each. There follows explanatory text for each phase, with the reparative phase being further sub-divided into the cartilaginous phase, and the mineralisation phase. This phase division clarifies the events occurring during fracture healing, and have been described over the years in investigative reports and review articles (Ham, 1974).

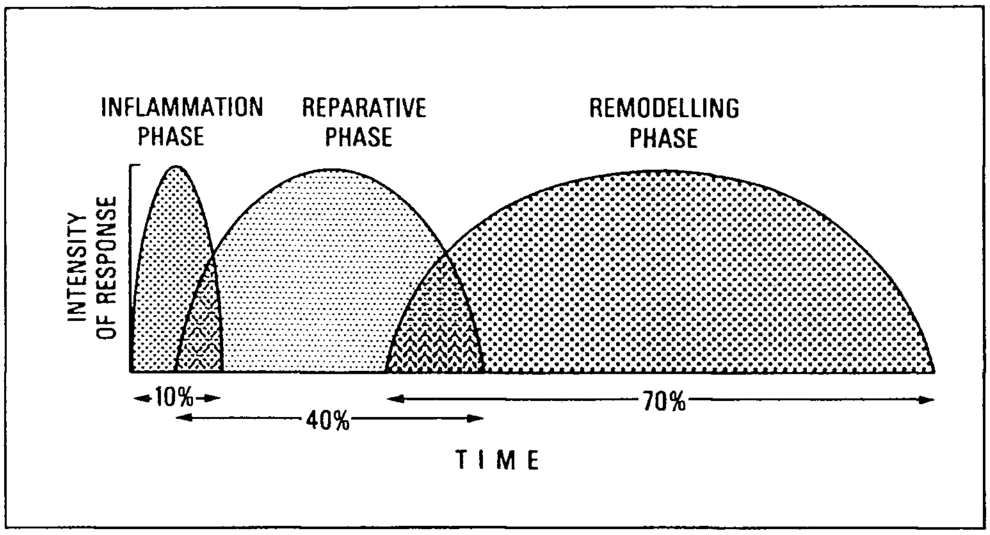


Figure 1.3 - An approximation of the relative amounts of time devoted to the inflammation, reparative, and remodelling phases in fracture healing (Rockwood et al., 1984).

1.3.1. Inflammatory Phase

Figure 1.4 shows that after a fracture the soft tissue envelope is torn and the numerous blood vessels crossing the fracture line are ruptured. Therefore an accumulation of hematoma within the medullary canal occurs, this blood rapidly coagulating to form a clot. As the blood supply is damaged, the osteocytes are deprived of oxygen and nutrients and so die as far back as the junction of collateral channels. Severely damaged soft tissues may contribute to the necrotic material in the region (Ham, 1974).

The presence of the necrotic material elicits an immediate inflammatory response. Vasodilation occurs with the blood vessels increasing in diameter and an exudate of proteins, plasma and white cells escape into the trauma region. A soft tissue cuff forms around the fracture site which increases both the cross-sectional area and the moment of inertia of bone, thereby greatly increasing the stiffness of the fracture. Prostaglandins are also released, these being associated with bone resorption, bone collagen synthesis and general cleanup of the fracture (Pan *et al.*, 1992).

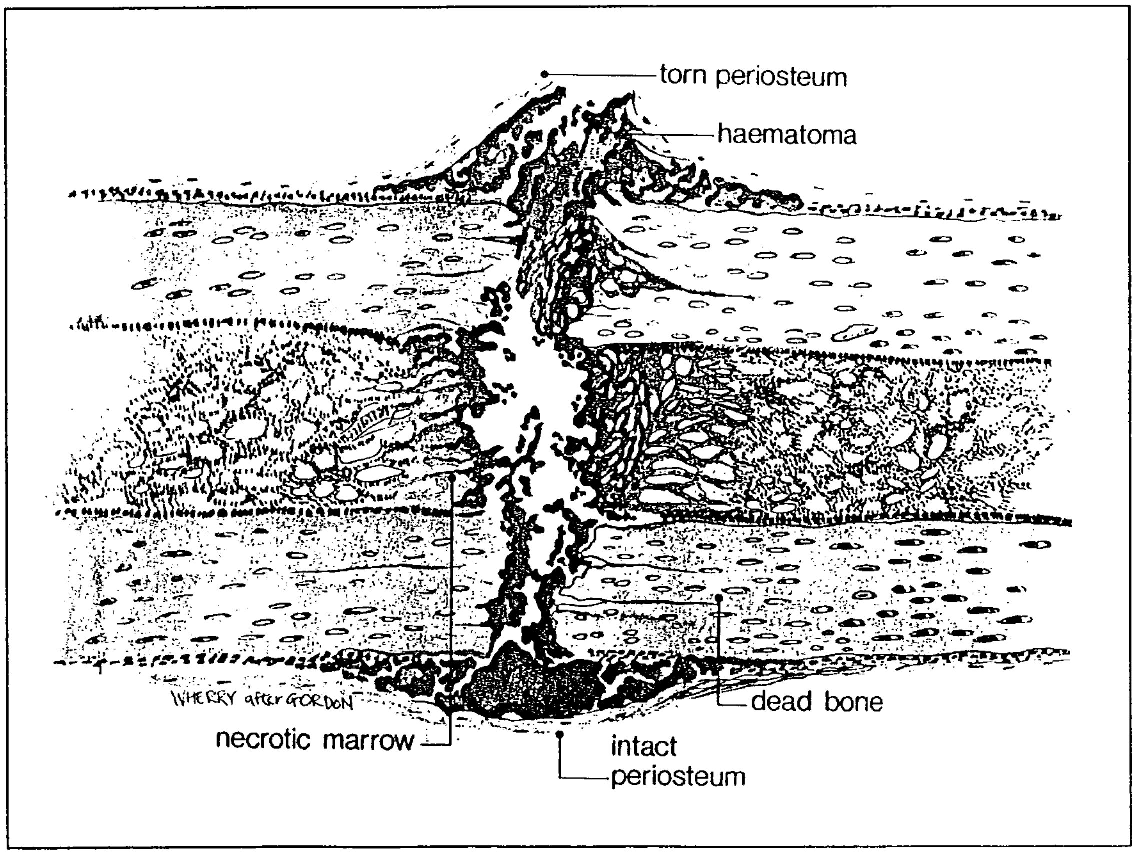


Figure 1.4 - The initial events involved in fracture healing of long bone. The periosteum is torn opposite the point of impact, and in many instances is intact on the other side. There is an accumulation of hematoma beneath the periosteum and between the fracture ends. There is necrotic marrow and dead bone close to the fracture line.

1.3.2. Cartilaginous Phase

This phase is otherwise known as the proliferative or soft callus phase. At this stage the microenvironment about the fracture is acidic, and during the repair process the pH level returns to neutral and then slightly alkaline (Heppenstall, 1980). Electronegativity is also found in the region, and unlike currents measured in intact bones, is not generated by stress. This degree of electronegativity slowly diminishes until the fracture is united (Rockwood *et al.*, 1984). Both these factors are stimuli for cellular activity aimed at fracture repair.

Repair is indivisibly linked with the ingress of capillary buds into the hematoma (Rockwood *et al.*, 1984), these first appearing from the periosteal vessels with the nutrient medullary artery becoming more important later in the process. The periosteum is usually torn at the fracture site which stimulates its osteogenic layer (White, 1991) and so many new active bone cells are found in this area during fracture healing (McKibbin, 1978), having ingress via these capillary buds. These cells differentiate into fibroblasts, chondroblasts and osteoblasts, depending on the local requirements (Heppenstall, 1980). The callus tissue shown in Figure 1.5 is formed by the mesenchymal cells which produce fibrous tissue, cartilage and osteoid. This leads to a gradual increase in fracture site stability, although not being related to the radiographic size of callus formed (Panjabi *et al.*, 1985), with medullary callus being formed later. Bone or cartilage is formed according to the oxygen tension; cartilage being formed at greater distances from the blood supply where oxygen tensions are fairly low. This cartilage is eventually resorbed with bone taking its place. Bone resorption also occurs at the fracture site for the removal of the necrotic bone fracture ends. These must be removed for new cartilage and bone to form in its place.

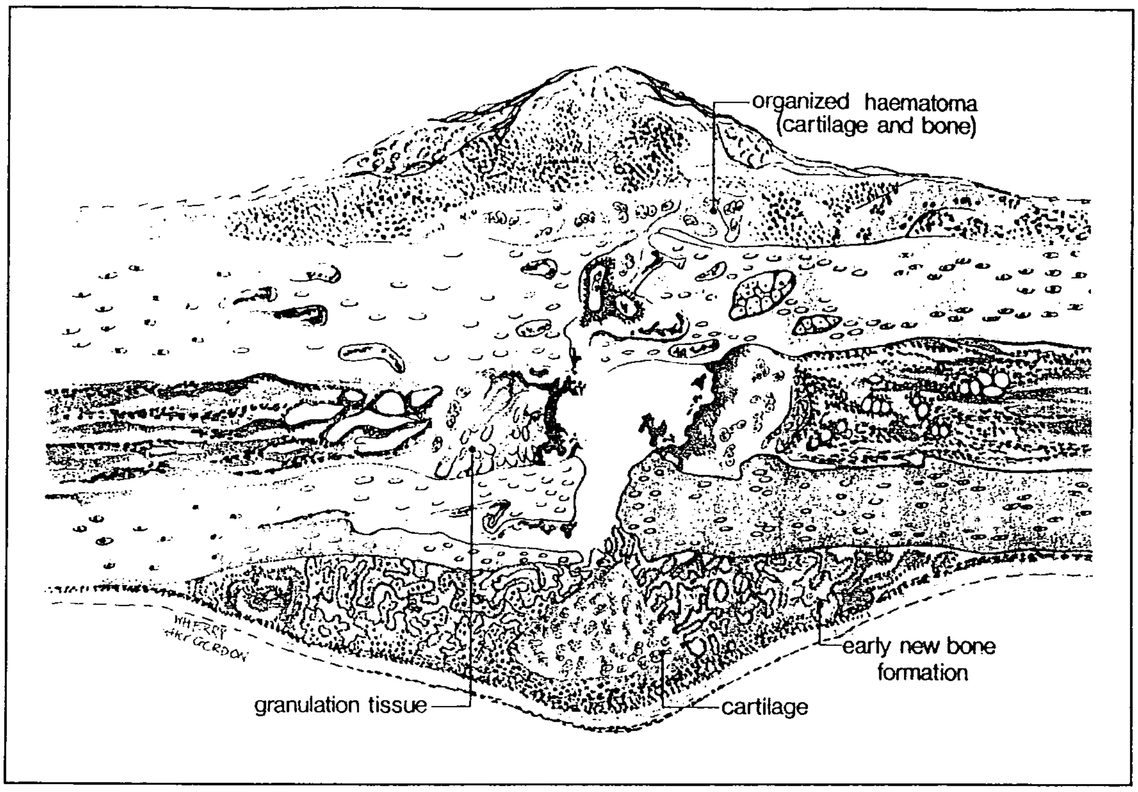


Figure 1.5 - Early repair. There is organisation of the hematoma, early primary new bone formation in subperiosteal regions, and cartilage formation in other areas (Rockwood et al., 1984).

1.3.3. Mineralisation Phase

This stage is also known as the hard callus and bony phase. It begins at 3 to 4 weeks post-fracture and continues until new bone unites the bone fragments. This varies in time according to the type of bone and fracture, but is in the region of 3 to 4 months post-fracture for long bones in adults. There is an accumulation of calcium hydroxyapatite crystals which occurs for the mineralisation of the collagen. The increase in fracture strength and stiffness seems to be related to the amount of new bone connecting the fracture fragments (Black *et al.*, 1984).

1.3.4. Remodelling Phase

As explained in Section 1.2.4, the function of osteoclasts is to resorb bone. The remodelling of the bone occurs by cutting cones made up of osteoclasts, these being followed by osteoblasts which deposit collagen matrix. These filling cones are tapered and extend a further distance longitudinally than the cutting cones due to the greater time required for collagen deposition. The cutting cones can advance a distance of 50 to 60 microns every 24 hours (Heppenstall, 1980).

These cones gradually resorb the woven bone of the callus, replacing it with the Haversian bone that was present prior to the fracture (Figure 1.6). These new struts of bone are deposited along the lines of force, the control mechanism being thought to be electrical (Rockwood *et al.*, 1984). Bone is known to be a piezoelectric material so that when subjected to stress electropositivity occurs on the convex surface and electronegativity on the concave surface. Circumstantial evidence indicates that regions of electropositivity are associated with osteoclastic activity and regions of electronegativity with osteoblastic activity (Bourne, 1971). Therefore Wolff's Law is explainable in terms of electrical activity which has a direct effect on cellular behaviour causing the bone to be altered according to the function demanded of it.

Cortical bone heals more slowly than cancellous bone due to the greater amount of bony tissue required, its more regular structure which requires more remodelling, and also because the marrow around the cancellous bone provides a source of osteoblasts local to the area of bone deposition. With favourable conditions cancellous bone may be united after just 4 weeks (Radin, 1987). However cortical bone usually requires about 8 to 12 weeks to heal (Figure 1.7).

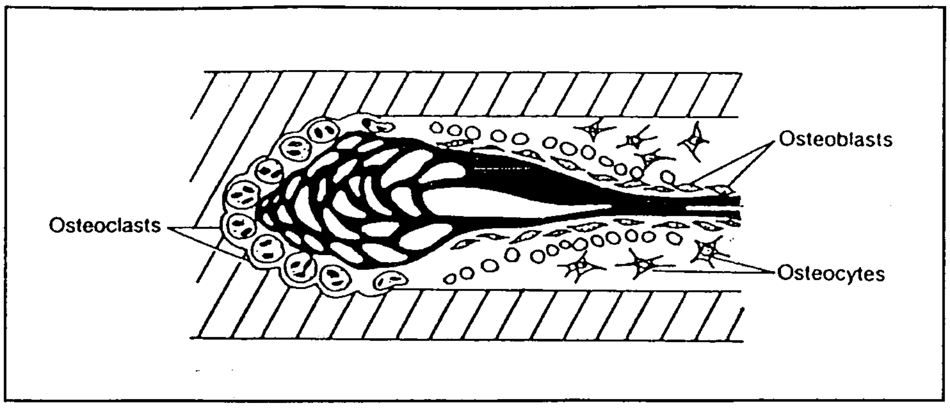


Figure 1.6 - The schematic cutting cone is moving from right to left through the bone. At the tip osteoclasts resorb bone; osteoblasts deposit new bone, are engulfed by the matrix they form, and so become osteocytes. New osteoblasts are produced from the capillary walls as the cutting cone moves through the bone tissue (Radin, 1987).

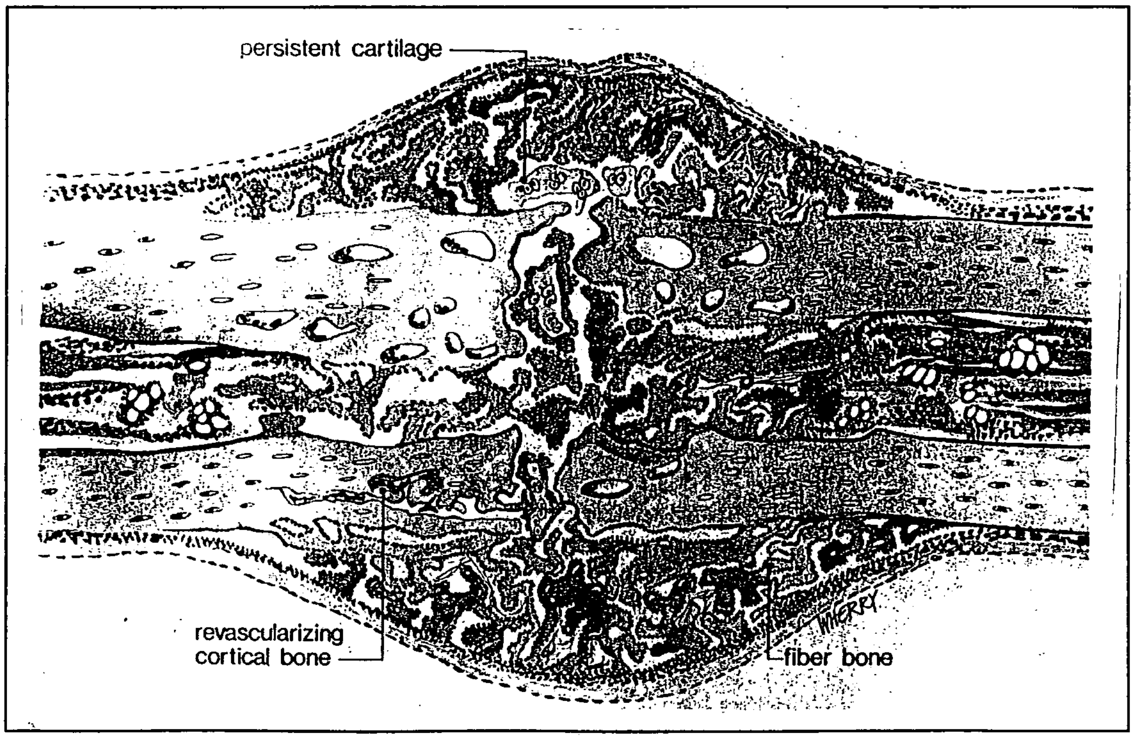


Figure 1.7 - At a later stage in the repair, early immature fibre bone is bridging the fracture gap. Persistent cartilage is seen at points most distant from ingrowing capillary buds. In many instances, these are surrounded by young new bone (Rockwood et al., 1984).

1.4. Factors Affecting the Speed of Fracture Healing

Factors which affect the rate of fracture healing can be conveniently sub-divided under two headings; factors which are local, and others which are systemic.

1.4.1. Local Factors

The degree of immobilisation with the amount of soft tissue trauma are probably of paramount importance to fracture healing, inadequate immobilisation leading to delayed union or non-union. This is probably because the initial fibrin scaffolding which is the first step of fracture repair is disrupted, causing the bony bridge of the external callus not to form properly. Fractures involving soft tissue trauma show retarded healing due to a decrease of differentiation of the mesenchymal cells and in their total number.

Factors which contributed most to delayed or non-union seem to be initial displacement, comminution, associated soft tissue injury and infection (Nicoll, 1964). Rockwood indicates that the fracture should be completely immobilised during the inflammatory stage so that the vascular supply could be reinstated (Rockwood *et al.*, 1984).

1.4.2. Systemic Factors

Fractures in young people heal more rapidly than those of adults, with the rapid remodelling that accompanies growth also allowing correction of a greater degree of deformity in the young. The reasons for this might be given by the results of experimental work with animals which showed that when young there is a more rapid differentiation of cells from the mesenchymal pool (Rockwood *et al.*, 1984).

As has been indicated before, electronegativity in bone has been linked with osteoblastic activity and so bone formation. It has been hypothesised that the application of electric currents directly to a human fracture or via the use of non-invasive electromagnets might therefore increase the rate of healing. A double blind patient trial to study the effect of pulsed electromagnetic fields on 45 tibial fractures with delayed union was carried out, with the conclusions being that significant improvements in the healing of patients occurred with active electromagnetic stimulation (Sharrard, 1990). However some reports believe the result of improved healing times are inconclusive (McKibbin, 1978).

It has been found that the healing rate can be increased by allowing small movements of the fracture site to occur. For example cyclic loading producing a small (≤ 1 mm) amount of micromovement of a fracture was applied and was found to improve healing (Panjabi *et al.*, 1977; and Goodship and Kenwright, 1985). It is probable that bone formation is stimulated by forces acting across the fracture site, as the lack of weight-bearing has been shown to decrease the amount of woven bone that is formed (Meadows *et al.*, 1990). This hypothesis is in agreement with Klein-Nulend *et al.* (1986), who found that compressive forces at the fracture sites in foetal mice stimulates rapid mineralisation of uncalcified matrix.

1.5. Post-trauma Osteoporosis

Osteoporosis is where there is a loss of bone, and changes in the cancellous pattern (Oxnard, 1993), so reducing the bone strength. During many rat experiments conducted in the 1950s, a rapid increase in bone mineral content following trauma occurred at the fracture site. However a decrease in the bone mineral quantity was noticed in the rest of the limb when compared with its opposite counter-part. This difference seemed to last for a longer period of time than that required for healing (Ulivieri *et al.*, 1990). This was found to be due to an increased rate of bone resorption (Wand *et al.*, 1992) as large resorption cavities were visible in the cortical bone (Young *et al.*, 1983).

Paavolainen and associates studied the healing of experimental fractures in rabbit tibiofibular bones treated by plates (Paavolainen *et al.*, 1979). During the first 9 weeks there was a progressive improvement in torsional strength reflecting the advancement of the union. From 9 to 24 weeks the torque capacity and energy absorption decreased while the torsional rigidity reached a steady state, concluding that after healing the continued presence of the implant has an adverse affect on the strength of cortical bone. This was verified by histological studies where after 9 weeks there was a rapid excavation and breakdown of the cortical wall, its porosity increasing from 9% to 37.5%. The same has been seen in human fractures, with loss of bone mineral being shown to have no correlation with the treatment method (Sarangi *et al.*, 1993). This effect is of long duration, for Nilsson (1966) found that this difference in porosity between the limbs took 6 to 7 years in males and 15 years in females to disappear. Post-traumatic osteoporosis can therefore lead to a weakness of the bone for many years which gives it a higher probability of refracture (Wand *et al.*, 1992).

A main factor for osteoblastic activity has been shown experimentally to be the amount of physical activity (Wand *et al.*, 1992). It is therefore thought that the main cause for post-traumatic osteoporosis is a reduced functional loading of the limb (Le Veau, 1992 and Whalen *et al.*, 1988), with the increased bone resorption in response to fracture probably being a contributory factor (Sarangi *et al.*, 1993).

Therefore the previous rationale in treating fractures by non weight-bearing until the healing was far advanced, has been discarded in favour of early partial weight-bearing. This avoids post-trauma osteoporosis and encourages healing by producing forces which result with naturally induced micromovement at the fracture site.

1.6. Fracture Treatment and Technique

The main causes for tibial fractures involve direct violent impact such as motorcycle and car accidents or indirect injuries such as from sport accidents and falls (Rockwood *et al.*, 1984). Normally a high energy impact results in greater soft tissue damage, skin loss, bone displacement and comminution, with the fracture often being transverse. In contrast, a low energy impact usually results in an oblique or spiral fracture.

As an important permissive factor of fracture healing is the degree of immobilisation, so fixation is required to maintain alignment and give stability during union of the bone. Various fixation methods are available, with the particular method chosen being dependant on the extent of damage to the soft tissue and bone, and also to the pre-disposition of the surgeon preferring one method to another.

1.6.1. Bracing and Casts

As a plaster cast provides good control of angulation but poor control of rotation and length (Latta *et al.*, 1991), it is normally applied after reduction from the knee to the ankle for simple low impact fractures. Braces are easily adjustable to compensate for the changing leg volume so that stability can be maintained, being used for fractures with minimal initial shortening and soft tissue damage. Forty years ago the routine treatment for an uncomplicated tibial fracture was a closed reduction followed by a non-weight bearing long leg cast which was worn for 10 weeks before another cast was applied allowing partial weight-bearing. Since then however, early weight-bearing is encouraged starting at between 10 to 16 days post-fracture, as this seems to reduce muscle atrophy and tissue edema and also shorten the post cast rehabilitation time (Rockwood *et al.*, 1984). This is probably due to the stimulating of osteoblastic activity so decreasing of disuse osteoporosis.

1.6.2. Intramedullary Nailing

Internal fixation is the general term for both intramedullary fixation using an intramedullary nail, and extra-medullary fixation by using plates and screws. Intramedullary fixation is good for short oblique fractures where a large displacement has occurred, and is also often used in comminuted fractures (Rockwood *et al.*, 1984). This is because the use of intramedullary nails results with minimal interfragmentory movement as the nail takes most of the bending, torsion and compression loads applied, so that direct healing of the cortical bone by remodelling occurs. However if a relatively flexible nail is used, some secondary healing may occur with the presence of external callus. The main disadvantage of this treatment method is that it is surgically traumatic and has a relatively high probability of infections, non-union and refracture (Gautier *et al.*, 1992). When the nail requires that the bone be reamed, up to 70% of the cortical blood supply can be disrupted (Whittle *et al.*, 1992) so slowing the healing rate. There is also a risk of mechanical failure of either the nail or the fixation screws due to the high loading they sustain (Latta *et al.*, 1991).

1.6.3. Plating

Plates are often applied to segmental and intra-articular fractures involving the tibial shaft and knee or ankle joint (Rockwood *et al.*, 1984). Although the plate is not able to resist the high bending moments and rotations which can be borne by an intramedullary nail, it does provide very rigid fixation due to the fracture site being compressed (Gautier *et al.*, 1992). As with an intramedullary nail, the strength and rigidity obtained with a plate is sufficient to enable immediate early limb function. The main problem observed with plate fixation is the devitalisation of adjacent tissue, subsequent skin breakdown and wound sepsis (Rockwood *et al.*, 1984). Also there is an immediate alteration of stresses in the bone from those to which the bone is accustomed, leading to possible stress fractures at the junction of the plate with the bone. Temporary osteopenia is caused by having stress protection under the plate, so that for over 6 months post-fracture the overall bone strength is reduced (Latta *et al.*, 1991). Care must be taken in weight-bearing shortly after removal of the plate, for refracture of the tibia may occur because of disuse osteoporosis (Rockwood *et al.*, 1984).

1.6.4. External Fixation

External fixation seems most useful in instances involving severe soft tissue wounds. It reduces the requirement to dissect soft tissue adjacent to the fracture site and may also be applied rapidly. An external fixator can also be adjusted to satisfy a particular treatment course, allowing very rigid fixation or more flexible fixation so inducing micromovement. The normal cyclical mechanical loading and strain in a tibia is disrupted if a very rigid fixator is applied, so by introducing micromovement improved osteogenesis at the fracture site may be observed (Goodship *et al.*, 1985, Egger *et al.*, 1993). Circular frames, whilst difficult to apply, have the advantages of resisting rotary and angulatory deformation whilst still allowing axial deflection which theoretically improves fracture healing. Problems encountered with external fixators involve the infection of the pin-tracts which can lead to loosening and decreased stability (Latta *et al.*, 1991).

1.7. Measuring Weight-Bearing

All these treatment methods allow the patient some degree of freedom of movement as the fracture is given stability and stiffness due to the fixation device used. As noted previously, the patient being allowed to walk on the fractured limb also has positive effects on the healing of the fracture, for osteoblastic activity is stimulated by the amount of physical activity (Wand *et al.*, 1992). It has also been noted that allowing micromovement at the fracture site has been shown experimentally to favour healing (Goodship and Kenwright, 1985). Rather than directly inducing this micromovement at the fracture site as did Kenwright *et al* (1991) via pneumatic pump attached to a sprung external fixator, the patients monitored during this study have been encouraged to weight-bear early, with the assumption that weight-bearing on fractured limb will naturally induce micromovement at the fracture site because the fixation device can never be infinitely stiff.

The basic feedback mechanism which ensures that the patient does not transmit too much weight through the fractured limb during fracture healing is pain (Dehne, 1980). This occurs via pain receptors at the fracture ends, which indicate pain when these ends move against each other, or more often discomfort when this movement is small. If the fracture is in an early stage of healing, its stiffness is less, and so the limb is more unstable than at a later period in the healing process.

Therefore measuring the amount of weight-bearing of a patient should give an increase with time as the fracture stiffness increases due to the fracture healing. The lack of change in weight-bearing over time might indicate complications in the fracture healing process, or the patient not weight-bearing as requested due to the gait pattern developed or because of laziness. Both of these are of clinical interest; the former being verified by a radiograph and perhaps requiring surgical intervention, the latter being of interest due to the prospect of a longer time for healing and subsequent rehabilitation if the patient continues in the same manner.

1.7.1. Weight-Bearing Measurement Methods

To measure weight-bearing in this study, the method of pressure sensing under the foot has been investigated. Another more limited and less accurate method of assessing weight-bearing might be to measure the micromovement induced at the fracture site (via sensors on an external fixator for example, as did Richardson *et al.*, 1992) and by estimating the combined fracture and fixator stiffness, calculating the weight-bearing. However estimating the current fracture stiffness is rather inaccurate as the fracture stiffness increases over time due to healing. Also this method is only feasible using an external fixator as the treatment method. Therefore for accuracy and flexibility of treatment, an attempt was made to measure the weight-bearing directly.

Lord *et al.*, (1986) reviewed a number of systems which have been devised in an attempt to identify high pressure areas underneath the foot which is of particular interest for conditions where pressure may be excessive, such as diabetic neuropathy and rheumatoid arthritis. Most foot pressure measurement systems are floor mounted, it being more difficult to measure pressure beneath the foot inside the shoe.

1.7.1.1. Floor Mounted Systems

Floor mounted systems have the benefit of measuring over the whole area of the foot. The main disadvantage of their use is that the patient can normally only take one step on the measuring area. This leads to the patient 'aiming' the foot for the measuring area when walking up to it, so increasing tension and altering the gait pattern, probably leading to a reading for weight-bearing on that step being different than that during the patient's normal gait (Whittle, 1991). A number of floor mounted systems have been used up to date some of which are detailed below.

Simple systems giving coarse readings of pressure which can be converted to force by multiplying by the area, include the Harris mat which is made of thin rubber whose upper surface consist of a series of ridges of different heights. This surface of the mat is coated with ink, paper is put on top of this mat, and the patient is asked to walk over the mat. The highest ridges compress under light load, with the lower ones requiring progressively greater pressures, therefore making the transfer of ink to the paper greater in areas of highest pressure. Other similar schemes include using pressure sensitive film instead of the paper and ink. The Pedobarograph uses an elastic mat laid over an edge-lit glass plate which, when the mat is compressed due to load, loses its reflectivity so becoming darker, this providing a quantitative measurement when recorded by a camera. Load cells have also been used which are placed as an array and walked on. Each measures the vertical force beneath a particular area of the foot, so when added together result in the weight-bearing. However the most accurate reading is obtained by using a force platform or force plate which measures the ground reaction force as a subject walks on it.

1.7.1.2. In-Shoe Devices

The advantage of using an in-shoe measuring system is that measurements can be taken for each step and so the patient is able to relax into their normal gait pattern, this resulting in more accurate measurements. Also by recording each step taken, variations in the gait whilst walking can be quantitatively measured by observing the changes in the weight-bearing value. However there are difficulties in obtaining accurate measurements due to the curvature of the surface of the sole of the foot, a lack of space for transducers, and the requirement for a large number of wires from inside the shoe to the measuring equipment. For these reasons, such systems usually measure pressure only in selected areas of the foot, contrasting with floor mounted systems which measure over the whole area of the foot (Whittle, 1991).

This study has sought to develop a weight-bearing measuring system that patients can use whatever the fixation method used for the fracture. An in-shoe measuring system has been devised and developed for this purpose, this method being chosen for its capability of monitoring all steps taken during walking, so that a more accurate average value can be gained for the weight-bearing with the standard deviation showing the variability of the gait. For ease of use and accuracy of data, the equipment had to be portable and small so that the patient would not be encumbered by it and so could walk using their normal gait. The aim of using such a system was to discover whether weight-bearing increased over time and whether any differences were apparent according to the treatment method employed.

1.8. History of Ambulatory Monitoring

The requirement for ambulatory monitoring was first envisaged by Dr. Norman J. Holter who was concerned with monitoring the heart. Certain heart conditions occurred for a small period of time with their effects lasting for the rest of the person's life, with these conditions being undetectable in an isolated laboratory (Meldrum, 1992). Holter wrote that more physical freedom was desirable to study the heart under realistic conditions of daily life (Holter, 1961) and also that significant electrocardiographic (ECG) changes might occur during the normal active day of a clinically normal individual (Holter, 1957). Therefore there was a need for ambulatory monitoring over an extended period of time.

For some time telephone ECG transmission occurred. The patient was confined at home, and the ambulatory monitor intermittently transmitted data of the patient's heart to a receiver linked to the telephone which in turn transmitted the data along the telephone line to the laboratory for analysis (Pratt *et al.*, 1988). Later generations stored the data in memory so that monitoring could occur at any time and the data transmitted via the telephone when the line became accessible. Other systems used a cassette tape to store continuously monitored data which was later analysed at the laboratory using a computerised scanning system (Pratt *et al.*, 1988).

With the advances in microprocessor technology, recording has moved from analogue to digital recording. The advantages are of speed and ease of data transfer and evaluation, without requiring an expensive piece of equipment. Also calculations can be performed during the recording period, such as discarding unessential data points (Pfister *et al.*, 1989). Using this feature, microprocessor based ambulatory monitors are able to monitor over extended periods of time without their memory being exhausted, for only data of interest is stored (Besag *et al.*, 1989). The storage method for such monitors is normally solid-state RAM technology, which having no mechanical 'moving parts' means is more robust and smaller, resulting in a monitor which is more compact and lighter, and so less obtrusive to the patient.

Attempts have been made at real-time automatic ECG recording and processing by the monitor, with only the results being stored in memory. There have however been concerns over the sensitivity and specificity of the results in relation to artefacts and frequencies of ventricular arrhythmias, especially with complex and repetitive forms (Kennedy *et al.*, 1987). However ambulatory monitors which perform real-time processing of data offer the ideal solution for applications requiring simpler analysis of data for the extraction of results.

Since this application requires fairly simple data analysis, which will be explained in the next Chapter, this can be performed in real-time with the results only being stored in memory. Therefore due to benefits associated with ready access to the results and with the solid-state technology involved, this type of ambulatory monitor was selected for design and development.

2. The Monitoring System

This chapter details the monitoring system, which comprises of the hardware and software of the ambulatory monitor, its interface for communication with the PC, and the PC's analysis and file manipulation program for the storage and display of the calculated results.

2.1. Hardware of the Ambulatory Monitor

This section describes the hardware and other components used to make up the ambulatory monitor. Section 2.1.1 deals with the internal contents of the monitor which give it its functionality. Sections 2.1.2 describe the extra components which are necessary to provide its user interface, and also details the monitor's housing. Finally, Sections 2.1.3 detail the RS-485 to RS-232 interface.

2.1.1. Internal Monitor Hardware

The intelligence or functionality of any computer is derived from the micro-processor, or Central Processing Unit (CPU), as it processes the string of commands which forms the program being executed. These commands perform very simple tasks and are represented as numbers in the computer. Many commands manipulate data in some form, and so a computer program consists of the string of command numbers interleaved with the required data numbers. This type of program code, which the CPU can execute directly is called machine code. Although it is theoretically possible for programmers to write machine code, the likelihood of mistakes is high because the code is extremely difficult to read, since it is just a long line of numbers. Therefore if there is a requirement for the programmer to have this level of command execution control, assembly language is used; this uses labels and symbols to represent the command names, jumps, etc.. This program is then 'assembled' which tokenises the labels into their corresponding machine code numbers resulting with the machine code program which can then be executed by the CPU. Assembly language is much more readable than machine code itself, and therefore the probability of errors is reduced. Both are called low-level languages because the programmer has control on the exact commands and the order in which they are executed.

However, most programming occurs in high-level languages. These are more readable still than assembly language, being closer to logical constructs of the English language itself. Rather than each command in the high-level language corresponding directly to a machine code instruction, each command corresponds to a number of them. These two factors combine to provide a great increase in programmer productivity due to the greater readability of the code which results in fewer errors and facilitates the finding of errors that do occur. Also, due to the conciseness of the code that is written since each command corresponds to a number of machine code instructions there is a smaller probability of errors being in the code as there is a smaller number of commands. The translation of the high-level language instructions to machine code instructions can occur in either of two ways; through interpreting the code written by the programmer, or by compiling it. Interpreting the code is where the programmer's code is stored in memory and each statement is translated into its machine code equivalent as the program is being executed. Compiling the programmer's code involves the computer first translating the whole program into the machine code equivalent, and then executing the translated version. Interpreting the code therefore causes the execution speed of the program to be much slower than the execution speed of the compiled version. However, the time involved in first compiling the programmer's code into machine code before it can be executed must also be considered, and when debugging a program (trying to find the errors and removing them) this causes the productivity of the programmer to decrease since there will always be a noticeable delay (of compilation) between each small change in the program implemented. If however the code were interpreted, the effect of any code changes would be observed almost instantaneously, even though the actual program execution would be slower.

The drawbacks of using high-level languages when writing code is that the programmer does not have full control over the commands executed by the CPU. This is because there is normally no access to the machine code commands, the compilation stage translating the programmer's code into a set of machine code instructions rather than just one. For most applications this is not a concern, but for some (for example the CPU accessing other parts of the computer like the display drivers) the programmer needs direct control at a low level (i.e. direct execution control) of the CPU functionality. This is because the high-level language can never be large enough in its different commands to be able to have separate commands which translate into every possible combination of machine code commands. This problem can be circumvented by the program being written mainly in a high-level language; but with sections which require the direct CPU command execution control (i.e. if the functionality required is not included in the high-level language) written in assembler.

The requirement for this application was to write a program to give the CPU and surrounding peripherals the functionality of an ambulatory monitor. To facilitate the writing of the program, a high-level language called 'C' was chosen as it also includes some low-level functions. However, as will be explained later, not all the monitor functionality was able to be written in C. Therefore a part of it was written in assembler.

Having decided upon the programming language requirements, the type of processor had to be chosen. Rather than decide on a specific processor for which the programming tools were available and then design the computer system (the CPU with all the other peripherals needed such as memory and Analogue to Digital converters or ADCs) a pre-fabricated computer system was chosen. This was obtained from P.S.I. Systems (17-18 Chelmsford Rd. Industrial Estate, Essex CM6 1XG) and is called the 'Mini-Module'. The other major benefit of choosing a complete system was that it was already interfaced to different programming languages which could therefore be used to write programs, these being Modula-2, C and assembler. This software interfacing included the writing of various routines and functions for the controlling of the peripherals by the high-level language in question, which results in a great deal of time being saved for the programmer, as little or no interfacing in assembler needs to be performed oneself.

The Mini-Module Printed Circuit Board (PCB) measures some ten by eight by a half centimetres in size. It contains a Philips 93C100 CPU (which is Motorola 68000 software compatible), EPROM (Erasable Programmable Read Only Memory) for program storage, RAM (Random Access Memory) for data storage with a lithium battery back-up for when the power is disconnected, a real-time clock, sixteen digital channels which can be independently configured for output or input, four analogue to digital converters, one digital to analogue converter, an RS-485 serial interface, a watch-dog timer, a power fail detector, an LCD (Led Crystal Display) adapter, a keyboard adapter, an expansion bus, and finally a 68000 compatible bus port for connection to external peripherals. In Appendix 1 are included further details and purposes for each component of the Mini-Module that was utilised.

2.1.2. Supplementary Monitor Hardware

The extra physical components required for the ambulatory monitor are described below. These include LEDs, switches, a power supply, and a box to house these and the Mini-Module.

2.1.2.1. The LEDs

As was mentioned previously, four LEDs are needed to provide the monitor's operator with its status. Each one is lit by setting the digital line to 0 so that it is driven by the 100 μAmp source to 5 Volts. This current is sufficient to light low power LEDs feebly but visibly, and so adequately. Another way of lighting the LEDs would have been to have one side connected to the 5 volt battery voltage, and the other to the digital line. When the line was 1 (meaning that it was being driven by the FET to 0 Volts) current would pass from the battery to the FET so lighting the LED, a resistor in series limiting this current. The former option was used since this results in a lower power consumption which is important in this application. Although the LEDs were not lit as brightly as they would be by using the latter option, they were still visible.

2.1.2.2. The Switches

Two switches were required; one for the power connection which would determine whether the monitor is switched on or off, and the other a 'depress on' switch to enable the operator to access different functions of the monitor program.

For the power supply connection switch, the power supply's ground was permanently connected to the Mini-Module's ground. The power supply's positive was connected to one side of the switch, the middle switch connector going to the Mini-Module's +5V rail. Therefore only when the switch was in one of the two possible positions would both leads would be connected so that current could flow.

For the other switch, a 'depress on' type was chosen, where the switch is closed only when the switch is being depressed. An 'input' digital line is attached to one side of the switch, and ground being attached to the other. The unset state for a line is logically zero which corresponds to the 100 μAmps source driving the line at 5 Volts. When the switch is closed, the line voltage is pulled down to 0 Volts (corresponding to 'on' when being read by the CPU) and the current is dissipated as heat by the internal resistance of the batteries and the wire. The CPU can easily access just the one digital line by applying a mask over the other lines when it is being read. Hence the CPU will ignore the other lines by comparing the port's value to a number using an AND function. This function compares the bit values representing two numbers, resulting in a 1 or 'on' if both numbers have a 1 in that position, and a 0 if not. For example 34 AND 66 returns 2 because their binary representations of 100010 AND 1000010 result in 0000010 for that is the only set bit common to both. So for this application, reading the port and performing an AND function with 00000001 will mask out the top seven bits, the answer returned being the last line value which is connected to one side of the switch.

2.1.2.3. The Power Supply

As the monitor's main requirement was of portability, a power supply made up of batteries was required so that the monitor would be freed from requiring the mains electricity supply. The voltage requirement for the monitor was determined by the Mini-Module; this being a maximum of about 5 Volts and a minimum of 4.75 Volts, which is where the power fail detector begins to operate. It was also thought important to use rechargeable batteries so that there would not be an on-going expense due to disposable batteries having to be replaced when discharged. The other criterion for the selection of batteries was physical size; to minimise battery size for them being housed in the same casing of the Mini-Module.

As ni-cad batteries are freely available and relatively inexpensive, this type of re-chargeable battery was chosen. Battery capacity is in the units of Amp Hour (Ah) which is equivalent to the sustainable current discharge for one hour. For example a 3Ah battery of output voltage 1.5 Volts could supply 3 Amps at 1.5 Volts (or 4.5 watts) for one hour before being discharged. Figure 2.1 lists the different battery types, their voltage output, and the maximum capacity that each holds.

Battery Type	Voltage	Capacity (Ah)
AAA	1.2 V	0.22
AA	1.2 V	0.65
C	1.2 V	1.5
PP3	9 V	0.11

Figure 2.1 - Various ni-cad battery types with their voltage and capacity

AA size batteries were chosen for their volume (including a battery holder) per capacity was smaller than for any other type.

Although their official rating is 1.2 Volts, the voltage output is not static but changes during discharge. Figure 2.2 shows how the voltage decreases for different discharge rates, with 'C' being the discharge rate to exhaust the battery in one hour. It can be seen that the voltage before discharging starts at 1.35 Volts, and reaches 1.2 Volts only a little before the battery is fully discharged. Therefore by using 4 batteries connected in series, a starting voltage of about 5.4 Volts occurs which decreases to 4.6 Volts just before the batteries are fully discharged. As the power fail detector occurs at about 4.75 Volts, this is a useful indicator to the operator of when the batteries need re-charging. The Mini-Module still functions correctly at the higher voltage of 5.4 Volts and so four AA size ni-cad batteries in series were chosen for the power supply.

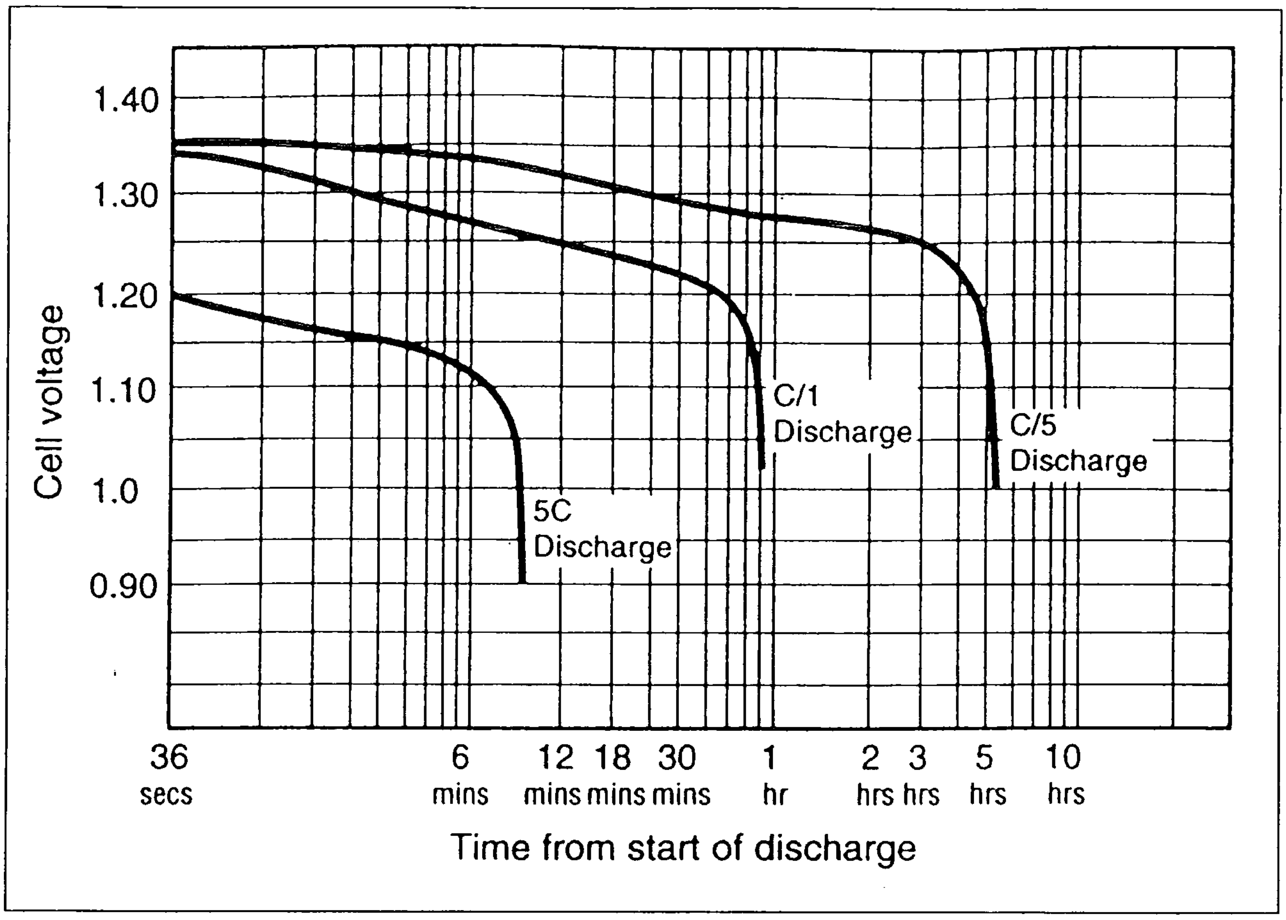


Figure 2.2 - Graphs showing typical ni-cad batteries' discharge times versus cell voltage for different discharge rates (RS Data Library, 1994).

The Mini-Module by itself requires almost 200 mA when running and almost 125 mA when the CPU is in stand-by mode. However the whole monitor consumes much more than this due to the need to power the signal conditioning units and when connected the RS-485 to RS-232 converter. When operating with the powering down of the processor in between samples enabled, the monitor consumes a total of about 225 mA. When the processor is not powered down, this rises to about 295 mA. When the converter is attached to the monitor for communication with the PC, an extra 105 mA is required, with the processor not being powered down in between samples.

As the monitoring sessions comprised of calibrating the transducers for each individual patient, walking the route with the patient, and finally down-loading the data to the PC, one can assume that the serial converter was attached to the monitor for about half the time. This gives an average current consumption of about 315 mA, assuming that the processor was powered-down in between samples when monitoring. This gives a discharge ratio of about C/8 with four batteries, with Figure 2.2 showing an estimated 6-7 hours of battery life. As another requirement was to have an ambulatory monitor which could function for a day without re-charging, it was therefore decided to include a second set of four batteries to be connected in parallel with the first set. The rating for the new power supply was therefore 5.2 Ah, which gave a discharge ratio of about C/16 resulting in an estimated battery life of 12-14 hours. This was deemed sufficient for the application's purposes, but for possible future purposes the option of further increasing battery life by the addition of external battery packs remains.

2.1.2.4. The Ambulatory Monitor's Box

The box's dimensions are 13 cm by 13 cm wide, and 7.5 cm deep. As can be seen in Figure 2.3, one side holds the switches and LEDs, another the connector for attachment to the signal conditioning units, and the third side houses the connector for attachment to the RS-485 to RS-232 converter. The Mini-Module is clearly displayed in the housing, whilst the eight batteries comprising the power supply can be seen in the lid.

Figure 2.4 shows the ambulatory monitor being worn by a patient. The patient is not unduly encumbranced when walking due to its small size and weight.

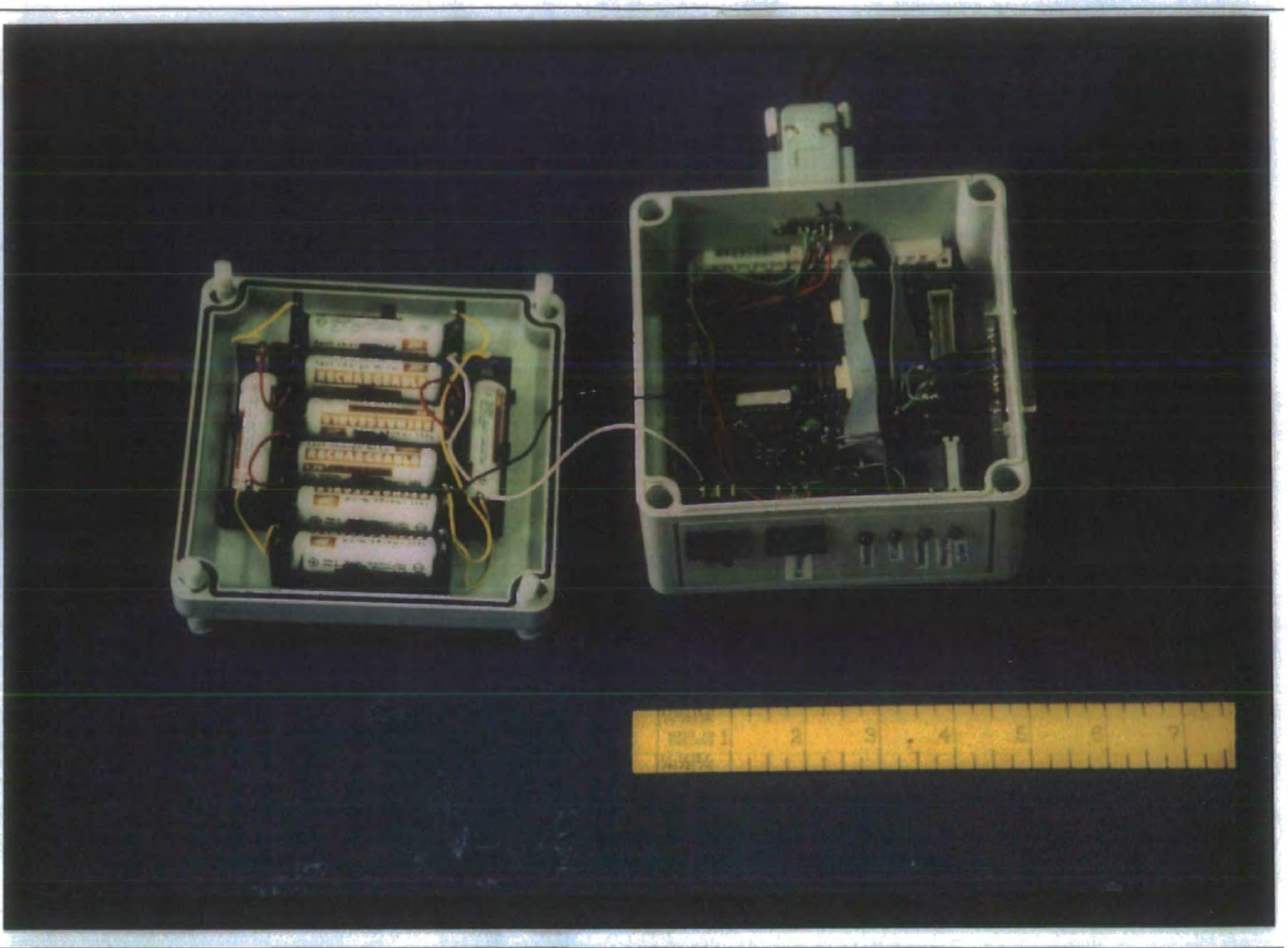


Figure 2.3 - A photograph of the ambulatory monitor with the casing opened, revealing the internal hardware

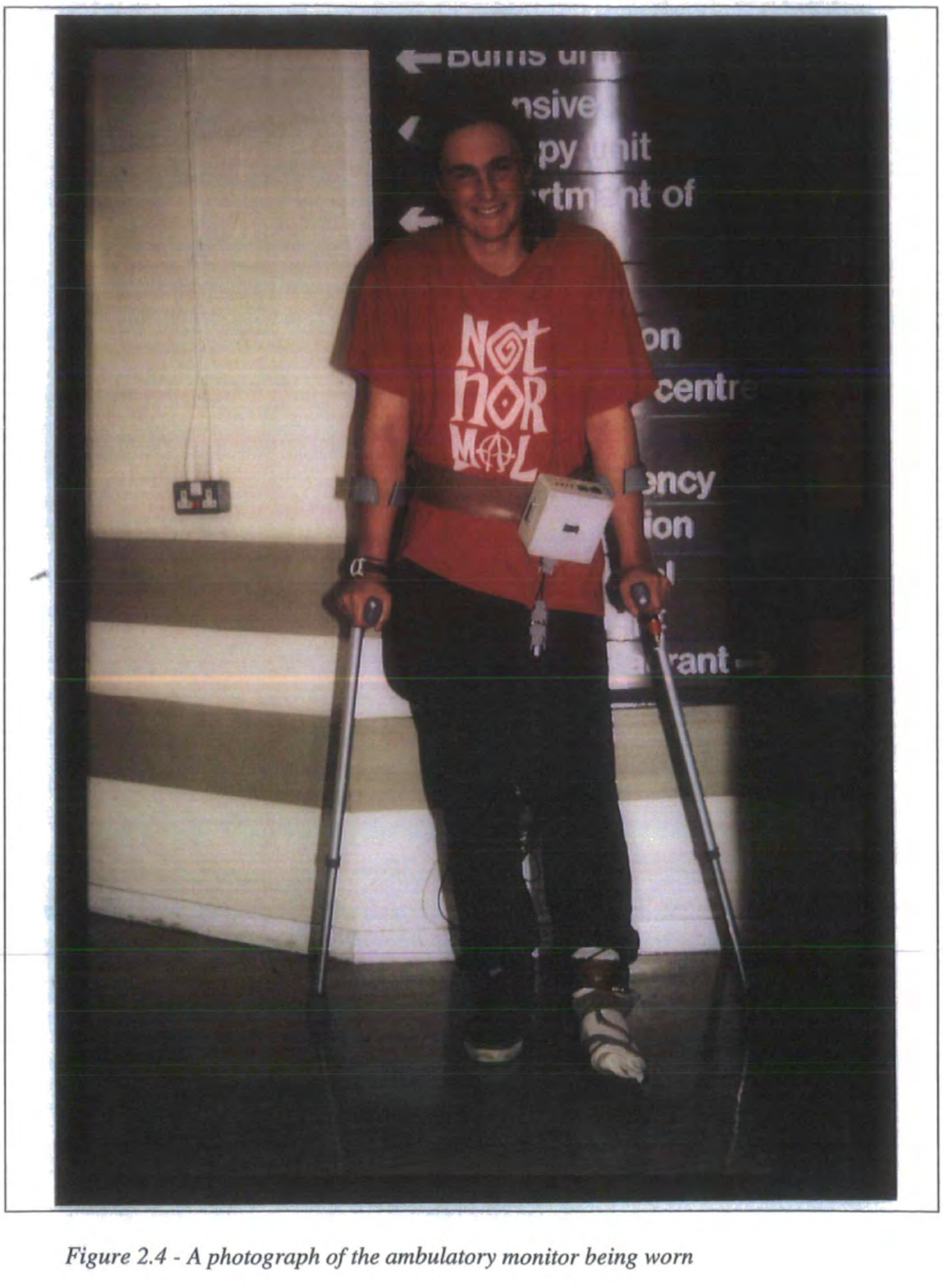


Figure 2.4 - A photograph of the ambulatory monitor being worn

2.1.3. Hardware Interfacing between the Ambulatory Monitor and the PC

The requirement of PC interfacing was necessary primarily to enable the data collected by the monitor to be down-loaded onto the PC for storage and analysis. The easiest means for this was to use the serial connection which is available to both the PC and the Mini-Module. However a conversion was needed for the Mini-Module's serial interface conforms to the RS-485 standard whilst PCs' conforms to the RS-232 standard. The converter's circuit is shown in Figure 2.5.

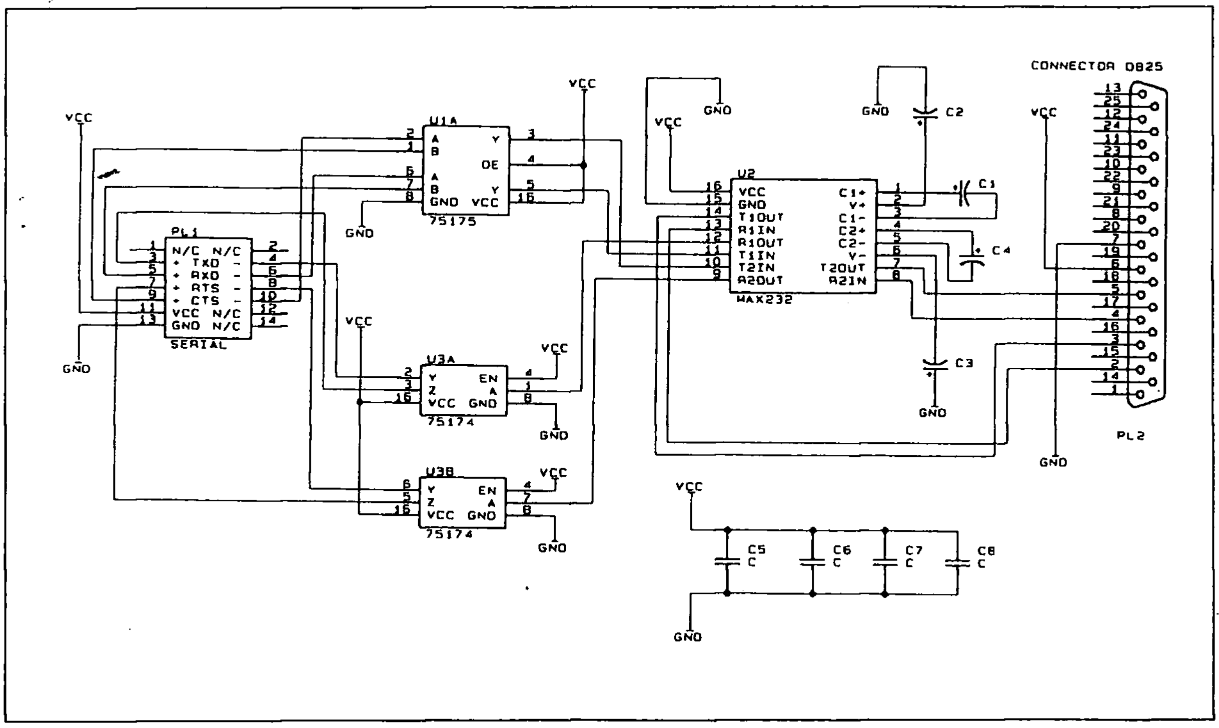


Figure 2.5 - The RS-485 to RS-232 converter circuit

The circuit was housed in a box 8.5 cm by 5.5 cm wide, and 4 cm deep. A photograph of the monitor connected to the PC via the converter is shown in Figure 2.6.

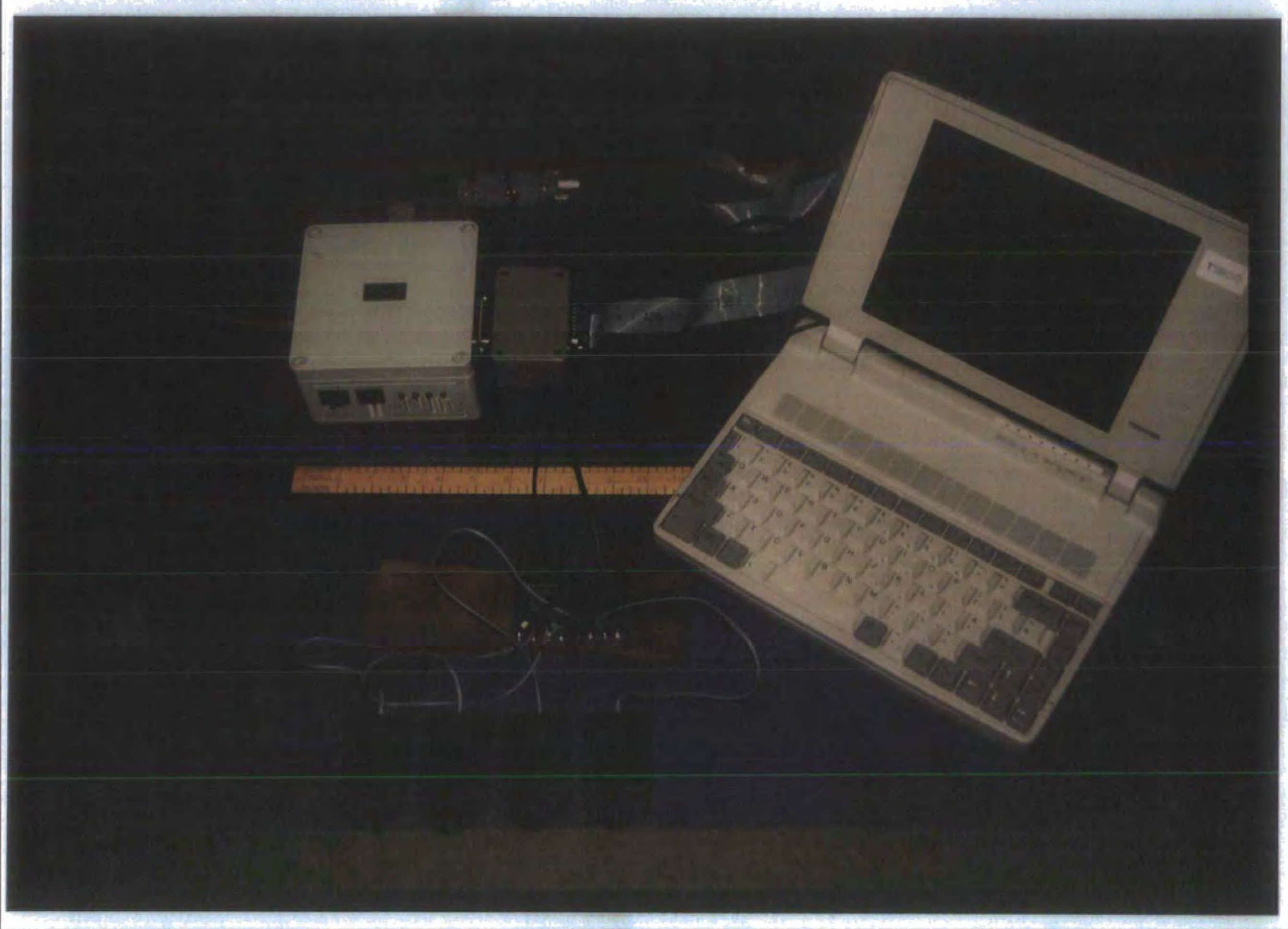


Figure 2.6 - A photograph of the whole monitoring system, with the ambulatory monitor connected to the PC.

The converter circuit is fast enough to allow the standard RS-232 serial communication speed of 9600 baud, which is equivalent in this case to 9600 bits per second or 1200 bytes per second of data being transmitted.

2.2. Software of the Ambulatory Monitor

As explained in the previous section, the programming language chosen for the monitor program implementation was C. This gave the necessary low-level functionality required for every part of the implementation except for the powering down of the processor to decrease the battery consumption, this being performed using a mixture of C and assembler.

The Mini-Module has a C compiler available for which the necessary interfacing of libraries has already been performed by P.S.I. Systems, which was used as the development package.

The development system consisted of a host PC and program development hardware for the Mini-Module. The host executed the text editor, the compiler, it having its own file storage capabilities for storing the C, assembler, and machine code files. By so doing, the Mini-Module does not require the large amounts of RAM needed to execute the compiler and store the files. Standard compilers generate machine code for the same processor type as that which executes the compiler. As the processors in PCs, being of the Intel '86 family, differ greatly from the Motorola 68000, a cross-compiler was used which executes on one processor type, generating machine code for another. During program development, the generated machine code program was tested by down-loading it from the host to the Mini-Module and then executing it. When connected to the host the Mini-Module could use the keyboard and screen directly by the host executing a terminal emulating program so causing it to function as a terminal to the Mini-Module. This aided testing by being able to view program states and variables on the screen.

The hardware attachment to the Mini-Module also aided program testing as it interfaced both the Mini-Module's inputs and outputs to easily controllable and viewable components. For example the ADCs are connected to potentiometers, the digital lines to switches and LEDs thus giving the capability of viewing and setting each one's state, and the DAC to an easily attachable point for a voltmeter or oscilloscope. It also includes two RS-232 serial ports, facilitating interfacing to the single or multiple hosts, however this latter option was not used during the application development. The use of twin hosts is sometimes beneficial as each host can run separate programs on the same Mini-Module, each being executed simultaneously by the multi-tasking Minos operating system.

A faster programming cycle was obtained by using a multi-tasking operating system on the host PC. This occurs because the text editor, compiler, and terminal emulating program can be simultaneously in the host's memory thus avoiding the time taken to continually load each program separately in turn during each compile and link cycle. Also whilst the compiler is compiling and linking, this being the greatest part of the cycle, other tasks can also be performed such as program editing or testing on the Mini-Module through the terminal emulating program.

2.2.1. General Program Overview

The following section highlights the main program workings by describing the general program flow during its execution. The explanation of the C language 'main()' function of the program is deemed sufficient for this.

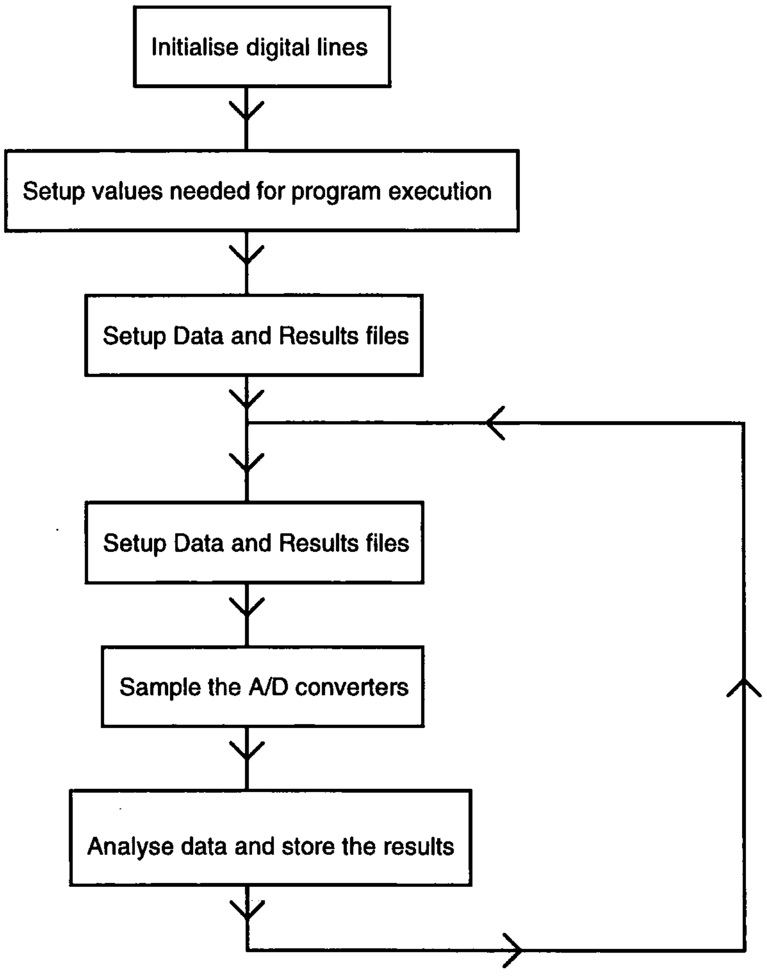

Initialise digital lines
Setup values needed for program execution
Setup Data and Results files
Setup Data and Results files
Sample the A/D converters
Analyse data and store the results

Figure 2.7 - A flowchart outlining the monitor program's general flow during execution

When program execution first commences, a number of initialisation stages are necessary before the monitoring of the ADCs can occur. First the digital lines are initialised. As each line can be set to function logically as an input or as an output line, the former or latter must be specified before usage. Four LEDs were used, and so the digital line that each was connected to was specified to be an output line by using the 'outch(line no.)' library routine. As the use of a switch for function selection was also required, another digital line was set to be an input line by using the 'inch(line no.)' routine. When the switch was depressed, the digital line became connected to ground so that its state changed from high to low voltage since the normal state for a digital line is to float high. By monitoring the value of this digital line the program could therefore determine whether the switch was being depressed.

The data required and generated by the program is stored in RAM in the format of files. The required data is stored in the 'Events' file, holding values such as the threshold value for an event to occur. The file is not deleted when the external battery supply is disconnected because it is designated as battery backed to the operating system. The program next checks for the existence of an Events file, and if not a new one is created with default values which can be subsequently modified by the operator.

The Data file stores the ADCs' sampled values. Any Data file present is next cleared from the RAM and a new one created. The Results file stores the results of the analysed data, with each result recorded corresponding to one weight-bearing event and including various information, for example the time of its occurrence. If no Results file already exists, for one could still be present from a previous session, it is created.

After the various initialisation stages, the program enters an infinite loop composing of various sections. The first periodically samples the ADCs, storing the data in the Data file. When the capacity of this file is filled, the program enters the next section where it is analysed, with any weight-bearing events being stored in the Results file. Finally the Data file is cleared and the ADCs are again sampled.

This execution loop can be halted to allow the operator to download the results onto a PC, or do a number of other functions. By connecting the Mini-Module to the PC via the serial link, and depressing the switch connected to the digital line, the Mini-Module can use the PC as a terminal if the PC executes the terminal emulating program. Since the majority of the loop execution time is spent in the ADCs' sampling stage, it is in this section that the switch is monitored. If the switch is depressed whilst loop execution is in either of the other stages, then there will be a delay of the execution of these stages being finished before the digital line is read. However, due to the this time period being in the order of milli-seconds, the delay will not be noticeable to the operator.

The following sections explain in greater detail the program's functionality. Each section deals with the stages of the general program flow diagram given in Figure 2.6. Section 2.2.2 elucidates further on the RAM files used for data storage and their creation. Section 2.2.3 details the ADCs' sampling stage, with the final section explaining the analysis of the Data file and the calculation of the results. For each of these sections, line numbers refer to Appendix 3.

2.2.2. Data Storage during Program Execution

As mentioned previously, the various types of data are stored in RAM as files. Space in RAM could have been directly allocated by the program by using the C function 'malloc', with the different types of data being stored in separate sections of memory. However, with this latter method of storage the data cannot be retained when the battery supply is disconnected as the contents of the RAM are cleared. This is not the case when using the files for data storage, for by using the 'datamod' library routine to specify a file, the Minos OS can ensure that its contents remain intact after the power supply has been disconnected. This is achieved by using the lithium battery back-up which is mounted onto the PCB and connected to the RAM. The data in RAM which is not found in a pre-assigned backed-up file is still contained in RAM but is subsequently overwritten, for the Minos OS only keeps files which have been set to be backed-up with the 'backup' library routine.

2.2.2.1. The Events File

The Events file is never erased and is always present in RAM since it contains the values required to control the monitor program operation. These are as follows; the threshold value above which an event occurs, the power down flag to indicate whether to power down the processor in between each ADCs' sample, the display flag indicating whether to display the ADCs' values on the screen, whether one or both legs are being simultaneously monitored, and the four scaling values used for each of the four pressure transducers' outputs. The monitor and PC software were under continuous development throughout the study, with the next addition to its functionality being the simultaneous monitoring of both legs. Unfortunately there was insufficient time to complete this, but what was written is included in the program to aid future development. An example of this redundancy is shown by the value in the Events file which will currently always be set to 1.

The 'open_event_file()' function of the monitor program performs the Events file creation (lines 1935 to 1947). A check is performed for whether an Events file already exists, and if not a new one is created. The size for this file is indicated at the start of the program by the label EVENT_SIZE, with DATA_SIZE and RESULTS_SIZE being used for the Data and Results files respectively. This increases the readability of the code and eases its modification, this being more important for the Data and Results files as the sizes for these are used extensively throughout the program, whilst EVENT_SIZE is only used once at file creation.

2.2.2.2. The Data File

The previous Data file is erased and a new one created after each main loop in the program, because once its contents are analysed they are no longer required. Rather than actually deleting the file and creating a new one in its place, the pointer to the file could have been set to the start of the file once again; with the next set of data from the sampled ADCs simply overwriting it. The reason for not adopting this functionally simpler approach is historical. During the initial monitor program development, it was useful to check the contents stored in the Data file. Therefore an option, which has now been removed, was to view and download the actual contents of the Data file when the Mini-Module was connected to the PC. If the contents of the Data file were to be viewed, then one would not be able to differentiate where the current data ended, and the previous loop's data began; therefore the former approach was adopted. The actual C program is not made more complex by using this former method, for to erase the file takes two lines of code (for example lines 1783 and 1784); whilst as has been seen before, its creation takes one line. As this is not a speed sensitive application, in the sense of requiring the greatest speed possible in program execution, the time overhead to delete and create a new file, rather than simply resetting its pointer to the start of the file, is not of significance.

To be able to specify the size of the file at its creation, an assessment of the amount of RAM that would be available was made. RAM is not only used as file storage space by the Minos OS, but also for the storage of the program's variables and pointers, and also the OS's own data whose amount varies during any program's execution. Just taking the OS's RAM use into account means that the overall amount which is usable by programs and data storage decreases from the 128 KBytes which is mounted on the PCB to about 100 KBytes. As the information stored in the Data file is transitory, for after each main program loop the contents are erased, its importance is far less than the contents of the Results file which are stored until downloaded to the PC. Therefore the size of the Data file was made much smaller (1 KByte) than that of the Results file

(90 KBytes). Not knowing exactly how much RAM was required by the Minos OS in file creation and maintenance or by the program's variables and pointer storage, resulted with not all the 100 KBytes being allocated for information storage in files. Where two legs to be simultaneously monitored, the file sizes would be halved to obtain 506 Bytes for each Data file and 45 KBytes for each Results file.

As will be explained in Section 2.2.3, the monitor program requires the time to be stamped at the start of the data file for the calculation of the inter-sample time. The time stamp contains the year, month, day of the month, hour, minute and second, and so is contained in six bytes. The remainder of the file stores the sum of the ADCs' values, giving a result of between 0 and 255 which can be stored in one byte. The maximum value of 255 corresponds to 255 kg of mass or 2448 Newtons sensed by the pressure transducers, and so is more than adequate for every eventuality.

2.2.2.3. The Results File

As explained previously, this file is 90 Kbytes in capacity, and it stores information about each event calculated during the analysis stage.

Before any event information is stored, the Results file is date stamped as this figure will be the same for all the events recorded. This occurs in lines 281 to 320, and as can be seen, the year, month and day of the month is recorded at the beginning of the file. This information takes up three bytes of storage, but by using a compression routine that will be detailed in Section 2.2.4, these three bytes of storage are compressed into two (lines 290 to 296). The next two bytes are set to 255 which indicates to the program the end of the stored results data. When events occur in the data file being analysed, these bytes are overwritten by the event information and the two bytes after that are set to 255. Therefore this end of file (EOF) indication, or more accurately the end of event information stored, as the Results file is a fixed length, traverses through the Results file as event information is recorded. This is so that the monitor displays or downloads only event information and not the whole Results file therefore saving transmission time. Also if there were no EOF indication every byte in the Results file would have to be set to zero at creation as any other value would be taken as event information.

The data stored for each event is as follows; the time of its occurrence, its peak value, its duration and the time between samples. The time stamp of its occurrence is the hours, minutes and seconds of the start of the event. The duration is the number of samples comprising the event, which is given two bytes of storage, and with the inter-sample time indicates the actual event duration in time. A future enhancement would be to store the calculated duration in time, as this would reduce the amount of storage required for each event. However currently the information stored for each event comprises seven bytes. These seven bytes of information are compressed into five bytes and then stored in the Results file, as will be explained in Section 2.2.4. Therefore the number of events which can be stored in the Results file is 18,431 this being obtained from the following calculation, there being three bytes required for the date stamp:

$$\frac{(90 \times 1024) - 3}{5}$$

Attempting to calculate the amount of time that the ambulatory monitor could function before all the memory was filled can only give an estimate as the exercise patterns adopted by subjects will vary. Assuming a worst-case scenario of the patient walking continuously with crutches at two steps per second (so resulting in one step per second being taken by the monitored leg) an event will be recorded and stored for every second of monitoring.

Therefore the Results file will be filled in 5 hours 7 minutes, this being calculated by:

$$\frac{18{,}431}{60 \times 60}$$

This almost gives a working day of monitoring before the results need to be downloaded onto a PC so that the Results file can be cleared and monitoring can continue. This is a worst case however, and it is highly improbable that a patient with crutches would walk continuously for five hours without taking rests. A more realistic calculation might be to think of a patient trying to exercise as much as possible during the day, whilst taking frequent rests. Assuming that the patient exercises by walking for ten minutes, resting for another quarter of an hour and resting for more time when eating a meal, means that there is enough memory for monitoring of a 24 hour period, as:

per hour exercising:	24 minutes
3 meals rest:	3 hours
In a 14 hour day:	$(14-3)\times 0.4 = 4.4$ hours

Therefore the limiting factor for length of unsupervised monitoring is the battery supply rather than the storage space in RAM.

2.2.3. The Sampling of the ADCs Stage

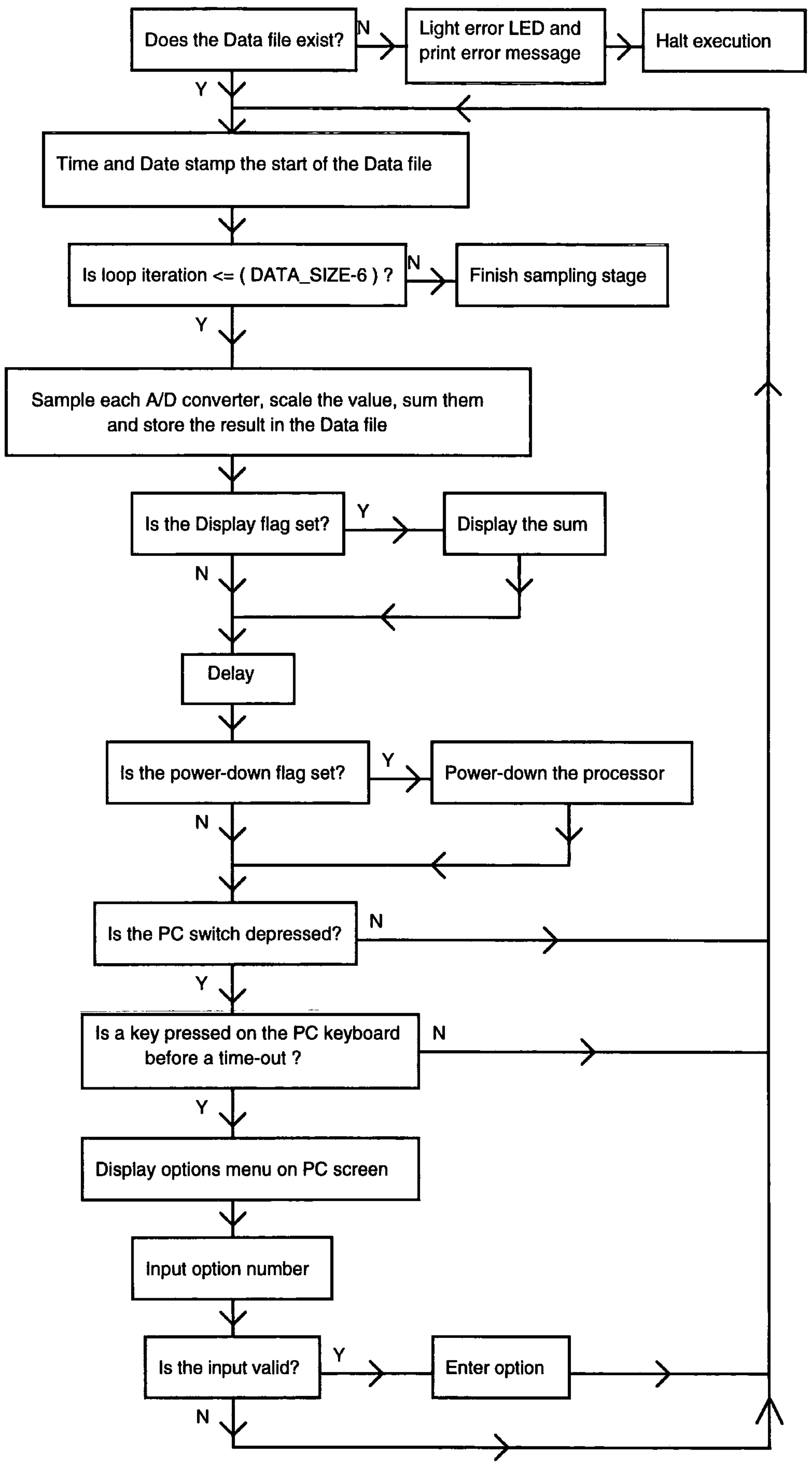
To aid the explanation of this section of the main program loop, a flowchart is given in Figure 2.8.

The first part of the sampling stage of the program checks to make sure that the required Data file exists in RAM. This should always be true, because due to the sequential nature of the program execution a new one will already have been created. If this is not the case, then due to a transitory fault a program error has occurred. Therefore all the LEDs are extinguished and the 'error' LED lit; an error message is sent to the serial interface, and the program's execution halted. Normally the ambulatory monitor would not be connected to the PC, so the error message would not be seen by the operator. However the LED would inform the operator that a fault had occurred, and the monitor could then be connected to the PC to view the error message and so give information on the reason why the program has halted.

The time and date is then stamped at the start of the Data file so that the time of occurrence for any sample in the file can be calculated, by time stamping the end of the file and dividing the difference by the number of samples.

Program execution then enters its sampling loop, through which it iterates for the number of bytes available for data storage in the Data file. This is equal to the DATA_SIZE label at the beginning of the program, minus the bytes used for the date and time stamps.

Figure 2.8 (overleaf) - A flowchart outlining the sampling of the ADCs stage


Does the Data file exist?
N
Light error LED and print error message
Halt execution
Y
Time and Date stamp the start of the Data file
Is loop iteration <= (DATA_SIZE-6) ?
N
Finish sampling stage
Y
Sample each A/D converter, scale the value, sum them and store the result in the Data file
Is the Display flag set?
Y
Display the sum
N
Delay
Is the power-down flag set?
Y
Power-down the processor
N
Is the PC switch depressed?
N
Y
Is a key pressed on the PC keyboard before a time-out ?
N
Y
Display options menu on PC screen
Input option number
Is the input valid?
Y
Enter option
N

The ADCs are then sampled, scaled by their respective scaling values in the Event file, and stored in an 'unsigned char' variable which is one byte in length. As the scaling values are integers of one byte wide, rather than floats which use a greater number of bytes for storage, each one is divided by a hundred and then multiplied with the sampled value. Therefore a scaling range of between 0 and 2.55 is available, in increments of 0.01. When the summed value was first viewed on the PC screen, it was found that even though no pressure was being applied to any transducer, a reading ranging from zero and twenty Newtons was displayed. This was due to the signal conditioning units giving a minimum voltage reading of between 0 and 0.02 Volts. So to make the final reading more accurate, each transducer's baseline reading was viewed and according to the amount of variation an equal amount was taken away from it. Lines 856 to 860 show this for the second ADC, the first's reading always being at zero Newtons and therefore requiring no modification. This ADC's reading corresponded for the majority of the viewed samples to twenty Newtons, so two decrements occur from its reading, each occurring only if its value is greater than zero otherwise the value would be stored as 255 because it is an 'unsigned char' variable. In the extremely unlikely event of the sum of the ADCs being found to be greater than 255, the sum is modified to 255 so that it can be stored as a byte in the Data file. Once written to the Data file, the file pointer is incremented so that it points to the next location of memory for storing the next value (line 912).

If the display flag in the Event file is set to one, then the sum is printed on the screen of the PC through the serial link. A delay of 0.01 seconds is needed immediately after printing so that the Mini-Module has time to send all the information along the serial line before the subsequent iteration round the loop when the next sampled sum is displayed. This delay occurs by using the 'delay(no_of_tens_of_milliseconds)' library routine in line 906. The effects of not having this delay is that after a number of successive iterations round the loop, the serial buffer will be filled. If further information is required to be transmitted, then the whole system hangs with the display, keyboard and file storage system of the PC also hanging.

Another delay of 0.01 seconds is programmed to occur which slows down the sampling rate from the kilo Hertz range, to tens of Hertz. If there were no delay the Data file would be filled every second and if a step was being taken which lasted two seconds, then two events would be recorded to have taken place as the Data file will have been filled twice. The slight decrease in accuracy of the peak value and the duration of the event by slowing the sampling rate is of negligible importance because the potential error introduced is of a much smaller order of magnitude being hundredths of seconds in comparison with the minimum of half a second that the foot is in contact with the ground when a patient using crutches takes a step.

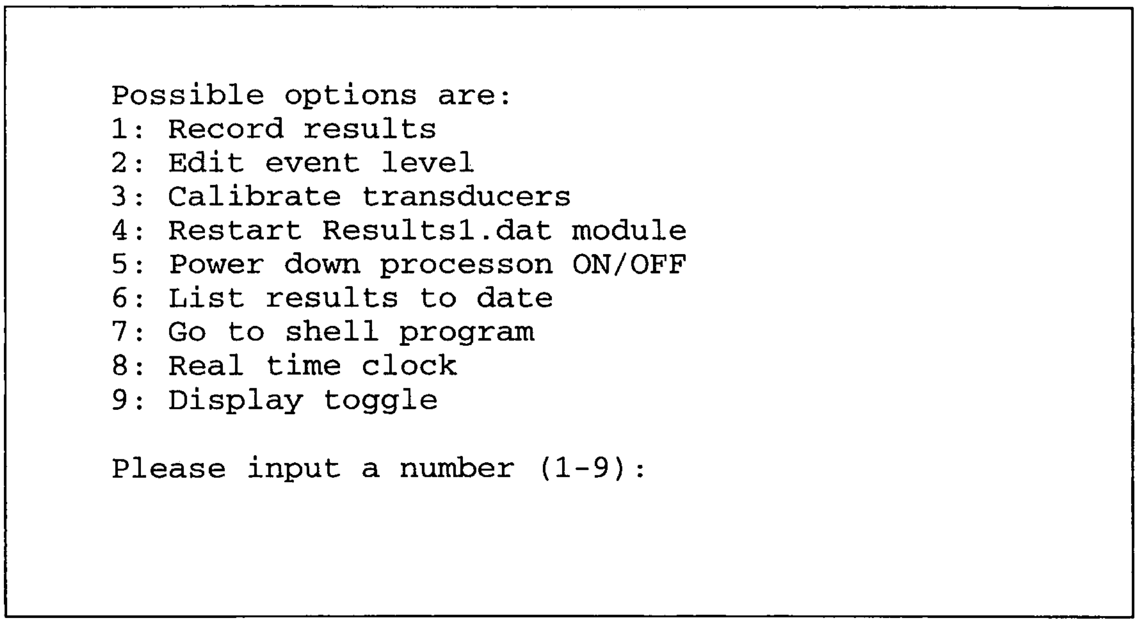
After this delay has passed, a further delay occurs if the power down flag in the Event file is set to 'ON' (defined as 1 in line 22). This instructs the program to power down the processor to stand-by mode for 0.1 of a second, the processor then consuming less power for that period. When in stand-by mode, certain parts of the processor do not function, and other parts function at the slower clock speed. Hence all interrupts must be disabled before setting the processor to stand-by mode, and only a limited number of its functions are available in this mode which are sufficient to perform checks for when the condition to power the processor back up occurs. Since the monitor program is written in C, no interrupts are used during its execution as these are only generally accessible using assembler routines. However the monitor program runs under the Minos OS which does use interrupts, for example to enable it to run various programs simultaneously using multi-tasking, and so the registers' contents had to be saved before the processor could be powered-down. To perform both these functions, C could not be used as it does not have the mechanism to access registers or peripherals directly. A routine was therefore written in assembler by P.S.I. Systems, using C to perform some initialisation tasks for it, such as the length of time required for the processor to be powered down. Lines 2024 to 2086 give the C initialisation functions for the function, which write the length of time which the processor is to be powered-down in the registers of the real-time clock (line 2031 in the 'writereg' function). The assembler listing was not available, and so is not listed in the appendices. However its functionality is as follows; the interrupt and register values are saved on the stack, and then the processor is powered-down. It waits for the required length of time, sets the processor to be driven by the faster oscillator, waits until this oscillator has become stable, and frees the processor so that it can continue operating.

Having performed all the stages of the ADCs' sampling, the program execution enters the second half of the pressure input stage loop which deals with the PC communication. This is effected by using the switch connected to the digital input line, which when depressed causes the line's value to drop from the 5 Volts to 0 Volts, as the other side of the switch is connected to ground. Even if the switch is depressed during the ADCs' sampling, the operator does not have enough time to release the switch before its state is read on entry to the second half of the loop. If the switch is being depressed, the digital line's value will have dropped from 1 to 0. The test occurs at line 932, with the switch being connected up to the digital line number 8, having an alias of 'SWITCH_PC_LINK'.

However, this switch might be accidentally depressed whilst monitoring and so would not be connected up to the PC. A check is required to ensure the ambulatory monitor is in fact connected to the PC and the switch was depressed intentionally by the operator, otherwise monitoring would cease whilst the program continually attempted to access the PC's screen to display its menu of options. This verification is performed by the 'link_test()' function of lines 1741 to 1758. The function executes a loop 500 times, each time monitoring the 'stdin' file to see if a key on the PC's keyboard is pressed by using the 'ready' library routine, and waiting for 0.01 seconds, thus taking a little over 5 seconds to execute. If a key on the PC is not depressed within that time limit, the program goes back to the ADCs' monitoring by commencing another pressure input stage loop.

If a key is depressed then its value is not lost from the 'stdin' file. However as the menu is not yet displayed on the screen, the operator might not remember the various options available, and each one's key for selection. Therefore the key depression is used simply to confirm to the monitor that it is in fact connected up to the PC, and its value is then discarded by using the 'scanf("%c", &input)' command (line 946) to clear the 'stdin' file buffer. Next the menu options are printed on the PC screen (lines 951 to 961) and another 'scanf' reads the operator's input. According to the input, the program execution enters the option's code. If the input doesn't correspond to any of the available options, the program continues sampling by commencing another pressure input stage loop.

The menu information is shown in Figure 2.9.



```
Possible options are:
1: Record results
2: Edit event level
3: Calibrate transducers
4: Restart Results1.dat module
5: Power down processon ON/OFF
6: List results to date
7: Go to shell program
8: Real time clock
9: Display toggle

Please input a number (1-9):
```

Figure 2.9 - The menu of options for the ambulatory monitor

The various options are clearly shown in this Figure. If option one is selected, the results currently stored are downloaded onto the PC. For this to occur, a file name must be chosen that it will be saved under, and which does not already exist in the current directory as otherwise the old file will be replaced by this one, its contents being lost. The choosing of a file name is performed by the 'get_outfile_name' function in lines 1688 to 1732. This specifies a file name which shows it to be a results file from the ambulatory monitor and which contains in the file name the date of the monitoring session. As the date when downloading the results might be different to that of when the monitoring session occurred, for example if the results were downloaded onto a PC the following day, the date of the Results file is incorporated into the file name. As a PC filename can have eight characters before the '.', and three characters after, the name format chosen is as follows. The first three characters are 'DAT', indicating to the PC analysis program that the file contains data downloaded from the ambulatory monitor. The next two characters are the day of the month, the next two the month of the year, and the eighth is the unit of the year; for example the year being 1994, the eighth character would be 4. This leaves the last three characters after the '.' unused. It was initially envisaged that there would be up to five different monitors simultaneously monitoring different patients. Therefore the last three characters of the filename were originally set to be from '001' to '005' according to the ambulatory monitor which was used for the patient. However it was subsequently decided to use just one monitor as the number of patients which were first envisaged did not materialise, and so the need for simultaneous monitoring sessions was not required. This left the last three characters of the file name redundant. Another use for them was found in that they could indicate a certain patient so that their record could easily be found by the data and analysis files having the last three characters of the file name set to the same number, for example '001' or '012' for the first or twelfth patient ever recorded. However as this patient information is not stored by the monitor, the last three characters are simply set to '000' and then modified by the PC analysis program during the analysis of the monitor results data. So for the monitoring session of date 19/04/94, the filename under which the results would be downloaded onto the PC would be 'DAT19044.000'.

If option two is selected, then the event threshold level can be changed (lines 1063 to 1091). Using a pointer to the RAM location storing the threshold level, this being the location in the Event file , this location can be directly set to the newly inputted value. To guard against operator input error, if the inputted value is less than 0 or greater than 65 kilograms then it is rejected and the operator is requested to key in another value.

The transducers can be calibrated by selecting the third option (lines 1099 to 1360). Calibration is required because each transducer has a fixed area, whilst the different parts of the foot under which each is attached have different areas through which the weight is transmitted, this being compounded by different feet sizes. Therefore the parts of greater area require a larger scaling value to ascertain the total weight transmitted across the area; whilst parts of smaller area require a smaller scaling value. These reasons are examined in greater detail in Chapter 3. Each scaling value is stored as an integer of one byte in the Event file and before scaling the sampled input, the value is divided by one hundred. Therefore the scaling range is from between '0' and '2.55'. The user can select which transducer's scaling value to change, and before doing so, the monitor displays fifty samples of just that transducer's output on the screen so that the operator can make a better judgement of what the scaling value should be. In between samples, the processor was powered-down as it was envisaged that this would normally occur during a monitoring session.

When selected, the fourth option shown in Figure 2.9 erases the contents of the Results file or files (lines 1372 to 1382). This option was implemented for cases when the commencement of a monitoring session is required, but the ambulatory monitor already holds some unwanted test results in memory. By selecting this option these results can be erased and the current date stamped at the start of the file in readiness for the monitoring session.

By selecting the fifth option, the operator can set the power down flag in the Event file (lines 1390 to 1408). By selecting the option so that it is set to 'ON' (defined as 1 in line 22) the processor is powered down in between samples, thus saving battery power.

The sixth option displays on the PC screen the results currently stored (lines 1417 to 1445). First the LED indicating that the monitor is transmitting information to the PC is lit. Next two temporary file pointers are set to the start of the Results file. The end of the stored data is indicated by having two consecutive bytes set to 255, so one of the temporary file pointers is incremented one byte and the two are then incremented simultaneously, the monitor displaying the value of each byte being pointed to. When both read 255, the end of the stored results has been reached and the monitor stops the incrementation and display of the temporary file pointers.

The seventh option (lines 1456 to 1458) synchronously enters the 'shell()' program which is distributed by P.S.I. Systems with the Mini-Module. This function (lines 2118 to 2504) is a simple command line interface to the Minos OS and was included for debugging purposes to verify the size of the RAM files that had been created.

Option eight deals with the time setting of the real-time clock (lines 1466 to 1584). The stored date and time is initially displayed on the screen, and the user can then request to change them if either is incorrect. For each value inputted by the operator, a check is made to validate it, for example in line 1483 a check is made to ensure that the hour value inputted is between zero and twenty-four. To access the time stored in the real-time clock, the 'getime(struct tm *time)' (line 1467) library routine is used. To store the date and time inputted by the operator, the 'setime(struct tm *time)' library routine is used (line 1579).

Finally, by selecting option nine, the operator can access the display flag in the Events file. Its setting is initially displayed, and the operator is given the option of changing it. If the display flag is set to ON, then the sampled total value for each leg during monitoring is displayed on the screen. This option is useful for the general verification that the transducer scaling values are correct, so that during initial monitoring the operator can confirm that the data values are feasible.

2.2.4. The Calculation of the Results Stage

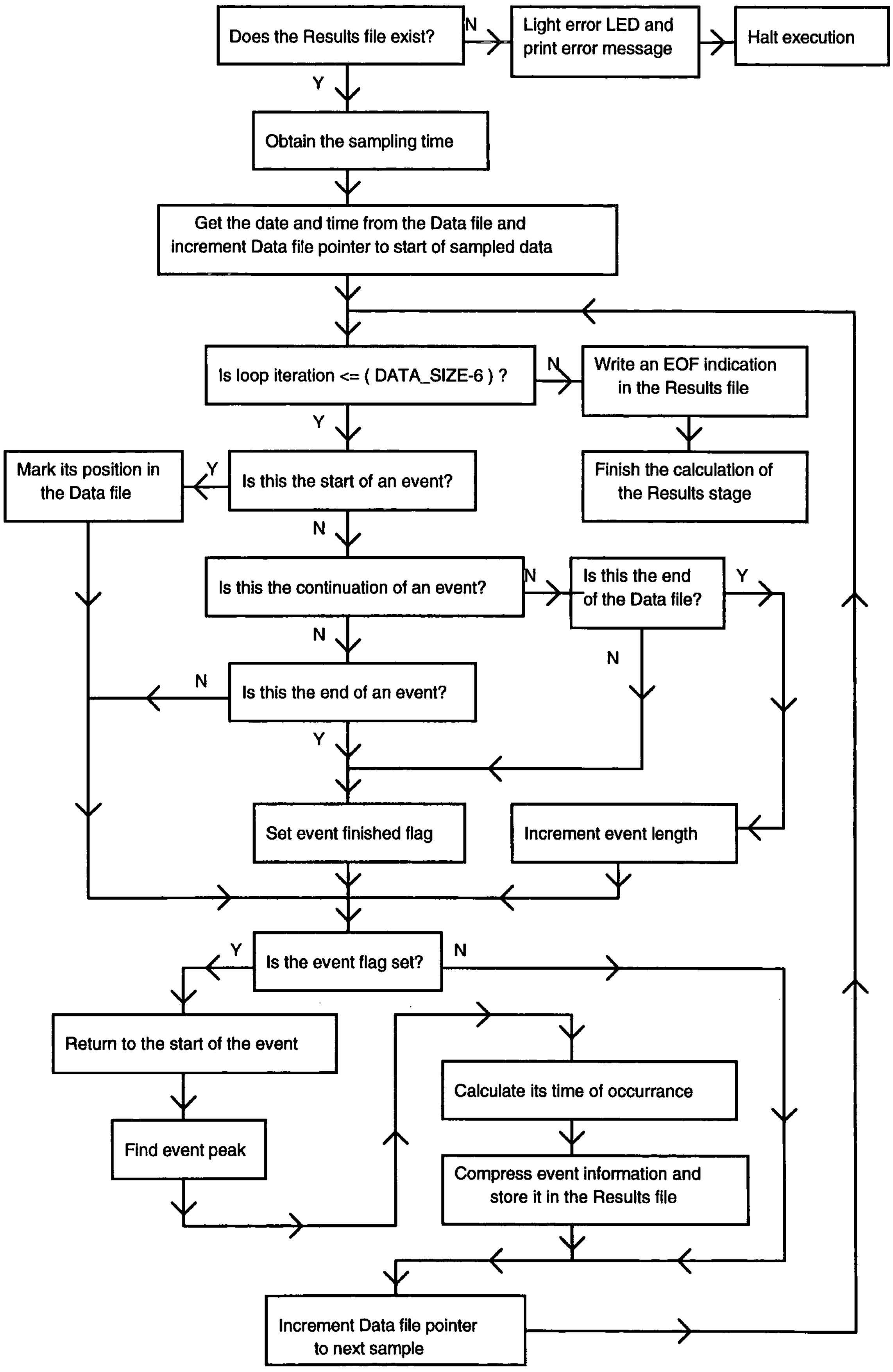
The flowchart shown in Figure 2.10 highlights the general program execution flow during this stage.

The calculation of the results is performed by the 'calc_results()' function (lines 475 to 660). Initially a test is performed to verify that the Results file exists, and if not then a transient fault or program error has occurred. All the LEDs are therefore extinguished apart from the error LED, and program execution enters into an endless loop, effectively halting operation (lines 646 to 657).

If the Results file is present, as should always be the case, the program next obtains the inter-sample time, this being calculated by the 'time_increment()' function (lines 665 to 724). The start and the end of the Data file was time stamped, and as its size and therefore the number of samples is known, the sampling rate can be calculated. The inter-sample time varies according to whether the processor is powered-down in between samples, assuming that the monitor is not displaying the data on the PC screen for this incurs extra delays. Currently the inter-sample time is stored for each event in the Results file, and downloaded for the analysis program on the PC for the calculation of its duration in time. Possible future development will results with the time duration for each event being stored, so saving RAM space.

The program therefore obtains the date and time at the start of the Data file and then enters into the main loop where the Data file will be analysed to obtain the event information.

Figure 2.10 (overleaf) - A flowchart outlining the calculation of the results stage


Does the Results file exist?
N
Y
Light error LED and print error message
Halt execution
Obtain the sampling time
Get the date and time from the Data file and increment Data file pointer to start of sampled data
Is loop iteration <= (DATA_SIZE-6) ?
N
Y
Write an EOF indication in the Results file
Finish the calculation of the Results stage
Mark its position in the Data file
Y
Is this the start of an event?
N
Is this the continuation of an event?
N
Is this the end of the Data file?
Y
N
N
Is this the end of an event?
N
Y
Set event finished flag
Increment event length
Y
Is the event flag set?
N
Return to the start of the event
Find event peak
Calculate its time of occurrance
Compress event information and store it in the Results file
Increment Data file pointer to next sample

The following checks (lines 521 to 547) record the start of an event, and calculates the number of samples which constitutes it. As mentioned before, its time occurrence and duration can then be calculated.

If the final check shown in Figure 2.10 is true, then the Data file pointer is taken back to the start of the event and the samples constituting the event are again examined to calculate the peak value of the event (lines 553 to 563). The time of its occurrence is then calculated with the date and time being first set to that at the start of the Data file. Even though the Data file is not large in size, the time of the event's occurrence might be in the next minute, and the next hour, and the next day, and the next year. Therefore when the seconds value is incremented by the samples into the Data file multiplied by the sampling time, thus obtaining the time of the event, a check is performed for whether it is now greater than 59. If this is so, the minute value is incremented, and the seconds value decreased by 60 until the seconds value is less than 60 (lines 575 to 578). As the minute value might be now greater than 59 the same is performed with relation to hours, next for the hour in relation to the day, the day in relation to the year, and then for the year itself. Finally the event information calculated is stored in the Results file.

The seven bytes of information (hour, minute, second of the event, its peak, its duration in number of samples which takes up two bytes, and the inter-sample time) are compressed and stored as five bytes of data. The compression methods used are bit shifting, and decreasing the accuracy of the data.

The first method is concerned with utilising all eight bits which comprise a byte of information. All computers store information as numbers in a binary format. A single byte can therefore store a number of between 0 and 255. However some of the values that are required to be stored have maximums less than this. For example the hour can be between 0 and 23 which in binary is represented as 10111 leaving the top three bits of the byte unused. By shifting the number up by three bits, the lower three can now be used for the start of the next number to be stored, and so on.

To elucidate further, the following example is given. Supposing that an event occurs at the 23rd. hour, at the 59th. minute, at the 59th. second. The binary representation for each is as follows:

Hour:	23	10111	- leaving 3 bits unused
Minute:	59	111011	- leaving 2 bits unused
Second:	59	111011	- leaving 2 bits unused

The bytes used to store this information would have their bits set as follows:

$$\underbrace{1\,0\,1\,1\,1}_{\text{hour}}\,\underbrace{1\,1\,1\qquad 0\,1\,1}_{\text{minute}}\,\underbrace{1\,1\,1\,0\,1\qquad 1}_{\text{second}}\,x\,x\,x\,x\,x\,x\,x$$

with the third byte having seven unused bits. Calculating the decimal equivalent of these binary representations, results with 191 for the first byte, and 125 for the second. The bit shifting operation is facilitated in C by the '>>' and '<<' operators (lines 605 to 614).

By limiting the event maximum to 127 Kg or 1219 Newtons, it can be stored in seven bits. The duration of an event in counts of samples might be from one to a very large number if the patient was standing for a long time without walking. However even if the duration of an event is long, as the Data file size is 1024 bytes, the longest event recorded will be 1024 sample counts. By assuming a maximum count duration of 511, especially as the patients were encouraged to walk during the monitoring session, it can be stored in 9 bits. However, by utilising the second compression method, that of decreasing the accuracy of the data, this nine bits of information can be stored in eight, so reducing the required two bytes to one. The duration value is simply divided by two, and before it is downloaded onto the PC, is multiplied by two. This means that even values will be accurate, and odd values will be rounded down to the lower even value. However, as each count constitutes 0.14 seconds if the processor is powered down in between samples, this slight inaccuracy is negligible.

Therefore as can be seen, the seven bytes of information requiring storage is compressed into four, giving a compression ratio of 33%. An improved Huffman coding scheme which codes each byte rather than just characters as in the original paper (Huffman, 1952) was also initially examined as a possible data compression method, but was discarded for the reason that the data requiring compression would be variable, with different patients monitored at different times throughout the day giving different results of weight-bearing, so that such methods that work on repeatability of data would not be very efficient if the code was previously calculated. In Section 5.3 of Chapter 5, there is explained how improved Huffman coding might be used for further compression by calculating the code during monitoring.

When the event information has been recorded, an EOF indicator is written to the Results file afterwards, so that if the monitor is switched off and then back on at a later time, the data already stored is retained and new results appended.

2.3. The PC Analysis Software

The following section describes the various parts of the program which analyses and stores the differing data and results files on the PC. As its general purpose and functionality have been explained in the overview at the start of this chapter, this section explains the various parts of this program in greater detail. To this end the various file structures and contents which are used by the program are detailed: these are then followed by the main menu which is shown in Figure 2.11 below, and then followed by Figure 2.12 which shows a flowchart of its general workings. The main body of this section deals with the explanations and screen displays of every option available to the operator during the program's execution.

2.3.1. The Various Files Used

The program requires and manipulates three different types of file; data, analysis and patient files. Each of these files is stored in different directories to ease file maintenance. Data files are generated by the ambulatory monitor, and down-loaded onto the PC. After having been analysed, they are moved to the '\data' directory of the hard-disk. Patient files are generated by the analysis program by the user inputting information on the patient; and are stored in the '\patients' directory. Analysis files are also generated by the program by analysing the data files, and are stored in the '\analysis' directory.

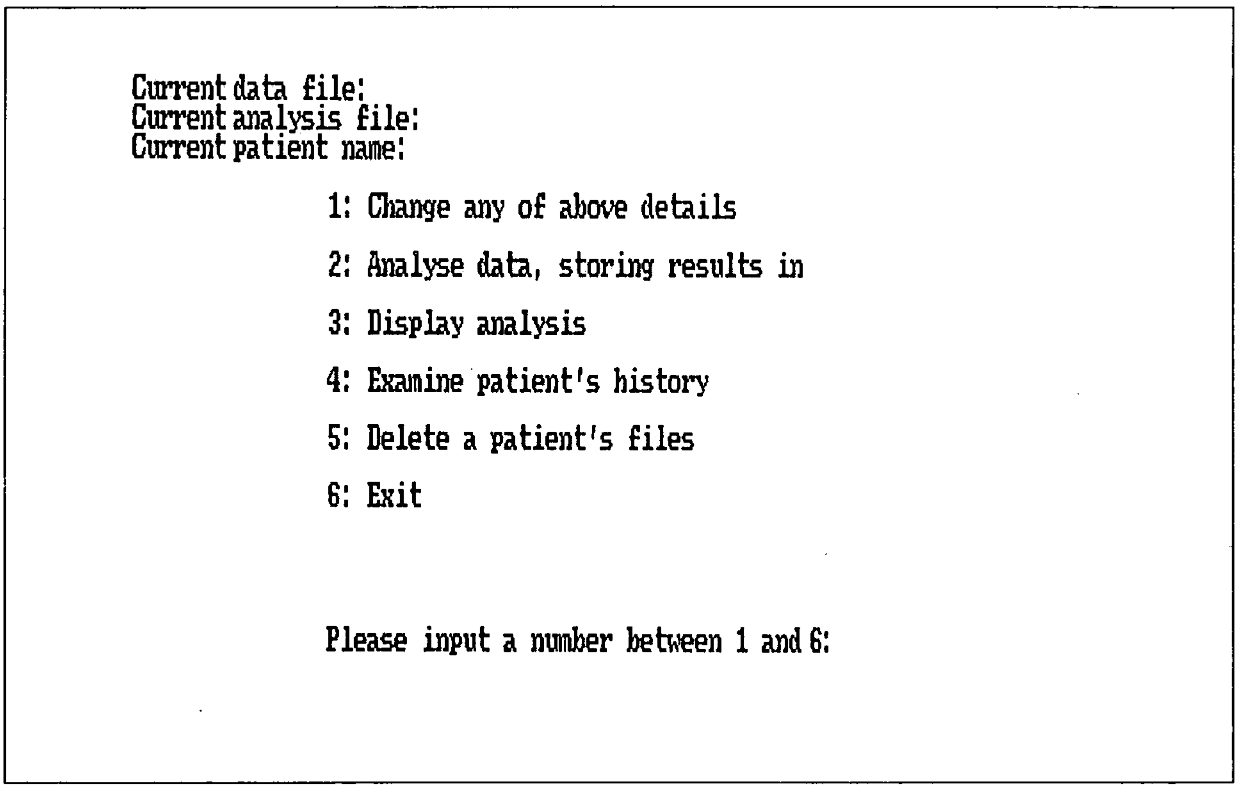
The data file name format has been explained in Section 2.2.3. It consists of twelve characters; eight then a '.' and three more at the end. The first eight indicate the file as a data file and also include the date of its creation. The first three characters are 'DAT', with the next two being the day, the next two the month, and the final one the (year - 1990). The final three characters give the number of the patient file which holds the details for the patient. So for example a data file generated on the 23rd. April 1993 for a patient with the patient file number being 030, would have the following data file name: 'DAT23043.030'. The first integer in the file corresponds to the number of legs being simultaneously monitored, and the second is the event level threshold. Next, the events information is stored which forms the bulk of the file. Each event recorded requires seven integers to store the information of hour, minute, second, event peak value, the duration of the event held by two integers, and the inter-sample time multiplied by one hundred. Finally, to indicate the end of the file after all the stored events, a single integer value '999' is stored.

The patient file name indicates to which patient it corresponds by its extension number after the '.'. So the thirtieth patient file generated would be given the name 'PATIENT.030'. The file itself contains information about the patient which is inputted by the operator before the file is created by the program. The information stored in this file remains unchanged during fracture healing, and so can be abstracted into this file so that it is not duplicated in all the patient's analysis files. Separated by carriage returns, the following information is stored; the patient's name, the date of birth, the hospital number, a 'R' or a 'L' indicating which of the right or the left leg is broken, the type of fracture, the position of fracture along the tibia, the treatment method, the patient's mass, and the date the fracture occurred.

The analysis file name takes a similar form to the data file name, except that its letter prefix is 'AN' rather than 'DAT'. The contents of each file consists of the following information separated by a carriage return. The patient name, the number of legs being monitored, the event threshold level, a list of twenty-four numbers indicating the number of events recorded in each hour of the day, the mean peak value weight for the events, the weight variance, the weight standard deviation, the mean number of counts duration of the event, the duration variance, the duration standard deviation, the number of weeks before the next appointment, and a string containing the notes made after the monitoring session.

2.3.2. General Program Structure

When execution of the program first begins, the main menu of options is displayed on the screen to the operator. This is shown in Figure 2.11 below.



```
Current data file:
Current analysis file:
Current patient name:

                    1: Change any of above details

                    2: Analyse data, storing results in

                    3: Display analysis

                    4: Examine patient's history

                    5: Delete a patient's files

                    6: Exit



                    Please input a number between 1 and 6:
```

Figure 2.11 - A screen display showing the main menu

As can be seen, there are five main options available to the user. The first option enables one or more of the current files to be changed (the current files are the ones currently being used, and are shown above the main menu, there being a data file, its corresponding analysis file, and the patient file). The second option allows the data file to be analysed and both the ensuing results and the initial file to be stored in their corresponding directories of the hard disk. The third option displays the analysis data on the screen in a graphical format. The fourth option allows the operator to examine the patient's history, this being both the notes taken for each monitoring session, and a graphical display of the patient's progress (in terms of weight-bearing on the fractured limb) over time. Finally, by selecting the fifth option the program is exited, and the operator is returned to the DOS prompt. Figure 2.12 is a flowchart which gives an overview of the program's workings, the code listing being given in Appendix 4. Subsequent line number references in Sections 2.3.* refer to this appendix.

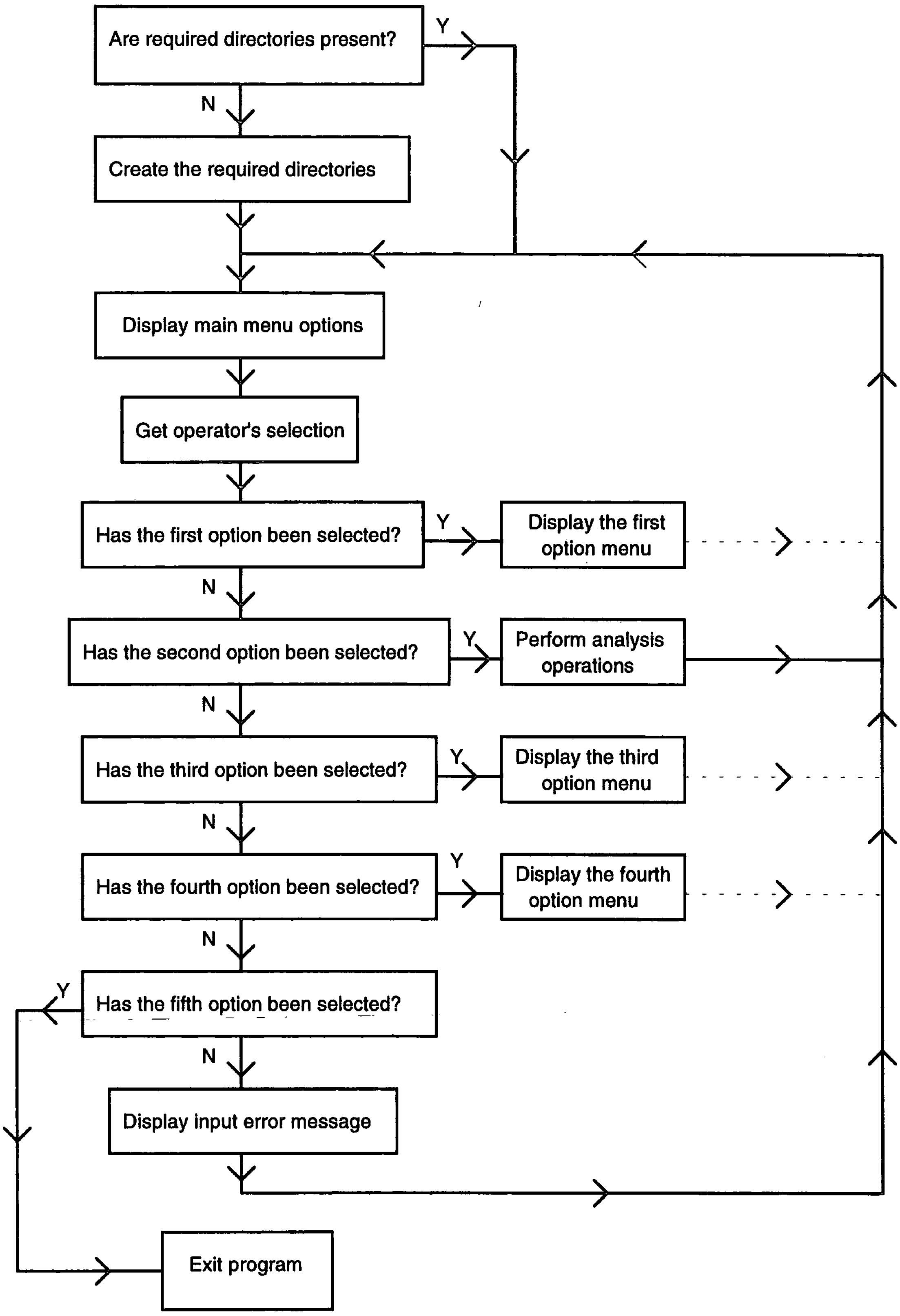

Are required directories present?
Y
N
Create the required directories
Display main menu options
Get operator's selection
Has the first option been selected?
Y
Display the first option menu
N
Has the second option been selected?
Y
Perform analysis operations
N
Has the third option been selected?
Y
Display the third option menu
N
Has the fourth option been selected?
Y
Display the fourth option menu
N
Has the fifth option been selected?
Y
N
Display input error message
Exit program

Figure 2.12 - A flowchart giving an overview of the program's general workings. The solid lines automatically proceed from the previous state, whilst the dashed lines show that the program will eventually proceed to the next state (after having entered and exited various sub-menus).

2.3.3. Program Initialisation

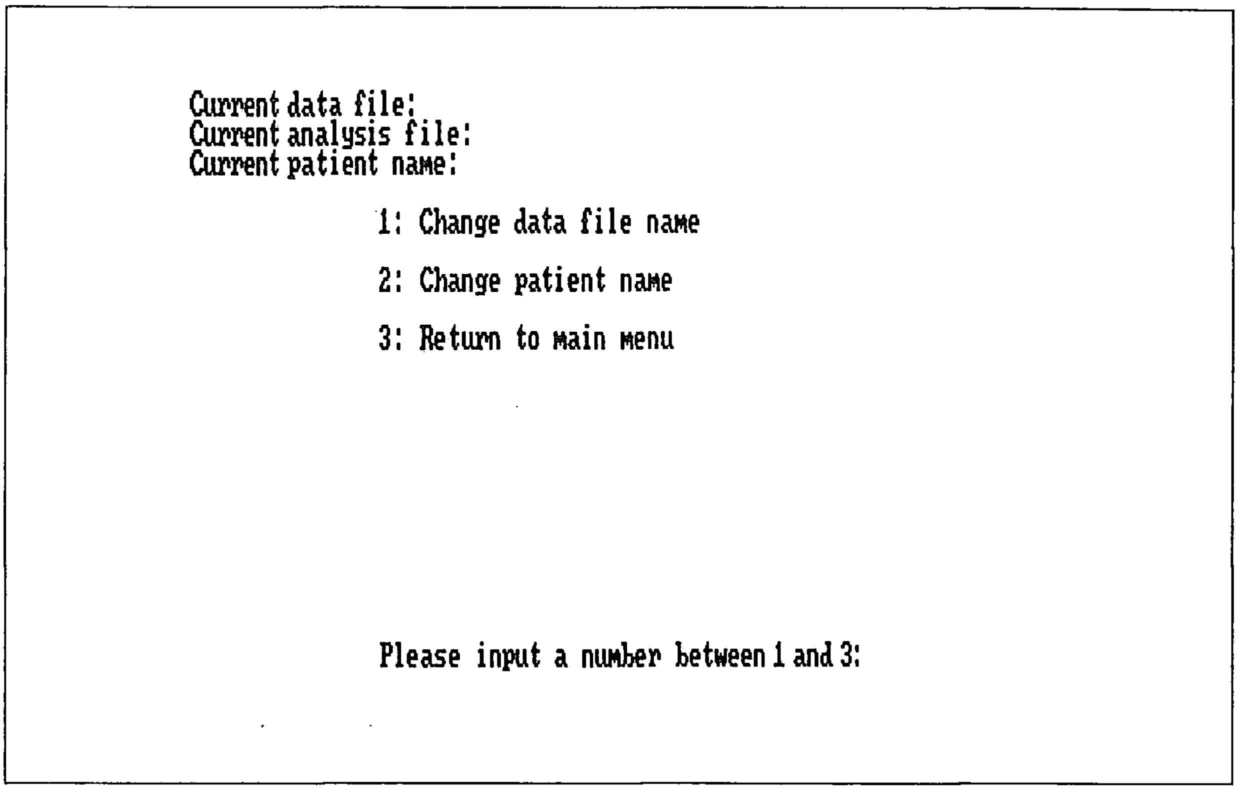
As there are a number of different display modes available to PCs, one had to be explicitly chosen for the displaying of the program's text and graphics. If the default option was kept, then older PCs whose display was of lower resolution would not be able to run the program properly as the display would be corrupted. Therefore the display was set to be black and white high-resolution CGA mode (line 74), which nearly all PCs have available, and although of lower resolution than the currently used VGA (640 by 480 pixels) and SVGA (800 by 600 pixels) standards, is still sufficient at 300 by 200 pixels to display all that is required.

The program then creates the required directories for the subsequent storage of the various types of file. Therefore the operator does not have to create these directories manually, when running the program for the first time on a PC.

The program checks to see which directories are present from the root directory, and only creates the ones missing. This check is performed in lines 90 to 107, using the 'system' command. Line 90 shows this, with a '\\' signifying the root directory. Just having the single '\' did not function as it is interpreted by the compiler as a control character. The directory names are saved in the present directory in a file called 'temp.dat'. This file is then opened for reading (line 95) and the finding of any of the three required directories' names in this file precludes these from being created in lines 112 to 117. This method of writing directory and file names to the 'temp.dat' file and subsequently opening the file for reading to access the information is used throughout the program for file and directory searching.

2.3.4. The First Option Menu

On having selected the first option, the program next displays the following menu (generated by lines 142 to 163).



```
Current data file:
Current analysis file:
Current patient name:
                    1: Change data file name

                    2: Change patient name

                    3: Return to main menu




                    Please input a number between 1 and 3:
```

Figure 2.13 - A screen display showing the first option menu

The details of the sub-menus accessible from this menu are detailed below, with their workings and functionality explained.

2.3.4.1. The First Option

Selecting the first option allows the operator, via further sub-menus, to either: input the new data file name, display the data files on the disk which are currently not yet analysed, display the analysed data files, or return to the previous menu. The middle two options have been implemented to aid the operator in the selection of the data file name.

Lines 238 to 417 are executed when the option to change the file name is selected. The 'input_file' function is called which calculates the data file name according to the date inputs from the operator (lines 2231 to 2339). The day of the month is first requested, next the month of the year, and finally the year itself. Each input is tested for validation, with the operator being asked to input another value until one is accepted. From these inputs, a string representation of the file name is built up, the date representation in the file name having been previously explained. This function simply returns the date followed by the '.' and a number corresponding to a previously specified patient name, leaving lines 256 to 260 to add the 'DAT' to the beginning of the file name indicating it as a data file name. If a patient name has not been previously specified (so that a patient file is not currently 'active') then one is requested from the operator (lines 2286 to 2294) and its validity is tested by lines 2296 to 2314. All the patient files are opened in turn (lines 2297 to 2299) to try and match the inputted patient name to the name held in one of the patient files. If a match does not occur, the patient name is rejected and the operator returned to the first option menu. Conversely if a match does occur, the patient file name extension is stored, for the patient's data and analysis files will have the same number extension.

The program next ascertains whether the specified data file has already been analysed (lines 278 to 411). If a data file has not yet been analysed, it does not have a patient number extension, but '.000', and is to be found in the current directory. Therefore lines 278 to 290 search the current directory for the data file, and if found, rename it with the number extension which represents the current patient name (lines 335 to 343). An analysis file name is then generated (lines 366 to 372) and if an analysis file of the same date and extension is not found on the hard-disk then a message is displayed for the operator to analyse the data file. This check is performed as a guard against an already analysed data file being found in the current directory and so confusing the program into believing that it had not yet been analysed.

The other two options in this menu are performed using the 'system' command in each case (lines 428 and 439), followed by a 'getch()' function call which waits until a key is pressed before continuing program execution.

2.3.4.2. The Second Option

Selecting the second option from the first menu allows the operator, via further sub-menus, to either: change the patient name, display the names of the patients with information files present on the hard-disk, input details for a new patient, or return to the previous menu.

Lines 506 to 533 are executed when the option to change the current patient name is selected. The operator inputs the first and last name of the patient, whose characters are all converted to lower case apart from the first letter of each word which is set in upper case. This is performed by the 'case_convert' function (lines 2346 to 2377), and so ensures that no errors in matching the two name pairs due to case variation occurs. Once converted, the inputted name is compared to the patient names of all the patient files on the hard-disk using the 'get_patient_file' function (lines 2190 to 2223). This iteratively opens each patient file to read the stored patient name to try and match the inputted name with the name in the patient file. If successful, the patient file name is returned, otherwise the string 'unsuccessful' is returned. Therefore if 'unsuccessful' is not returned, the patient name and patient file name are stored in global variables (lines 520 to 523) so that the patient's related information can be readily accessed. A new patient name having been accepted, the current data and analysis file names are deleted, as they will refer to the previous patient.

Lines 505 to 589 are executed when the option to view the names stored in the patient files is selected. Each of the patient files are iteratively opened and the patient name read and displayed on the screen. This displaying is performed by lines 576 to 585 which print the name, displaying three columns of names before inserting a carriage return.

When the option to input new patient details is selected, lines 602 to 867 are executed. The operator is asked to input a new patient name which is converted to lower case apart from the first letter of each name which is in upper case to avoid subsequent mismatching. This inputted name is next compared to every name stored in the patient files, to ensure that the operator does not input details for the same patient twice. If no match occurs, then the patient file names are iteratively obtained and the last three characters of each being converted to an integer (lines 657 to 668). By storing the greatest of these integer numbers, the patient file's number which was last generated is obtained. Incrementing this and converting it back to a three character string results with the new patient file name extension. The following inputs are then requested from the operator, with a validation check being performed when possible; the date of birth, the hospital number, whether the right or the left leg is fractured, the fracture type, the position of the fracture, the fracture treatment, the patient's body mass, and the date of when the fracture occurred. These details which include the patient's name are written to the newly generated patient file.

2.3.5. The Second Option Menu

This option is selected by the operator to analyse the data file. Before doing so, a check is performed to ensure that the currently selected data file name is valid, since this was found to be useful during the debugging stage. This will also guard against the possibility of the stored data file name not having been specified, or having become corrupted during program execution. A check is also performed to make sure that a patient name has been specified, and if either is invalid the operator is returned to the main menu.

After having read in the first two values of the file, these being the number of legs monitored and the event level threshold, the analysis of the events information takes place. The complete analysis of the data file occurs by a number of read passes through it, each pass calculating different analysis results. The first pass is performed by lines 943 to 955, with the number of events in each hour being recorded as well as a sum of the peak event values and the number of the events. Next the new analysis file is generated with the patient name, the number of legs monitored, and the event level threshold being written to it. Twenty-four numbers corresponding to the number of events for each hour of the day are next printed to the file, each being separated by a space. The peak value mean is calculated by dividing the sum by the number of the events, which is then also written to the file. Using the C command 'rewind()' , the data file pointer is taken back to the start of the file and the next pass occurs (lines 974 to 995). This time the event duration is summed and the square deviation of the peak mass value is calculated in line 985 by using the following formula:

$$\sum [(peak - massMean)^2]$$

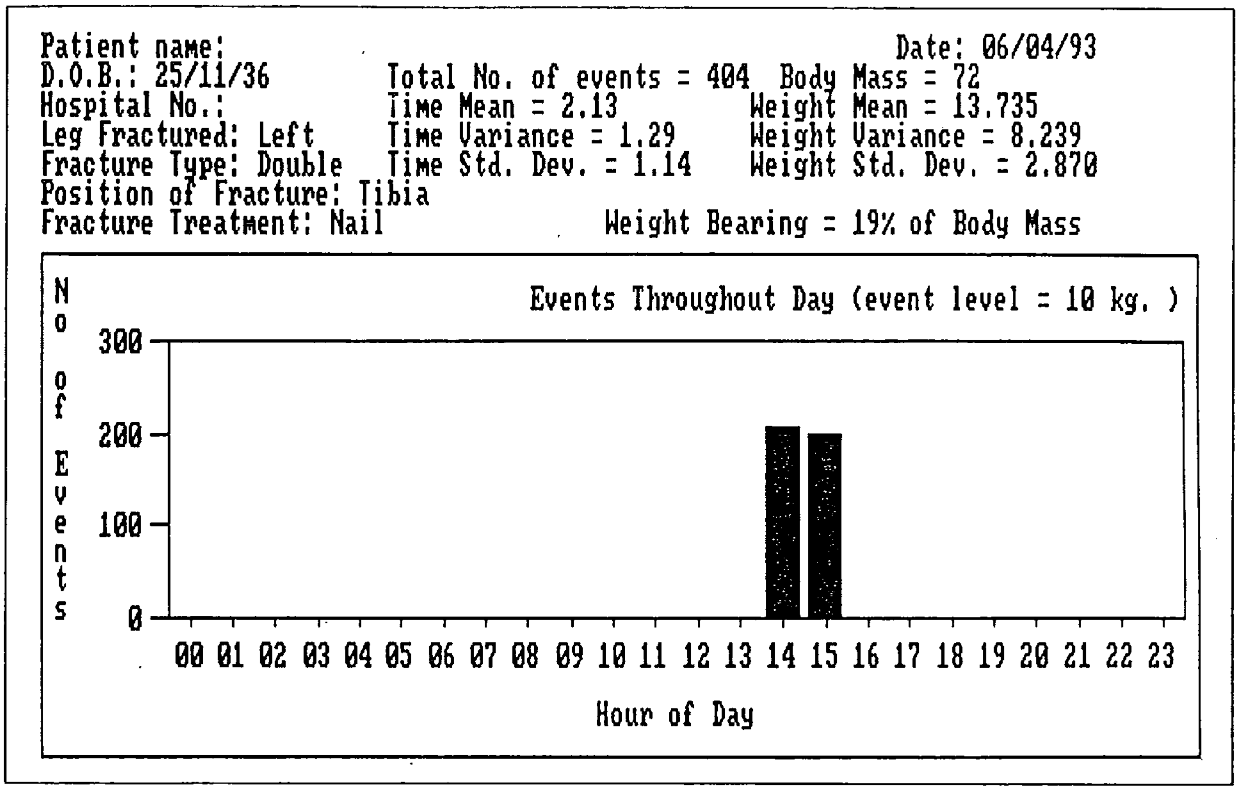
When the end of the data file is reached, the mass variance is calculated by dividing the square deviation by the number of events. The standard deviation is then calculated as the square root of the variance. Both the variance and the standard deviation are finally written to the analysis file.

The final pass through the data file occurs at lines 1006 to 1023. The duration variance and standard deviation is calculated during this pass, with the duration mean, variance and standard deviation being written to the analysis file. The operator is then asked to input the number of weeks before the next appointment which is also written to the file, '0' being inputted if the patient is being discharged. This was to be used by the program to calculate how many monitoring sessions were to be expected at any day. Unfortunately there was insufficient time to implement this function, but the data is still recorded so that the information is present and the file structure is constant were this to be implemented in the future.

Finally the operator has an opportunity to type in notes and observations taken during the monitoring session (lines 1052 to 1104), these being printed to the analysis file as a single string. As each character types is inputted directly into a string, deletes are recorded as an extra character in the string even though on the screen the previous character displayed is automatically deleted. Therefore before printing the string to the file, its characters are iteratively compared to the delete character which has the ASCII value 8 (lines 1085 to 1104). Two character indices into the string are used, one which holds the position of the current character being read in, and the other the being the position of the current character being written to. Each loop iteration then increments both indices, and replaces the character at the write index with that of the read index. A copy of the original string is not required as a delete character simply results in the read index being incremented whilst the write index is decremented so subsequently deleting the previous character. The conclusion of this operation is the writing of the newly formatted string to the file, and the moving of the data file from the current to the '\data' directory (lines 1111 to 1123).

2.3.6. The Third Option Menu

Selecting this option displays the analysis of the data file on the screen in a partly graphical, partly textual form. A check is performed to ensure that the analysis file exists, and if so the program execution proceeds with line 1157 onwards. An example of the screen display is shown in Figure 2.14 below.



```
Patient name:                                              Date: 06/04/93
D.O.B.: 25/11/36       Total No. of events = 404  Body Mass = 72
Hospital No.:          Time Mean = 2.13          Weight Mean = 13.735
Leg Fractured: Left    Time Variance = 1.29      Weight Variance = 8.239
Fracture Type: Double  Time Std. Dev. = 1.14     Weight Std. Dev. = 2.870
Position of Fracture: Tibia
Fracture Treatment: Nail              Weight Bearing = 19% of Body Mass
```

Figure 2.14 - A screen display showing a monitoring session's results. The patient name and number have been deleted for confidentiality.

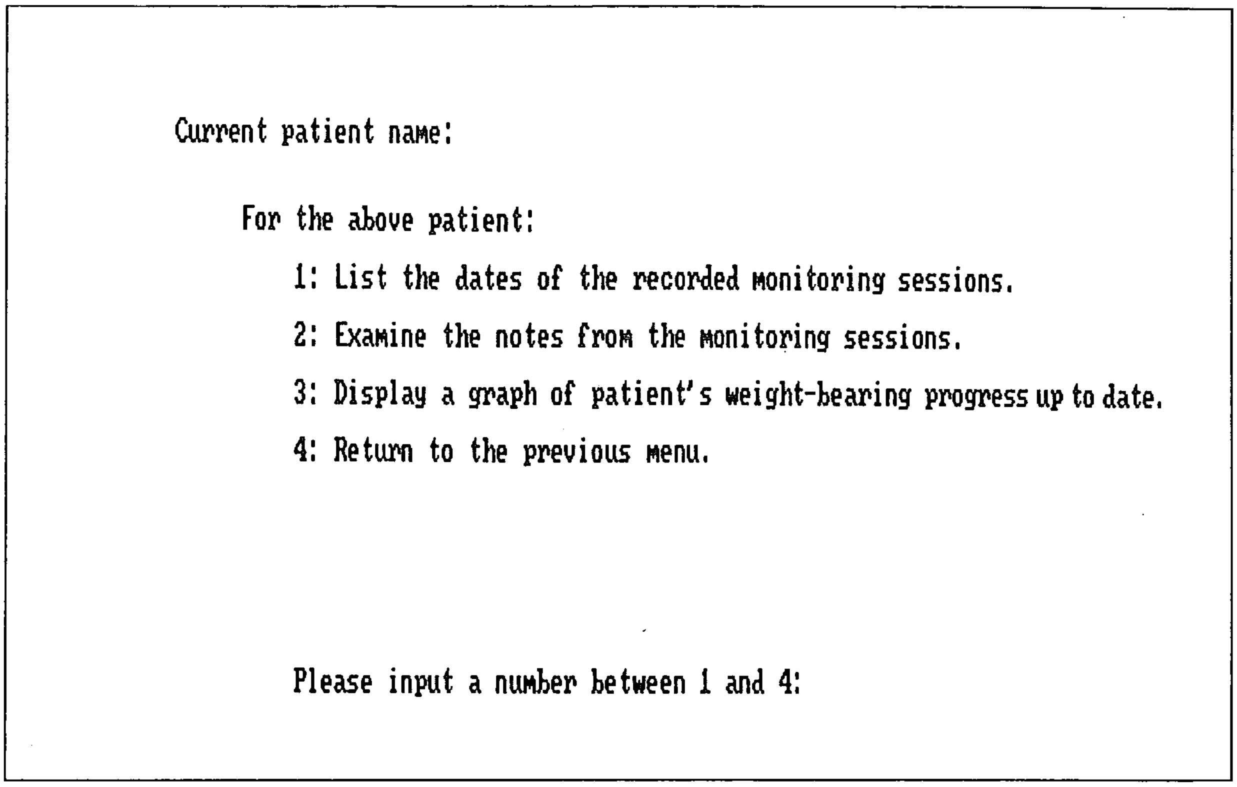
The patient name is first read in from the analysis file, and the corresponding patient file name obtained using the 'get_patient_file' function. This is required to obtain the following information for the screen display: the date of birth, the hospital number, which leg is broken, the fracture type, the fracture position, the fracture treatment, and the body mass (lines 1171 to 1183). From the analysis file name, the date of the monitoring session is obtained (lines 1185 to 1195). The file is then read to obtain the following information; the number of legs monitored, the event level threshold, the number of events in each hour, the peak mass mean, the peak mass variance, the peak standard deviation, the duration mean, the duration variance, and the duration standard deviation (lines 1197 to 1206). These are displayed on the screen with the percentage weight bearing, which is calculated by:

$$\frac{meanMass}{bodyMass} \times 100$$

The Microsoft C presentation graphics library routines are used to display a bar chart (lines 1289 to 1314), the chart window size being specified by setting the 'env.chartwindow' part of the structure (lines 1310 to 1313), and the chart displayed by the '_pg_chart' command in line 1314.

2.3.7. The Fourth Option Menu

The patient's history can be examined in various ways by selecting this option. Before the sub-menu is displayed, a check is made for whether a patient name has been specified. If not, then the operator has the option to input one, or return to the menu (lines 1353 to 1366). The inputted name is compared to the name in the patient files for validation, the operator being offered the opportunity of inputting another name until validation occurs. Figure 2.15 below shows the sub-menu which is then displayed.



```
Current patient name:

    For the above patient:
        1: List the dates of the recorded monitoring sessions.
        2: Examine the notes from the monitoring sessions.
        3: Display a graph of patient's weight-bearing progress up to date.
        4: Return to the previous menu.



        Please input a number between 1 and 4:
```

Figure 2.15 - A screen display showing the fourth option menu. The patient name has been deleted for confidentiality.

2.3.7.1. The First Option

When selected this option displays the dates of all the monitoring sessions that have occurred for the patient. All the analysis files for the patient, i.e. all those whose extension is the same number as the patient file are iteratively obtained, and by using the 'get_date' function, are converted to a standard date representation and printed on the screen (lines 1445 to 1467).

The get_date function is listed in lines 2147 to 2182. Its input is a file name, and as this might be a data or an analysis file a check of the first character is performed to determine which. This is needed because for a data file the prefix before the date section is 'DAT' being three characters, whilst with the analysis file it is 'AN' being two. The date is then extracted from the name, and put character by character into a static string 'date' in the format 'day/month/year'. A pointer to this is then returned, but as 'date' is defined as a static its contents are not deleted when this function is exited.

2.3.7.2. The Second Option

By selecting this option the notes taken during the monitoring sessions are displayed on the screen. The initial code is similar to that of the previous option, for all the analysis files of the patient need to be accessed, as they contain the notes.

The date of each monitoring session is obtained using the 'get_date' function having given the analysis file name as its input (line 1502). This is printed on the screen followed by the string containing the patient notes which has been extracted from the analysis file character by character (lines 1529 to 1540) to circumvent any maximum string length problems which might occur using the 'fscanf' command to obtain the string in one operation.

2.3.7.3. The Third Option

Selecting this option displays a graph of the patient's weight-bearing progress up to date. An example screen is shown in Figure 2.16.

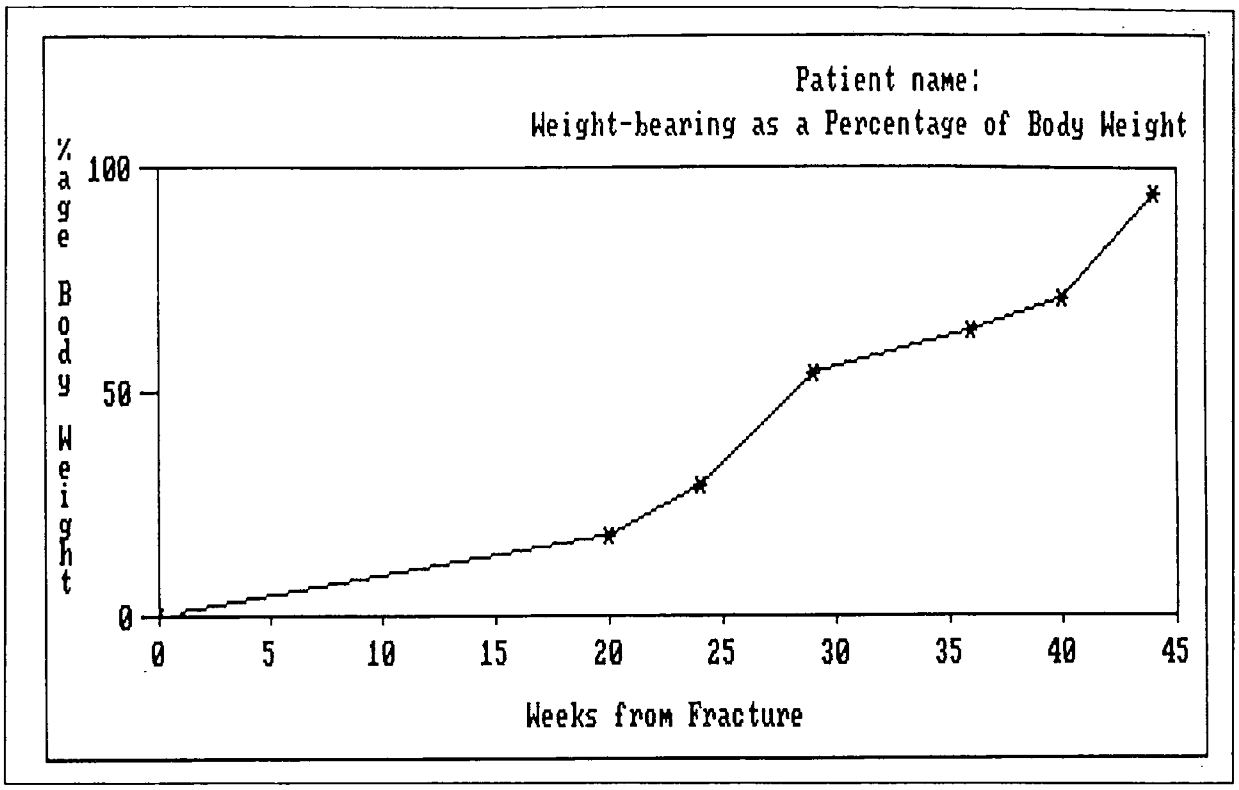


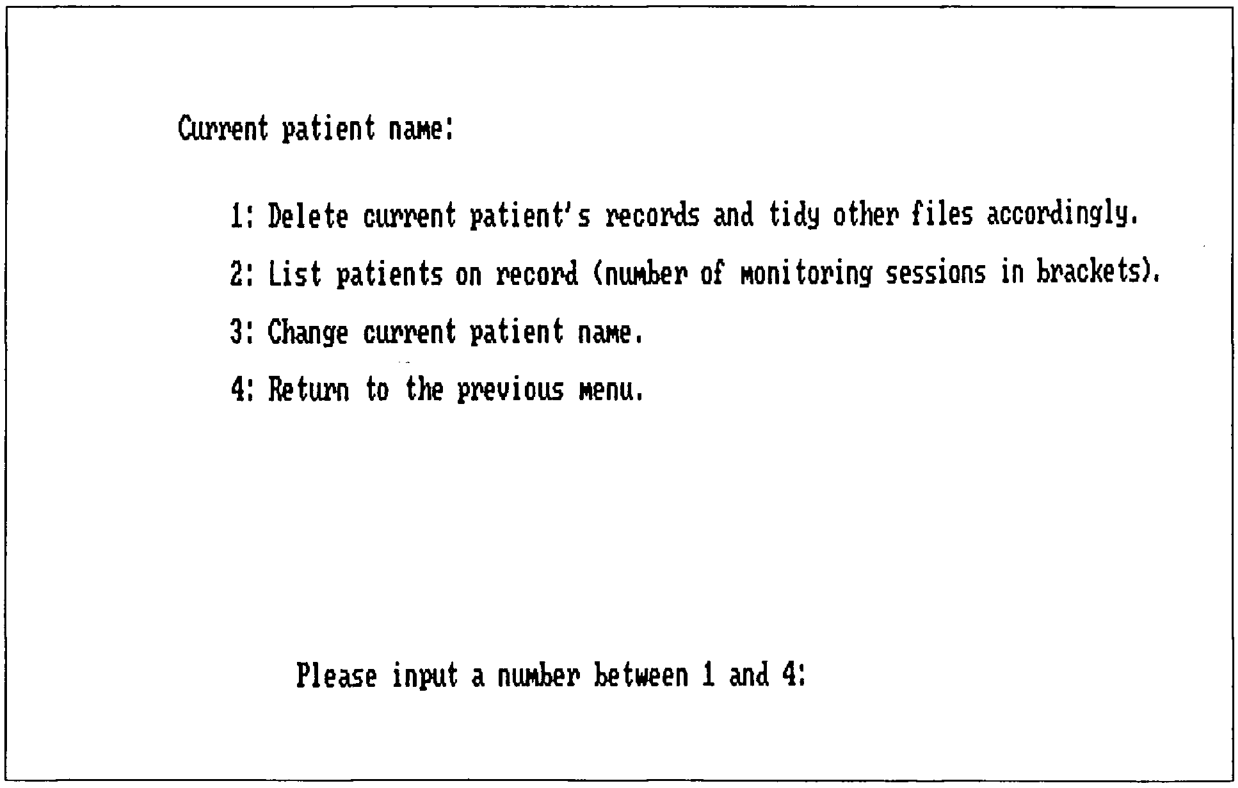
Figure 2.16 - A screen display showing a patient's weight-bearing progress up to date. The patient name has been deleted for confidentiality.

The initial code is again similar to that of the previous options as each analysis file requires accessing for the peak mass mean value. With the body mass value which is gained from the patient file, this is used to calculate the mean percentage weight-bearing. From this file is also obtained the date of fracture.

For each point to be plotted on the graph, the number of weeks from the fracture and the mean percentage weight-bearing is required. The number of weeks is calculated by the 'calc_no_of_weeks' function, which takes as its inputs the year, month, day of when the fracture occurred, and the current year, month and day. The code for this function is given in lines 2116 to 2140. The weight-bearing is calculated by the 'calc_weight_bearing' function which is given in lines 2083 to 2104, and takes the analysis file name and the patient's body mass as its inputs. This then opens the file, reads the mean peak mass of the session, calculates and returns the weight-bearing figure. As was the case for the displaying the bar chart, the drawing of this graph uses some of the Microsoft C presentation graphics library routines.

2.3.8. The Fifth Option Menu

As there are a number of files associated with each patient, a separate option has been implemented to allow the program to remove all the files, rather than the operator having to manually remove them. The subsequent patients' files are also renamed so that the patient file number does not remain unused. If selected the sub-menu shown in Figure 2.17 is displayed.



```
Current patient name:

    1: Delete current patient's records and tidy other files accordingly.
    2: List patients on record (number of monitoring sessions in brackets).
    3: Change current patient name.
    4: Return to the previous menu.



            Please input a number between 1 and 4:
```

Figure 2.17 - A screen display showing the fifth option. The patient name has been deleted for confidentiality.

2.3.8.1. The First Option

This is the main option of the menu, and is selected when the operator requires the deletion of a patient's data, analysis and patient files. This would not be frequently selected as old patient details are normally retained, but during the patient trials it was found that with a couple of patients only one monitoring session took place, the patient not returning for further monitoring sessions. Therefore it might be useful in the future to delete all files relating to a patient.

Firstly the number of patient files is counted as this figure will be required later. Next the suffix of the patient file corresponding to the patient name is obtained (lines 1780 to 1784) and by using the 'system' command all the data, patient, and analysis files having that same suffix are deleted (lines 1790 to 1803). However, there will now remain a blank patient number allocation in the midst of a block of allocated numbers, for example if files for patient 020 have been deleted when there are patient files up to 030. When assigning a number for newly inputted patient details, this free number will not be allocated as 031 will be chosen which is the next free number after the last generated patient file. To avoid the possibility of exhausting of all the one thousand possible numbers over time, the next section of the code for this option (lines 1811 to 1921) decrements the patient number extensions of all the files whose numbers are greater than the deleted one. This therefore ends with the greatest patient number being one less than previously for the patient, data, and analysis files.

2.3.8.2. The Second Option

This is an enhanced version of the option available when changing patient details, and is useful for the operator to check the number of files that will be deleted. When selected, the names stored in all the patient files are displayed, with a number in brackets after each one indicating the number of monitoring sessions that have occurred for that patient.

This latter function is performed by lines 1967 to 1991. All the data files for the patient having the patient file extension are counted, and the patient name and number of monitoring sessions are then printed on the screen in a single column, there being three columns displayed across the screen (lines 1973 to 1991).

2.3.8.3. The Third Option

This option was included to enable the operator to immediately change the patient name after having decided with the aid of option two which required deletion.

The 'get_patient_file' function is used to obtain the patient file name from the patient name inputted by the operator. Only if a patient file exists with the same patient name is the name accepted.

2.3.9. The Sixth Option

The final option available on the main menu is to exit the program. This is included so that the program can set the display mode back to the default mode (line 2072) which was being used when program execution first began.

3. Pre-Clinical Trials

3.1. The Initial Sensory Equipment Configuration

To measure weight-bearing, the sensory equipment is required to measure force, for weight-bearing is the force transmitted through the fractured leg. It was decided to use pressure transducers for this purpose. Although just measuring pressure and thus force over a certain area, each pressure transducer output can be calibrated by a scaling value in the monitor software so that the reading corresponds to the force across a greater or lesser area. Different calibration values could therefore be used for the various parts of the underside of the foot for different patients each of which have differing areas.

Initially the weight-bearing sensory equipment consisted of two pressure transducers of half an inch in diameter and their respective signal conditioning unit which had inputs for two transducers. Both of these were purchased from M.I.E. Medical Instrumentation, Leeds, UK. The pressure transducers work on an electrical resistive principle, and consist of two sheets of polymer laminated together, one holding a conducting track, and the other the force sensing resitor polymer area. This makes them durable, vibration insensitive, temperature and moisture resistant. Also, in comparing them with conductive rubber, little hysteresis is exhibited. Thus they were viewed as being very suitable for the in-shoe monitoring function.

The voltage outputs from the signal conditioning unit is read by the ADCs of the ambulatory monitor, but as the outputs are not linear with respect to the applied pressure at the transducer, they first had to be calibrated. This was performed on a Hounsfield testing machine and rather than apply the load directly to the transducer, the elasticity of the underside of the foot and the insole was modelled by testing the transducers in between two sheets of resilient foam. This was important as the two surfaces between the transducers during the patient trials are elastic, which means that the pressure would not necessarily be linear with the load, since as the load increases the surface area through which the load was transmitted could also slightly increase. The area of foam in contact was about 4 cm^2, this being an estimate of the minimum area that each transducer would be required to indicate the force across. The calibration graph was found to be almost identical for both transducers, and so the average values of both graphs were stored in the monitor program for calculating the load. A graph showing the transducer output against the applied load is shown in Figure 3.1.

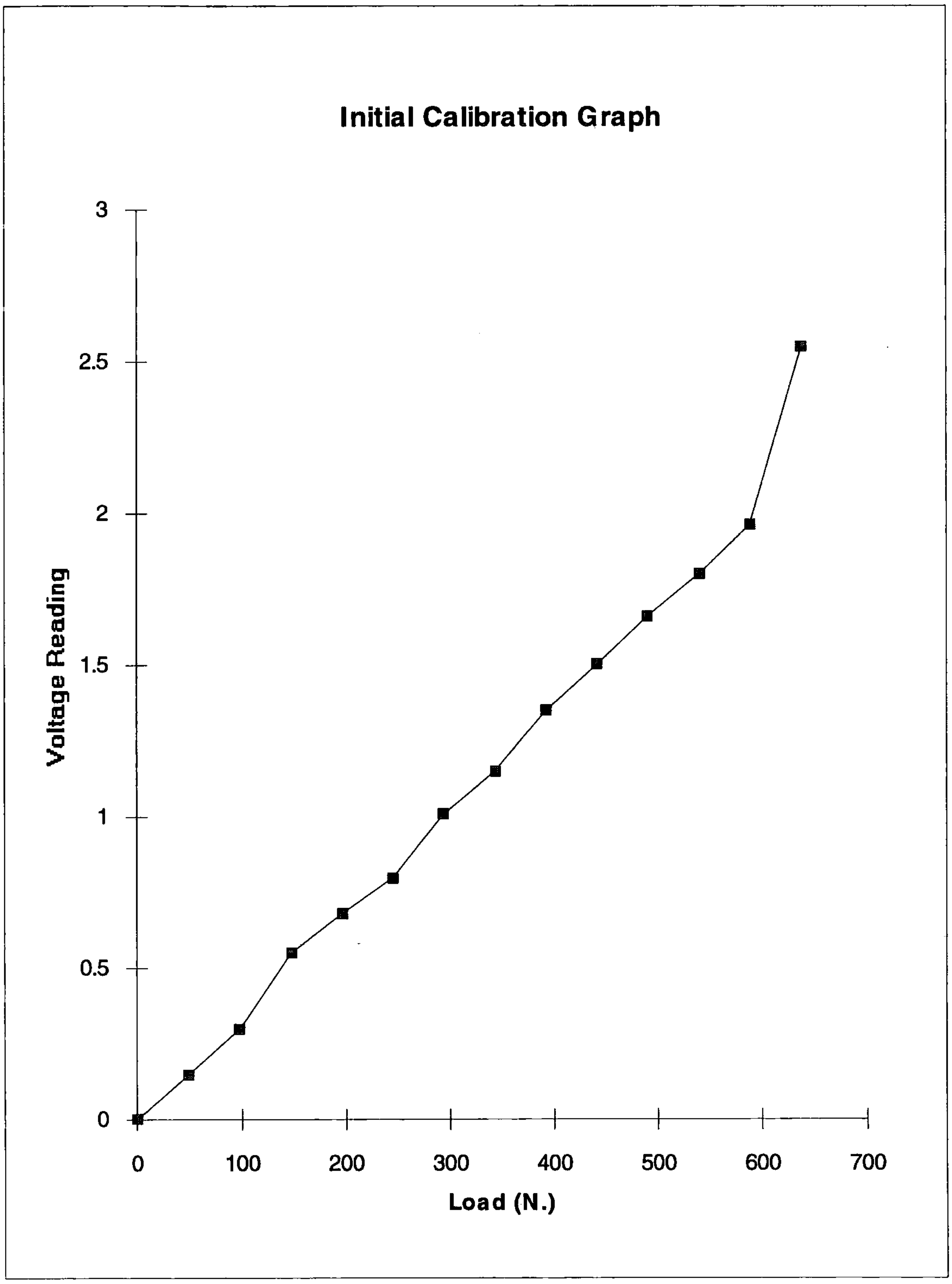


Figure 3.1 - Calibration graph for each transducer

Therefore the first calibration occurs in the monitor program obtaining the load by calculating the gradient in between the points on the graph, rather than assuming the graph as linear and storing just one scaling constant to convert the voltage read to load sensed. However this first calibration is not sufficient to give generically accurate load readings because the different parts of the underside of the foot vary in area as do the actual feet sizes. Also the elasticity of the underside of the foot varies between patients, mostly due to the soft tissues varying with age, the greater the age the less the elasticity, causing a smaller surface area which can lead to a greater pressure for the same applied load. Therefore a scaling factor was also used for each of the signal conditioner's inputs to the monitor, which could be modified separately by the operator through the monitor software. So in effect, two separate calibrations occur which in conjunction enable the monitor to store accurate weight-bearing data.

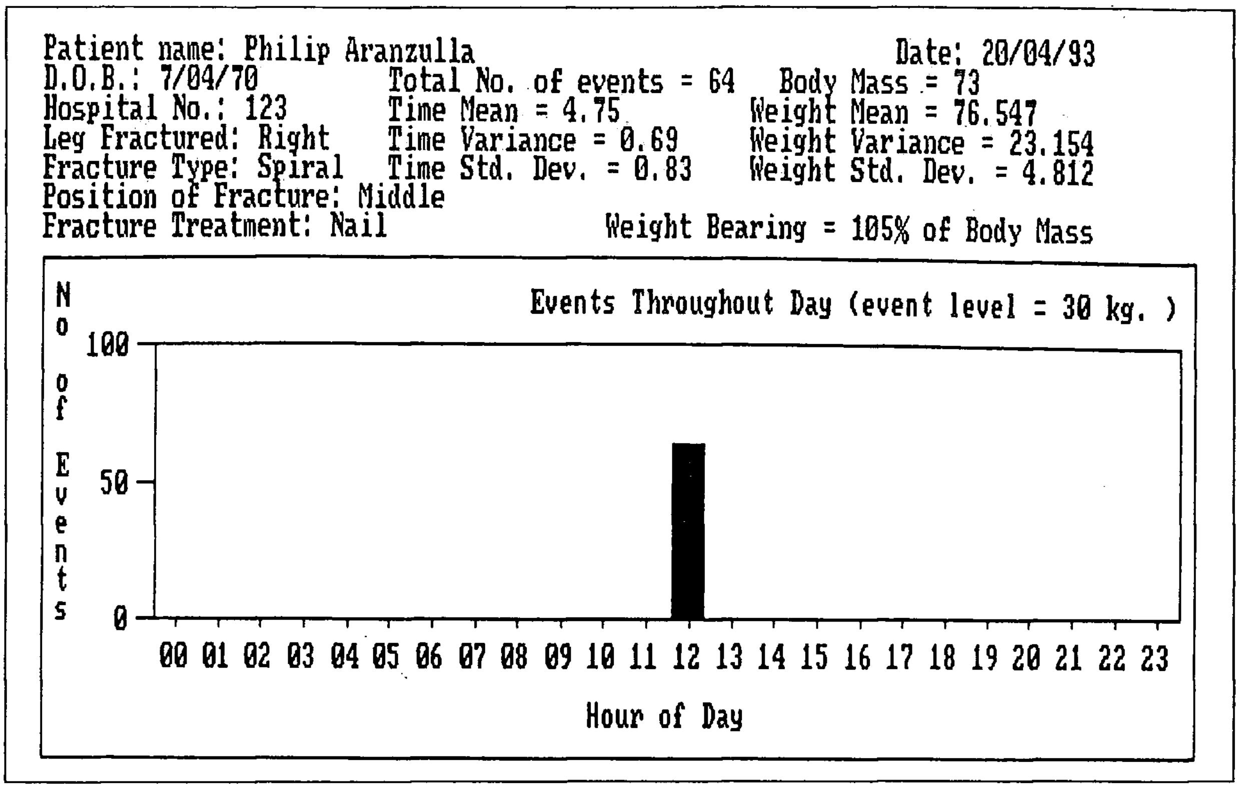
The transducers were attached by double-sided tape to the hospital plaster shoe which was used for the trials. The signal conditioning unit has inputs for two pressure transducers and was attached to a leather strap which fitted round the patient's ankle, as the wires of the transducers were relatively short. A benefit of this arrangement was that there was only one lead from the ankle to the monitor so reducing the possibility of it interfering with the patient's natural gait.

One transducer placed under the calcaneous, and the other under the first metatarsal head. The reason for this positioning of the transducers was suggested by, amongst others, Duckworth *et al.* (1982), who measured pressures under the foot and found that the highest pressure concentrations were under the calcaneous, and under the first and the second to the fourth metatarsal heads. However as the first metatarsal head was shown to have its pressure distributed almost directly over the head itself, rather than over a larger area, as with the other metatarsal heads, the area under the first metatarsal head was chosen for monitoring.

Before a monitoring session the monitor inputs' scaling values had to be especially calibrated for that patient. After having attached the equipment, the subject was asked to stand with the foot of the fractured leg on a set of bathroom scales and the other foot on the floor. The reading on the scales was therefore the amount of total weight being transmitted through the fractured leg, and the ambulatory monitor reading was required to be identical for the monitor's inputs to be correctly calibrated so that the local weight readings directly under the transducers equalled the total weight. This was achieved by altering the scaling values of the monitor's inputs. During this calibration phase, the operator also visually inspected the way in which the subject was standing on the scales so that an estimate of the weight ratio between the calcaneous and the metatarsal heads would be gained. This was compared to the individual monitor's input readings and further modification of the scaling values occurred as necessary. This calibration now having been performed, the monitoring session could commence by resetting the monitor and so clearing the data file, and allowing the subject to walk on a pre-defined route. At the end of the route, the monitor and sensory equipment was removed from the subject, and the results down-loaded to the PC for analysis and display of the data. If the subject had not been previously tested, then their details were inputted into the PC monitoring program first, with analysis occurring subsequently.

3.2. Results from the Pre-Clinical Trials

A number of subjects with unfractured limbs were monitored initially, with the expectation that each session's results would indicate an approximately 100% weight-bearing average. However this was not found to be the case, with variations being between 70% and 120%. It was thought that a factor affecting the accuracy of the data was the positioning of the transducers in the plaster shoe. The shoe was affixed to the foot by means of two pairs of velcro straps, which were thought to be insufficient to prevent the foot moving from its original position during walking. Even if this movement was small, due to the pressure concentrations under the foot occurring only in specific areas (Duckworth *et al.*, 1992) there might be a large resultant change in pressure and hence the weight-bearing reading. To circumvent this problem the subject wore an elastic tubigrip sock, and the transducers were affixed directly to the sock and therefore to the underside of the areas of interest of the foot. Further trials were performed with this new configuration, and it was found that the results obtained were more consistent and repeatable, an example being shown in Figure 3.2. This shows the PC screen when running the PC analysis program and displaying the monitoring session results. As can be seen, the average percentage weight-bearing is 105%, the standard deviation being 4.8 and the average number of samples comprising the event being 4.75, with standard deviation of 0.8. The occurrence of the percentage weight-bearing reading above 100% of body weight is expected due to the larger magnitude of the ground reaction force vector at the heel contact and push off stages. As the gait pattern was normal and unchanging the standard deviation of the weight-bearing at 46 on an average of 734 Newtons (i.e. 6%) might be due to some of the peak weight-bearing values occurring in between samples, for the sampling interval was 0.14 seconds, so that different events have slightly different weight-bearing peaks.



```
Patient name: Philip Aranzulla                                    Date: 20/04/93
D.O.B.: 7/04/70         Total No. of events = 64   Body Mass = 73
Hospital No.: 123       Time Mean = 4.75          Weight Mean = 76.547
Leg Fractured: Right    Time Variance = 0.69      Weight Variance = 23.154
Fracture Type: Spiral   Time Std. Dev. = 0.83     Weight Std. Dev. = 4.812
Position of Fracture: Middle
Fracture Treatment: Nail                 Weight Bearing = 105% of Body Mass
```

Figure 3.2 - A screen display of the results for the pre-clinical trail using a normal gait pattern.

Another trial was performed with the subject being asked to walk with a limp so entering immediately the flat foot stage on ground contact which was intended to imitate walking with a fractured tibia. By so doing the force throughout the leg is reduced, which is shown by the smaller magnitude of the ground reaction force vector during the mid-stance phases in Figure 3.5 and more clearly in Figure 3.3.

This occurs because the heel contact stage and the start of the flat foot stage is the weight acceptance stage, where the body decelerates its forward velocity. This deceleration is mostly due to the rising of the trunk between heel contact and foot flat as the horizontal kinetic energy is converted to potential energy. Whilst the trunk is ascending an acceleration upwards greater than gravity occurs, and from Newton's Third Law of Motion it can be seen that a force acts upwards, which by Newton's Second Law means that an equal force acts downwards combining with the body weight to generate a greater magnitude of the ground reaction force vector. This trunk rising does not occur when the patient places the foot flat at ground contact because the trunk has not been lowered to its full extent which occurs at heel contact resulting in less force being transmitted through the leg as the acceleration does not occur.

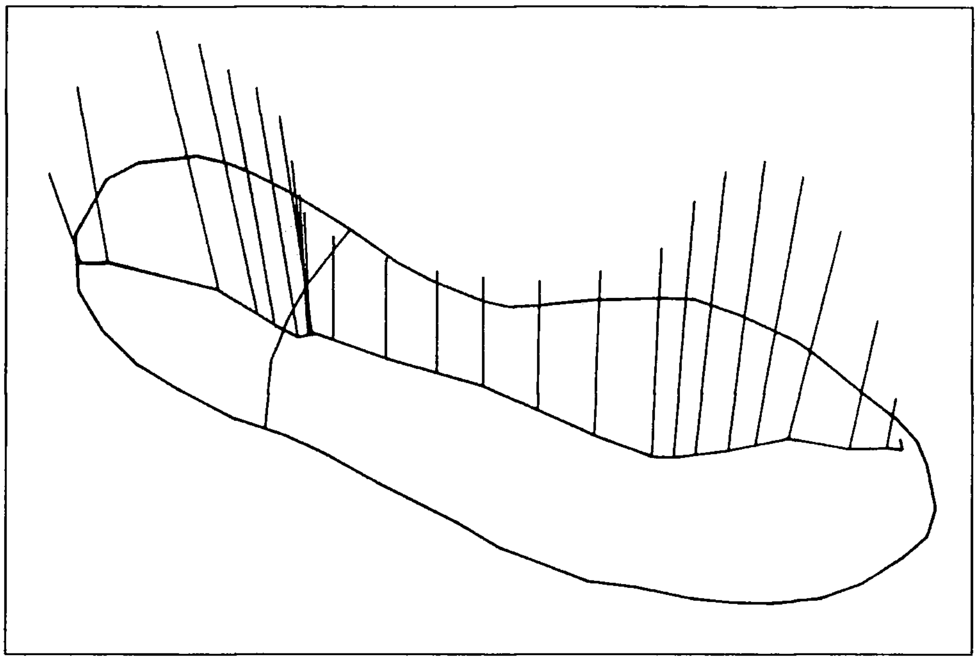
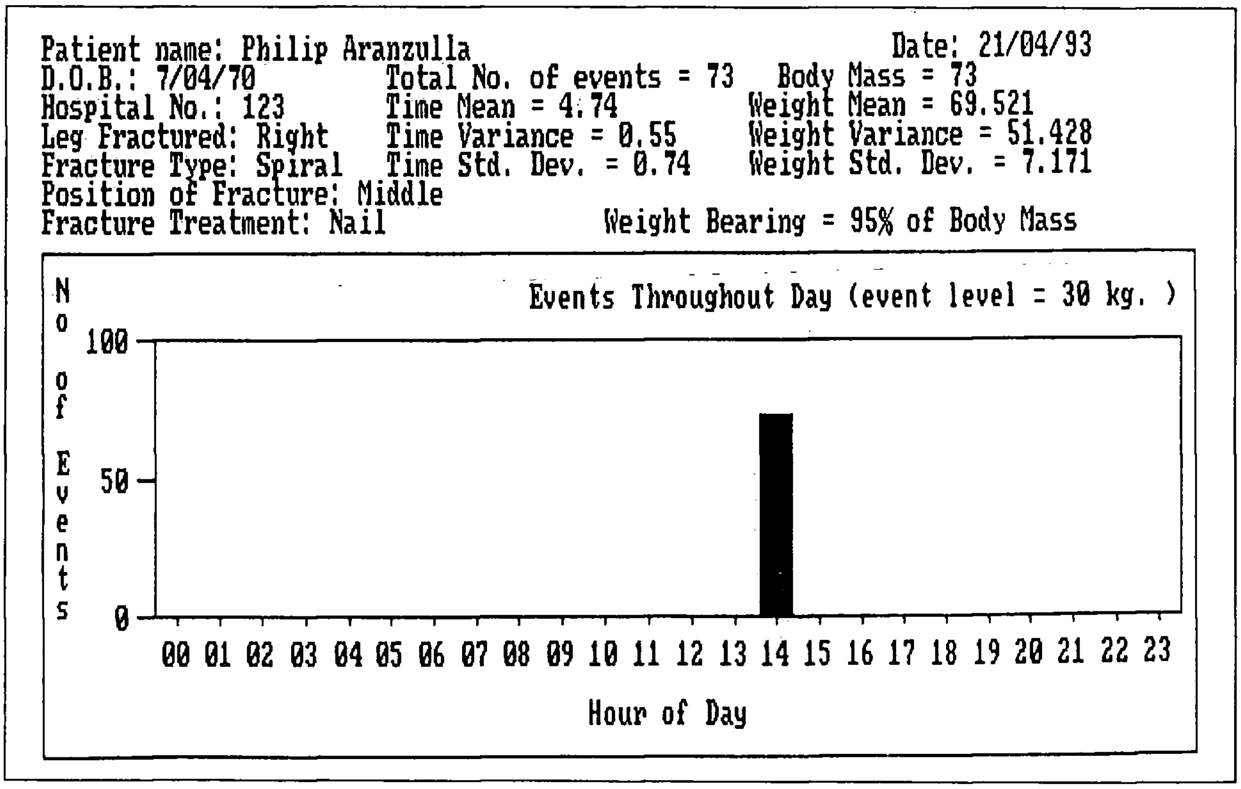


Figure 3.3 - Foot outline, centre of pressure and sagittal plane representation of ground reaction force vector; right foot of a normal male subject walking in shoes. As force is a vector, its magnitude and direction are indicated by the length of the lines and their orientation (Whittle, 1991).

The stance phase ending at heel off rather than push off also lowers the force through the leg as shown by the lower force vector magnitudes during the mid-stance phase in Figure 3.3 and Figure 3.5. The magnitude of the reaction force is greatest at the end of the heel off stage and at the start of the toe off stage as a large plantarflexing moment is generated to oppose the large external dorsiflexion moment, this extra force being transmitted to the ground which compounds with the weight to increase the magnitude of the reaction force. Therefore by excluding both the heel contact to foot flat stage and the push off stage, the force transmitted through the leg for the stance phase is fairly constant at the minimal amount for normal gait.

The results for the pre-clinical trial with limping (Figure 3.4) clearly show the reduced average weight-bearing at 95%. The standard deviation at 69 from 667 Newtons (i.e. 10%) is slightly higher than before, and probably indicates the variations between steps due to the subject having to 'imitate' a gait pattern which is not natural to them. Interestingly the average number of samples per event is similar at 4.7, even though the average stride time was lower. This indicates that the stance phase for the unmonitored leg was of longer duration than that of the monitored and limping leg which is reasonable as the limping mechanism's aim is to reduce the load on the limb. As the stride time is lower for pathological gaits, the effect of the peak value occurring in between samples lessens because the weight-bearing curve over time becomes more smoothed, so in effect the accuracy of the monitor readings will increase. As satisfactory results were obtained for both pre-clinical trials, the patient trials were commenced.



```
Patient name: Philip Aranzulla                                    Date: 21/04/93
D.O.B.: 7/04/70          Total No. of events = 73   Body Mass = 73
Hospital No.: 123        Time Mean = 4.74          Weight Mean = 69.521
Leg Fractured: Right     Time Variance = 0.55      Weight Variance = 51.428
Fracture Type: Spiral    Time Std. Dev. = 0.74     Weight Std. Dev. = 7.171
Position of Fracture: Middle
Fracture Treatment: Nail                Weight Bearing = 95% of Body Mass
```

Figure 3.4 - A screen display of the results for the pre-clinical trial using a limping gait pattern.

3.3. The Final Sensory Equipment Configuration

However during the early stages of patient monitoring the results obtained were highly variable, there being great changes from one monitoring session to the next. The explanation for this follows, for there was another factor which affected the accuracy of the data. This was highlighted by Hutton *et al.* (1979), who studied the distribution of the load under the normal foot during walking. When the foot makes contact with the floor, the weight through the leg is transmitted to the floor across various areas of the underside of the foot, and due to Newton's Second Law equal and opposite ground reaction forces are produced. As force is a vector, having magnitude, position and direction, the resolving of all the force vectors results with a single ground reaction force vector. Hutton *et al.* used an array of load cells to calculate parts of the ground reaction force vector, which was plotted over time along the imprint of the foot. The ground reaction force vector moves from the heel to the ball and toes of the foot during the stance phase (which is when the foot is in contact with the ground) due to the weight transmitted moving during the stages between heel contact and toe off. Therefore the sampling of the ground reaction force at various intervals during the stance phase results with what is called a 'Butterfly diagram', this being a plot of all the instances of the ground reaction force vector over time during the stance phase, and an example is shown in Figure 3.5 which was obtained using a force plate.

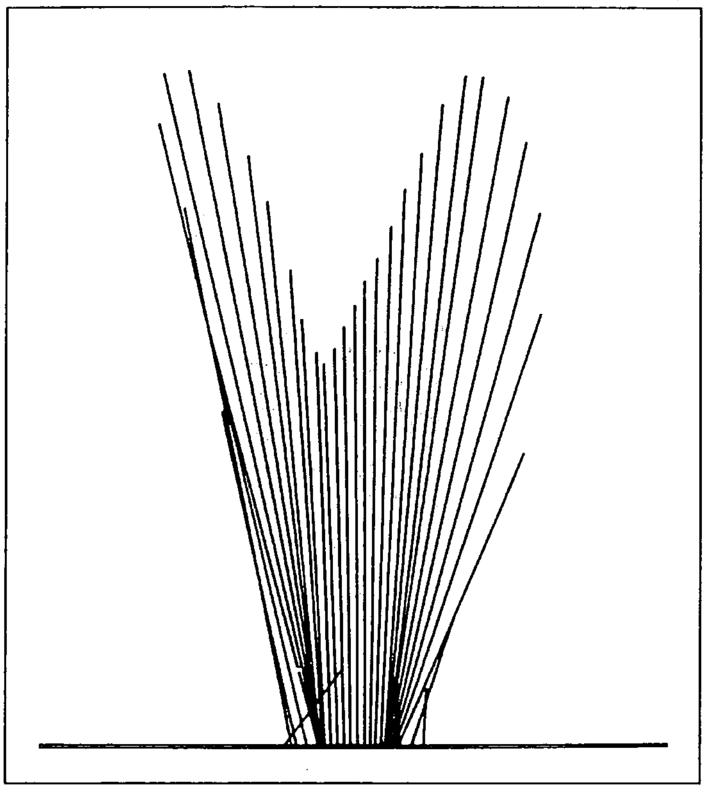


Figure 3.5 - 'Butterfly diagram' of the ground reaction force vector at 20 ms intervals, progression being from left to right (Whittle, 1991).

By using load cells Hutton *et al.* was not able to obtain the direction of the ground reaction force vector but only its position and magnitude. As Figure 3.6 shows, this information was sufficient however to be able to plot the vector's position with time, superimposed over the outline of the foot. By doing this for different subjects, it was discovered that there were quite significant variations in the centre of pressure line, especially when the gait pattern was affected by pathological factors, as in Figure 3.7. For example, with a fractured tibia the heel contact stage might be reduced as well as the toe off stage so that the foot enters the flat foot position immediately on ground contact, leaving the ground during the heel off stage, and so shortening the ground reaction force vector line. Therefore these variations between patients and between monitoring sessions over time for the same patient could result in different weight-bearing readings for the same weight transmitted due to the centre of pressure line being closer to or further away from the transducer underneath the first metatarsal head, since if it were closer then a higher reading would be registered and vice versa.

Therefore it was thought that two pressure transducers were not sufficient for the obtaining of accurate weight-bearing data. The monitor program was therefore modified in order to be able to accept another two transducers, and these were added with the aid of some simple hardware modifications which included the purchasing of another signal conditioning unit. Figure 3.8 shows the new sensory equipment configuration which incorporate both the affixing of the transducers directly to a tubigrip, and increasing the number of transducers to four.

The trials continued using the new configuration, and the subsequent results data found to be satisfactory. This confirmed that the equipment which had been developed is capable of obtaining fairly accurate weight-bearing data.

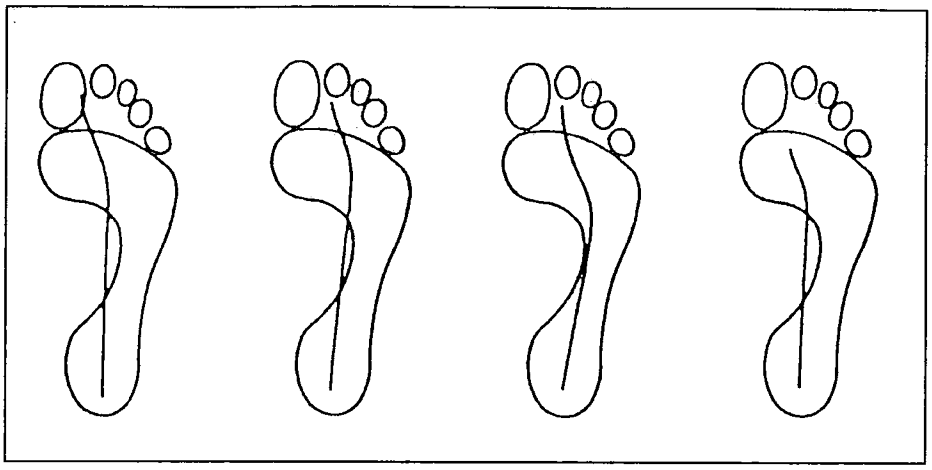


Figure 3.6 - Some examples of the variation seen in the centre of pressure line for normal subjects (Hutton et al., 1979).

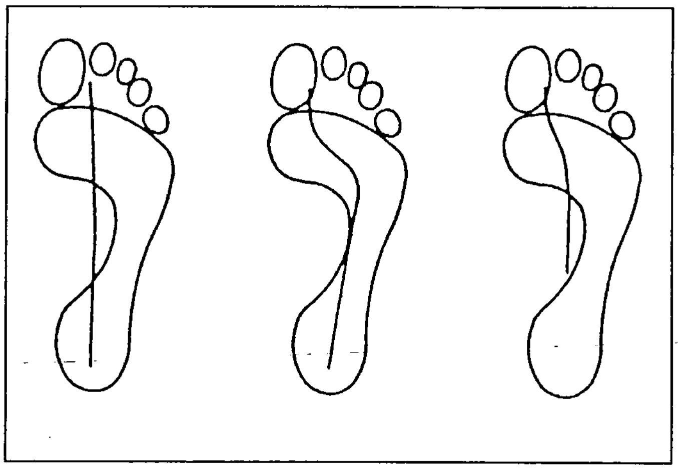


Figure 3.7 - Examples of the variation seen in the centre of pressure line for subjects with pathological gait patterns. The first two diagrams are from patients with rheumatoid arthritis, the third being from a patient with dropfoot (Hutton et al., 1979).

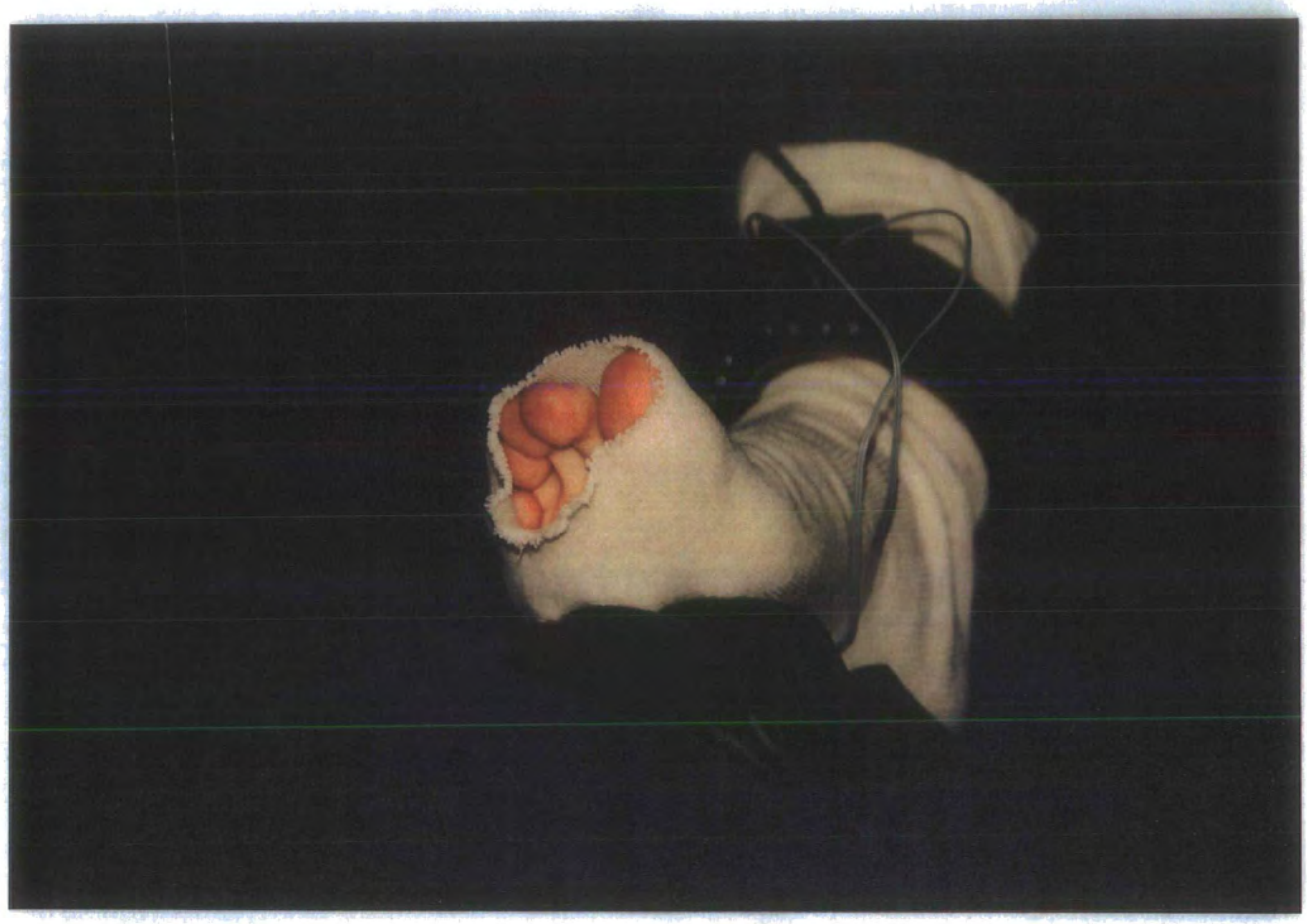


Figure 3.8 - The final sensory equipment configuration.

4. Clinical Trials

4.1. Introduction

The clinical trials took place in Middlesborough General Hospital in parallel with fracture clinic sessions. Two afternoon fracture clinics were attended each week from April 1993 to December 1993 and patients with tibial fractures at these clinics were tested with the ambulatory monitor. Although the fundamentals of the monitoring system were operational in April, further development of the equipment occurred throughout the patient monitoring period.

The procedure for the clinical trials was approved by the Hospital Ethics Committee, as shown in Appendix 2, and was as follows. After having attached the monitoring equipment, the subject was asked to stand with the foot of the fractured leg on a set of bathroom scales and the other foot on the floor. As the scales' reading was the amount of total weight being transmitted through the fractured leg, the scaling values of the monitor's inputs were adjusted until the monitor's reading was identical. During this calibration phase, the operator also visually inspected the way in which the subject was standing on the scales so that an estimate of the weight ratio between the calcaneous and the metatarsal heads would be gained. This was compared to the individual monitor's input readings and further modification of the scaling values occurred as necessary. This calibration now having been performed, the data file was cleared by resetting the monitor, and the subject guided to walk a pre-defined route which was about 250m in length, its geometry being shown by Figure 4.1. At the end of the route, the monitor and sensory equipment was removed from the subject, and the results down-loaded to the PC for analysis and display of the data. If the subject had not been previously tested, then their details were inputted into the PC monitoring program first, with analysis occurring subsequently.

In total 37 different patients were monitored during these sessions. The original plan had been to monitor each patient from the initial weight-bearing period right through to when they were discharged. Each patient could then be categorised according to sex, age and fracture treatment method with the effect of differences within each group and between groups being noted. In practice however, a large number of these patients did not attend subsequent appointments or changed to another fracture clinic session and so further monitoring of such patients was not possible. In fact three or more monitoring sessions were obtained for only 9 of the patients. Seven of these patients' analysis results are detailed below, with a collation of the results following. The other two patients' results are not detailed as both suffered from problems during the development of the instrumentation, due to only two transducers being used.

For each patient there are four graphs plotted; one showing the weight-bearing against time another the other the step duration, or the time that the foot is in contact with the ground, against time; another the time taken to walk the prescribed route against time post-fracture; and the final one the number of events recorded whilst the patient was walking the prescribed route. The values for the second graph have to be calculated as the analysis program's output is the average number of samples which comprise an event. The number of samples was therefore multiplied by the known intersample period to obtain the average step duration. As the processor power down option on the ambulatory monitor program was selected for all the monitoring sessions, by multiplying the value by the known inter-sample period of 0.14 seconds the duration time is obtained. The values for the third graph are obtained by subtracting the time at the first event from that of the last for the monitoring session's Data file. Different patients' third and fourth graphs can be compared with each other because the route prescribed for the monitoring session was the same on every occasion, and so each monitoring session's distance is the same.

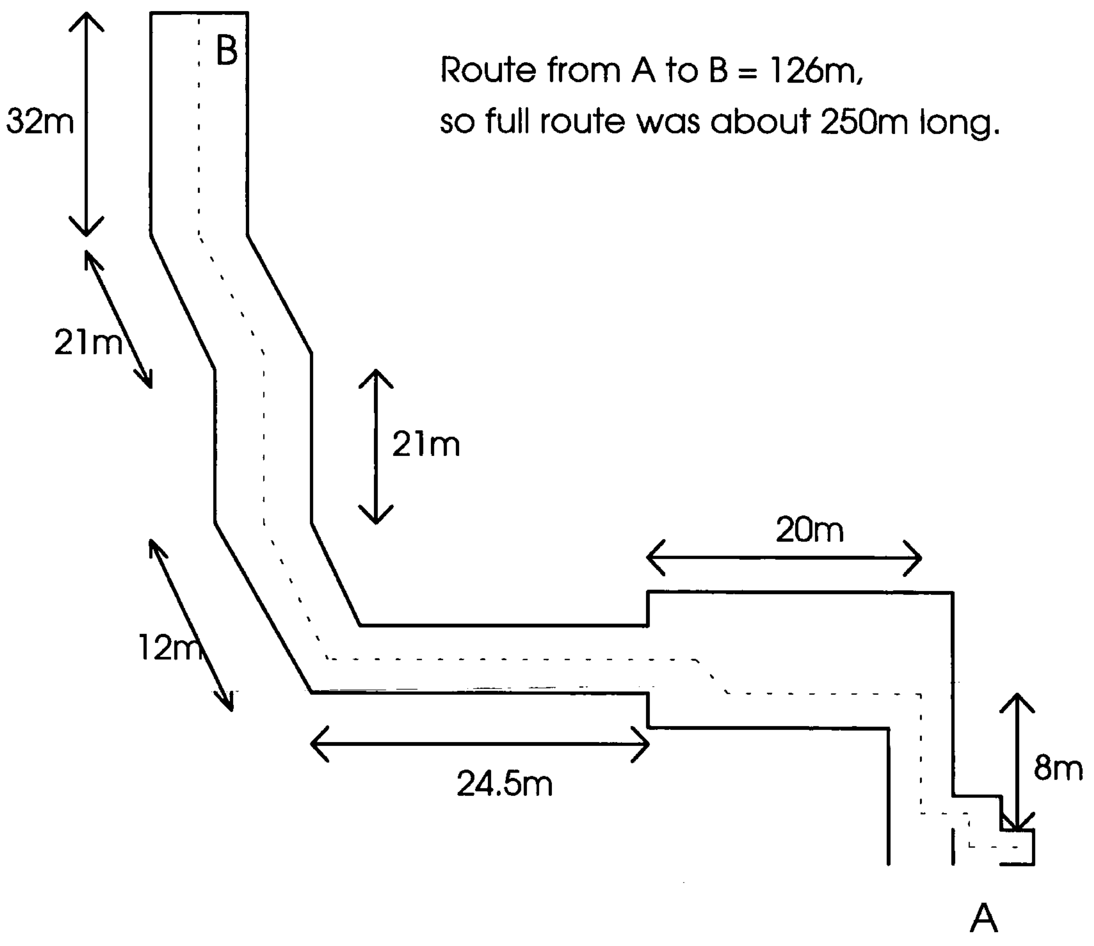


Figure 4.1 - The geometry of the route each patient walked when monitored. The patient walked from A to B, returning to A again.

With both the mean and standard deviation plotted on the first two graphs, a quantitative representation of the weight-bearing and parts of the gait pattern are available. The standard deviation of the weight-bearing quantitatively shows the amount of patient uncertainty and 'testing' of the weight-bearing potential of the fractured leg. The standard deviation of the step duration also quantitatively indicates patient uncertainty in walking, with a high value indicating that the patient was constantly modifying the gait pattern perhaps due to a feeling of instability in the limb. A high value for the weight-bearing standard deviation would normally, but not necessarily, be coupled with a high value for the step duration standard deviation. The monitor therefore provides extra information over visual gait analysis which is valuable in determining the state of the fractured limb.

Before the full patient results are given, the incorrect results for one patient obtained using two transducers are given. These highlight the problems encountered with just using two transducers, which forced the change to monitoring with four described in the previous chapter.

The following 66 year old female patient of weight 528 Newtons was treated with a cast. This is a relatively unusual treatment for an adult and especially elderly patient, but as the patient was very fit with a history of walking and dancing, it was thought unnecessary to use a plate, external fixator or intra-medullary nail even though the fracture was of both the tibia and fibula. The first monitoring session occurred at 14 weeks post-fracture and although a slow pace with a noticeable limp was employed, the recorded average weight-bearing value was 113% of body weight which seemed high. At 19 weeks the patient was again tested and an average weight-bearing reading of 49% of body weight was obtained, this seeming much too low as the patient had by now returned to dancing four times a week. The final reading of 52% of body weight at 23 weeks post-fracture again was too low as the patient was walking unaided for at least a mile each day. The reason why the average weight-bearing and standard deviation values are incorrect, as explained in the previous chapter, is because only two transducers were used. Therefore their accurate positioning is vital as even a slight displacement of a couple of millimetres can result in a large difference in the pressure sensed and thus the weight-bearing value. Also one expects the patient's gait pattern to change in some measure over the healing period, this affecting the position of the centre of pressure line, and therefore altering the pressure sensed by a transducer in the same position as during a previous measurement. These two factors combine together to affect the accuracy of the weight-bearing data when just two pressure transducers are used for monitoring, for ultimately it can only be by chance that the transducer at the metatarsal heads is positioned correctly. The outcome of incorrect positioning is shown below, with an almost inverted average weight-bearing graph, for it should have started at less than 100% of body weight and possibly risen to that value. However all the step duration readings are correct for these are not influenced by the weight-bearing value and therefore incorrect transducer positioning because for all the monitoring sessions an event threshold value of 96 Newtons (ie.10 kg) was used. The fact that the step duration is greater for week 14 than for the other weeks tallies with the observation during the monitoring session that the patient was walking slowly and carefully as the route was further than the patient had walked since the fracture occurred. As the fracture healed the patient become more confident adopting a faster pace of walking which is shown by the lower step duration.

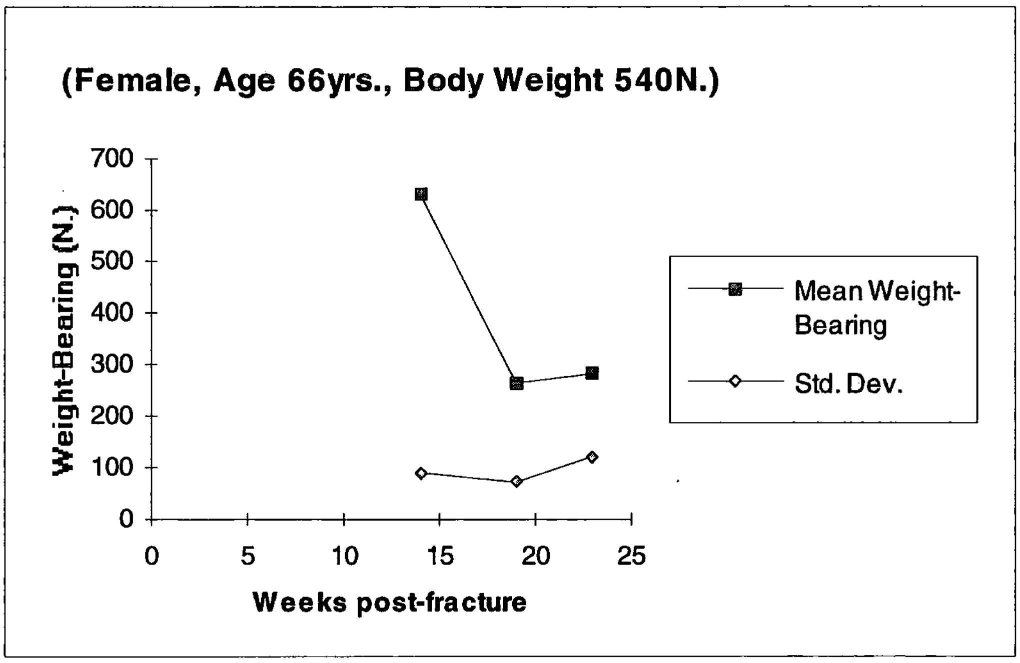


Figure 4.2 - Graphs showing the mean and standard deviation of the weight-bearing with time post-fracture for a patient

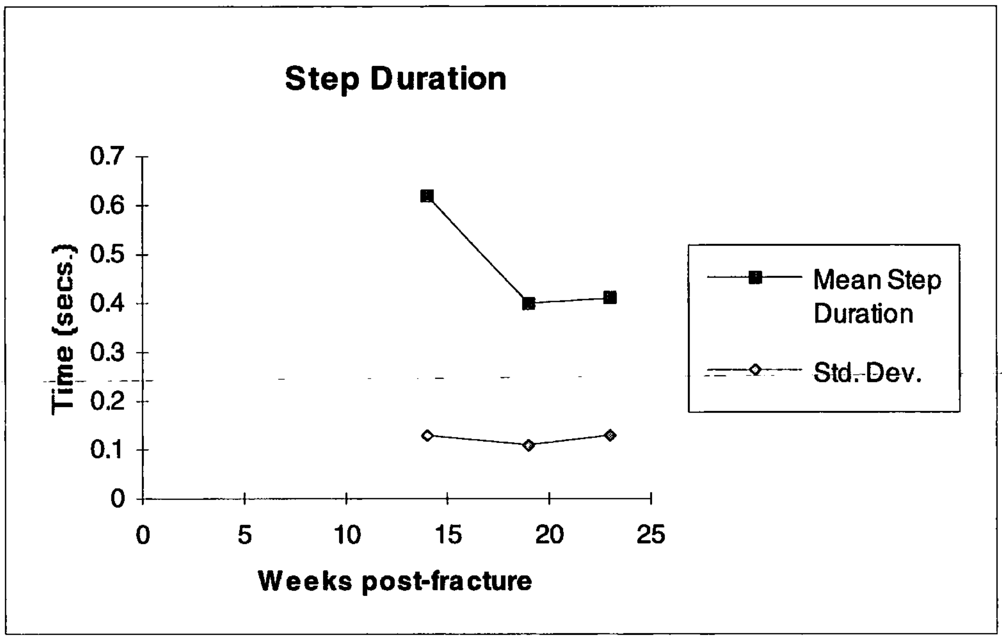


Figure 4.3 - Graph showing the mean step duration with time post-fracture for a patient

4.2. Individual Patient Results

4.2.1. Patient 1

The following patient was a 57 year old male of 72 kg who was treated by an intra-medullary nail for a segmental mid-shaft right tibial fracture. During the monitoring period the mean weight-bearing increased from 19% to 100% of body weight.

Radiographs at week 9 indicated that very little callus had formed, so the patient remained in a non weight-bearing cast. The patient therefore began weight-bearing relatively late at week 17 which accounts for the low weight-bearing value at week 20.

As can be seen in Figure 4.4, a large increase in mean weight-bearing occurred between weeks 24 and 29 post-fracture, this being from 30% to 54% of body weight. The patient was walking with the aid of crutches, and by week 29 the gait pattern was much more fluid and confident, with no perceptible limp, the stiffness and strength of the leg obviously having increased so that the patient felt more confident to increase weight-bearing. This however does not explain the large decrease in step duration recorded during this monitoring session and shown in Figure 4.5. Examining the data obtained from the ambulatory monitor indicated that there was a fault with the monitor software as there was only a small number of events with most being of 1 sample in duration, so explaining the values for week 29 in Figures 4.6 and 4.7. This fault occurred due to the changing of the monitor software during its continuous development and enhancement, so that the previous data was reliable even though the current was not. The fault was rectified after the monitoring session, so that subsequent data was again accurate.

By week 36, the patient was using one stick in opposition, with a slight limp being noticeable. This limp was still apparent at week 40, but the patient confirmed this to be habitual and was consciously trying to rectify this. A stick in opposition was still being used, but not in the house. Excluding week 29, Figure 4.5 shows a general trend towards a longer step duration up to week 40. Examining Figures 4.6 and 4.7 reveals that the velocity and stride length increased up to week 36 post-fracture for the distance traversed was the same for all monitoring sessions, with the stride length increasing still further by week 40. Although the patient was actually using a faster velocity the increased time that the foot was in contact with the floor and the increased stride length indicate a more symmetrical gait pattern as both stance phases tend towards equal length. This must occur as the stride length is increasing due to the fractured leg being more extended as its stance phase has more normal heel contact and foot flat stages, this being indicated by the increasing time that the foot is in contact with the floor. Therefore a perceived increased stability and strength of the leg by the patient is indicated.

Finally by week 44, the patient was walking much more confidently and with greater fluidity without the aid of a stick, the limp having been almost totally eradicated. The velocity was also greater which was shown by the slight decrease in the step duration in Figure 4.5, and the lower session duration in Figure 4.6. Figures 4.6 and 4.7 show a general increase in step duration during the healing period.

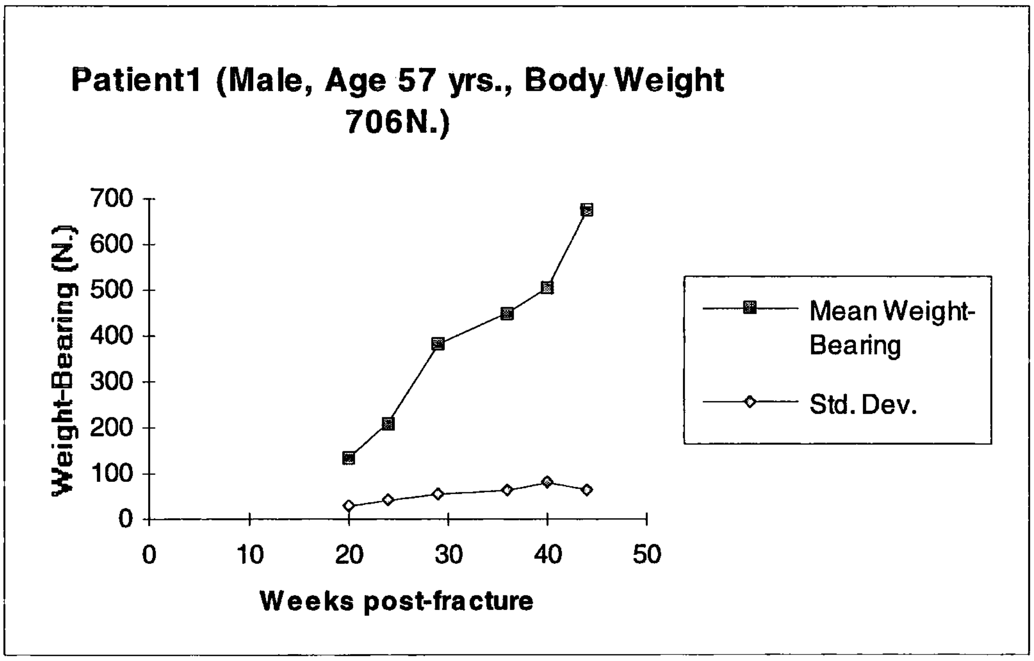


Figure 4.4 - Graphs showing the mean and standard deviation of the weight-bearing with time post-fracture for a Patient 1

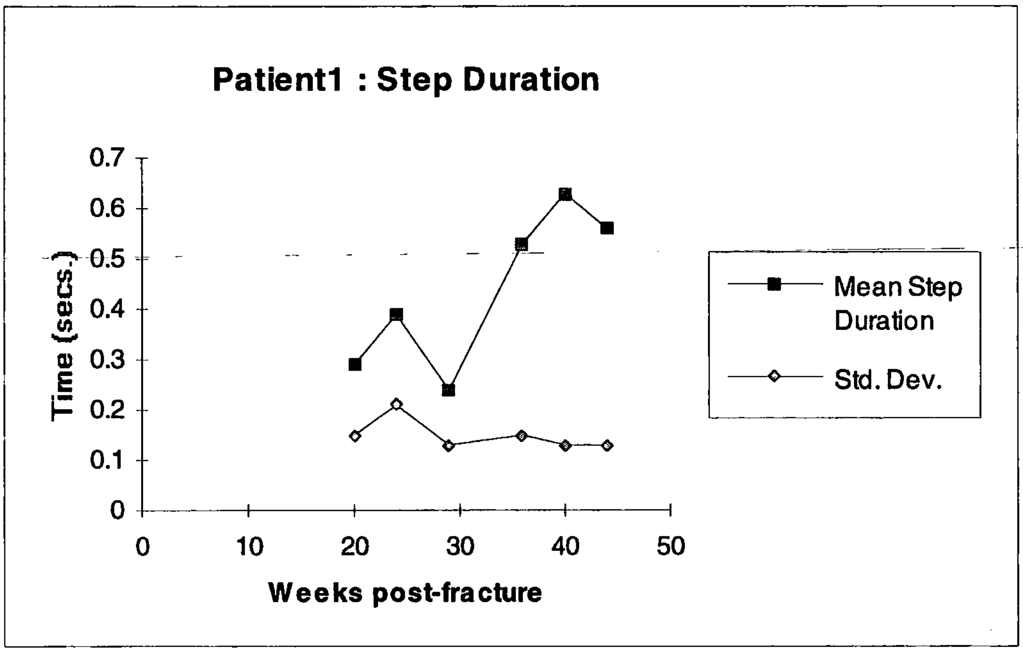


Figure 4.5 - Graphs showing the step duration with time post-fracture for Patient 1

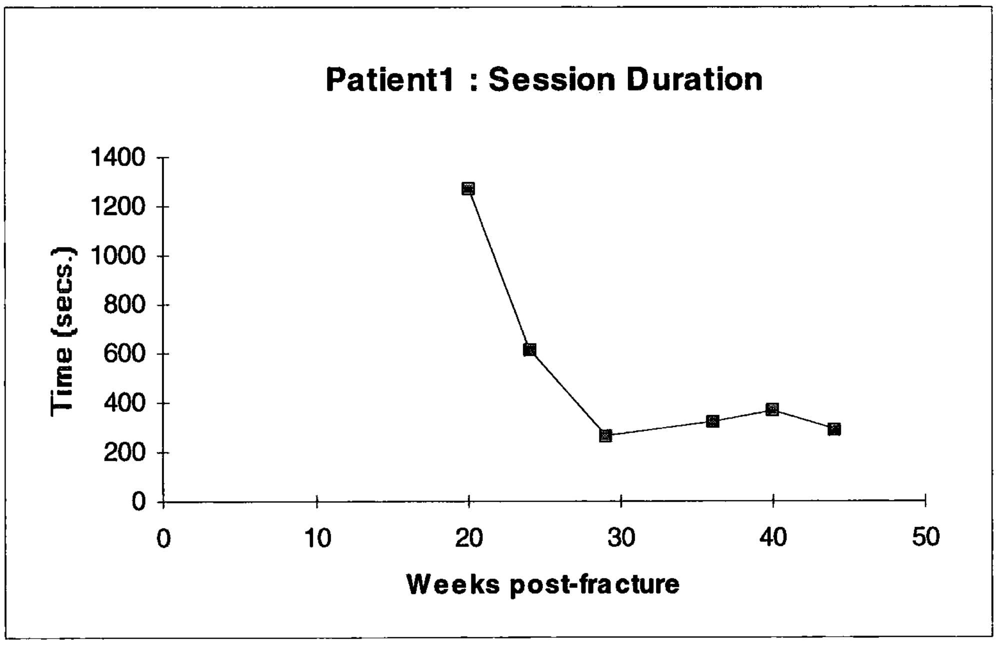


Figure 4.6 - Graph showing the monitoring sessions' duration with time post-fracture for Patient 1

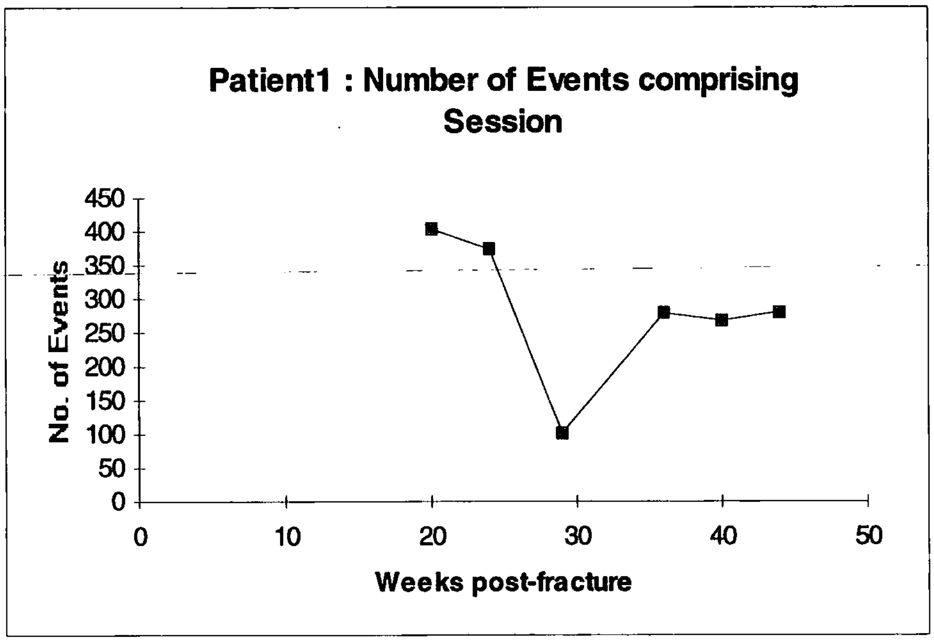


Figure 4.7 - Graph showing the number of events for a session with time post-fracture for Patient 1

4.2.2. Patient 2

This patient was a 61 year old female of 63 kg who was fit and was treated by an external fixator for a comminuted proximal tibial fracture of the left leg. Five monitoring sessions occurred between weeks 37 and 49 post-fracture. The long healing time for the fracture was probably due to it having been initially treated conservatively with a non weight-bearing plaster and due to this not providing satisfactory results, changing the treatment method to an external fixator.

By week 3 post-fracture the X-rays showed that early callus formation was occurring, and at week 6 the plaster was changed to a walking plaster. However at week 10 the X-rays indicated that no bony union had taken place, and although X-rays for subsequent weeks indicated the union as progressing, by week 28 a slight movement at the fracture site was observable even though the radiographs revealed a bridging of bone across the fracture site. Therefore at week 33 an external fixator was applied to provide a more stable and stiffer reduction of the fracture to facilitate its healing.

The monitoring session at week 37 recorded the first time the patient was weight-bearing since the operation to apply the fixator. This resulted in the higher standard deviation reading of Figure 4.8, as the patient was unsteady in her steps. It also resulted in a long average step duration and high standard deviation shown in Figure 4.9, indicating that the patient walked with slower steps and again with more uncertainty and unsteadiness, the relatively small velocity being shown by the long duration of the standard walking circuit in Figure 4.10.

It is interesting to see the weight-bearing value decreasing from 57% to 48% by week 42. This was due to the patient adopting a three-point swing through gait pattern with the crutches (Whittle, 1991), which decreases the weight-bearing as the weight is transmitted through both the legs during the stance phase of the gait cycle, even though the patient was walking with greater confidence. This is also shown by the large decrease in step duration, and the low standard deviation value indicating that this gait pattern had become habitual to the patient. Figure 4.10 shows that the patient was actually walking with the greatest velocity of all the monitoring sessions that took place.

By week 45 the average weight-bearing had decreased further to 32% of body weight. The pin tracts had become infected two weeks previously which caused discomfort during weight-bearing and also resulted with a limp which had not been noticed previously. To minimise this discomfort and pain the patient therefore automatically reduced the weight-bearing, one indication of this being the adopted limping gait pattern, another being the decreased step duration, as the time when weight-bearing occurred was decreased. This had the effect of decreasing the velocity, shown by the increase in time taken in Figure 4.10, and Figure 4.11 shows the stride length being decreased as more steps were taken to finish the route.

The infection was treated by a course of antibiotics, and the external fixator was removed the following week and the patient again monitored, the equipment indicating an average weight-bearing of 34% of body weight. During this session, the patient walked with the aid of crutches and with a noticeable limp. The removal of the fixator decreased the total stiffness of the leg and so increased the perceived instability of the fracture. This is shown in this instance by the higher weight-bearing standard deviation value, the decreased step duration and the high standard deviation value of the step duration.

The above statements are supported by the step duration increasing at the last monitoring session because the fracture had become more rigid as the healing progressed, the patient herself indicating that the leg felt stronger. Also the weight-bearing standard deviation value is greatly decreased as the gait pattern adopted changed to being more uniform. However the most conclusive datum is the average weight-bearing for week 49, which shows a large increase to 52% of body weight. Nevertheless this is actually a relatively low weight-bearing value, which was due to the patient becoming accustomed to using the three-point swing through gait pattern with the crutches which decreases the weight-bearing.

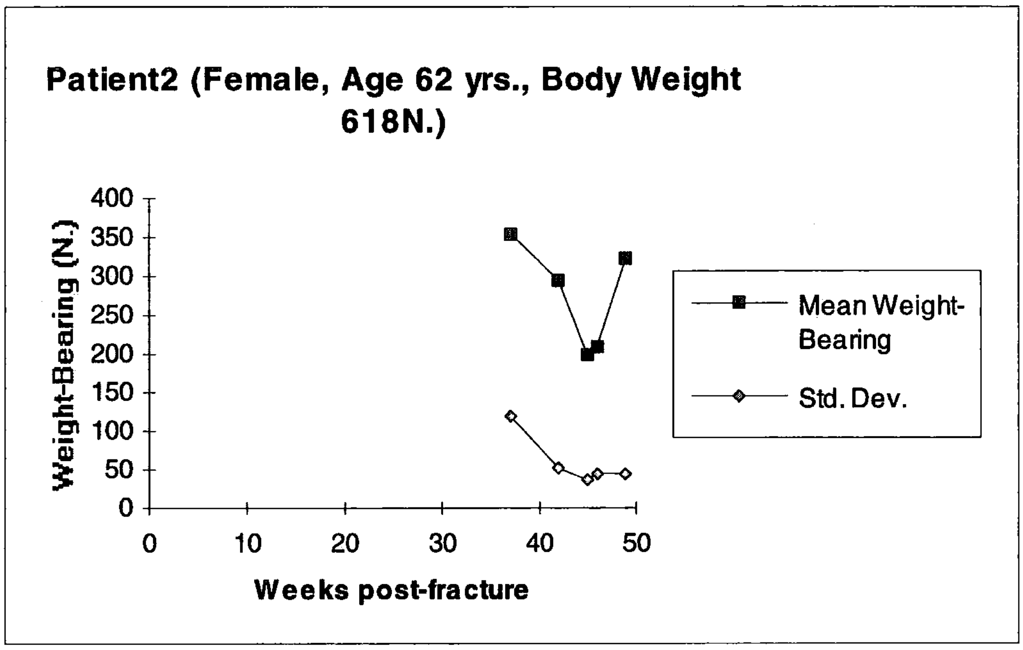


Figure 4.8 - Graphs showing the mean and standard deviation of the weight-bearing with time post-fracture for Patient 2

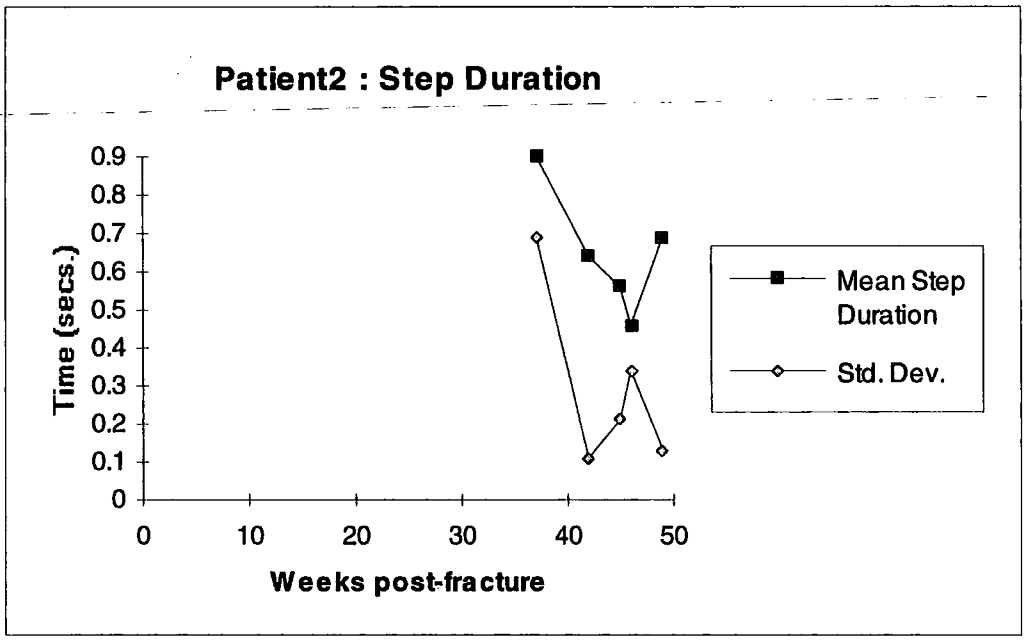


Figure 4.9 - Graphs showing the step duration with time post-fracture for Patient 2

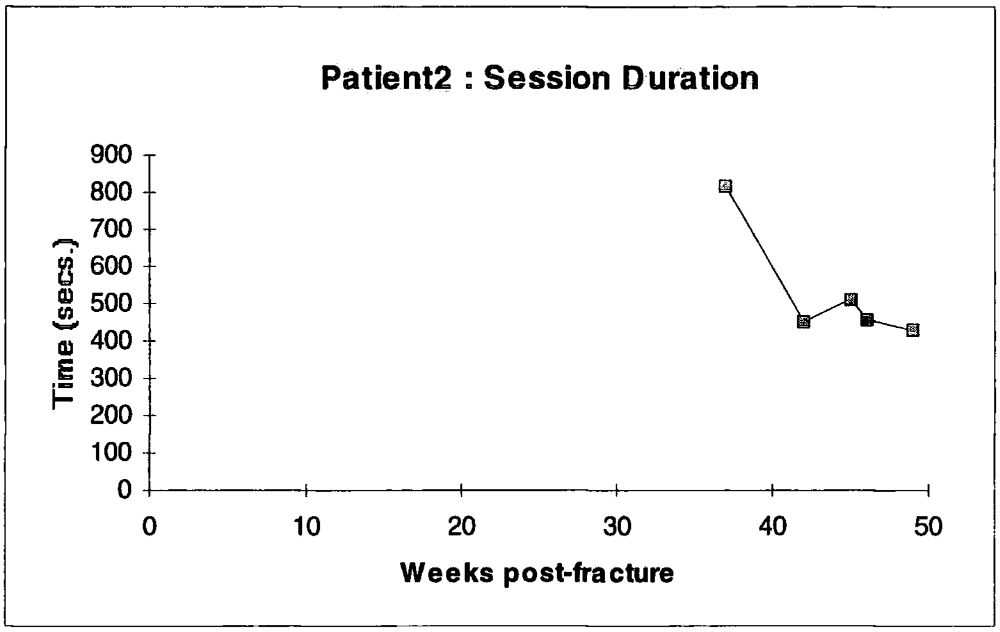


Figure 4.10 - Graph showing the monitoring sessions' duration with time post-fracture for Patient 2

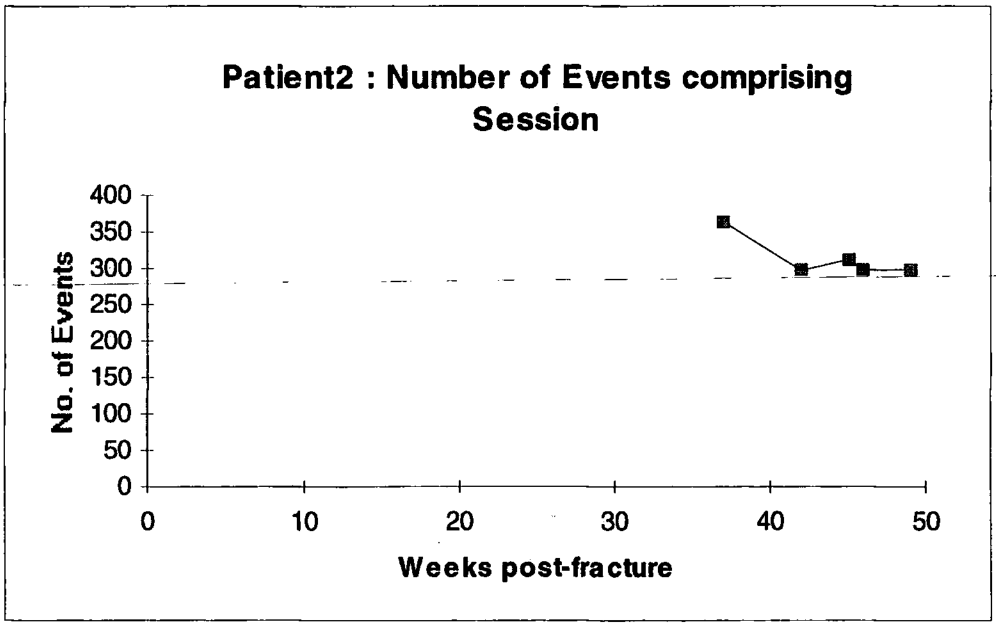


Figure 4.11 - Graph showing the number of events for a session with time post-fracture for Patient 2

4.2.3. Patient 3

This 43 year old male patient of mass 83 kg was treated with a buttress plate. The fracture was a comminuted displaced mid-shaft fracture of the left tibia. The use of a buttress plate resulted in a fracture which was as stiff or stiffer than other treatment methods (Mow *et al.*, 1991). This effect is shown by the greater weight-bearing recorded at a relatively short time post-fracture. Unfortunately this patient's monitoring sessions occurred at the start of the monitoring period and so only two pressure transducers were used. The mean weight-bearing data from these last two monitoring sessions again illustrate the problems that occur with using only two pressure transducers.

The monitoring session at 5 weeks post fracture recorded the first time the patient bore weight since the time of fracture, an average weight-bearing of 20% of body weight being measured as shown in Figure 4.12. Unlike the other patients, this patient immediately adopted a regular gait pattern as was indicated by the low weight-bearing and step duration standard deviation values. By week 8, when the X-rays showed evidence of fracture union, the patient was walking regularly with the aid of a stick in opposition, recording a reading of 104% of body weight which seems slightly high considering the early stage in fracture healing. By week 15 the patient was walking confidently without the aid of the stick and with a slight limp. The recorded average weight-bearing reading was 72% of body weight.

The fairly constant weight-bearing standard deviation value might indicate that the patient started and continued using their normal gait pattern. This is corroborated by Figure 4.13 which shows that the mean step duration for each monitoring session is fairly constant, at slightly over 0.5 seconds, with the standard deviation being comparatively low at about 0.14 seconds. The first session's higher value is understandable due to it being the patient's first weight-bearing occasion since fracture.

fracture. However the decreases in Figures 4.14 and 4.15 show that a gradual increase in velocity of gait and stride length occurred with time post-fracture, and if the same gait pattern were being used a decrease in the mean step duration should be visible. Therefore some increase in the step duration relative to the gait cycle time must have occurred, but in relation to other patients it was relatively small.

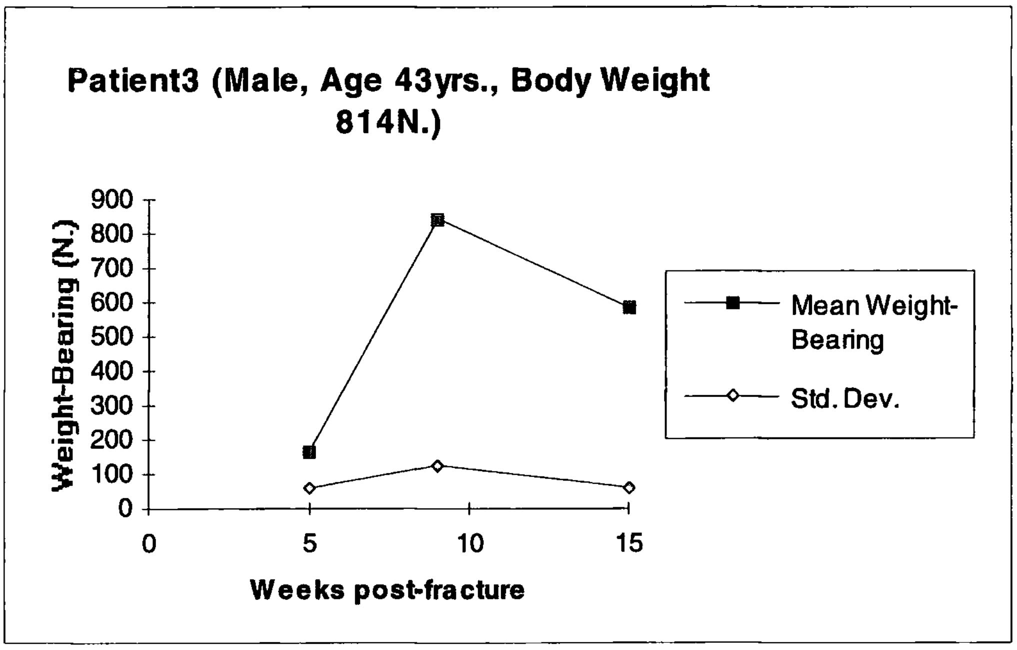


Figure 4.12 - Graphs showing the mean and standard deviation of the weight-bearing with time post-fracture for Patient 3

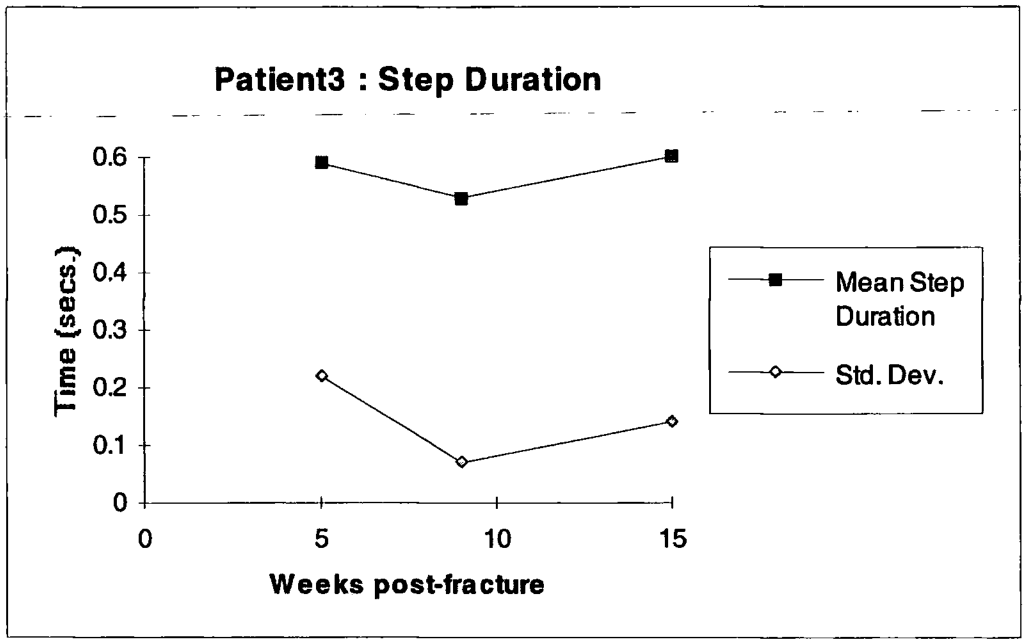


Figure 4.13 - Graphs showing step duration with time post-fracture for Patient 3

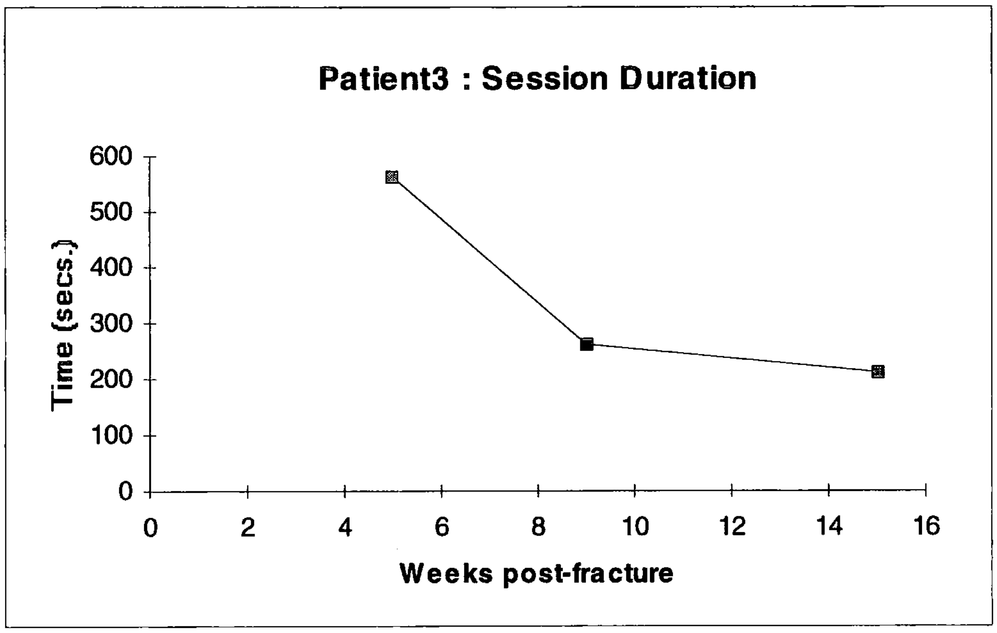


Figure 4.14 - Graph showing the monitoring sessions' duration with time post-fracture for Patient 3

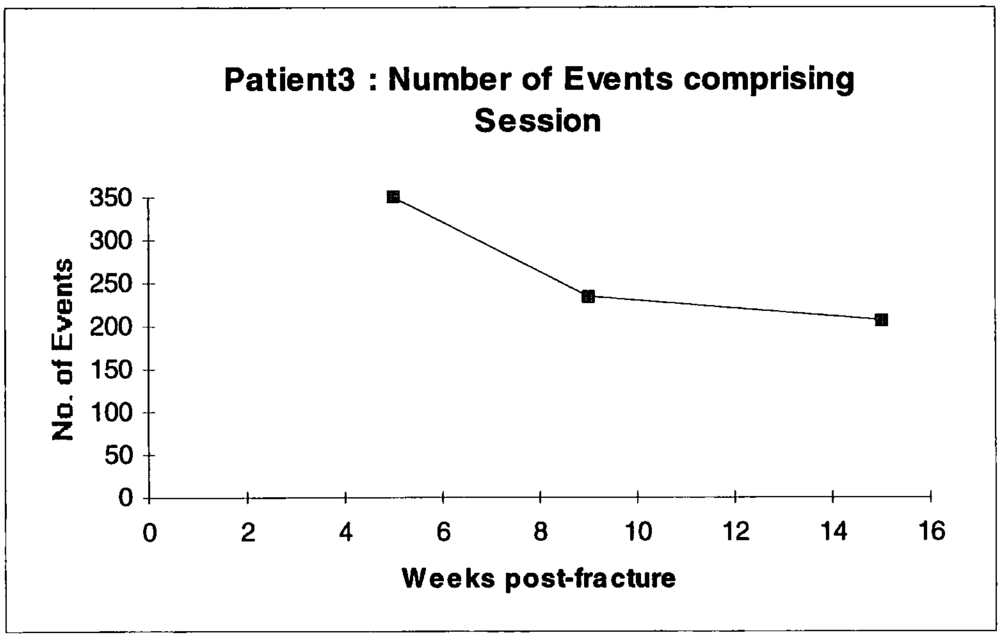


Figure 4.15 - Graph showing the number of events for a session with time post-fracture for Patient 3

4.2.4. Patient 4

This 74 year old male patient of mass 62 kg had a spiral mid-shaft fracture of the left tibia, and was treated with a compression plate.

By the time of the first monitoring session at week 14, the patient was walking unaided apart from a stick in opposition. The weight-bearing value of 53% of body weight recorded for this session as shown in Figure 4.16 therefore seems low. Examining the actual monitor data reveals that a number of events have a duration of 1 sample. This occurred due to the same software error as for patient 1 at week 29 as these monitoring sessions occurred during the same fracture clinic. This explains the high step duration standard deviation and possibly the low mean step duration in Figure 4.17.

The subsequent monitoring sessions' readings of 95% of body weight at 19 weeks and 90% of body weight at 35 weeks are more reasonable. The decreasing standard deviation values, from about 10 to 5 indicate that the patient was easing into a more normal gait pattern over this period of healing. This view is further corroborated by the average duration for each event increasing over time and the number of events decreasing in Figure 4.19 for the same session duration shown in Figure 4.18. These indicate that the patient was gradually using a more symmetrical and normal gait pattern for the stride length increased by the stance phase of the fractured leg becoming more normal, therefore causing both stance phases of the gait cycle to become more equal in duration.

The relatively high step duration standard deviation at week 35 was due to the patient having to occasionally stop when walking due to obstructing groups of people which explains the higher session duration and higher number of events as the patient had to stand still at various times, these of course being recorded as events. By again examining the actual monitor data, it can be seen that in fact most of the events' duration is 5 samples or 0.7 seconds, leading to a low standard deviation value if the few long duration events are omitted.

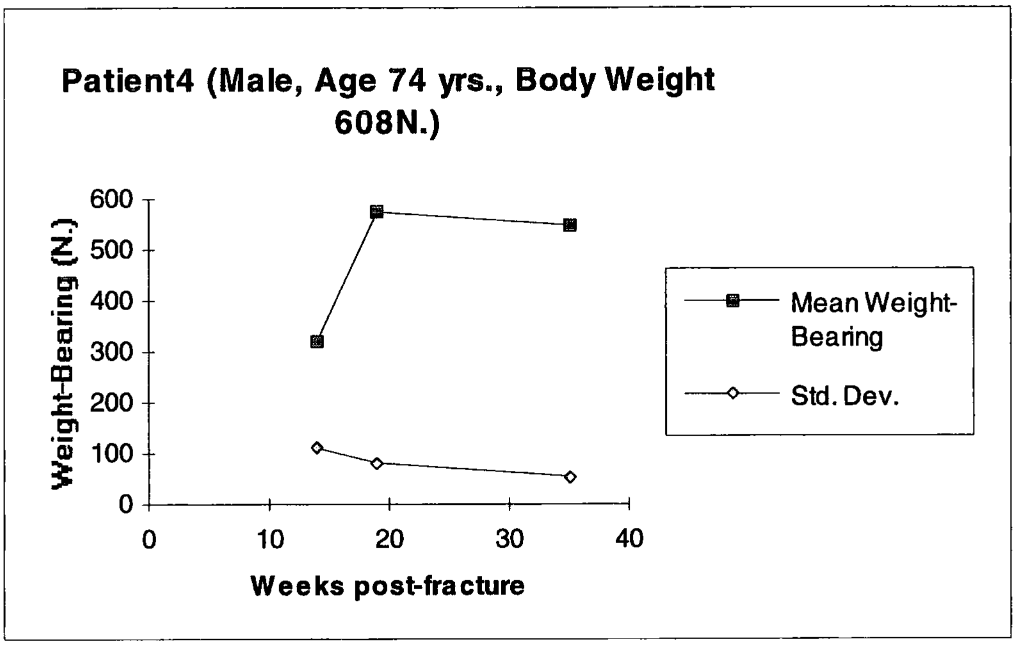


Figure 4.16 - Graphs showing the mean and standard deviation of the weight-bearing with time post-fracture for Patient 4

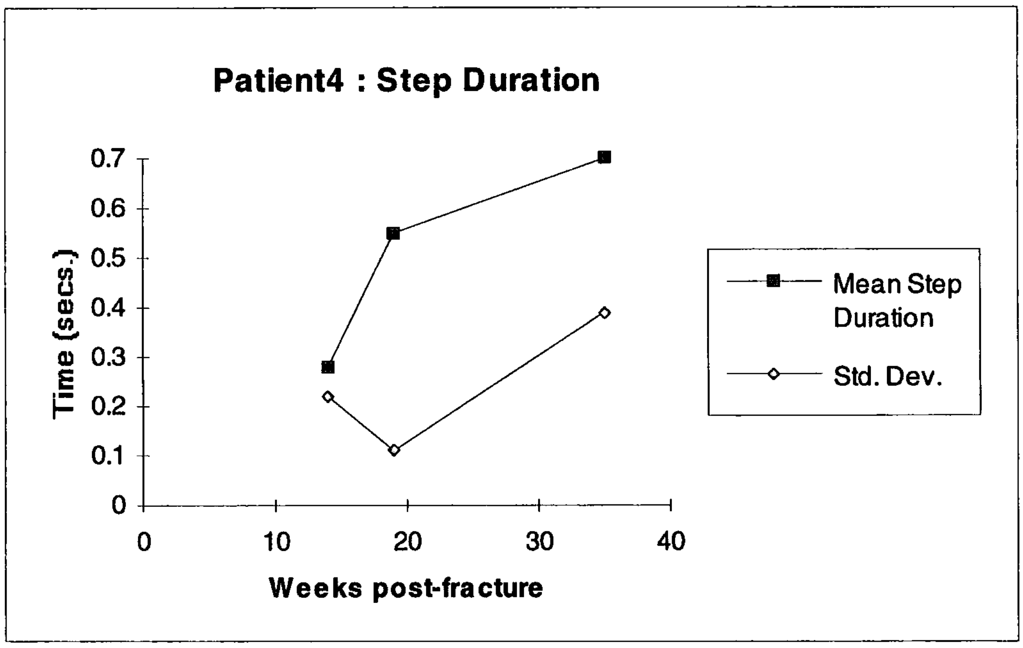


Figure 4.17 - Graphs showing the step duration with the time post-fracture for Patient 4

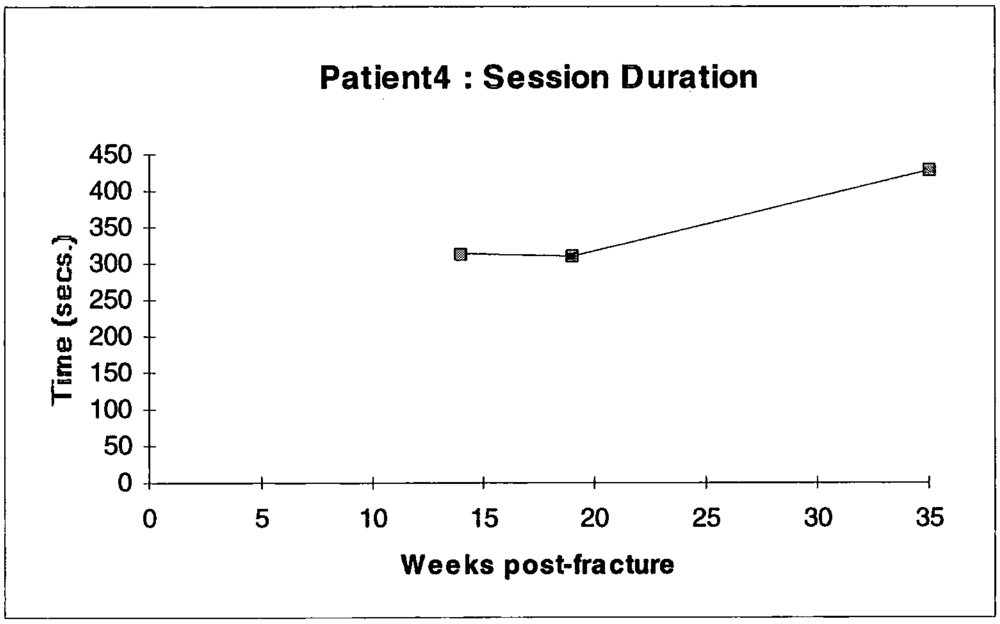


Figure 4.18 - Graph showing the monitoring sessions' duration with time post-fracture for Patient 4

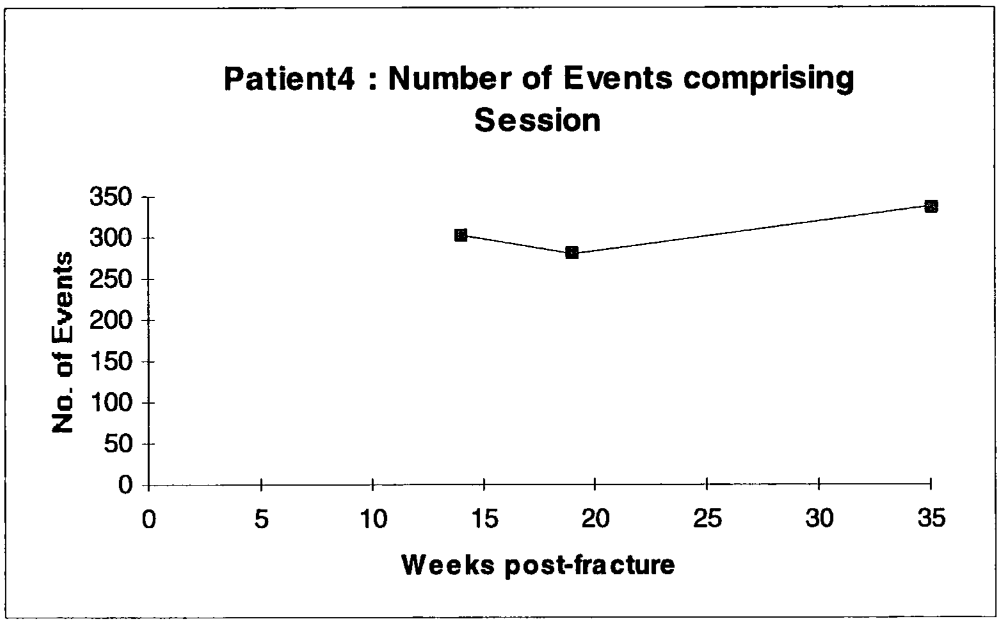


Figure 4.19 - Graph showing the number of events for a session with time post-fracture for Patient 4

4.2.5. Patient 5

This 17 year old male patient of mass 75 kg sustained a compound comminuted mid-shaft fracture of the left tibia, and was treated with an intra-medullary nail.

For the first monitoring session at week 8 post fracture, the patient had stopped using crutches and sticks, the long leg plaster had just been removed and a brace being worn instead for this and all the subsequent sessions. A 56% of body weight average weight-bearing value was recorded for this session as shown in Figure 4.20, this being the first time the patient was weight-bearing without a plaster. Even though the patient compensated for this with less weight-bearing, the standard deviation values are small, signifying that the patient was confident about walking with minimal unsteadiness in the fractured limb because an unvarying gait pattern was adopted. This is also shown by the step duration mean in Figure 4.21 being fairly constant throughout all the monitoring sessions, and the standard deviation being relatively low, apart from the results at week 24 post-fracture.

However this does not mean that a normal gait pattern was adopted for Figures 4.22 and 4.23 show a decreasing session duration and less number of events for the session. Therefore an increased stride length and relative step duration occurs implying that the stance phase is modified but not to the same degree as with the other patients for the real step duration increases only slightly.

By week 13 the average weight-bearing had increased to 90% of body weight, the patient walking with a slight limp. The final two sessions at weeks 18 and weeks 24 recording average values of 81% and 83% of body weight respectively which seem low even though the interlocking screws of the nail had by this time been removed. The abnormally high step duration standard deviation for week 24 is explained by examining the monitor data, for this reveals the patient stood still a number of times during the monitoring session, as indicated by the increased session duration. The route normally walked was obstructed and so was cut short, explaining the lower number of events for this session.

The continual increase in step duration, velocity and stride length indicates that as the fracture healed, the patient adopted a more uniform and regular gait pattern for the leg could transmit more weight and was stiffer.

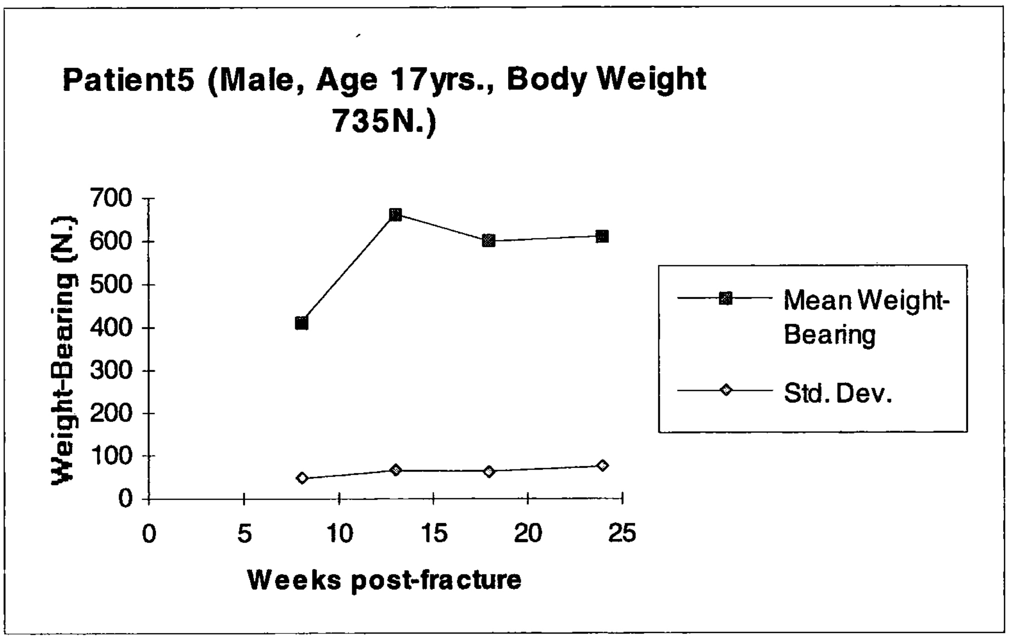


Figure 4.20 - Graphs showing the mean and standard deviation of the weight-bearing with time post-fracture for Patient 5

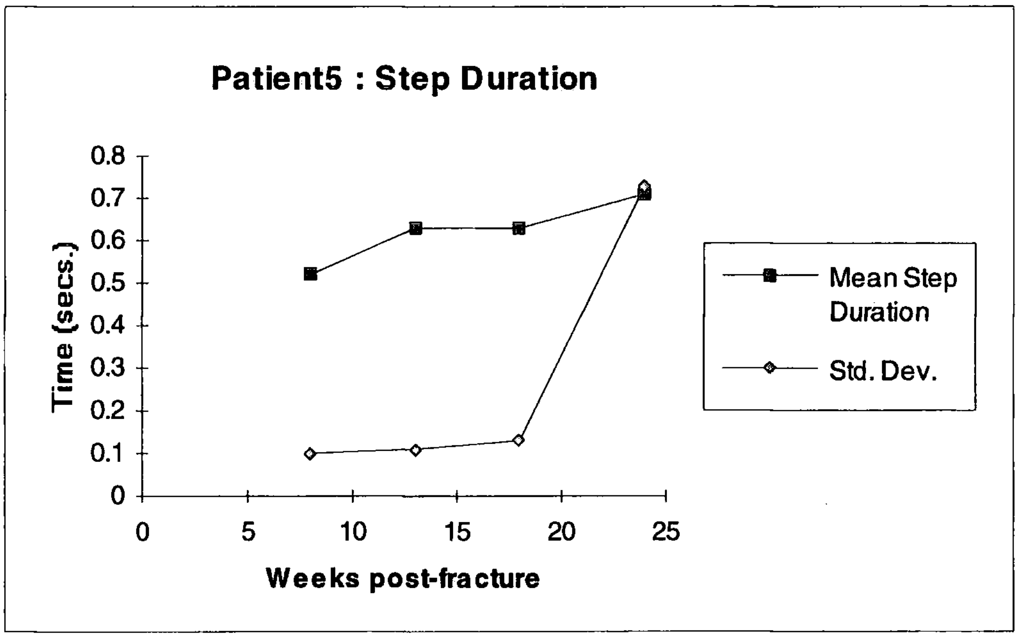


Figure 4.21 - Graphs showing the step duration with time post-fracture for Patient 5

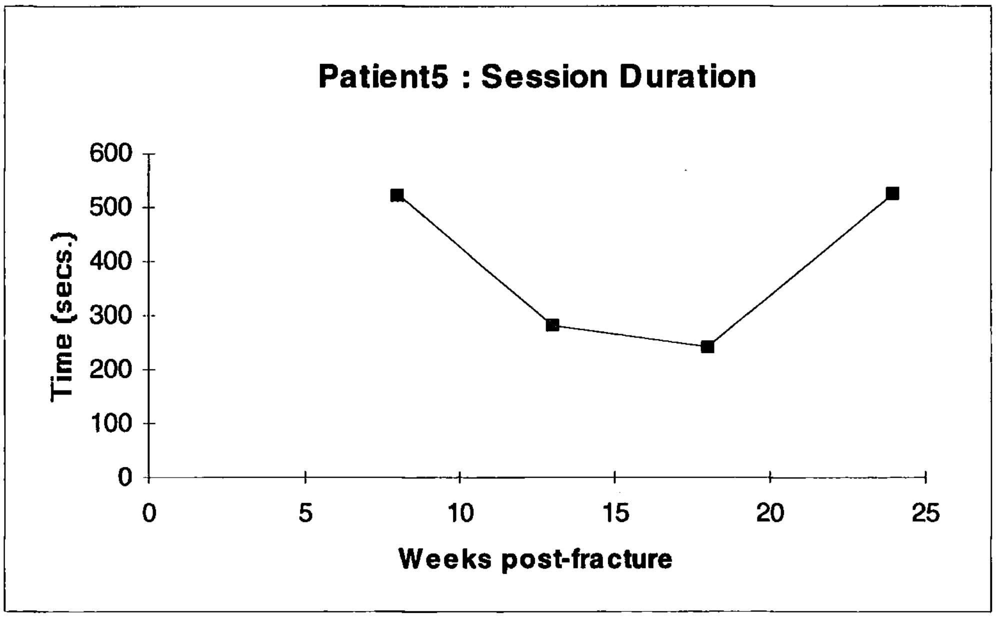


Figure 4.22 - Graph showing the monitoring sessions' duration with time post-fracture for Patient 5

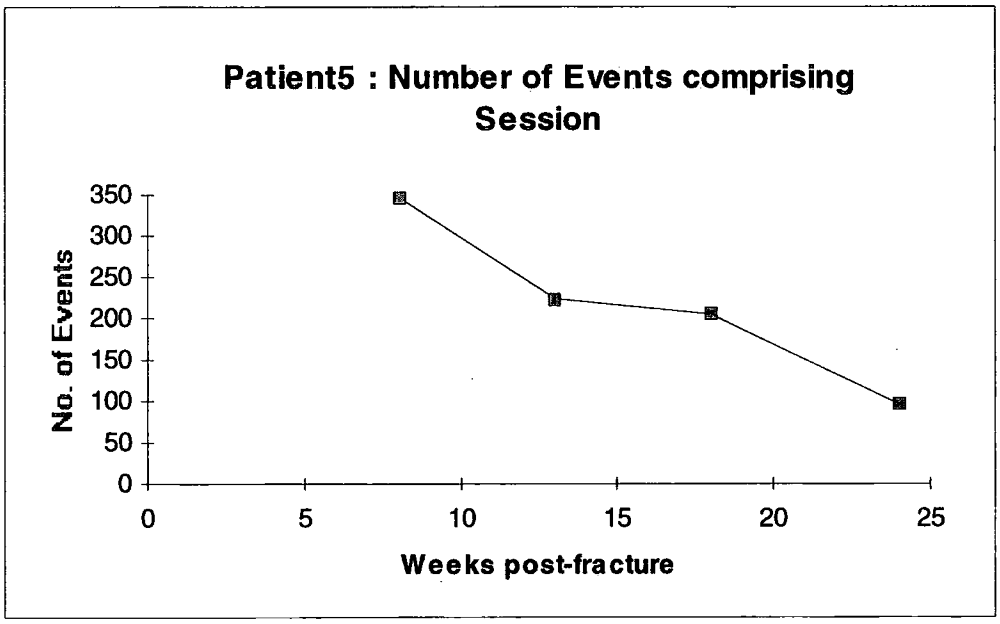


Figure 4.23 - Graph showing the number of events for a session with time post-fracture for Patient 5

4.2.6. Patient 6

This 27 year old male patient of mass 67 kg sustained a displaced mid-shaft fracture of the left tibia, and was treated with an external fixator.

For the monitoring session at week 6 the patient was using crutches and was weight-bearing for the first time. This is perhaps why a low 34% body weight average weight-bearing in Figure 4.24 and the long average step duration and standard deviation in Figure 4.25 were measured, as the patient walked slowly and carefully using the crutches to minimise the weight-bearing on the fractured leg. This is shown by Figure 4.26, with the carefulness when walking being indicated by the large number of events in Figure 4.27.

At week 10 post-fracture the fixator was dynamised as radiographs indicated that a satisfactory amount of callus was present. The monitoring session for that week recorded an average weight-bearing of 82% of body weight, with the patient walking more quickly and with greater confidence, whilst still using crutches. This is shown by the lower mean step duration and greatly decreased session duration and number of events. Although the patient walked more quickly than Patient 2 on their second monitoring session, as seen by comparing Figure 4.10 with Figure 4.26, the mean duration of each step was slightly higher, indicating that this patient was walking with a more natural and symmetrical gait pattern.

By week 27, the fixator had already been removed a month prior to this session, the radiographs showed evidence of union. For this session the patient was walking normally and without crutches. The low weight-bearing and step duration standard deviations indicate a regular gait pattern, with the relatively long step duration and fast pace of walking adopted indicating a normal gait pattern. This implies that the leg had healed to such a degree that it was of sufficient stiffness to permit (almost) normal loading.

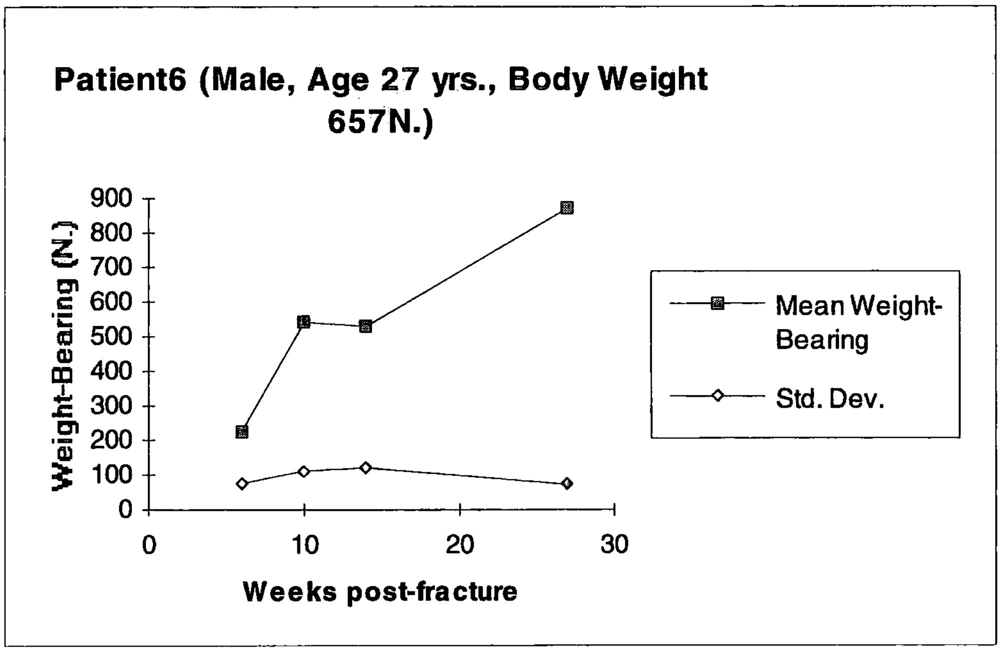


Figure 4.24 - Graphs showing the mean and standard deviation of the weight-bearing with time post-fracture for Patient 6

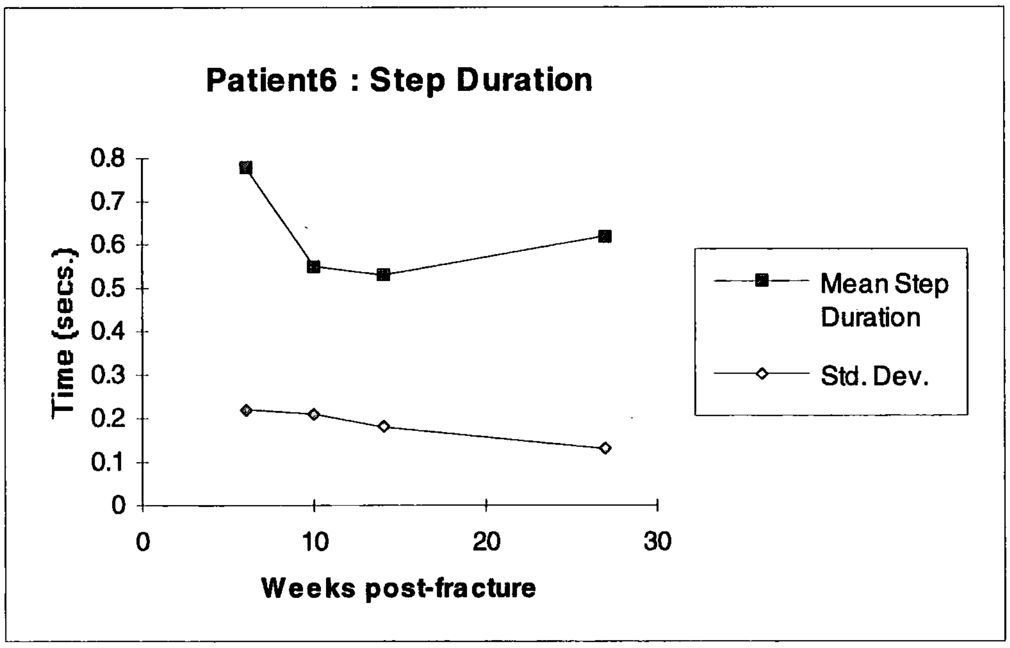


Figure 4.25 - Graphs showing the step duration with time post-fracture for Patient 6

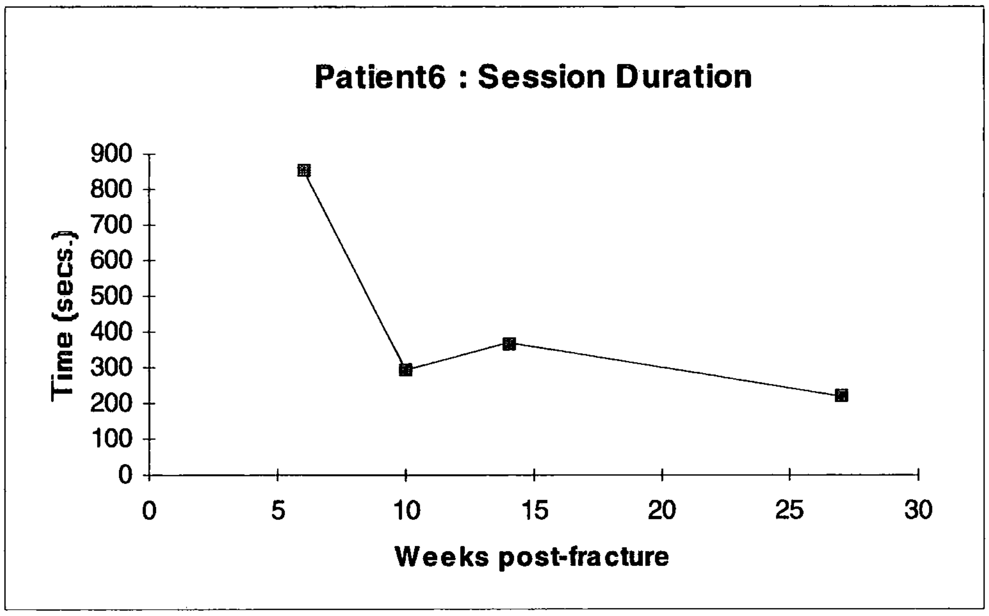


Figure 4.26 - Graph showing the monitoring sessions' duration with time post-fracture for Patient 6

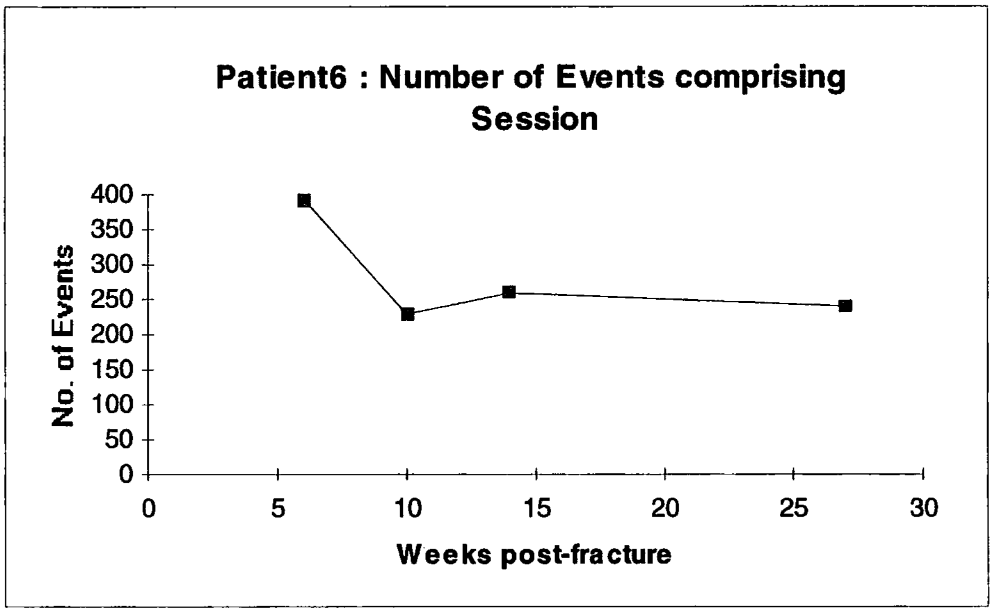


Figure 4.27 - Graph showing the number of events for a session with time post-fracture for Patient 6

4.2.7. Patient 7

This 60 year old male patient of mass 85 kg was treated with an external fixator for a non-union of a previous compound comminuted fracture.

For the first monitoring session at 17 weeks post fracture the patient had the external fixator removed but was still using crutches. This accounted for the low 57% of body weight weight-bearing average recorded and shown in Figure 4.28. The higher weight-bearing and step duration standard deviations shown in Figures 4.28 and 4.29 are probably due to the patient not being confident in weight-bearing on the fractured leg, due to the fixator having been dynamised just before the monitoring session. The higher session duration in Figure 4.30 and greater number of events for that session in Figure 4.31 support this.

The crutches were discarded by week 19, with a corresponding increase in the average weight-bearing to 91% body weight. By week 25, the average weight-bearing was 94% body weight with a corresponding increase in the average duration for each event as the patient resumed a normal gait pattern, as shown by the higher walking speed and stride length.

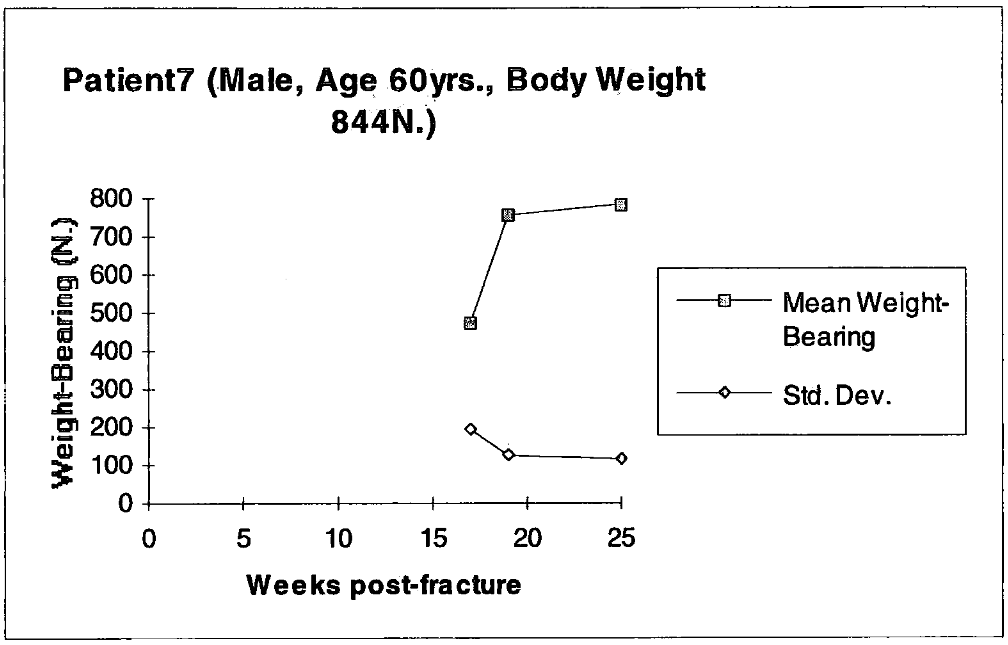


Figure 4.28 - Graphs showing the mean and standard deviation of the weight-bearing with time post-fracture for Patient 7

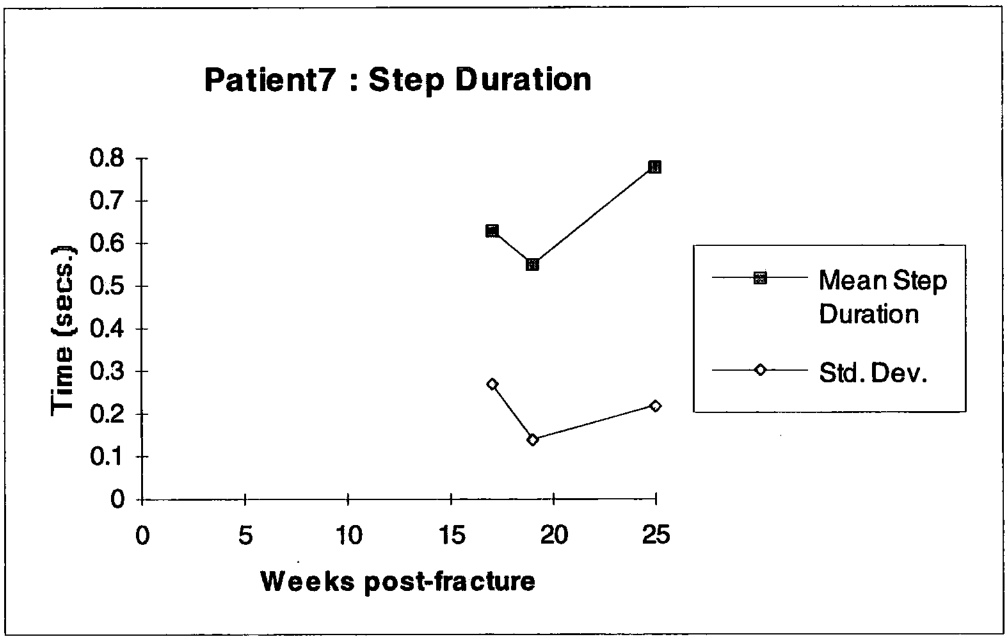


Figure 4.29 - Graphs showing the step duration with the time post-fracture for Patient 7

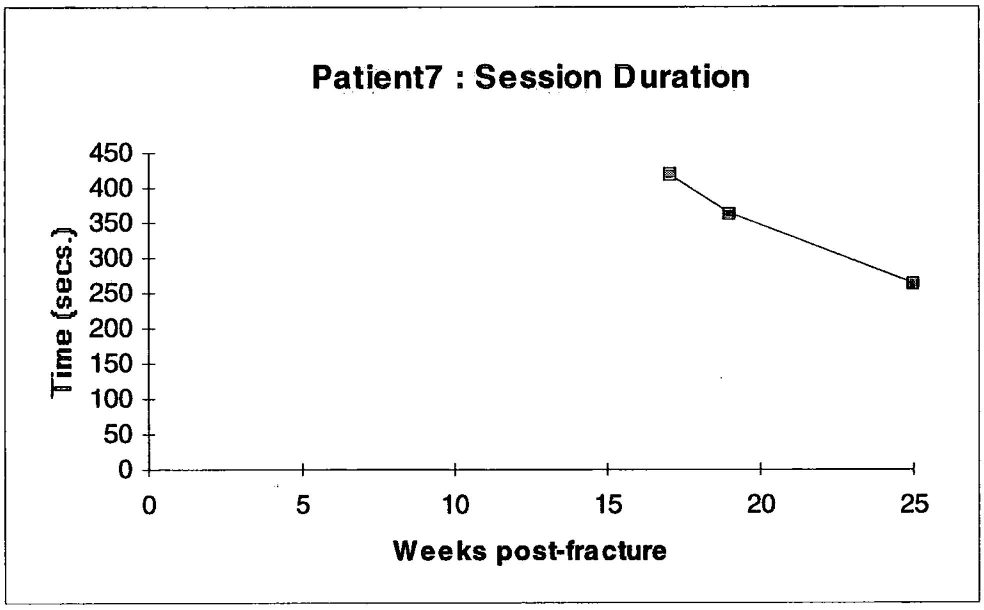


Figure 4.30 - Graph showing the monitoring sessions' duration with time post-fracture for Patient 7

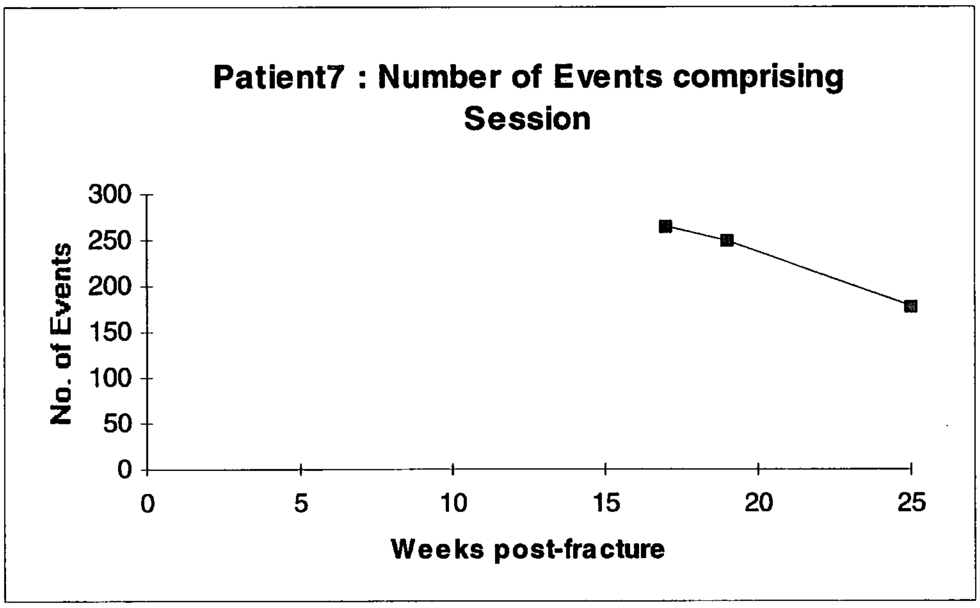


Figure 4.31 - Graph showing the number of events for a session with time post-fracture for Patient 7

4.3. Group Results

It was first envisaged that group result bar charts could be constructed for the different categories of fracture and fracture treatment method, however the lack of patient data precluded this occurring. Therefore only the general results and the children's, adults', and elderly adults' results follow. The results are presented as the mean of all the patients' average weight-bearing value, with the standard deviation of this mean also being shown.

4.3.1. General Patients' Results

Figure 4.31 below shows the mean weight-bearing results for all the patients regardless of age, sex, treatment method or type of fracture. Even though these factors which affect the rate of fracture stiffness over time and so weight-bearing are not considered, it can be seen that there is a general trend of increased weight-bearing up to week 28 post-fracture.

Keeping in mind the fact that only a small data set was obtained therefore possibly causing abnormalities in the group results, the following observations from the results are noted. The increasing weight-bearing over time does not seem to be linear with time post-fracture. Weeks 4 to 14 post-fracture seems to indicate a linear increase in weight-bearing. Week 14 to 24 seems to show a fairly constant mean weight-bearing value, with weeks 24 to 28 showing a large linear increase in mean weight-bearing. Week 36 onwards show the results for patients with delayed fracture union, with an increase in mean weight-bearing over time being observable.

Biologically, these times post fracture tie in with certain stages of fracture healing. Week 14 occurs in the latter half of the mineralisation phase. It seems reasonable that when the fracture increases in stiffness due to the callus being progressively calcified that a progressive increase in weight-bearing should occur. Week 14 to 24 is when the majority of bone remodelling occurs, so a fairly constant weight-bearing value seems reasonable for a stage where old bone is being resorbed and new Haversian bone laid instead. Week 24 to 28 is possibly when the Haversian bone along the lines of force fully unite the fracture ends and so greatly strengthen and stiffen the fracture site, by this stage the fracture being said to be healed.

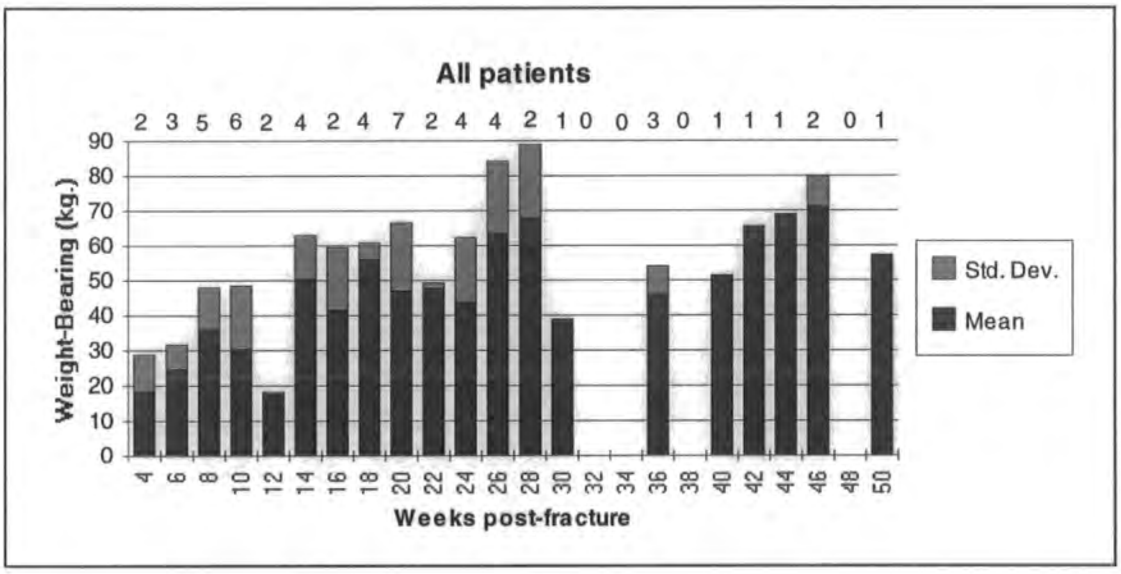


Figure 4.31 - Weight-bearing over time post-fracture for all the patients. The number of patients indicated at each week is given above the each column.

4.3.2. Children Patients' Results

The data obtained for children up to 16 years is shown below in Figure 4.32. Due to the small sample set no observations about general trend can readily be made. What can be observed however is that the fractures healed more quickly than with the adult patients, even though all the children's fractures were treated conservatively with a plaster. Even though this provides less support and so causes less overall stiffness at the fracture site, these young patients also bore significant percentages of body weight much earlier than the adult patients.

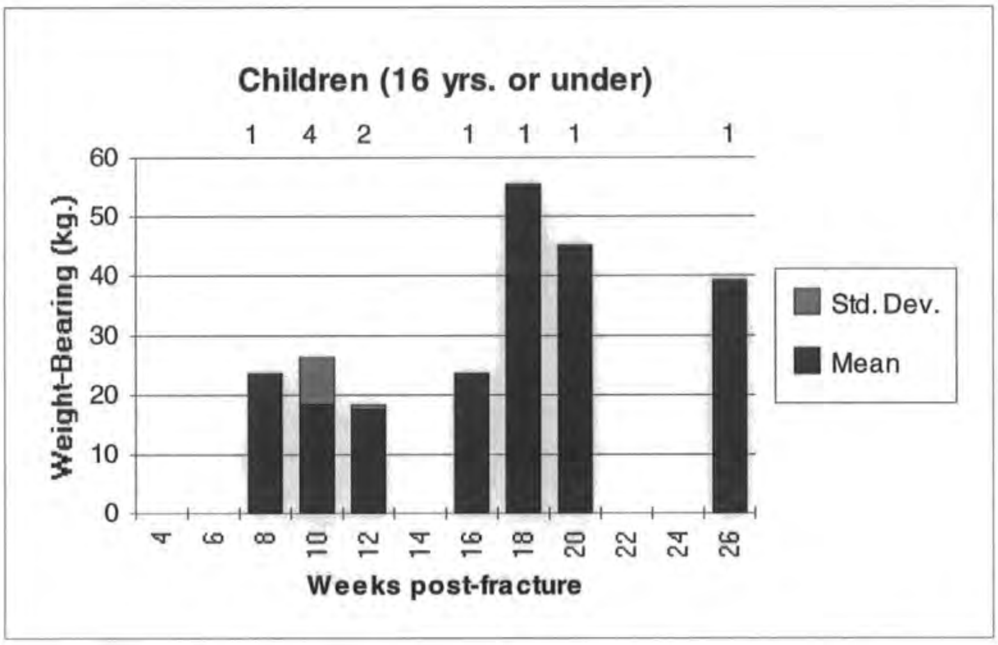


Figure 4.32 - Weight-bearing over time post-fracture for the patients 16 years old or under.

4.3.3. Adult Patients' Results

The mean weight-bearing results over time for the adult patients between 16 and 55 years old are shown in Figure 4.33. As with the general results, it can be observed that there is an increase in weight-bearing up to week 14, this being similar to a previous study (Cunningham *et al.*, 1989). A fairly constant mean weight-bearing value occurs from week 14 to week 24, and a large increase in mean weight-bearing from week 24 to week 28. The similarity in trends between these and the general results might be expected however, for the bulk of the general results are composed of these adult ones. This factor is evidenced by the trend described with the general results being shown more clearly here.

However rather than with there being a linear increase in weight-bearing up to week 14, an increase showing a decreasing positive gradient is noticeable. This is more reasonable than a linear increase, for whatever the treatment method, initially a greater increase in rigidity occurs with lesser subsequent increases. This is because the fixation method will give an initial stiffness at the fracture site, with a slow gradual increase in stiffness from then on as calcification of the callus occurs. This increase in stiffness was shown by Richardson *et al.* (1992) to be exponential with time post-fracture. Due to the main feedback mechanism limiting the weight-bearing being pain or discomfort which is governed by the amount of movement at the fracture site, one might expect there it be a close correlation with fracture stiffness and weight-bearing over time post-fracture. Although the sample set is too small to make definitive empirical deductions regarding this hypothesis, one can see from Figure 4.33 that an exponential increase in weight-bearing after offsetting the weight-bearing possible due to the fixator stiffness is not at great variance from the recorded results.

The results for weeks 42 onwards are for patients who were treated conservatively with a plaster the fracture subsequently ending with delayed union and requiring another fixation method.

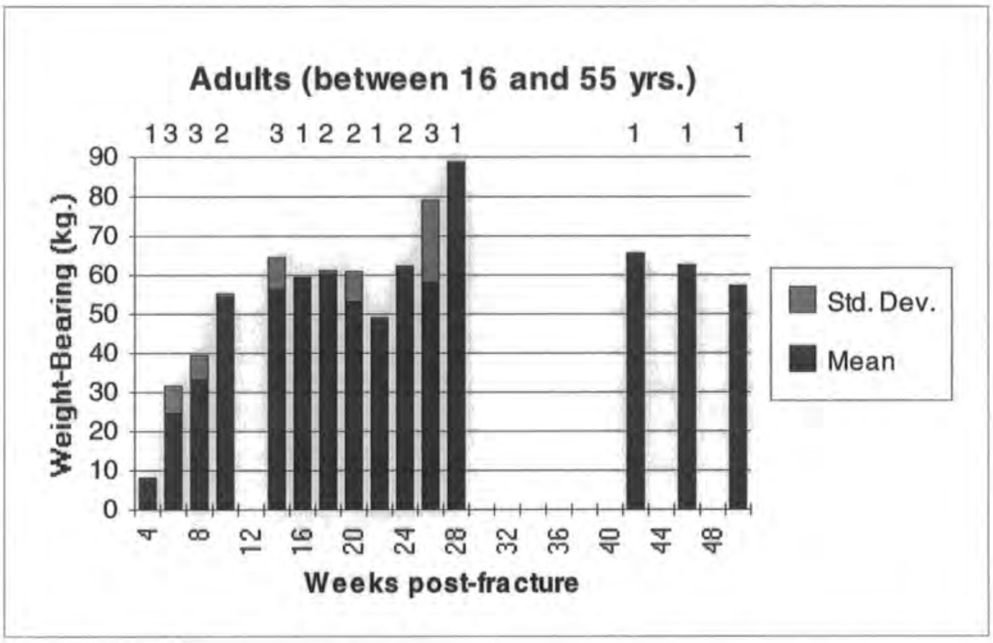


Figure 4.33 - Weight-bearing over time post-fracture for the patients between 16 and 55 years of age.

4.3.4. Elderly Adults' Results

The results for the adult patients aged 55 years and over are shown in Figure 4.34. As with the children's results, there are too few elderly adult results to be able to make mean weight-bearing trend observations. However what is noticeable is that the fractures seem to take longer to heal for there is a spread of similar weight-bearing results throughout all the weeks post-fracture recorded.

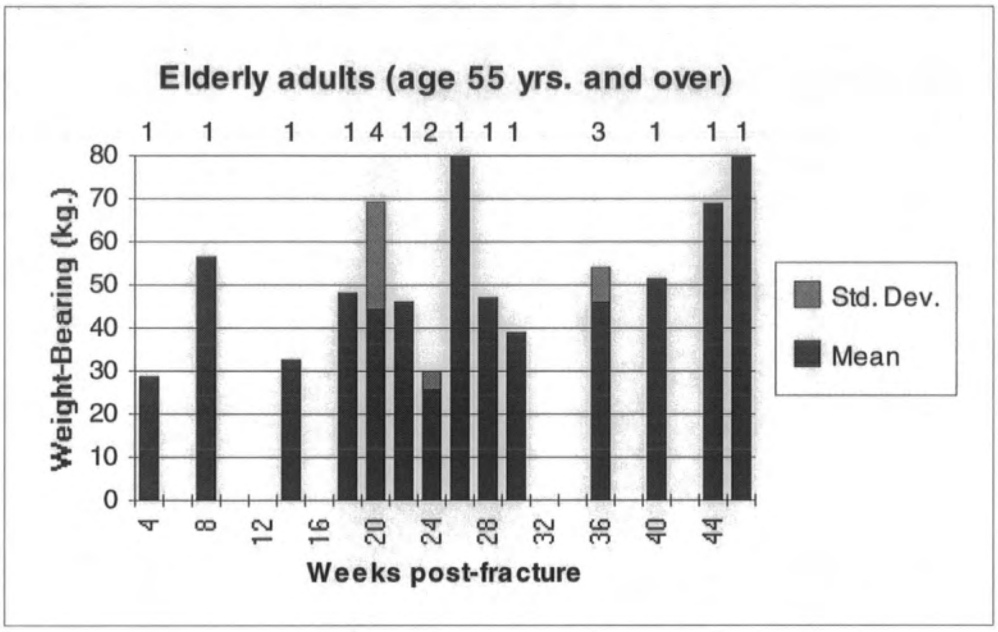


Figure 4.34 - Weight-bearing over time post-fracture for the patients aged 55 years and over.

5. Discussion and Conclusions

This chapter is composed of three sections; discussions regarding the global aspects of the results obtained, the clinical benefits of using ambulatory monitoring for weight-bearing, and the scope for further development and applications of the monitoring system.

5.1. Discussion of the Results

The ambulatory monitor software performed as desired, but when the monitor was operated during the software's development, the data obtained would occasionally be inaccurate. The inaccuracies have been detailed in the previous chapter.

5.1.1. Step Duration

A patient with a fractured tibia should walk with a pathological gait pattern. This is because the patient will attempt to minimise the weight-bearing through that leg. As has been explained in Chapter 3, this in general takes the form of the stance phase for the fractured leg omitting, or greatly modifying, the normal heel contact, foot flat, and heel off, toe off stages. Since the ground reaction force magnitude is greater at these stages, if the patient omits or modifies these stages then the weight-bearing is consequently reduced. This is because during these stages the centre of gravity of the trunk rises from its lowest to its highest position, and this raising of the trunk results in an increased load through the leg. This pathological gait pattern has visible characteristics, for example the knee flexes upon entering and during the mid-stance stage to minimise the trunk rising, which is observed as a 'limp'.

As the stance phase for the fractured leg will have some stages omitted, its duration will be less than with the non-fractured leg's stance phase. During the healing process the fracture gradually becomes stronger and stiffer, so causing the pathological gait pattern to change towards a more normal gait pattern, therefore extending the stance phase time for the fractured leg towards that of the other leg. During the early stages of fracture healing the patient probably walks carefully and slowly, feeling instabilities in the fracture leg, but as healing progresses the patient changes to a higher cadence, so causing the actual step duration to remain constant or possibly decrease. Hence, during healing, the step duration for the fractured leg increases provided the cadence does not increase too much during the healing period.

Group step duration column charts have not been included in the previous chapter because it was felt that due to the large variations of cadence in the normal gait patterns of different subjects, changes in an individual's step duration could be obscured by the varying cadences of others. Hence one must look to the individual patient results to ascertain whether the above hypothesis is empirically justified.

Table 5.1 shows both the step duration and the session duration for the first and last monitoring session of each patient. Examining only the step duration, it can be seen that in the majority of instances there is an increase over the fracture healing period. This is not however true for Patient 2, 3 and 6 where there seems to be a constant or decrease in the step duration. Therefore one cannot only look at the step duration but must take into account the gait velocity to assess the step duration relative to the step duration of the other foot. As it has not been possible to monitor this during the study, an indication of this relative step duration can be gained by examining the session duration, since a constant step duration with a decreased session duration means an increased relative step duration; therefore the session durations have also been included in Table 5.1.

Patient	1	2	3	4	5	6	7
First Session at Week post-fracture	20	37	5	14	8	6	17
Step Duration (secs.)	0.3	0.9	0.6	0.28	0.5	0.78	0.63
Session Duration (secs.)	1272	816	562	314	524	852	420
Final Session at Week post-fracture	44	49	15	35	24 (18)	27	25
Step Duration (secs.)	0.6	0.7	0.6	0.7	0.7 (0.65)	0.6	0.8
Session Duration (secs.)	294	428	212	428	526 (242)	240	264

Table 5.1 - Table showing the step duration and session duration over time

It can be seen that in almost every case there is a large decrease in session duration, with five patients showing at least a halving in the time taken to complete the standard circuit. As Patient 5 had a non-standard last monitoring session, having to stand a number of times and walking a shorter route, if the results from the second from last monitoring session are used instead (as shown in brackets) we find that this figure rises to six out of the seven patients. To obtain a quantitative measurement for the step duration change relative to the un-fractured leg's step duration, the following formula was used:

$$RSD = \frac{relativeStepDurationChange}{relativeSessionDurationChange}$$

relative in the calculation meaning relative to itself, for example:

$$relativeStepDurationChange = \frac{NewStepDuration}{OldStepDuration}$$

Table 5.2 shows this quantitative figure which combines the effects of both the step and session duration. This clearly shows that over the fracture healing period there is an increase in the relative step duration indicating that the shorter stance phase relative to the normal, non-fractured, leg increases in relative duration, therefore becoming more like the normal leg's in duration and characteristics. In cases where the monitoring began when patients were just beginning to weight-bear, as with patients 3, 5, and 6, the relative change over the healing period was a lengthening in relative step duration of over 2.5 times.

Patient	1	2	3	4	5	6	7
Relative change	8.7	1.5	2.7	1.8	2.8	2.7	2

Table 5.2 - Table showing the relative changes in step duration for each patient

5.1.2. Stride Length

Stride length is linked with the relative step duration, a more normal gait pattern producing a greater stride length, as including the heel contact and toe off stages enables the leg to be extended to a greater degree in the swing phase. Therefore it would seem reasonable that an increased relative step duration should be coupled with an increased stride length.

During this study stride length was not measured directly. However an indication of stride length can be gained by examining the number of events recorded for the monitoring session, this being the number of steps taken by the fractured leg while completing the standard circuit, and thus the number of gait cycles needed to complete the circuit. Table 5.3 shows this for each patient. Patients 4 and 5 are indicated in brackets since the data from the second from last session was used instead of the final one due to the final one being corrupted by obstructions where the patient had to stand occasionally in one case, and a shorter route walked in the other. As the number of events is inversely proportional to the stride length, by inverting the figures in Table 5.3 an indication of the stride length is obtained, these data being shown in Table 5.4.

Table 5.4 shows that for each patient there is an increase in stride length over the healing period, up to a maximum of a 70% increase. However data is not well correlated with the step duration data given in Table 5.2.

Patient	1	2	3	4	5	6	7
Relative change	0.7	0.82	0.59	(0.92)	(0.59)	0.56	0.67

Table 5.3 - Table showing the relative changes in the number of events per sessions for each patient

Patient	1	2	3	4	5	6	7
Relative change	1.43	1.22	1.7	(1.09)	(1.7)	1.79	1.49

Table 5.4 - Table showing the relative changes in the stride length for each patient

Whilst it can generally be said that the greater is the increase in step duration the greater is the increase in stride length, this does not apply to Patient 1. This is probably due to the effect of using crutches where a swing through gait can be employed, so causing a greater stride length with a small step duration.

5.1.3. Weight-Bearing

The main applicationary object of this study was to monitor weight-bearing changes over the period of fracture healing. It was hypothesised that a gradual increase in weight-bearing would occur over the period, as the fracture site became stiffer and stronger as healing progressed.

As the individual and group results show, a gradual increase in the weight-bearing did occur over the healing period, this increase generally being non-linear. It has been previously speculated that the reason for this is that the increase in stiffness at the fracture site is non-linear over time, as was experimentally demonstrated by Richardon *et al.* in 1992, who found that, discarding the stiffness of the fixation device, the stiffness at the fracture site increased exponentially with time post-fracture.

This gradual increase in weight-bearing over time post-fracture leads to the conclusion that in the absence of pain or discomfort to the patient, there is another feedback mechanism regulating the amount of weight-bearing through the fractured leg. The results of this study certainly indicate that another feedback mechanism is active, but without having obtained measurements local to the fracture site, for example movement at the fracture site during weight-bearing, these results do not lend direct support to the above hypothesis. Perhaps this feedback mechanism is linked with the interfragmentary strain, for if this is too high, then healing cannot progress. This is often seen by resorption at a small fracture gap to allow granulation tissue and callus to form in a lower-strain environment (O'Sullivan *et al.*, 1989).

A progression in fracture healing does not however necessarily mean an increase in weight-bearing, as Figure 4.7 for Patient 2 shows. The mean weight-bearing for the second monitoring session was lower than that measured previously because the patient had adopted a three-point swing through gait pattern even though the velocity of gait was increased as shown by Figure 4.9. Even the decreased step duration shown in Figure 4.8 was not visible to the observer for the patient walked without a limp or noticeable discomfort. Three weeks later the monitoring session recorded a mean weight-bearing even lower, for a pin tract infection had occurred which caused discomfort to the patient when weight-bearing thus causing the patient to lower weight-bearing to minimise this discomfort. However when a course of antibiotics had healed the infection, a much higher weight-bearing average was recorded. Even so, this was thought to be low because of the gait pattern adopted by the patient. Removing the crutches and allowing the patient to walk with sticks could have forced a higher weight-bearing value.

5.2. Clinical Benefits of using Ambulatory Monitoring for Measurements

The measurement of weight-bearing via ambulatory monitoring can aid the clinician in forming an assessment of the fracture healing by providing further information on limb function which is not available from radiographs. Although this study's aim was not to provide a method to assess the stage of fracture healing, the results from the monitoring of weight-bearing indicate that such data might be useful in such assessment. However as extensive experience in data interpretation are required to give advice based on such measurements, X-rays or other investigations will always be needed for a final decision (Bergmann *et al.*, 1990).

However although some indication of the healing is given, such data really shows the patient's ability to weight-bear on the fracture, this being a combination of conscious and sub-conscious awareness. Normally the only information from the patient that can be gleaned regards pain, discomfort, and unsteadiness. However these are rather subjective, and with no quantitative data the clinician is often forced to conjecture as to the state of the fracture with the aid of previous experience of the length of time normally required for the fracture to heal. Obtaining a quantitative measurement from the patient allows the clinician to include this to aid his assessment of healing. As ambulatory monitoring is non-invasive, data can be quickly and easily obtained from the patient. This data might enable the clinician to provide a more effective course of mobilisation for the treatment of the fracture, for example with the use of crutches, sticks or neither. An example of this was shown with the results obtained for Patient 2, who although was walking quicker and with a greater stride length by week 42 post-fracture, was actually weight-bearing less due to the gait pattern adopted with the crutches. The lower weight-bearing is contrary to expectations, for an increased velocity in walking normally results with an increase in weight-bearing (Jahnke *et al.*, 1992). Therefore the decrease is due to the change in gait pattern, for differing gait patterns result with differing weight-bearing (Olsson, 1992). However the effect of this gait pattern was not easily visible to the observer and so in such cases the patient might be encouraged to continue in the same manner because of the increase in patient confidence suggested by the higher gait velocity. A more effective treatment however would be to force the patient to produce a greater weight-bearing by perhaps replacing the crutches with two sticks.

Using ambulatory monitoring to measure the relative step duration might also aid the clinician as this also gives an indication of the progress of fracture healing. This is because with a longer step duration relative to the unfractured leg's step duration, the patient will have a greater weight-bearing average, so it is in effect an estimate of the weight-bearing. Ambulatory monitoring of the relative step duration is easier and more accurate than the weight-bearing directly, for accurate weight-bearing requires a greater number of transducers which have to be accurately placed at the load bearing areas of the foot. However changes in relative step duration can only indicate a change in weight-bearing not its magnitude, and so such data on its own might not be so helpful to the clinician. Therefore the direct monitoring of weight-bearing and relative step duration would be the best solution because the relative step duration data also gives useful indications of the gait pattern.

5.3. Possible Future work on the Further Development and Application of the System

To increase the accuracy of the weight-bearing data obtained from the monitor, more pressure transducers are required to be placed at the load bearing areas of the foot so that the scaling values for all the transducers will tend to one as the total load will tend towards being the actual load rather than a scaled estimate. This will also results with less cumbersome monitoring sessions for the personal calibration of the scaling values for each patient will not be required. Zweifel *et al.*, demonstrated in 1992 a weight-bearing monitor whose shoe insole had between five and seven pressure transducers affixed to it during different tests. Although this was not strictly speaking an ambulatory monitoring system, in that the cables from the transducers trailed across the floor to a desktop computer, the insole measuring system is relevant to the equipment developed during this study. By using more transducers and modifying the program, it might be also possible to obtain data of other aspects of the gait pattern, such as the areas of greater loading bearing.

Direct monitoring of the step duration of the fractured leg relative to the normal leg would be of great benefit, for one could then perform more detailed experiments and monitor how the relative step duration changes over the monitoring session, and according to the distance walked. By so doing, more informative information might be obtained from a patient as regarding the fracture condition. Also the correlation between increased relative step duration and fracture healing might be tested further. To record this data, both legs are required to be simultaneously recorded. Therefore the software and hardware of the ambulatory monitor would require modification, as well as the PC analysis program.

Previous studies, for example Richardson *et al.* (1992), have shown that fracture stiffness increases exponentially with time post-fracture. This greater stability should result with greater weight-bearing being possible. Although the results from this study are not at variance with this hypothesis, further trials are needed for its confirmation. Were these trials to be performed in conjunction with fracture stiffness measurements, then this hypothesis might be quantitatively proved or disproved. Although both Richardson *et al.* (1992) and Kenwright *et al.* (1991) measured fracture stiffness via the external fixator used during fracture treatment, this would also be possible with internal fixation by using strain gauge transducers and telemetry (Bergmann *et al.*, 1990).

Increases in the amount of data recorded would require an improvement in the size of storage space for the monitor to keep the capability of 24 hour monitoring sessions. Rather than developing the compression capability further, the first modification that would be made regards the information stored for each event. As has been explained previously, by calculating and storing the step duration in time instead of the duration in samples and the inter-sample time, the amount of storage required for the information of one event would decrease by one byte.

However the greater increase in storage capability would be obtained by further data compression, which as has been indicated previously, would occur by using an improved Huffman compression technique. Traditional implementations of Huffman compression techniques have calculated and stored the code using sample data, before the actual data has been recorded. This method is not feasible for this application because the data differs between patients and also between different monitoring sessions of the same patient. However if the code were to be calculated when the Results file became full, then the optimum compression would be obtained for the stored data. The currently stored data would then be compressed, and using the same code, subsequent event data from the monitoring session would be compressed in real-time.

5.4. Conclusions

An ambulatory monitor has been developed which records the weight-bearing, duration, and time for each step of the fractured leg that occurs during the monitoring session. By calibrating the transducer scaling values for each individual patient, reliable data are obtained. A program executing on a PC which analyses, displays and manipulates the various files has also been written.

This system is able to quantitatively record the patient's weight-bearing and step duration over the monitoring session, storing and displaying the mean, standard deviation of each, and the weight-bearing as a percentage of body weight. Also the weight-bearing progress with time gained from all the monitoring sessions recorded can be displayed. By comparing the session duration for the standard circuit, an indication of the change in the velocity of gait can be obtained. Also the change in the relative stride length over the fracture healing period is gained by the alteration in the number of events recorded for the standard circuit.

This equipment was used to monitor 37 patients with tibial fractures. After further modification, the equipment was found to record reliable data, and subsequently weight-bearing with time was shown to increase non-linearly with time post-fracture. An increase in step duration relative to the step duration of the normal leg also occurred, indicating a gradual change in the gait pattern adopted, tending towards a normal gait pattern with time. The same was found with the stride length, again indicating a gradual change towards a more normal gait pattern with time. An increase in velocity of gait was also observed over the healing period, suggesting greater confidence in walking as healing progressed.

These results are not by themselves sufficient to diagnose the state of the fracture, but they do give an indication of the progression of the fracture healing. Further trials are required to quantify the expected weight-bearing over the fracture healing period for the general case, and were these to be performed in conjunction with fracture stiffness measurements, a relationship between the two might be derived.

6. References

BERGMANN G, GRAICHEN F, ROHLMANN A. Implantable Telemetry in Orthopaedics. *Forschungsvermittlung der FU, Berlin*, 1990.

BESAG FMC, MILLS M, WARDALE F, ANDREW CM, CRAGGS MD. The validation of a new ambulatory spike and wave monitor. *Electroencephalography and clinical Neurophysiology* 1989; 73: 157-161.

BLACK J, PERDIGON P, BROWN N, POLLACK SR. Stiffness and strength of fracture callus. Relative rates of mechanical maturation as evaluated by a uniaxial tensile test. *Clinical Orthopaedic Related Research* 1984; 192: 278-288.

BOURNE GH. The Biochemistry and Physiology of Bone, 2nd Ed. *Academic Press, New York*, 1971.

COOK JE. Assessment of tibial fracture healing using Dual Energy X-ray Absorptiometry. *M.Sc. Thesis*, 1993.

CUNNINGHAM JL, EVANS M, KENWRIGHT J. Measurement of fracture movement in patients treated with unilateral external skeletal fixation. *Journal of Biomedical Engineering* 1989; 11: 118-122.

DEHNE E. The rationale of early functional loading in the healing of fractures: a comprehensive gate control concept of repair. *Clinical Orthopaedics and Related Research* 1980; 146(Jan.-Feb.): 18-27.

DUCKWORTH T, BEETS RP, FRANKS CI, BURKE J. The measurement of pressures under the foot. *Foot & Ankle*, 1982; 3: 130-141.

EGGER EL, GOTTSAUNER-WOLFF F, PALMER J, ARO HT, CHAO EYS. Effects of axial dynamisation on bone healing. *The Journal of Trauma* 1993; 34(2): 185-192.

GAUTIER E, PERREN SM, GANZ R. Principles of internal fixation. *Current Orthopaedics* 1992; 6: 220-232.

GRAY H. Gray's Anatomy, 33rd Ed. *Longman's, UK*, 1964.

GOLDSTEIN SA, WILSON DL, SONSTEGARD DA, MATTHEWS LS. The mechanical properties of human tibial trabercular bone as a function of metaphyseal location. *Journal of Biomechanics* 1983; 16(12): 965-969.

GOODSHIP AE, KENWRIGHT J. The influence of induced micromovement upon the healing of experimental tibial fractures. *The Journal of Bone and Joint Surgery* 1985; 67-B(4): 650-655.

HAM AW. Histology, 7th Ed. *JB Lippincott, Philadelphia*, 1974.

HOLTER NJ. New method for heart studies. *Science* 1961; 134: 1214.

HOLTER NJ. Radioelectrocardiography: a new technique for cardiovascular studies. *Annual New York Academic Science* 1957; 65: 913.

HUFFMAN D. A method for the construction of minimum redundancy codes. *Proceedings of the IRE* 1952; 40(9): 1098.

HUTTON WC, DHANENDIAN M. A study of the load under the normal foot during walking. *International Orthopaedics*, 1979; 3: 153-157.

JANKE MT, HESSE S, SCHREINER C, MAURITZ K. Dependency of ground reaction forces, loading and unloading rates of gait velocity, stride length, and constitutional factors in hemiparetic patients. *Proceedings of the European Symposium on Clinical Gait Analysis* 1992: 164-167.

KELLEY A, POHL I. A book on C. *Benjamin/Cummings Publishing Co.*, 1990.

KENNEDY HL *et al.* Ambulatory electrocardiography and computer technology: practical advantages. *American Heart Journal* 1987; 113: 186.

KENWRIGHT J, RICHARDSON JB, CUNNINGHAM JL, WHITE SH, GOODSHIP AE, ADAMS MA, MAGNUSSEN PA, NEWMAN JH. Axial movement and tibial fractures. *The Journal of Bone and Joint Surgery* 1991; 73-B: 654-659.

KLEIN-NULEND J, VELDHUIJZEN JP, BURGER EH. Increased calcification of growth plate cartilage as a result of compressive force in vitro. *Arthritis and Rheumatism* 1986; 29(8): 1002-1009.

LATTA LL, ZYCH GA. The mechanics of fracture fixation. *Current Orthopaedics* 1991; 5: 92-98.

LE VEAU BF. Williams and Lissners Biomechanics of Human Motion, 3rd Ed. *WB Saunders Company, USA*, 1992: 29-59.

LORD M, REYNOLDS DP, HUGHES JR. Foot pressure measurement: a review of clinical findings. *Journal of Biomedical Engineering* 1986; 8: 729-736.

McKIBBIN B. The biology of fracture and healing in long bones. *The Journal of Bone and Joint Surgery* 1978; 60-B(2): 150-162.

MEADOWS TH, BRONK JT, CHAO EYS, KELLY PJ. Effect of weight-bearing on healing of cortical defects in the canine tibia. *Journal of Bone and Joint Surgery* 1990; 72-A, 7: 1074-1080.

MELDRUM SJ. Ambulatory monitoring: an evolving concept. *Biological Engineering Soceity, Physiological Monitoring Group*;18th. November 1992.

MICROSOFT. C for yourself. *Microsoft Corporation*, 1990.

MOW VC, HAYES WC. Basic Orthopaedic Biomechanics. *Raven Press, USA*, 1991: 93-142.

NICOLL EA. Fractures of the tibial shaft: A survey of 705 cases. *The Journal of Bone and Joint Surgery* 1964; 46-B(3): 373-387.

NILSSON BER. Post-traumatic Osteopenia: Quantitative study of the bone mineral mass in the femur following fracture of the tibia in man using americium-241 as a photon source. *Acta Orthopaedica Scandinavica* 1966; 91(37): 14-24.

OLSSON E. Partial weight-bearing ambulation - the unloading effect of assistive devices and gait patterns. *Proceedings of the European Symposium on Clinical Gait Analysis* 1992: 104-106.

ONI OOA, HUI A, GREGG PJ. The healing of closed tibial shaft fractures. *Journal of Bone and Joint Surgery* 1988; 70-B: 787-790.

O'SULLIVAN ME, CHAO EYS, KELLY PJ. The Effects of Fixation on Fracture-Healing. *Journal of Bone and Joint Surgery* 1989; 71-A: 306-310.

OXNARD CE. Bone and bones, architecture and stress, fossils and Osteoporosis. *Journal of Biomechanics* 1993; 26: 63-79.

PAAVOLAINEN P, SLATIS P, KARAHARJU E, HOLMSTROM. The healing of experimental fractures by compression osteosynthesis I Torsional strength. *Acta Orthopaedica Scandinavica* 1979; 50: 369-374.

PAAVOLAINEN P, SLATIS P, KARAHARJU E, HOLMSTROM. The healing of experimental fractures by compression osteosynthesis II Morphometric and chemical analysis. *Acta Orthopaedica Scandinavica* 1979; 50: 375-383.

PAN WT, EINHORN TA. The Biochemistry of Fracture Healing. *Current Orthopaedics* 1992; 6: 207-213.

PANJABI MM, WHITE AA, SOUTHWICK WO. Temporal changes in the physical properties of healing fractures in rabbits. *Journal of Biomechanics* 1977; 10: 689-699.

PANJABI MM, WALTER SD, KARUDA M, WHITE AA, LAWSON JP. Correlations of radiographics analysis of healing fractures with strength: a statistical analysis of experimental osteotomies. *Journal of Orthopaedic Research* 1985; 3: 212-218.

PFISTER CJ, HARRISON MA, HAMILTON JW, TOMPKINS WJ, WEBSTER JG. Development of a three-channel, 24-h ambulatory esophageal pressure monitor. *IEEE Transactions on Biomedical Engineering* 1989; 36(4): 487-490.

PRATT CM *et al.* Ambulatory electrocardiographic recordings: the Holter monitor. *Current Problems in Cardiology* 1988; 13(8): 519-586.

PSI SYSTEMS. Mini-Module manual. *P.S.I. Systems*, 1991.

RADIN EL. Orthopaedics for the Medical Students. *JB Lippencott Company, Philadelphia*, 1987: 9-34.

RICHARDSON JB, KENWRIGHT J, CUNNINGHAM JL. Fracture stiffness measurement in the assessment and management of tibial fractures. *Clinical Biomechanics* 1992; 7: 75-79.

ROCKWOOD CA, GREEN DP. Fractures in Adults, 2nd Ed. *JB Lippincott Company, Philadelphia*, 1984.

RS Data Library, 1994.

SARANGI PP, WARD AJ, SMITH EJ, STADDON GE, ATKINS RM. Algodystrophy and osteoporosis after tibial fractures. *The Journal of Bone and Joint Surgery* 1993; 75-B: 450-452.

SHARRARD WJW. A double-blind trial of pulsed electromagnetic fields for delayed union of tibial fractures. *The Journal of Bone and Joint Surgery* 1990; 72-B(3): 347-355.

SHIPMAN P, WALKER A, BIRCHELL D. The human skeleton. *Harvard University Press, Massachusetts,* 1985: 18-63.

ULIVIERI FM, BOSSI E, AZZONI R, RONZANI C, TREVISAN C, MONTESANO A, ORTOLANI S. Quantification by Dual Photon Absorptiometry of local bone loss after fracture. *Clinical Orthopaedics* 1990; 250: 291-296.

WAND JS, SMITH T, GREEN JR, HESP R, BRADBEER JN, REEVE J. Whole-body and site specific bone remodelling in patients with previous femoral fractures: Relationships between reduced physical activity, reduced bone mass and increased bone resorption. *Clinical Science* 1992; 83: 665-675.

WHALEN RT, CARTER DR, STEELE CR. Influence of physical activity on the regulation of bone density. *Journal of Biomechanics* 1988; 21(10): 825-837.

WHITE TD. Human Osteology. *Academic Press, USA,* 1991.

WHITTLE AP, RUSSEL TA, TAYLOR CJ, LAVELLE DG. Treatment of open fractures of the tibial shaft with the use of interlocking nailing without reaming. *The Journal of Bone and Joint Surgery* 1992; 74-B(8): 1162-1171.

WHITTLE MW. Gait Analysis: an introduction. *Butterworth-Heinemann* 1991.

WOLFF J. Das gaetz der transformation. Transformation der knochen. *Hirshwald, Germany,* 1892.

YOUNG DR, NIKLOWITZ WJ, STEELE CR. Tibial changes in experimental disuse osteoporosis in the monkey. *Calcified Tissue International* 1983; 35: 304-308.

ZWEIFEL HJ, KESSELRING J, ARLANCH C, WILLI P, BERNEGGER U, JEHLE A. Erfahrungen mit p-gait-analysis. *Proceedings of the European Symposium on Clinical Gait Analysis* 1992: 260-263.

Appendices

Appendix 1: The Mini-Module PCB Components

The following sections detail the Mini-Module P.C.B. components which are referred to by the Hardware section of Chapter 2. Where relevant explanations of the necessity and function of components is also included.

A1.1. The Micro-Processor

The CPU on the Mini-Module is a Motorola 68000 software compatible processor; the Philips 93C100. The older Motorola 68000 processor has a slower clock-speed, and needs a number of extra external peripheral interfacing chips to design and build a computer, which the 93C100 includes on-board the processor chip. These are a clock or oscillator, external vectored interrupts, memory interfacing chips, and (for the bus used on the Mini-Module) an I2C bus interface.

Apart from the faster clock speed of 30 MHz (the 68000 having a maximum of 12 MHz) the main functional difference is that the 93C100 also has a second on-board oscillator which drives it at the slower speed of 5 MHz; this feature being used for when the processor is in 'stand-by' mode. When in this state the processor consumes less power which is important in power sensitive applications such as that of ambulatory monitoring.

A1.2. The Erasable Programmable Read Only Memory (EPROM)

A computer system needs memory for the purpose of storing the program whilst it is being executed by the processor, and for storing and manipulating the data that is produced.

EPROM is 'programmed' (meaning that each memory location's content is set to a value) by applying different voltages to various pins of the casing. This is done automatically by an EPROM programmer, which stores the file and transfers it to the EPROM. Depending upon the size of the program or data being stored, this can take one or two minutes. The EPROM chips can then be inserted into the sockets provided on the PCB of the Mini-Module, and their contents read by the processor. To erase the memory of its contents, the silicon chip is exposed through the clear 'window' in the casing to ultra violet light for some twenty minutes.

As programming and re-programming of an EPROM is a long process, taking up to half an hour, this type of memory can not be used for applications which involve constantly changing values; such as the data generated by a program, or in this case read in by the monitor. However it can be used for unvarying data such as the program code itself, and initialising data which does not change and is needed when commencing program execution. A benefit of using EPROM rather than other types of memory for program storage is that the contents are not lost when the memory is disconnected from the power supply, which means that battery power is saved and the monitor need only be powered for the time period when the data is being gathered, rather than having to constantly power it in order to keep the program in memory.

The Mini-Module is flexible on the differing sizes of EPROMs that it can use. Either CMOS or NMOS types can be used. These are based on different technologies and function differently in operation although performing the same task. CMOS type of EPROM was chosen for that consumes less power than the equivalent sized NMOS EPROM. The size of memory of the EPROM can be from 16 KBytes to 256 KBytes each, giving an overall memory of between 32 KB and 512 KB as two EPROMs are used. The memory size chosen was of 128 KB each (giving 256 KB in total), to ensure that there would be ample room in which to store the program code and the initialising data.

The EPROM speed of operation (when returning a specified memory location's value) is slower than for other types of memory, and much slower than the CPU operational speed. To circumvent such problems, the Mini-Module uses an asynchronous bus interface which means that the speed of each access cycle is controlled by the device being accessed, and not by the CPU. Therefore the Mini-Module has some external (to the CPU) timer logic which forces each EPROM read cycle to be at least 350 ns allowing the use of EPROMs with access times of up to 250 ns. However this application is not adversely affected by the slower memory speed because for most of its execution time the program will be periodically monitoring and storing the ADCs' values. In fact it will have to be slowed down even further in its processing speed in between taking individual readings from the ADCs, otherwise the sampling rate would be in the thousands rather than in the tens of hertz range.

A1.3. The Random Access Memory (RAM)

RAM is available in two types; static and dynamic. Each type of is of different technology and construction; each location in dynamic memory being a capacitor and resistor, whilst in static memory it is a transistor. Dynamic memory is therefore much easier and more compact to manufacture on silicon and so costs less than its static equivalent. However as each location value is stored by the capacitor charge (a zero value being no charge stored and a one being charge stored) it has to be 'refreshed' periodically for it to be maintained. This means that dynamic memory has a greater power consumption than static memory since when a small charge is given to the base of the transistor (signifying a one for current will now flow from the collector to the emitter) it remains there until it is changed or the power is switched off. Static RAM is also much faster in operation than dynamic RAM as the dynamic memory is limited in speed to the capacitor discharge rate. In quantitative terms this gives an access time of 20 ns for static RAM and 80 ns for dynamic RAM.

The Mini-Module is fitted with 128 KB of static RAM which is therefore of benefit over dynamic RAM in its overall power consumption. Since the program and initialising data is stored on EPROM, all of this memory area (apart from that required by the operating system) can be utilised by program generated data. As there is an interface to the 68000 bus, external memory can be added to form a total of 2 MBytes (as the address bus has a total of 20 lines) should applications require it. For this application however, 128 KB of RAM was deemed to be sufficient.

A1.4. The Battery Back-up

The Mini-Module also has a nickel cadmium (ni-cad) battery mounted on the PCB, which is connected to the static RAM when the external power supply, which in this case is the set of batteries, is disconnected. This battery can supply enough power for the RAM to keep its contents for up to about 250 hours, because static RAM consumes very little power when in an 'idle' state, which is when its contents are not being accessed or set. As explained previously, the life for this battery would be very much shorter if dynamic RAM was used, due to the different technology it employs.

The ni-cad battery has a discharge ratio of ten to one. This means that an external power source must be connected for 10% of the time for the battery to remain charged. For this application, the Mini-Module would be powered only when it was being used to monitor a patient, but when the monitoring trial finishes the results are down-loaded onto a PC for storage. Therefore even if patient trials were infrequent, so causing the battery-back up to fully discharge, no important data remains in the RAM after a trial, except some initialising values which can be re-inputted, meaning that no important data will be lost.

A1.5. Real Time Clock

The real time clock provides a clock facility which counts in 1/100ths. of a second. It also includes a calendar, and a timer which can count for up to 99 days. Also an alarm facility is included, which can generate an interrupt at a particular date or time of the clock timer. This clock can give time facilities to the Mini-Module's programs which has been utilised for this application.

A1.6. Digital Input/Output Communications

Analogue communication consists of a varying voltage signal, the amplitude indicating the 'number' being transmitted. Digital communication does not have this flexibility of a varying signal amplitude as the voltage level can be either 'on' or 'off', corresponding to either 5 Volts or 0 Volts respectively. Representing a one or zero is therefore straight-forward, and for other values a number of digital lines can be used in parallel, with the value being encoded in a binary format. It has become standard to have digital lines in multiples of eight; so that an 8-bit processor would normally communicate with other peripherals across an eight or sixteen line data bus, so being able to directly manipulate an eight or sixteen bit number (i.e. between 0 and 255 or 0 and 65535 respectively).

The Mini-Module does not only permit external analogue communications (accepting inputs via the ADCs, and generating an output through the Digital to Analogue converter or DAC) but also external digital communication facilities through four eight bit digital ports, which are basically four sets of eight parallel digital lines. Each port is quasi bi-directional which means that although physically it is only an output port, it can also be programmed to be an input port. To understand why this is possible, it is necessary to examine the digital line more closely.

The high level for each digital line is provided by a 100 µAmps current source with the low level output being provided by a high current field effect transistor (FET) which can accommodate an input current of up to 25 mAmps. Therefore each line will read as high (5 Volts) when not being driven, by having been set by the program to a logical 'off', and it will be read as low (0 Volts) when it is set to 'on', as the FET will then be 'active'. When being driven by an outside source, a high voltage value will cause a digital line's voltage to remain at 5 Volts, and a low voltage value will drive the line to 0 Volts as the relatively small 100 µAmps will be dissipated by the external equipment since the current will flow from the Mini-Module to the connected external equipment, effectively acting as an earth for the digital line.

Each port has a change of state detector which periodically compares the state of the pins of the port with a copy of the state of the pins when the port was last read. When a difference is noted, an interrupt is generated. This is then removed by either the port returning to its original state or it being read by the CPU. Therefore a port can be used for input purposes by either waiting for the interrupts to occur, as the initial state is known, or by periodically sampling the port and ignoring the interrupts that will be generated on each change of state.

For this application there is a requirement to use five digital lines. The first is needed as a digital input to 'read' the state of a switch, so that when the switch is closed different program functions can be enabled. The other four are needed to be used as outputs, to drive four Light Emitting Diodes (LEDs) which display to the operator the different states of the program executing on the Mini-Module. Both are detailed in the next part which deals with peripherals required for the monitor which were not found directly mounted on the PCB.

A1.7. Analogue to Digital Converters (ADCs)

The Mini-Module has four of ADCs which include a sample and hold amplifier. Each ADC is an 8 bit device (meaning that the range of possible digital outputs is from 0 to 255) and the input range is from 0 to 2.55 Volts. This therefore gives a sensitivity of 10 mV per bit over its input range. The ADCs can be configured for a number of different input modes, giving four single ended inputs or two differential inputs.

With single ended input mode, the input is connected to the positive input of the ADC, and the voltage measured between the input and the analogue ground of the Mini-Module. To make sure that the ground voltage levels are the same for both the Mini-Module and the external voltage source which is being measured, the external source's ground can be connected to the analogue ground of the Mini-Module. The use of this connection method gives the possible utilisation of four ADCs, and it works satisfactorily using short cables in low noise environments. However if the environment is noisy (i.e. there is a relatively high amount of electromagnetic radiation in the area) a voltage will be induced in the cable which will superimpose on the voltage being measured to give a higher or lower voltage reading at the ADC than that generated by the external voltage source. This problem is exacerbated the greater the cable length as a greater voltage can be induced. In low noise environments the use of a long cable will result in a voltage drop due to its internal resistance, for the longer the cable the greater the resistance its resistance, so giving a lower voltage reading at the ADC.

Differential input mode works by connecting the two inputs from an external voltage source to two separate ADCs, one to its positive input and the other to its negative input, the voltage reading then being the difference between the two. This method has the advantage of noise immunity, for if a voltage is induced it will be induced to the same degree on both inputs because they are normally tied together so there is no possibility of each one being affected by different electromagnetic radiation sources, as might happen if the leads were metres apart. However since the voltage in one cable is different than in the other cable, a voltage can be induced from the higher voltage to the lower voltage cable by coupling. Therefore shielded cables are used, with the shields being connected to the analogue grounds of both the Mini-Module and the external voltage source, so reducing the common mode voltage, and also further reducing the noise sensitivity. Since two ADCs are required for each voltage source being measured, using this method means that only two different voltage sources can be monitored.

The final connection mode possible is the quasi differential mode. Each channel's negative input is connected to the same negative ADC input, with the positive voltage source inputs connected to separate ADCs' positive inputs. By using this method of connection, three different ADCs are available for monitoring use. Also this mode offers noise immunity for the cables and for voltage drops over long distances, but not to the same degree as with using differential input mode.

For this application, each pressure transducer was connected to a signal conditioning unit which returned a separate voltage reading for each transducer to the monitor. Therefore each transducer's reading, via the signal conditioning unit, would be monitored by a separate ADC. The environment where the equipment would be in use is in a hospital's outpatients department, where there would not be any extra-ordinary levels of electro-magnetic radiation. Also because the cables connecting the signal conditioning units would be less than a metre in length, for the ambulatory monitor would be worn on a belt round the waist and the signal conditioning units positioned at the ankle, no noticeable voltage drop should occur. All these factors, plus the fact that some measure of immunity to noise is possible by the use of shielded cables, combined to the decision to use single ended input mode, so that up to four transducers could be monitored. As shall be seen later on, this was important to be able to obtain accurate weight-bearing data.

A1.8. The RS-485 Port

The RS-485 serial communication standard provides serial communication using two differential lines for each channel. This allows the use of simple twisted pair cabling, and so will provide a high degree of noise immunity when the cable has to traverse long distances.

An RS-485 port is provided on the Mini-Module as standard, which provides it with serial communication capability. For this application the serial connection is required to interface to an I.B.M. compatible Personal Computer (PC) . However PCs are fitted with RS-232 standard serial ports which are not compatible with the RS-485 standard. Therefore an RS-485 to RS-232 converter was built which provided the necessary conversion so that the PC and Mini-Module could communicate with each other. This is detailed in a subsequent part of this Chapter.

A1.9. The Watch-Dog

A watch-dog is a timer chip which is reset by a pulse on its trigger line. If a pulse does not occur within a specified time, the watch-dog generates an interrupt. Using a watch-dog gives a computer some fault-tolerance capabilities for a program or more usually for an operating system. This functions in the following manner; a pulse is regularly transmitted to the watch-dog, but if a fault occurs so that a pulse is not sent to it, an interrupt is generated which can be specified to jump to a memory location for the execution of a specific part of the program, which might for example jump back to the start of the program or function that was being executed, the benefit being that no data would be lost. This is a feasible scenario because most faults that occur are transient faults rather than hardware faults; for example connecting or disconnecting a high current device to the same mains supply as the computer will generate a voltage spike and possibly a transient fault if the computer power supply is not sufficiently shielded. If this were to occur, the program counter might become corrupted and so send the CPU to a different memory location possibly sending the program or operating system into an infinite loop. Therefore the instruction to send a pulse to the watch-dog would not be processed and so the pulse would not be sent. An interrupt would therefore be generated, and the specified code processed could then send the program counter to restore control to the start of the operating system, so enabling the computer to overcome the transient fault whilst keeping the majority of its previously generated data.

A watch-dog timer is present on the PCB, to which if a pulse is not received on its trigger line by 400 ms, it resets the Mini-Module. When using the multi-tasking Minos operating system, the individual programs do not have to periodically send a pulse to the watch-dog as this is done by the operating system. If the watch-dog feature is not required in an application it can be disabled by removing a link on the Mini-Module.

In this application, the monitor program was executed under the Minos operating system and so the watch-dog was enabled, as its functionality would be beneficial if the ambulatory monitor were to be used in an environment where there was relatively high electro-magnetic radiation that might affect the Mini-Module circuitry. When executing programs under the Minos OS, a reset is generated if the watch-dog interrupt occurs. Therefore if a transient fault were to occur and a reset was generated by the watch-dog timer, the CPU would go to the start of the program but with the collected data, which had not yet been downloaded onto the PC, still being intact since it is stored in its own RAM file.

A1.10. The Power Fail Detector

Present on the PCB is also a power fail detector. This is connected to the power supply and monitors its voltage. If the voltage level drops below about 4.75 Volts, the power fail detector resets the Mini-Module. This feature is useful in this particular application because the power supply will be a set of batteries with their general discharge characteristic being that the voltage decreases as they are used (the battery characteristics will be detailed in Section 2.1.2.3). Therefore to have the Mini-Module being reset when the batteries' voltage is low, will indicate to the user that they need changing. If no reset occurred, the ambulatory monitor would continue to appear to function normally as the status LEDs would continue to light; but the Mini-Module would produce some transient faults in program operation since the voltage is not high enough to drive the transistor transistor logic (TTL) circuitry properly.

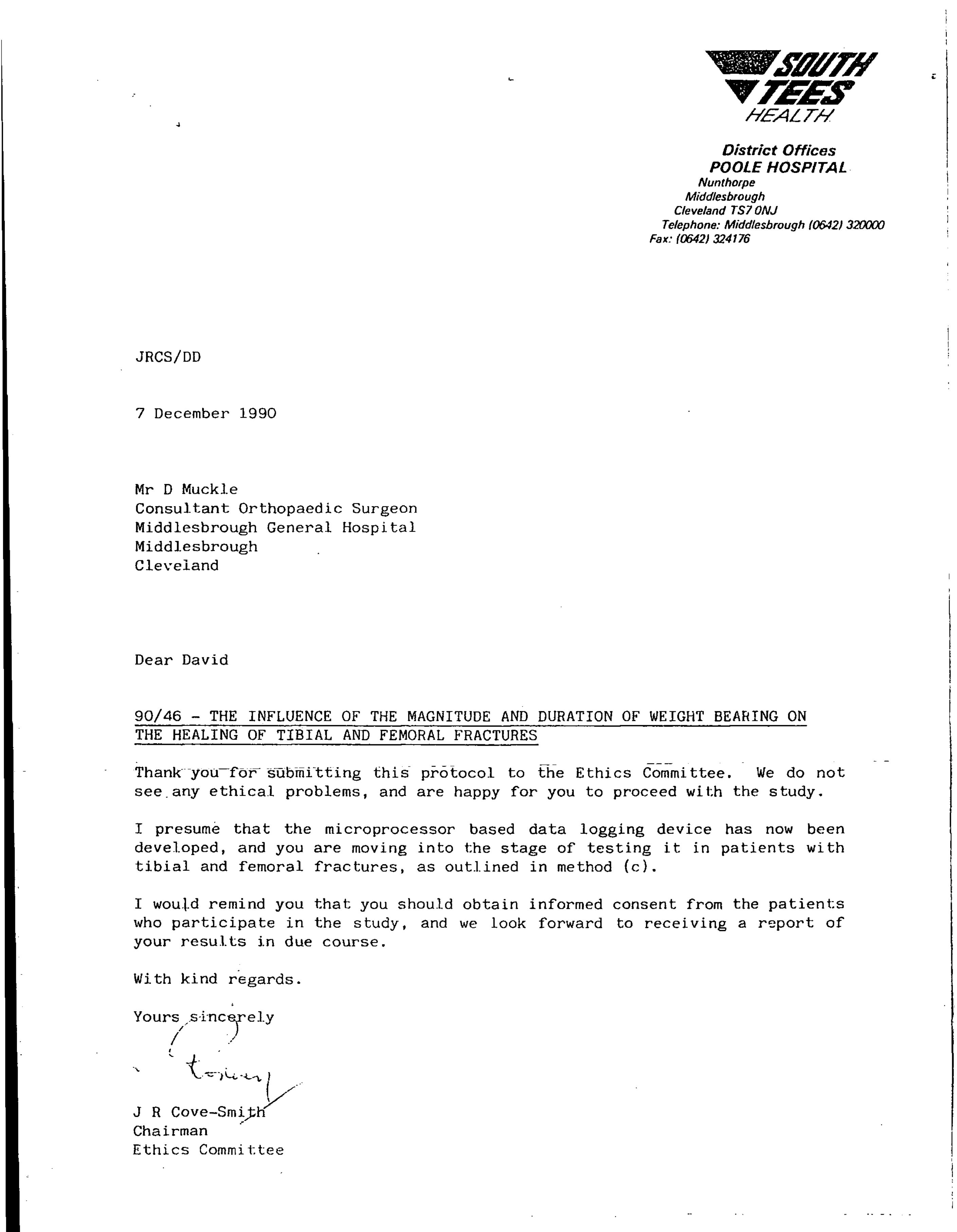
A1.11. Other PCB Components

The PCB holds a number of other components which are not utilised for this application. There is a DAC, a keyboard port and an LCD port. The keyboard and LCD ports are not required since through the RS-485 port the PC's keyboard and screen are utilised when required.

The Mini-Module also has three different bus standards available for external connection. An I^2C bus is used by the 93C100 to interface to other peripherals on the PCB, and a connector is also provided for external peripherals. A 64 pin expansion connector is also provided, this bus having three basic modes of operation which allows access to 68000 memory (for external memory expansion), 68000 peripherals and 8051 peripherals. Each mode uses the same address and data lines, but a different set of control lines.

As all the hardware needed for this application was already provided on the Mini-Module PCB, no external peripherals were needed so that neither of the expansion connectors were used.

Appendix 2 : Ethical Approval and Original Project Protocol



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JRCS/DD

7 December 1990

Mr D Muckle
Consultant Orthopaedic Surgeon
Middlesbrough General Hospital
Middlesbrough
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Dear David

<u>90/46 - THE INFLUENCE OF THE MAGNITUDE AND DURATION OF WEIGHT BEARING ON THE HEALING OF TIBIAL AND FEMORAL FRACTURES</u>

Thank you for submitting this protocol to the Ethics Committee. We do not see any ethical problems, and are happy for you to proceed with the study.

I presume that the microprocessor based data logging device has now been developed, and you are moving into the stage of testing it in patients with tibial and femoral fractures, as outlined in method (c).

I would remind you that you should obtain informed consent from the patients who participate in the study, and we look forward to receiving a report of your results in due course.

With kind regards.

Yours sincerely

[illegible]

J R Cove-Smith
Chairman
Ethics Committee

PROJECT PROTOCOL

TITLE: The influence of the magnitude and duration of weight-bearing on the healing of tibial fractures.

BACKGROUND

Fracture healing is influenced by the prevailing mechanical environment at the fracture site (1-4). Fractures which have been accurately reduced and in which there is minimal interfragmentary strain, heal directly by primary means (1,2), whereas fractures which are less rigidly fixed heal by secondary bone healing with external callus formation, the amount of callus depending on the rigidity of the fixation (1, 3, 4).

The rate of increase of fracture stiffness and strength can be influenced by the rigidity of the fixation system, this being seen in both experimental (3-5) and clinical studies (7). Most conservatively treated tibial fractures show incomplete reduction and so indirect healing with external callus formation leads to the most effective and rapid healing of the fracture. The potential therefore exists to use weight bearing to produce axial loading of conservatively treated tibial fractures and hence stimulate callus formation.

To encourage fracture healing by secondary means, early weight bearing is prescribed and encouraged to provide the axial strain at the fracture site necessary to promote callus formation (6). In a photogrammetric study, Lippert and Hirsch (8) demonstrated that large amounts of movement at the fracture site (up to 5 mm) are possible during normal activities in fractures treated by cast. In studies of patients being treated by cast braces for femoral shaft fractures, the loading of the fractured limb during healing has been measured (9, 10) and has been shown to increase with increasing time post-fracture. More recently, Cunningham *et al* (11) studied weight bearing and fracture movement at set intervals during healing in a small group of patients treated with unilateral external skeletal fixation. Despite being encouraged to weight-bear on their fractured limb, weight bearing was less than 50% of body weight during the first two months post fracture. It is in this early stage of healing that axial strain at the fracture site appears to be most effective in promoting healing (4). In all of these studies the results represent the weight bearing achieved during the tests and direct inference cannot be made that such weight bearing was the norm when the patient was at home.

As healing of the fracture progresses, the ability of the patient to weight bear on the fractured limb increases, perhaps as a result of a bio-feedback mechanism of biological self-control of fracture site strain, as suggested by Lazo-Zbikowski *et al* (12).

In fractures, the level and frequency of weight bearing will affect fracture healing, and information on weight bearing during treatment would be invaluable in assessing treatment methods, (ie casts, internal and external fixation) patient motivation and injury and fracture type on the ability of the patient to weight bear. By being able to determine favourable influences on weightbearing, then increased callus formation and more rapid fracture healing could result. The information obtained from measurements of weight bearing could also be used as an indication of the extent of fracture repair if correlated with clinical, radiological and mechanical (13) assessments of union. This technique, when developed, would be potentially applicable to other orthopaedic treatments where a measure of patient activity either pre- or post-surgery (e.g. total hip and knee replacement) is required.

METHODS

Microprocessor based data logging devices

Ambulatory monitoring of patients has become a widespread clinical diagnostic technique over the past 25 years. Probably the best known example is recorded electrocardiography (Holter monitoring) which was reported as early as 1961 (14) and detected ST segment changes in patients during symptomatic anginal attacks.

Three distinct recording methods are presently available, these are continuous, intermittent (patient or time activated) and real time analytical recorders. Continuous, two-channel analogue Holter tape-recorders are the most widely used in the field. Most are now cassette based and offer reasonable recording fidelity, but are bulky and thus inconvenient to use. Patient-activated recorders are limited in their use since they must be activated by the patient in response to symptoms so large amounts of important data may be missed. An additional drawback is the limited memory of many of the present systems and the lack of input channels.

Real-time analysers are recorders with the ability to analyse the incoming signal in real-time, subsequently storing examples of abnormalities. Unfortunately these real-time analysers have difficulty in reading through ambient noise, this is a major problem especially when dealing with ECG signals.

In order to investigate weightbearing achieved during fracture treatment it is proposed to develop a microprocessor based instrumentation and data acquisition system. This system would need to be portable, self powered, unobtrusive and be able to monitor patients for long unsupervised periods, possibly away from the hospital environment. The use of a microprocessor-based system would enable the device to be "intelligent" - making decisions as to whether data was useful or erroneous. This would allow data compression to take place allowing an extended monitoring period. This monitoring period could also be prolonged by the use of real-time analysis of the data.

Force measurement system

Forces and pressures under the foot have been measured using single and multi-element force plates and optical methods (15, 16), however the use of such systems is restricted to a laboratory environment,. Sensors have been developed which fit inside the shoe and allow a continuous measure of activity (17), although not of the magnitude of the loading applied. In this project the aim is to enable a continuous measurement of limb loading to be made over a period of time. The distribution of the loading over the foot is not considered to be as important as the magnitude of the load applied to the limb, and so it is initially intended to develop a force measurement system based on two miniature pressure transducers, positioned over the area of the fore-foot and the heel. Alternative methods of measuring pressures under the foot will also be explored, including the use of piezoelectric polymers, specifically polyvinylidene fluoride (PVDF), although the costings in this proposal are based on the available technology of a pressure transducer system.

PLAN OF INVESTIGATION

a) Force measurement system

It it proposed to develop a compact force measurement system which will enable continuous measurements of loading and the duration of loading applied by the foot of the fractured leg. This system would consist of a pressure measuring element or elements utilising an array of small pressure transducers or alternatively could be constructed from a piezo-electric polymeric material. A suitable power supply and amplification for such a pressure sensitive element will be developed and incorporated within the data recording equipment.

b) Data logging system

It is proposed to base this system around a commercially available microprocessor system (15) which uses an industry standard Motorola 68000 compatible microprocessor chip. This system is based on a small (100 mm x 115 mm) printed circuit board that contains the microprocessor, 128K of static RAM (random access memory), an interactive programming language and sufficient input/output for this stand-alone application.

To allow a specific system for the investigation of weightbearing during fracture treatment to be designed, finance for the development of a system comprising:

IBM compatible PC (386)
Printer
PSI Systems development system (PSI-J100)
Cross Assembler for 68000 cpu or Cross Compiler for 68000 cpu
ROM splitter software
S-Record generator

is requested. In addition, once developed, individual systems would be required to enable clinical trials to be carried out on fracture patients. This would require finance for:

10 off PSI-K100 mini-module controllers and a budget for miscellaneous analogue and digital electronic components.

c) Clinical testing

Preliminary testing of the force measurement and data logging system will be carried out on a small series of volunteer subjects to determine the accuracy and reliability of these systems. Subsequently, a series of about 20 - 30 patients being treated by cast,, internal and external fixation for tibial fractures will be fitted with the measurement and logging system, and measurements of the amount and duration of fracture loading will be made continuously throughout treatment. In addition to the usual clinical and radiological assessment of healing, mechanical assessments of healing will be made using either ultrasound (16) or a direct method of measuring fracture stiffness (13, 17).

JUSTIFICATION FOR SUPPORT REQUESTED

The support requested will enable a postgraduate research assistant to carry out the investigations described in detail in Section 4 above. The research assistant would be employed by the University of Durham, and housed in the Bioengineering Laboratory in the School of Engineering and Computer Science at that University. The research assistant would be responsible to Dr J L Cunningham. During the clinical testing, the research assistant would be required to make frequent visits to Middlesbrough General Hospital, and travel costs associated with these visits have been included in the application.

REFERENCES

1. McKibben, B. The biology of fracture healing in long bones. J. Bone and Joint Surg. 60B, 152-162, 1978.

2. Perren, S.M. Physical and biological aspects of fracture healing with special reference to internal fixation. Clin. Orthop. Rel. Res. 138, 175-196, 1979.

3. Sarmiento, A., Schaeffer J.F., Beckerman L, Latta L.L. and Eris, J.E. Fracture healing in rat femora as affected by functional weight bearing. J. Bone and Joint Surg. 58A, 369-375, 1977.

4. Goodship A.E. and Kenwright J. The influence of induced micromovement upon the healing of experimental tibial fractures. J. Bone and Joint Surg. 67B, 650-655.

5. Woolf J.W., White A.A., Panjabi M.M. and Southwick, W.O. Comparison of cyclic loading versus constant compression in the treatment of long bone fractures in rabbits. J. Bone and Joint Surg. 63A, 805-810, 1981.

6. Sarmiento, A. Function bracing of tibial fractures. Clin. Orthop. Rel. Res. 105, 202-219, 1974.

7. Kenwright, J., Richardson, J.B., Cunningham, J.L., White, S.H., Goodship, A.E., Adams M.A., Magnussen, P.A. and Newman J.H. Axial movement and tibial fractures. A controlled randomised trial of treatment. J. Bone and Joint Surg. 73-B,654-659, 1991.

8. Lippet, F.G. and Hirsch, C. The three-dimensional measurement of tibial fracture motion by photogrammetry. Clin. Orthop. Rel. Res. 105, 130-143, 1974.

9. Meggit, B.F., Juett, D.A. and Smith, J.D. Cast-bracing for fractures of the femoral shaft. A biomechanical and clinical study. N. Bone Joint Surg. 63-B,12-23, 1981.

10. Wardlaw, D. M^{C}Lauchlan, J., Pratt, D.J. and Bowker, P. A biomechanical study of cast-brace treatment of femoral shaft fractures. J. Bone Joint Surg. 63-B, 7-11, 1981.

11. Cunningham, J.L., Evans M and Kenwright J. Measurement of fracture movement in patients treated with unilateral external skeletal fixation. J. Biomed. Eng. 11, 118-122, 1989.

12. Lazo-Zbikowski, J. Aguilar, F., Mozo, F., Gonzales-Buendia, R. and Lazo, J.M. Biocompression external fixation: sliding external osteosynthesis. Clin. Orthop. Rel. Res. 206, 169-184, 1986.

13. Cunningham, J.L., Kenwright, J. and Kershaw, C.J. Biomechanical measurement of fracture healing. J. Med. Eng. and Technol. 14, 92-101, 1990.

14. Holter, N. (1961). New method for heart studies. Science, 134, 1214-1220.

15. Hutton, W.C. and Dhanendran, M. A study of the distribution of load under the normal foot during walking. Int. Orthop. 3, 153-157, 1979.

16. Duckworth, T., Betts, R.P., Franks, C.I. and Burke, J. The measurement of pressures under the foot. Foot & Ankle 3, 130-141, 1982.

17. Harris, D., Gwillim, J., Cochrane, G. and Hopkins, S. Monitoring performance and activity. 10th Annual Report of the Oxford Orthopaedic Engineering Centre, 80-84, 1983.

18. PSI Systems Mini-module Hardware Manual PSI-K100/3.

19. Cunningham, J.L. and Kershaw, C.J. Ultrasonic assessment of fracture healing. Brit. J. Radiol. 63, 393, 1989.

20. Shah, K.M., Nicol, A.C. and Richardson, J.B. A method of non-invasive fracture stiffness measurement. Proc. 6th Meeting of the European Society of Biomechanics, C10, 1988.

Appendix 3 : The Ambulatory Monitor Program Listing

```
/* This programme is in a finished and working state, all options      */
/* having been fully tested.  However due to its evolution             */
/* during trials parts of one feature, that due to time limitations was */
/* not finished, remain in the code (for aiding future extension of the */
/* programme).  This feature is the simultaneous monitoring of 2 legs.  */
/* Therefore currently only 1 leg can ever be monitored during a trial  */
/* meaning that 'legs_monitored' is always 1.                           */

#include <stdio.h>
#include <minos.h>
#include <moddef.h>
#include <i2c.h>
#include <time.h>
#include <mriext.h>
#include <string.h>
#include <errno.h>
#include <stdlib.h>
#include "moddef.h"
#include "procs.h"
#include "minos.h"

#define ON                      1
#define OFF                     0
#define SUCCESSFUL              1
#define UNSUCCESSFUL            0
#define DATA_SIZE               212
#define RESULTS_SIZE            30000
#define EVENT_SIZE              8 /* event size, power down, display,
legs_monitored, calibrate_value0, 1, 2, 3 */
#define EVENT_LEVEL1            30
#define DATA_FILE               1
#define RESULTS_FILE            2
#define SECONDS                 0
#define HUNDREDTHS_OF_SECS      1
#define RECORDING               6
#define PC_LINK                 4
#define TRANSMITTING            2
#define ERROR                   0
#define MEMORY_FULL             0
#define SWITCH_PC_LINK          8

typedef char tname[10];

load ( char * );
extern int _paths[];
void *sysmem( int, int );
char *clearwhite( char * );
char *getcmd( char *, char * );
char *getarg( char *, char *, int );
void *link( char * );
int save_file( FILE * , int );
float time_increment( void );
void calc_results( void );
void pressure_input( void );
int open_data_file( int );
int open_results_file( int );
int open_event_file( void );
void setup_datamods( void );
void writereg( int, int );
void writebcdreg( int, int );
void sleep( int, int );
int link_test( void );
void stamp_results( int );
unsigned char get_adc( int );
void switch_on( int );
void switch_off( int );
unsigned char interpolate( int, unsigned char, unsigned char, unsigned char
);
```

```
void get_outfile_name( char * );
void error( void );
void startup_event_file( void );
void setup_event_file( void );


/* The following structures, pointers, etc. are defined globally for */
/* ease of implementation. */

struct moddef *results1;
struct moddef *results2;
struct moddef *event;
struct moddef *data1;
struct moddef *data2;
struct moddef *test;
unsigned char *cur_result1;
unsigned char *cur_result2;
unsigned char *cur_event;
unsigned char *power_down;
unsigned char *display;
unsigned char *legs_monitored;
unsigned char *calibrate_value0;
unsigned char *calibrate_value1;
unsigned char *calibrate_value2;
unsigned char *calibrate_value3;
unsigned char *cur_data1;
unsigned char *cur_data2;
struct tm tim;
struct tm *cur_time;
char outfile_name[13];
char module_name[]="000";

/* Below are variables used by shell(). */

tname types[] =
{
      "Program",
      "Dit",
      "Driver",
      "System",
      "Modula",
      "Data"
};

char Buffer[80];
FILE *in;                       /* Holds path to be used for input */
FILE *out;                      /* Holds path to be used for output */
int coproc;                     /* Flag to show concurrent execution */
int Inp_Path;
int Out_Path;


/* The following routine is called at the initialisation stage of the   */
/* program if this is the first time it is being run (ie. there is no    */
/* event file present in memory with assigned flags for program          */
/* operation and scaling values for the transducer calibration.          */
/* Therefore the flags and scaling values are set to initial defaults). */

void startup_event_file()

{

cur_event = (unsigned char *) event + event -> start;

*cur_event = EVENT_LEVEL1;      /* Threshold minimum value for the      */
                          /* occurrance of an event.              */
cur_event++;
*cur_event = ON;        /* Processor power down = ON */
power_down = cur_event; /* The power_down (and subsequent pointers) are */
                  /* strictly necessary, but they aid in program  */
                  /* readability and give a slight speed increase */
                  /* at the expense of extra memory usage.        */
```

```

cur_event++;
*cur_event = OFF;        /* Display = OFF */
display = cur_event;

cur_event++;
*cur_event = 1;          /* No. of legs_monitored = 1 */
legs_monitored = cur_event;

cur_event++;
*cur_event = 120;         /* Calibrate_value0 = 0.90 (Calcaneous    */
                    /* transducer scaling value).           */
calibrate_value0 = cur_event;

cur_event++;
*cur_event = 85;        /* calibrate_value1 = 0.75 */
calibrate_value1 = cur_event;

cur_event++;
*cur_event = 120;        /* calibrate_value2 = 0.75 */
calibrate_value2 = cur_event;

cur_event++;
*cur_event = 120;        /* calibrate_value3 = 0.75 */
calibrate_value3 = cur_event;

cur_event = (unsigned char *) event + event -> start;

}


/* The following routine is called at the initialisation stage of the   */
/* program if the program was run previously and therefore the battery  */
/* backed RAM still contains the previous events file.  It therefore    */
/* just sets the pointers to point to the relevant part of the file     */
/* storing their value.                                                  */

void setup_event_file()

{
cur_event = (unsigned char *) event + event -> start;

cur_event++;
power_down = cur_event;

cur_event++;
display = cur_event;

cur_event++;
legs_monitored = cur_event;

cur_event++;
calibrate_value0 = cur_event;

cur_event++;
calibrate_value1 = cur_event;

cur_event++;
calibrate_value2 = cur_event;

cur_event++;
calibrate_value3 = cur_event;

cur_event = (unsigned char *) event + event -> start;

}


main()

{
int run=SUCCESSFUL,i, outcome;
```

```
FILE *fptr;

initi2c();      /* This initialises the Mini-module i2c bus for I/O */

cur_time = &tim;        /* The library functions which access the       */
                       /* real-time clock return to a structure of type*/
                       /* tm.  Therefore tim stores the values, and a  */
                       /* pointer to it (cur_time) is used to access   */
                       /* them.                                        */

/* The following lines set the digital channels to either inputs or     */
/* outputs (the input needed only for the channel connected to the      */
/* switch which when depressed indicates to the Mini-module to attempt  */
/* to access the PC via the serial interface.                           */

outch( RECORDING );
outch( PC_LINK );
outch( ERROR );
outch( TRANSMITTING );
inch( SWITCH_PC_LINK );

/* The following simply switch off the leds.    */

switch_off( RECORDING );
switch_off( PC_LINK );
switch_off( ERROR );
switch_off( TRANSMITTING );

outcome = open_event_file();    /* An attempt is made to set up an      */
                          /* events file which is only successful */
                          /* if there is none already present.    */

if( outcome==SUCCESSFUL )       /* If first time round, setup variables */
                          /* (pointers).                          */
      startup_event_file();
else
      setup_event_file(); /* Started up with event file already present */

setup_datamods();       /* This function deletes any data files present */
                       /* and makes new blank ones.  It also creates    */
                       /* new results file(s) if not already present.  */

while( 1 ) {     /* endless loop */

      setup_datamods();       /* Clears data files.   */

      pressure_input();       /* This function samples the A/D        */
                          /* converters until the data file(s) are*/
                          /* full.  In this function the sampling */
                          /* can be interrupted for PC access for */
                          /* downloading results etc..            */

      calc_results();         /* This function analyses the data      */
                          /* file(s) and stores the information   */
                          /* for any events that occur.           */

      }

error();        /* program execution should never get here */

}


/* This routine stamps each result file with the year, month, and day of*/
/* month.  As this information is the same for all events, it is only   */
/* stored once at the start of each Results file.  The tree items of    */
/* information are compressed into two bytes by bit shifting.           */

void stamp_results( int no_of_legs )

{
unsigned char ctime1, ctime2;   /* These 2 variables hold the compressed*/
```

```
                                /* information.                         */
getime(cur_time);             /* The cur_time pointer of type tm structure    */
                          /* points to a tim of type structure tm which    */
                          /* stores the time information.                 */

ctime1 = (unsigned char) ((cur_time -> tm_year)-1);
ctime1 = ctime1 << 1;
ctime1 += (unsigned char) (cur_time -> tm_mon) >> 3;
ctime2 = (unsigned char) (cur_time -> tm_mon) & 7;

ctime2 = ctime2 << 5;
ctime2 += (unsigned char) (cur_time -> tm_mday) & 31;

if( no_of_legs == 2 ) {
      *cur_result2 = ctime1;
      cur_result2++;
      *cur_result2 = ctime2;
      cur_result2++;
      *cur_result2 = 255;     /* Two subsequent 255s indicate the end */
                          /* of the results currently stored in    */
                          /* the Results file.                     */
      cur_result2++;
      *cur_result2 = 255;
      cur_result2++;
      }

*cur_result1 = ctime1;
cur_result1++;
*cur_result1 = ctime2;
cur_result1++;
*cur_result1 = 255;
cur_result1++;
*cur_result1 = 255;
cur_result1++;

}


/* The following two routines are written for better code readability.  */
/* When switching a LED on, the digital line is actually turned off,    */
/* and vice versa.                                                       */
/* For both, function is the digital line number (defined above as a    */
/* 'function' eg. TRANSMITTING).                                         */

void switch_on( int function )

{

turnoff( function );

}


void switch_off( int function )

{

turnon( function );

}


/* This function is called from the presure_input function, when the    */
/* operator selects option 1 (record results) from the options menu.    */
/* This function is then called with the 'function' variable being      */
/* RESULTS_FILE.  In fact, DATA_FILE is never called, but was originally*/
/* used for debugging purposes.                                          */

int save_file( FILE *fptr, int function )

{
int     i, temp_i, outcome=UNSUCCESSFUL, year, month, d_month,
        hour, min, sec, temp, max_value, msb;
unsigned char *temporary;

switch( function ) {
case RESULTS_FILE:
        outcome = SUCCESSFUL;
        cur_result1 = (unsigned char *) results1 + results1 -> start;
        temporary = (unsigned char *) results1 + results1 -> start;

        year = (*cur_result1 >> 1) & 127;
        month = (*cur_result1 & 1) << 3;
        cur_result1++;
        month += ((*cur_result1 & 224) >> 5);
        d_month = *cur_result1 & 31;

        cur_result1++;
        temporary = cur_result1;
        temporary++;

        fprintf(fptr,"%d\r\n",*legs_monitored);
        fprintf(fptr,"%d\r\n",*cur_event);


        /* The while loop below continues until 255 255 is reached in   */
        /* the file (which is the end of file marker.                   */

        while ( (*cur_result1!=255) && (*temporary!=255) ) {
                hour = *cur_result1 >> 3;
                min = (*cur_result1 & 7) << 3;
                cur_result1++;
                min += (*cur_result1 & 224) >> 5;
                sec = (*cur_result1 & 31) * 2;
                if ( sec>59 ) {
                        sec = 59;
                        }
                cur_result1++;

                fprintf(fptr,"%d ",hour);
                fprintf(fptr,"%d ",min);
                fprintf(fptr,"%d ",sec);

                max_value = (*cur_result1 >> 1) & 127;
                msb = *cur_result1 & 1;

                fprintf(fptr,"%d ",max_value);
                fprintf(fptr,"%d ",msb);
                cur_result1++;

                for ( temp=0; temp<2; temp++ ) {
                        fprintf(fptr,"%d ",*cur_result1);
                        cur_result1++;
                        }

                fprintf(fptr,"\r\n");

                temporary = cur_result1;
                temporary++;

                }

        fprintf(fptr,"999");    /* This is the end of file marker for   */
                            /* the PC data file.                   */

        backup(results1,0);     /* These lines delete the Results1.dat  */
        unfix("Results1.dat");  /* file, and open a new one (effectively*/
        open_results_file(1);   /* just deleting the old contents.      */


        /* Opening a new results file also writes 255 255 as the first  */
        /* 2 unsigned char numbers.  Therefore the start for new data   */
        /* for the results file is already incremented twice with the   */
        /* end of file marker.  Therefore it is decremented twice so    */
        /* that new results data can be written from the start of the   */
        /* file.                                                        */

        cur_result1--;
        cur_result1--;

        fprintf(fptr,"%c", 0x0D);
        fprintf(fptr,"%c", 0x0A);
        fprintf(fptr,"%c", EOF);

        printf("\r\n");

        break;

case DATA_FILE:
        outcome = SUCCESSFUL;
        cur_data1 = (unsigned char *) data1 + data1 -> start;

        for ( i=0; i<DATA_SIZE; i++ ) {
                if ( (i%20)==0 ) {
                        fprintf(fptr,"%c", 0x0D);
                        fprintf(fptr,"%c", 0x0A);
                        }
                fprintf(fptr,"%d ",*cur_data1);
                cur_data1++;
                }

        fprintf(fptr,"%c", 0x0D);
        fprintf(fptr,"%c", 0x0A);
        fprintf(fptr,"%c", EOF);
        break;

        }

return ( outcome );     /* 'outcome' is SUCCESSFUL if either of the 2   */
                        /* case branches have been entered; otherwise it*/
                        /* is UNSUCCESSFUL.                             */

}


/* This function is called from the main() function, after the         */
/* pressure_input function has been called.  This function analyses the */
/* data file, storing the results file the information for any events   */
/* that occur.                                                          */

void calc_results()

{
int     data_counts, i, c, max_value=0, counts, start=-1, finish=0,
        year, yday, month, sec_temp, min_temp, hour_temp, day_month,
        isdst, hour, min, sec;
unsigned char ctime1, ctime2, ctime3;
float time_inc;
unsigned char m_days[]={31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31};


/* First a test is performed to ensure that the Results file exists for */
/* the number of legs specified (currently there can only be 1).        */

if ( (*legs_monitored==1) && ((test=link("Results1.dat"))!=NULL) ) {
        time_inc = time_increment();    /* The inter-sample time */

        if (*display==ON)
                printf("\r\nTime inc:%f ", time_inc);

        cur_data1 = (unsigned char *) data1 + data1 -> start;

        year = *cur_data1;
        cur_data1++;
        month = *cur_data1;
        cur_data1++;
        day_month = *cur_data1;
        cur_data1++;
        hour = *cur_data1;
        cur_data1++;
        min = *cur_data1;
        cur_data1++;
        sec = *cur_data1;
        cur_data1++;

        sec_temp = sec;
        min_temp = min;
        hour_temp = hour;
        start=-1; finish=0;

        data_counts = DATA_SIZE-12;     /* -12 because the first 6 and  */
                                    /* last 6 bytes are used for    */
                                    /* the start and finish time    */
                                    /* stamps.                      */

        for ( i=0; i<data_counts; i++ ) {
                if ( start == -1 )      /* start==-1 when current       */
                                    /* position is not in an event. */
                        counts=0;       /* So current number of samples */
                                    /* comprising the event is 0.   */

                if ( (*cur_data1 > *cur_event) && (start==-1) ) {
                /* ie the start of an event */
                        start = i;      /* The position of the start of */
                                    /* the event in the file.       */
                        counts = 1;     /* Currently event comprises of */
                                    /* 1 samples.                   */
                        }

                else if ( *cur_data1 > *cur_event ) {
                /* ie already in an event */
                        if ( i==data_counts-1 ) /* If at the end of the */
                                            /* data file.           */
                                finish = start+counts;

                        else    /* Otherwise increment the number of    */
                                /* samples comprising the event.        */
                                counts++;
                        }

                else if ( (*cur_data1 < *cur_event) && (start!=-1) )
                /* ie the end of an event */
                        finish = start+counts;


                if ( finish != 0 ) {
                /* ie an event has just finished */

                        /* First rewind pointer to the start of the event*/
                        for( c=0; c<counts; c++ ) {
                                cur_data1--;
                                }

                        /* Next obtain the peak for the event.  */
                        for ( c=0; c<counts; c++ ) {
                                if ( *cur_data1 > max_value )
                                        max_value = *cur_data1;
                                cur_data1++;
                                }

                        /* '.._temp' has previously been set to the time*/
                        /* at the start of the data file.               */

                        /* Now set 'sec' to the middle sample of the    */
                        /* event.  This might take it over 60, so after */
                        /* 'min', 'hour', 'yday', 'year' are incremented*/
                        /* as required.                                 */
                        sec = sec_temp+((finish-(counts/2))*time_inc);
                        min = min_temp;
                        hour = hour_temp;
                        while ( sec > 59 ) {
                              sec -= 60;
                              min += 1;
                              }
                        while ( min > 59 ) {
                              min -= 60;
                              hour += 1;
                              }

                        /* This calculates the yday. */
                        yday = 0; c=0;
                        while( month != (c+1) ) {
                              yday += m_days[c];
                              c++;
                              }
                        yday += day_month;

                        while ( hour > 23 ) {
                              hour -= 24;
                              yday++;
                              }

                        while ( yday > 365 ) {
                              yday -= 365;
                              year++;
                              }

                        /* The time stamp information is now compressed */
                        /* from 3 bytes to 2.                           */
                        ctime1 = (unsigned char) hour;
                        ctime1 = ctime1 << 3;
                        ctime1 += (unsigned char) (min >> 3) & 7;
                        ctime2 = (unsigned char) min & 7;
                        ctime2 = ctime2 << 5;
                        ctime2 += (unsigned char) ((sec/2) & 31);
                        ctime3 = (max_value & 127) << 1;

                        /* The top-most bit of the counts value is      */
                        /* packed at the end of the 3rd byte.           */
                        ctime3 += (counts >> 8) & 1;

                        *cur_result1 = ctime1;
                        cur_result1++;
                        *cur_result1 = ctime2;
                        cur_result1++;
                        *cur_result1 = ctime3;
                        cur_result1++;
                        *cur_result1 = counts & 0xFF;    /* LSB of counts */
                        cur_result1++;
                        *cur_result1 = (unsigned char) (time_inc*100);
                        cur_result1++;

                        finish = 0;      /* Reset these variables to     */
                        start = -1;      /* continue analysisng the data */
                        max_value = 0;   /* file for more events.        */

                        }

                  cur_data1++;

                  }

            /* At the end of the current results data in the results file,  */
            /* put 255 255 as the end of file marker.                       */
            *cur_result1 = 255;
            cur_result1++;
            *cur_result1 = 255;
            cur_result1--;

            }
```

```

else {  /* If the Results1.dat file is not found, an error has occurred. */
        switch_off( RECORDING );
        switch_off( PC_LINK );
        switch_off( TRANSMITTING );
        switch_on( ERROR );

        if( *legs_monitored==1 )
              printf("\r\n!!! ERROR !!! :- Results1.dat not found");

        while(1) ;     /* Infinite loop, ie. programme halts at this point
*/

        }


}


/* This function calculates the inter-sample time. */

float time_increment()

{
int     i, start_year, start_month, start_day_month, start_isdst,
        start_hour, start_min, start_sec, finish_year, finish_month,
        finish_day_month, finish_isdst, finish_hour,
        finish_min, finish_sec, hours, mins, secs;
unsigned char *file_time;
float time, inc_time;

file_time = (unsigned char *) data1 + data1 -> start;

start_year = *file_time;
file_time++;
start_month = *file_time;
file_time++;
start_day_month = *file_time;
file_time++;
start_hour = *file_time;
file_time++;
start_min = *file_time;
file_time++;
start_sec = *file_time;
file_time++;

for ( i=0; i<(DATA_SIZE-12); i++ )
        file_time++;

finish_year = *file_time;
file_time++;
finish_month = *file_time;
file_time++;
finish_day_month = *file_time;
file_time++;
finish_hour = *file_time;
file_time++;
finish_min = *file_time;
file_time++;
finish_sec = *file_time;
file_time++;

/* If finish_hour<start_hour it means that the start was before         */
/* midnight with the finish being after.  Therefore add 24 to           */
/* finish_hour.                                                         */
if ( finish_hour < start_hour )
        finish_hour += 24;

hours = finish_hour - start_hour;
mins = finish_min - start_min;
secs = finish_sec - start_sec;

```

```
time = (hours*60*60) + (mins*60) + secs;

/* The inter-sample time is the time duration for all the samples of    */
/* the data file divided by the number of samples.                       */
inc_time = time/(DATA_SIZE-12);

return ( inc_time );

}


/* This function is called from the pressure_input function.  It        */
/* calculates the mass from the pressure transducer reading.  This       */
/* occurs from its stored calibrated pressure transducer values for      */
/* masses applied in multiples of 5 kg.  It uses the interpolate         */
/* function to interpolate between these calibrated values to obtain the*/
/* corresponding mass for the inpuuted pressure transducer reading.      */

unsigned char get_adc( int no )

{
unsigned char value;
unsigned char ad[]={0,15,30,55,70,85,105,115,135,150,169,182,195,255};
      /* These are the calibration pressure transducer values for each*/
      /* multiple of 5 kg.                                            */

int flag=0, i;

value = adc( no );


/* If the pressure transducer values are either 0 or 255, then set to   */
/* 1 and 254 respectively so that the calibration values either side of */
/* can be obtained.                                                     */

if ( value==0 ) {
      value=1;
      flag=1;
      }

/* It should not be possible to get a value above 255 but just in case
...*/
else if ( value >= 255 ) {
      value=254;
      flag=1;
      }


/* The following code calculates which calibration value is just above  */
/* the inputted value from the pressure transducers.  It then re-sets   */
/* the inputted values to 0 or 255 if required.                         */

for ( i=0; ad[i]<value; i++ ) ;
if ( flag==1 ) {
      if ( value==254 )
            value=255;
      else
            value=0;
      }

value = interpolate( i, value, ad[i-1], ad[i] );

return( value );

}


unsigned char interpolate( int lower_val, unsigned char value,
      unsigned char lower_calibration, unsigned char upper_calibration )

{
int i;
```

```
float answer;

/* During calibration it was found that a slight pressure was required  */
/* before the reading changed from 0.  This is added (0.275).           */

answer = 0.275+(5.0*(value-lower_calibration))
            / ((float)upper_calibration-lower_calibration);
answer += (lower_val-1)*5.0;

return( (unsigned char) answer );

}


/* It is in this function that the programme spends most time during    */
/* execution.  The function is called by the main() function after      */
/* having cleared the data files.                                       */

void pressure_input()

{
int sum, data_counts, i, temp, outcome=UNSUCCESSFUL, count, test, flag,
      set_sec, set_min, set_hour, set_mday, set_mon,
      set_year, set_wday, set_yday, set_isdst;
unsigned char adc0, adc1, adc2, adc3;
unsigned char *temp1_results;
unsigned char *temp2_results;
char file_name[10],input;
unsigned char m_days[] = {31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31};
static float calibrate_value=1.0;
FILE *fptr;

/* First a test is performed to ensure that there is a data file present.
*/

if ( (*legs_monitored==1) && ((data1=link("Data1.dat"))!=NULL) ) {
      switch_on( RECORDING );
      getime(cur_time);


      /* The start of the data file is time stamped. */

      cur_data1 = (unsigned char *) data1 + data1 -> start;
      *cur_data1  = cur_time -> tm_year;
      cur_data1++;
      *cur_data1 = cur_time -> tm_mon;
      cur_data1++;
      *cur_data1 = cur_time -> tm_mday;
      cur_data1++;
      *cur_data1 = cur_time -> tm_hour;
      cur_data1++;
      *cur_data1 = cur_time -> tm_min;
      cur_data1++;
      *cur_data1 = cur_time -> tm_sec;
      cur_data1++;

      data_counts = DATA_SIZE-12;     /* -12 because there are 2 time */
                                 /* stamps (one at the beginning */
                                 /* and the other at the end)    */
                                 /* each taking 6 bytes each.    */

      for ( i=0; i<data_counts; i++ ) {
            adc0 = (unsigned char) ((get_adc(0))*(*calibrate_value0)/100);
            adc1 = (unsigned char) ((get_adc(1))*(*calibrate_value1)/100);


            /* The following decrements are needed for when no load */
            /* is applied on the transducers, a value of 1 or 2     */
            /* would be read from the A/D 1.                        */

            if( adc1>0 )
                  adc1--;
```

```
    if( adc1>0 )
        adc1--;


    adc2 = (unsigned char) ((get_adc(2))*(*calibrate_value2)/100);
    adc3 = (unsigned char) ((get_adc(3))*(*calibrate_value3)/100);


    /* Only one decrement is required for A/D 2 for its no  */
    /* load value would be 0 or 1.                          */

    if( adc2>0 )
        adc2--;


    /* By using 'sum' which is an int, the summation is     */
    /* forced to be an int so causing there to be no        */
    /* 'wrap-around' if the sum was greater than 255.       */

    sum = adc0;
    sum = sum + adc1;
    sum = sum + adc2;
    sum = sum + adc3;


    /* If 'sum' is greater than 255, then set it to 255 so  */
    /* it can be stored in 1 byte.  This gives the monitor a*/
    /* range of up to 255 kg (more than enough)!            */

    if( sum > 255 )
        sum = 255;

    /* The transducers' sum (kg) is then stored in the data */
    /* file.                                                */
    *cur_data1 = sum;


    /* If the display toggle (accessed from the operator    */
    /* menu is ON, then print 'sum' on the screen.          */

    if ( *display==ON ) {
        printf(" %d",*cur_data1);

        /* A delay is now required, otherwise there is a*/
        /* danger of the RS-485 buffer overflowing,     */
        /* resulting with the display, keyboard and file*/
        /* storage system hanging.                      */

        delay(1);
        }

    /* The data file pointer is now incremented so that it  */
    /* points to the next free byte.                        */

    cur_data1++;


    /* A delay is specified to slow the sampling rate, or it*/
    /* would be in the kilo(?) Hertz range. */

    delay(1);


    /* If the operator has specified that the processor     */
    /* should be powered down in between samples, then do so*/
    /* for 0.1 seconds (excluding time for re-starting it.  */

    if ( *power_down==ON )
        sleep( 10, HUNDREDTHS_OF_SECS );


    /* Test for the PC switch on the monitor having been    */
```

```
             /* triggered (ie requesting a PC link).                   */

             if ( ch(SWITCH_PC_LINK)==0 ) {
                    switch_off( RECORDING );
                    switch_on( PC_LINK );

                    /* It might have been depressed by accident.    */
                    /* Therefore check for a key being depressed on */
                    /* the keyboard to confirm.                     */

                    outcome = link_test();
                    if ( outcome == SUCCESSFUL ) {

                           /* Clear the key depressed from the     */
                           /* buffer.                              */

                           scanf("%c", &input);


                           /* Print on the screen the options menu*/

                           printf("\r\n\n Possible options are:");
                           printf("\r\n 1: Record results");
                           printf("\r\n 2: Edit event level");
                           printf("\r\n 3: Calibrate transducers");
                           printf("\r\n 4: Restart ""Results1.dat""
module");
                           printf("\r\n 5: Power down processor ON/OFF");
                           printf("\r\n 6: List results to date");
                           printf("\r\n 7: Go to shell program");
                           printf("\r\n 8: Real time clock");
                           printf("\r\n 9: Display toggle");
                           printf("\r\n\n Please input a number (1-9): ");


                           /* Put a delay to let the serial port   */
                           /* catch up with the program.           */

                           delay(50);


                           /* Get the operator input.              */

                           scanf("%c", &input);
                           printf("\r\n");


                           /* If option '1' is chosen, save the    */
                           /* results file onto the PC disk.  Then */
                           /* clear the results and data files from*/
                           /* memory and restart monitoring.       */

                           if ( input=='1' ) {
                                 switch_on( TRANSMITTING );

                                 /* For ease of programmer change*/
                                 /* the PC file's name is        */
                                 /* abstracted into a separate   */
                                 /* function (so can easily be   */
                                 /* changed for the whole        */
                                 /* programme).                  */

                                 get_outfile_name( outfile_name );
                                 printf("\r\nSaving 'Results1.dat' module
as '%s' on the hard disk.\r\n\n",outfile_name);

                                 fptr = fopen(outfile_name,"w");
                                 outcome = save_file( fptr, RESULTS_FILE );
                                 fclose(fptr);


                                 /* Perform a kind of reset.     */
```

```
                                /* Delete the data and results  */
                                /* files, and create new ones.  */
                                /* Also reset the loop variable */
                                /* and data/results files       */
                                /* pointers after time stamping.*/

                                /* First delete the data file.  */

                                backup(data1,0);
                                unfix("Data1.dat");


                                /* Next create a new one and    */
                                /* time stamp it.               */

                                open_data_file(1);

                                getime(cur_time);
                                cur_data1 = (unsigned char *) data1 +
data1 -> start;
                                *cur_data1  = cur_time -> tm_year;
                                cur_data1++;
                                *cur_data1 = cur_time -> tm_mon;
                                cur_data1++;
                                *cur_data1 = cur_time -> tm_mday;
                                cur_data1++;
                                *cur_data1 = cur_time -> tm_hour;
                                cur_data1++;
                                *cur_data1 = cur_time -> tm_min;
                                cur_data1++;
                                *cur_data1 = cur_time -> tm_sec;
                                cur_data1++;


                                /* Next delete the results file. */

                                backup(results1,0);
                                unfix("Results1.dat");


                                /* And create a new one.        */

                                open_results_file(1);

                                cur_result1--;
                                cur_result1--;
                                       /* as created with 255 255 */

                                /* Finally reset the loop variable */

                                i=0;

                                switch_off( TRANSMITTING );

                                }


                          /* If option '2' is selected, the event */
                          /* level is printed on the screen, and  */
                          /* the operator has the option to change*/
                          /* its value.                           */

                          else if ( input=='2' ) {
                                printf("\r\nCurrent event level set at %d
kg.",*cur_event);
                                printf("\r\nDo you wish to change this
level? (Y/N) ");
                                scanf("%c",&input);
                                if ( (input=='Y')||(input=='y') ) {
                                       printf("\r\nEnter new level: ");
                                       scanf("%d",&test);
                                       while ( (test>65)||(test<0) ) {
                                        printf("\r\nRange is 0 to 65
kg. Please try again: ");
                                        scanf("%d",&test);
                                        }
                                    *cur_event = (unsigned char) test;
                                    printf("\r\n\nLevel set at %d
kg.\r\n",*cur_event);
                                    }
                                else {
                                    printf("\r\n");
                                    }

                                /* A delay is required to       */
                                /* ensure that the serial port  */
                                /* has caught up with the       */
                                /* programme.                   */

                                delay(10);
                                }


                            /* If option '3' is selected, the       */
                            /* operator can view the individual     */
                            /* transducers' input value and change  */
                            /* each one's scaling value.            */

                            else if ( input=='3' ) {
                                printf("\r\nWhich transducer do you wish
to calibrate:");
                                printf("\r\nCalcaneus(1), First Metatarsal
Head (2), Fifth Metatarsal Head (3),");
                                printf("\r\nThird Metatarsal Head (4), or
monitor all three at once (5): ");
                                scanf("%c",&input);
                                printf("%c\r\n",input);
                                fflush(stdin);

                                if ( input=='1' ) {
                                    printf("Current calibration value is
%d.\r\n",*calibrate_value0);
                                    delay(50);
                                    flag=OFF;
                                    count=0;
                                    while( flag==OFF ) {
                                        printf("%d ",(unsigned char)
((get_adc(0))*(*calibrate_value0)/100) );
                                        delay(4);
                                        sleep( 10, HUNDREDTHS_OF_SECS
);
                                        if ( count==50 ) {
                                            printf("\r\nInput 1 to
continue, 2 to change calibration value, 3 to end calibration: ");
                                            scanf("%c",&input);
                                            printf("%c\r\n",input);
                                            if ( input=='1' )
                                                count=0;
                                            else if ( input=='2' )
{
                                                printf("\r\nSet
calbration value * 100 (currently %d) to (max 255): ",*calibrate_value0);

    scanf("%d",&test);

    *calibrate_value0 = (unsigned char) test;

    printf("\r\nCalibration value set at
%.2f\r\n",(*calibrate_value0/100.0));
                                                count=0;
                                                }
                                            else
                                                flag=ON;
                                                printf("\r\n");
                                                }

                                        count++;

                                        }

                                }


                        else if ( input=='2' ) {
                                printf("Current calibration value is
%d.\r\n",*calibrate_value1);
                                delay(50);
                                flag=OFF;
                                count=0;
                                while( flag==OFF ) {
                                        adc0 = (unsigned char)
((get_adc(1))*(*calibrate_value1)/100);
                                        if( adc0>0 )
                                                adc0--;
                                        if( adc0>0 )
                                                adc0--;

                                        printf("%d ", adc0);

                                        delay(4);
                                        sleep( 10, HUNDREDTHS_OF_SECS
);
                                        if ( count==50 ) {
                                                printf("\r\nInput 1 to
continue, 2 to change calibration value, 3 to end calibration: ");
                                                scanf("%c",&input);
                                                printf("%c\r\n",input);

                                                if ( input=='1' )
                                                        count=0;
                                                else if ( input=='2' )
{
                                                        printf("\r\nSet
calbration value * 100 (currently %d) to (max 255): ",*calibrate_value1);

        scanf("%d",&test);

        *calibrate_value1 = (unsigned char) test;

        printf("\r\nCalibration value set at
%.2f\r\n",(*calibrate_value1/100.0));
                                                        count=0;
                                                        }
                                                else
                                                        flag=ON;

                                                printf("\r\n");
                                                }

                                        count++;

                                        }

                                }


                        else if( input=='3' ) {
                                printf("Current calibration value is
%d.\r\n",*calibrate_value2);
                                delay(50);
                                flag=OFF;
                                count=0;
                                while( flag==OFF ) {
                                        adc0 = (unsigned char)
((get_adc(2))*(*calibrate_value2)/100);
```

```
                                                            if( adc0>0 )
                                                                    adc0--;

                                                            printf("%d ", adc0);

                                                            delay(4);
                                                            sleep( 10, HUNDREDTHS_OF_SECS
);
                                                            if ( count==50 ) {
                                                                    printf("\r\nInput 1 to
continue, 2 to change calibration value, 3 to end calibration: ");
                                                                    scanf("%c",&input);
                                                                    printf("%c\r\n");

                                                                    if ( input=='1' )
                                                                            count=0;
                                                                    else if ( input=='2' )
{
                                                                            printf("\r\nSet
calbration value * 100 (currently %d) to (max 255): ",*calibrate_value2);

        scanf("%d",&test);

        *calibrate_value2 = (unsigned char) test;

        printf("\r\nCalibration value set at
%.2f\r\n",(*calibrate_value2/100.0));
                                                                            count=0;
                                                                            }
                                                                    else
                                                                            flag=ON;

                                                                    printf("\r\n");
                                                                    }
                                                            count++;

                                                            }

                                                    }


                                            else if( input=='4' ) {
                                                    printf("Current calibration value is
%d.\r\n",*calibrate_value3);
                                                    delay(50);
                                                    flag=OFF;
                                                    count=0;
                                                    while( flag==OFF ) {
                                                            adc0 = (unsigned char)
((get_adc(3))*(*calibrate_value3)/100);

                                                            printf("%d ", adc0);

                                                            delay(4);
                                                            sleep( 10, HUNDREDTHS_OF_SECS
);
                                                            if ( count==50 ) {
                                                                    printf("\r\nInput 1 to
continue, 2 to change calibration value, 3 to end calibration: ");
                                                                    scanf("%c",&input);
                                                                    printf("%c\r\n");

                                                                    if ( input=='1' )
                                                                            count=0;
                                                                    else if ( input=='2' )
{
                                                                            printf("\r\nSet
calbration value * 100 (currently %d) to (max 255): ",*calibrate_value3);

        scanf("%d",&test);

        *calibrate_value3 = (unsigned char) test;

        printf("\r\nCalibration value set at
%.2f\r\n",(*calibrate_value3/100.0));
                                                                        count=0;
                                                                        }
                                                                else
                                                                        flag=ON;

                                                                printf("\r\n");
                                                                }
                                                        count++;

                                                        }


                                                }


                                        /* Whilst the above options     */
                                        /* deal with just one transducer*/
                                        /* value at a time, the last    */
                                        /* option prints all 4 values   */
                                        /* simultaneously.              */

                                        else if( input=='5' ) {
                                                delay(50);
                                                flag=OFF;
                                                count=0;
                                                while( flag==OFF ) {
                                                        adc0 = (unsigned char)
((get_adc(0))*(*calibrate_value0)/100);
                                                        adc1 = (unsigned char)
((get_adc(1))*(*calibrate_value1)/100);
                                                        adc2 = (unsigned char)
((get_adc(2))*(*calibrate_value2)/100);
                                                        adc3 = (unsigned char)
((get_adc(3))*(*calibrate_value3)/100);
                                                        if( adc1>0 )
                                                                adc1--;
                                                        if( adc1>0 )
                                                                adc1--;
                                                        if( adc2>0 )
                                                                adc2--;

                                                        printf("%d;%d,%d,%d     ",
adc0,adc1,adc3,adc2);

                                                        delay(4);
                                                        sleep( 10, HUNDREDTHS_OF_SECS
);
                                                        if ( count==100 ) {
                                                                printf("\r\nInput 1 to
continue, 2 to end monitoring: ");
                                                                scanf("%c",&input);
                                                                printf("%c\r\n");

                                                                if ( input=='1' )
                                                                        count=0;
                                                                else
                                                                        flag=ON;

                                                                }
                                                        count++;

                                                        }

                                                }
                                        else
                                                printf("\r\nNo transducer chosen.");

                                        delay(50);

                                        }
```

```


                          /* If option '4' is selected, the old   */
                          /* results file is cleared and a new one*/
                          /* started (so that old results data is */
                          /* effectively deleted).  This is useful*/
                          /* so that the operator can be sure that*/
                          /* when starting a monitoring session   */
                          /* the date of the results file will be */
                          /* correct.                             */

                          else if ( input=='4' ) {
                                printf("\r\nStarting new 'Results1.dat'
module with today's date.\r\n\n");
                                backup(results1,0);
                                unfix("Results1.dat");
                                open_results_file(1);
                                cur_result1--;
                                cur_result1--;
                                delay(10);

                                }


                          /* If option '5' is selected, the       */
                          /* current setting for the power-down   */
                          /* toggle is displayed, and the operator*/
                          /* has the option of changing it.       */

                          else if ( input=='5' ) {
                                printf("\r\nPower down toggle is currently
");
                                if ( *power_down==ON )
                                      printf("ON.");
                                else
                                      printf("OFF.");

                                printf("\r\nDo you want to change this
setting? (Y/N) ");
                                scanf("%c",&input);
                                if ( (input=='y')||(input=='Y') ) {
                                      if ( *power_down==ON )
                                            *power_down=OFF;
                                      else
                                            *power_down=ON;
                                      }

                                }


                          /* If option '6' is selected, the data  */
                          /* currently held in the results file   */
                          /* is displayed.  Therefore all bytes   */
                          /* are displayed up to 255 255 which is */
                          /* the end of file marker.              */

                          else if ( input=='6' ) {
                                switch_on( TRANSMITTING );

                                printf("\r\nData in results1 file is as
follows:\r\n\n");
                                temp1_results = (unsigned char *) results1
+ results1->start;
                                printf("%d ",*temp1_results);
                                temp1_results++;
                                printf("%d\r\n",*temp1_results);
                                temp1_results++;
                                temp2_results = temp1_results;
                                temp2_results++;
                                temp=0;
                                while (
(*temp1_results!=255)&&(*temp2_results!=255) ) {
```

```
                                        printf("%d ",*temp1_results);
                                        temp1_results++;
                                        temp2_results++;
                                        temp++;
                                        if ( (temp%5)==0 )
                                             printf("\r\n");
                                        if ( temp<100 )
                                             delay(1);
                                        }

                                   delay(50);
                                   switch_off( TRANSMITTING );
                                   }


                              /* selecting option '7' enters the      */
                              /* operator in the shell programme.     */
                              /* This option is useful for debugging  */
                              /* purposes, but was left in so that if */
                              /* needed the operator could check as to*/
                              /* whether the various data files had   */
                              /* been instantiated as required.       */

                              else if ( input=='7' ) {
                                   shell();
                                   }


                              /* Selecting option '8' prints the      */
                              /* current date and time, with the      */
                              /* operator having the option to change */
                              /* it.                                  */

                              else if ( input=='8' ) {
                                   getime(cur_time);
                                   printf("\r\n\nCurrent settings are:");
                                   printf("\r\n\nDate: %d/%d/%d",cur_time-
>tm_mday, cur_time->tm_mon, ((cur_time->tm_year)-1));
                                   printf("\r\nTime: %d:%d:%d",cur_time-
>tm_hour, cur_time->tm_min, cur_time->tm_sec);
                                   printf("\r\n\nDo you want to change the
settings? (Y/N)");
                                   scanf("%c",&input);
                                   printf("%c\r\n",input);

                                   if ( (input=='Y')||(input=='y') ) {
                                        flag=OFF;
                                        while( flag==OFF ) {
                                             printf("\r\nInput hour: ");
                                             scanf("%d",&test);
                                             if ( (test>-1) && (test<24) )
                                                  flag=ON;
                                             else
                                                  printf("\r\nOh, really
??!!");
                                             }
                                        set_hour = test;
                                        flag=OFF;
                                        while( flag==OFF ) {
                                             printf("\r\nInput minute: ");
                                             scanf("%d",&test);
                                             if ( (test>-1) && (test<60) )
                                                  flag=ON;
                                             else
                                                  printf("\r\nOh, really
??!!");
                                             }
                                        set_min = test;
                                        set_sec = 0;
                                        flag=OFF;
                                        while( flag==OFF ) {
```

```
                        printf("\r\nInput day of
month: ");
                        scanf("%d", &test);
                        if ( (test>0) && (test<32) )
                                flag=ON;
                        else
                                printf("\r\nOh, really
??!!");
                        }
                set_mday = test;
                flag=OFF;
                while( flag==OFF ) {
                        printf("\r\nInput month of
the year (1-12): ");
                        scanf("%d",&test);
                        if ( (test>0) && (test<13) )
                                flag=ON;
                        else
                                printf("\r\nOh, really
??!!");
                        }
                set_mon = test;
                flag=OFF;
                while( flag==OFF ) {
                        printf("\r\nInput year (year-
1900): ");
                        scanf("%d",&test);
                        if ( (test>-1) && (test<100)
)
                                flag=ON;
                        else
                                printf("\r\nOh, really
??!!");
                        }
                set_year = test;
                flag=OFF;
                while( flag==OFF ) {
                        printf("\r\nInput day of week
(Sunday = 0): ");
                        scanf("%d",&test);
                        if ( (test>-1) && (test<8) )
                                flag=ON;
                        else
                                printf("\r\nOh, really
??!!");
                        }
                set_wday = test;
                flag = OFF;
                while( flag==OFF ) {
                        printf("\r\nInput daylight
saving time (0, 1): ");
                        scanf("%d",&test);
                        if ( (test>-1) && (test<2) )
                                flag=ON;
                        else
                                printf("\r\nOh, really
??!!");
                        }
                set_isdst = test;
                test = 1;
                set_yday = 0;
                while ( test != set_mon ) {
                        set_yday += m_days[test-1];
                        test++;
                        }

                cur_time->tm_sec = set_sec;
                cur_time->tm_min = set_min;
                cur_time->tm_hour = set_hour;
                cur_time->tm_mday = set_mday;
                cur_time->tm_mon = set_mon;
                cur_time->tm_year = set_year;
```

```
                        cur_time->tm_wday = set_wday;
                        cur_time->tm_yday - set_yday;
                        cur_time->tm_isdst = set_isdst;

                        setime( cur_time );

                        }


                    }


                /* Finally, selecting option '9' prints*/
                /* the current power-down setting, with */
                /* the option to change it.             */

                else if ( input=='9' ) {
                    printf("\r\nDisplay toggle is currently
");
                    if ( *display==ON )
                        printf("ON.");
                    else
                        printf("OFF.");

                    printf("\r\nDo you want to change the
setting? (Y/N) ");
                    fflush(stdin);
                    scanf("%c",&input);
                    if ( (input=='Y')||(input=='y') ) {
                        if ( *display==ON )
                            *display=OFF;
                        else
                            *display=ON;
                        }
                    }


                }

            switch_off(PC_LINK);
            switch_on(RECORDING);

            }

        }
    outcome = SUCCESSFUL;


    /* Finally at the end of the filling of the data file, the      */
    /* current date and time is again recorded (for the calculating */
    /* of the inter-sample time),                                   */

    getime(cur_time);

    *cur_data1  = cur_time -> tm_year;
    cur_data1++;
    *cur_data1 = cur_time -> tm_mon;
    cur_data1++;
    *cur_data1 = cur_time -> tm_mday;
    cur_data1++;
    *cur_data1 = cur_time -> tm_hour;
    cur_data1++;
    *cur_data1 = cur_time -> tm_min;
    cur_data1++;
    *cur_data1 = cur_time -> tm_sec;
    cur_data1++;


    /* It was thought beneficial to extend the functionality of     */
    /* this monitor programme to have the option of monitoring 1 or */
    /* 2 legs simultaneously (therefore using 4 or 2 transducers for*/
    /* each foot respectively).  Not enough time was found to       */
```

```
            /* complete this extension, but the code that for now will never*/
            /* be executed has been left to facilitate future work.        */

            if( *legs_monitored==2 ) {
                   *cur_data2  = cur_time -> tm_year;
                   cur_data2++;
                   *cur_data2 = cur_time -> tm_mon;
                   cur_data2++;
                   *cur_data2 = cur_time -> tm_mday;
                   cur_data2++;
                   *cur_data2 = cur_time -> tm_hour;
                   cur_data2++;
                   *cur_data2 = cur_time -> tm_min;
                   cur_data2++;
                   *cur_data2 = cur_time -> tm_sec;
                   cur_data2++;
                   }

            }

     else    {
            switch_off( RECORDING );
            switch_off( PC_LINK );
            switch_off( TRANSMITTING );
            switch_on( ERROR );

            /* Prints the appropriate error message for debugging purposes  */
            /* (as program execution should never arrive at this point).    */

            printf("\r\n!!! ERROR !!! :- Data1.dat not found");

            while(1) ;  /* Infinite loop, ie. programme halts at this point.*/

            }

     }


     /* This function builds up the file name for the file which will be     */
     /* saved to the PC disk using a pre-defined stub and the date of the     */
     /* results file.                                                         */

     void get_outfile_name( char *file_name )

     {
     int year, month, d_month, i, temp;

     /* The results file date is stored at the start of the file. */

     cur_result1 = (unsigned char *) results1 + results1->start;


     /* Then need to uncompress it.  */

     year = (*cur_result1 >> 1) & 127;

     printf("\r\nyear=%d\r\n",year); delay(5);

     month = (*cur_result1 & 1) << 3;
     cur_result1++;
     month += ((*cur_result1 & 224) >> 5);
     d_month = *cur_result1 & 31;


     /* Finally build up the file name and return it via the inputted char   */
     /* pointer.                                                              */

     *file_name = 'd';
     file_name++;
     *file_name = 'a';
     file_name++;
     *file_name = 't';
```

```
file_name++;
*file_name = (d_month/10) + 48;
file_name++;
*file_name = d_month-((d_month/10)*10) + 48;
file_name++;
*file_name = (month/10) + 48;
file_name++;
*file_name = month-((month/10)*10) + 48;
file_name++;
*file_name = year-((year/10)*10) + 48;
file_name++;
*file_name = '.';
strcat( file_name, module_name );

}


/* This function is called from the pressure_input function to check    */
/* whether a key on the PC keyboard is depressed (after the PC switch on*/
/* the monitor having been triggered).  The routine monitors the stdin  */
/* stream for a short period of time, returning the SUCCESSFUL if a key */
/* has been depressed, and UNSUCCESSFUL if not.                         */

int link_test()

{
int i, outcome=UNSUCCESSFUL;
FILE *input;

input = stdin;

for ( i=0; i<500; i++ ) {
      if ( ready(fileno(stdin)) > 0 ) {
            outcome = SUCCESSFUL;
            }

      delay(1);

      }

return( outcome );

}


/* This function is called from the main() function.  It deletes any    */
/* data files present (creating new ones in their place) and creates new*/
/* results file(s) if none are present.                                 */

void setup_datamods()

{
int i=0, outcome;
unsigned char *next_result;

/* If legs_monitored==2, then there should be 2 data/results files      */
/* present (or 1 if previously only 1 leg was being monitored).         */
/* Therefore first call open_data_file(1) which tries to create a new   */
/* data file for 1 leg being monitored (successul only if no data files */
/* are present) and then removes the data file for leg 1.               */
/* Therefore 2 data files can now be created, and the programme has     */
/* switched from having 1 data file to 2.                               */

if( *legs_monitored==2 ) {      /* This clears Data1.dat if present */
      open_data_file(1);
      backup(data1,0);
      unfix("Data1.dat");
      }

/* The required number of data files (currently always 1) are created.  */
/* Returns SUCCESFUL only if no data files are present.                 */
```

```
outcome = open_data_file(*legs_monitored);

if ( outcome==UNSUCCESSFUL ) {      /* Therefore a data file is present. */
      /* If 2 legs are being monitored, data file for leg 1 has       */
      /* already been deleted.  Therefore just delete the data file   */
      /* for leg 2.                                                   */
      if( *legs_monitored==2 ) {
            backup(data2,0);
            unfix("Data2.dat");
            }

      else {                                /* ie. legs monitored=1 */
            backup(data1,0);
            unfix("Data1.dat");
            }


      /* Can now successfully create the required number of data files.*/

      open_data_file(*legs_monitored);

      }


/* Set up the data file pointers to point to the start of the file.     */

if( *legs_monitored==2 )
      cur_data2 = (unsigned char *) data2 + data2 -> start;
cur_data1 = (unsigned char *) data1 + data1 -> start;


/* Now create the results files if none are already present. */

outcome = open_results_file(*legs_monitored);

if( *legs_monitored==2 ) {
      /* Move the results file pointer to the end of the recorded     */
      /* data by putting the file pointer to the start of the file and*/
      /* searching through it until the end of file marker is found   */
      /* (this being 255 255).                                        */

      cur_result2 = (unsigned char *) results2 + results2 -> start;
      next_result = (unsigned char *) results2 + results2 -> start;
      next_result++;
      for (i=0;
(!((*cur_result2==255)&&(*next_result==255)))&&(i<(RESULTS_SIZE/2)); i++) {
            cur_result2++;
            next_result++;
            }

      /* If the file memory is full, then can not store more results  */
      /* so stop monitoring, light the memory full LED, and print a   */
      /* relevant message.  If the monitor is not connected to the PC,*/
      /* the operator will just see the LED indication but will be    */
      /* also able to read the message indication by switching off the*/
      /* monitor, connecting to the PC and switching it back on (as   */
      /* this routine will be onw of the first executed when the      */
      /* programme is re-started).                                    */

      if ( i == (RESULTS_SIZE/2) ) {
            printf("\r\nMemory of Results2.dat is full...");
            switch_on( MEMORY_FULL );
            while(1) ;
                  /* Infinite loop, ie. programme halts at this point */
            }

      cur_result1 = (unsigned char *) results1 + results1 -> start;
      next_result = (unsigned char *) results1 + results1 -> start;
      next_result++;
      for (i=0;
(!((*cur_result1==255)&&(*next_result==255)))&&(i<(RESULTS_SIZE/2)); i++) {
            cur_result1++;
```

```
                next_result++;
                }

        if ( i == (RESULTS_SIZE/2) ) {
                /* Results1.dat is full, so stop recording */
                printf("\r\nMemory of Results1.dat is full...");
                switch_on( MEMORY_FULL );
                while(1) ;
                        /* Infinite loop, ie. programme halts at this point */
                }

        }

else {
        cur_result1 = (unsigned char *) results1 + results1 -> start;
        next_result = (unsigned char *) results1 + results1 -> start;
        next_result++;
        for (i=0;
(!((*cur_result1==255)&&(*next_result==255)))&&(i<RESULTS_SIZE); i++) {
                cur_result1++;
                next_result++;
                }

        if ( i == RESULTS_SIZE ) {
                /* Recording file is full, so stop recording */
                printf("\r\nMemory is full...");
                switch_on( MEMORY_FULL );
                while(1) ;
                        /* Infinite loop, ie. programme halts at this point */
                }

        }

}


/* This function is called by the setup_datamods function.  According   */
/* to 'no_of_legs', it creates the data file(s) only if not already      */
/* present, returning SUCCESSFUL or UNSUCCESSFUL.                        */

int open_data_file( int no_of_legs )

{

if( no_of_legs == 2 ) {
        /* When called, the data file 1 has already been deleted.       */
        /* Therefore just check for whether data file 2 is already      */
        /* present.                                                     */
        if ( (data2=link("Data2.dat"))==NULL ) {
                data2 = datamod("Data2.dat", (DATA_SIZE/2), 0);
                backup(data2, 1);
                data1 = datamod("Data1.dat", (DATA_SIZE/2), 0);
                backup(data1, 1);
                return ( SUCCESSFUL );
                }
        }

else {          /* 1 leg being monitored. */
        if ( (data1=link("Data1.dat"))==NULL ) {
                data1 = datamod("Data1.dat", DATA_SIZE, 0);
                backup(data1, 1);
                return ( SUCCESSFUL );
                }
        }

return ( UNSUCCESSFUL );

}


/* This function is called near the beginning of the main() function.   */
/* It creates an event file if one does not already exist.               */
```

```

int open_event_file()

{

if ( (event=link("Event.dat"))==NULL ) {
       event = datamod("Event.dat", EVENT_SIZE, 0);
       backup(event, 1);
       return( SUCCESSFUL );
       }

return( UNSUCCESSFUL );

}


/* This function is called from a number of places, and according to    */
/* 'no_of_legs' creates the results file(s) and sets the results files  */
/* pointers to the start og the file.                                    */

int open_results_file( int no_of_legs )

{
int outcome;

if( no_of_legs == 2 ) {
       if ( (results2=link("Results2.dat"))==NULL ) {

              /* ie. no of legs being monitored has just been changed */
              /* from 1 to 2 (or just initialising at beginning of    */
              /* execution. So if Results1.dat is present, it is      */
              /* cleared.                                             */

              if( !((results1=link("Results1.dat"))==NULL) ) {
                     backup(results1, 0);
                     unfix("Results1.dat");
                     }


              /* Next the results files are created, with the file    */
              /* pointers being set to the start of the files.        */

              results2 = datamod("Results2.dat", (RESULTS_SIZE/2), 0);
              backup(results2, 1);
              cur_result2 = (unsigned char *) results2 + results2 -> start;

              results1 = datamod("Results1.dat", (RESULTS_SIZE/2), 0);
              backup(results1, 1);
              cur_result1 = (unsigned char *) results1 + results1 -> start;


              /* Finally the current date is stored at the start of   */
              /* the files.                                           */

              stamp_results(2);


              return( SUCCESSFUL );

              }

       }

else {           /* ie. only 1 leg being monitored so only 1 results file */

       if ( (results1=link("Results1.dat"))==NULL ) {

              /* This means that execution is at the initialisation stage.
*/

              results1 = datamod("Results1.dat", RESULTS_SIZE, 0);
              backup(results1, 1);
```

```
                cur_result1 = (unsigned char *) results1 + results1 -> start;

                stamp_results(1);

                return( SUCCESSFUL );

                }

        }

return ( UNSUCCESSFUL );

}


/* This function is called by the sleep and writebcd functions, and is  */
/* used when powering down the processor.  It writes 'data' into the    */
/* specified 'reg' of the real-time clock.                              */

void writereg( int reg, int data )

{
char buffer[3];

buffer[0] = reg;
buffer[1] = data;
i2c(buffer, buffer, 2, 0, 0x50);

}


void writebcdreg( int reg, int data )

{

writereg( reg, (data/10)<<4+(data%10) );

}


/* This function is called by the pressure_input function for the       */
/* powering down of the processor in between samples.  Currently only   */
/* the HUNDREDTHS_OF_SECONDS option is used, but the SECONDS case has   */
/* been included to facilitate future possible future extension of the */
/* programme.  The amount of time to leave the processor in 'sleep' mode*/
/* is stored in the RAM of the real-time clock, before the assembler    */
/* routine pd() is called which saves the interrupts, disables them,    */
/* and then powers down the processor for the specified period of time. */

void sleep( int time, int function )

{
writereg( 0, 0x0c);

switch( function ) {
case SECONDS:
        if (time > 3600) {
                time = time /3600;
                writereg( 8, 0x0c);
                }
        else if( time > 60 ) {
                time = time / 60;
                writereg( 8, 0x0b );
                }
        else {
                writereg( 8, 0x0a );
                }
        writebcdreg( 7, 100-time );
        pd();
        writereg( 0, 0x08 );
        break;
```

```
case HUNDREDTHS_OF_SECS:
      writereg( 8, 0x09 );
      writebcdreg( 7, 100-time );
      pd();
      writereg( 0, 0x08 );
      break;

      }

}


/* This function is currently just called from the main() function.     */
/* It is placed where it should never be executed, so that if it is ever*/
/* entered then a possible hardware fault (or transient fault) has      */
/* occurred.  It was left in as a separate function so that it would be */
/* available for use for general error handling during future extension.*/

void error( void )

{

/* The program execution should never get here */

switch_off( RECORDING );
switch_off( PC_LINK );
switch_off( TRANSMITTING );
switch_on( ERROR );

/* Helpful (?!) error message.... */

printf("\r\nThis is an impossible error (if that helps at all) ....");

while(1) ;      /* Infinite loop, ie. programme halts at this point */

}


/* The following functions are the code and related functions used      */
/* by the shell() programme accessed through the options menu.          */

shell()
{
      int stopflag;
      int pid;
      char Cmd[32];
      char Arg[32];
      char *ptr;

      stopflag = 0;
      printf("PSI Systems 'C' Support\n\n\r");
      fflush(stdout);
      do
      {
            do
            {
                  fputs("C > ",stdout);
                  fflush(stdout);
                  readln(0,Buffer,80);
            }
            while( Buffer[0] == 13 );

            Inp_Path = -1;
            Out_Path = -1;
            in = stdin;
            out = stdout;
            coproc = 0;

            if( doargs() )
            {
                  ptr = getarg(Buffer,Cmd,0);
                  if( !cmpnam( "d",Cmd ) )
```

```
                        {
                                ptr = clearwhite( ptr );
                                if( *ptr < 32 )
                                        *ptr = 0;
                                debug( ptr );
                        }
                        else if( !cmpnam( "load",Cmd ) )
                        {
                                ptr = getarg(Buffer,Arg,1);
                                load(Arg);
                        }
                        else if( !cmpnam( "mdir",Cmd ) )
                        {
                                mdir();
                        }
                        else if( !cmpnam("procs",Cmd) )
                        {
                                proc();
                        }
                        else if( !cmpnam("lock",Cmd) )
                        {
                                ptr = getarg(Buffer,Arg,1);
                                lock(Arg);
                        }
                        else if( !cmpnam("unlock",Cmd) )
                        {
                                ptr = getarg(Buffer,Arg,1);
                                unlock(Arg);
                        }
                        else if( !cmpnam("unload",Cmd) )
                        {
                                ptr = getarg(Buffer,Arg,1);
                                if( unfix(Arg) )
                                {
                                        tsterror("Can't unload module");
                                }
                        }
                        else if( !cmpnam("quit",Cmd) )
                        {
                                stopflag = 1;
                        }
                        else
                        {
                                if( (pid=chain(Cmd,4096,Inp_Path,Out_Path)) == -
1)
                                {
                                        tsterror("Can't create new process");
                                }
                                else if( !coproc )
                                {
                                        death( pid );
                                        wait();
                                }
                        }
                }
        }
        while( stopflag != 1 );
}


/* This routine locates the named module then sets      */
/* the battery backup marker on it's RAM                */
/*                                                      */

lock( name )
char *name;
{
        void *Pointer;
        if( (Pointer = link(name)) == NULL )
        {
                tsterror("Can't find module");
        }
        else
        {
                if( backup( Pointer,1 ) )
                {
                        tsterror("Can't lock module");
                }
        }
}


/* This routine locates the named module then clears     */
/* the battery backup marker on it's RAM.                */

unlock( name )
char *name;
{
        void *Pointer;
        if( (Pointer = link(name)) == NULL )
        {
                tsterror("Can't find module");
        }
        else
        {
                if( backup( Pointer,0 ) )
                {
                        tsterror("Can't unlock module");
                }
        }
}

load( name )
char *name;
{
        int Path;
        int Size;
        unsigned char *Buffer;

        Path = open(name,3);
        if( Path == -1 )
        {
                tsterror("Can't open file");
        }
        else
        {
                Size = fsize(Path);
                if( Size == -1 )
                {
                        tsterror("file size");
                        return(0);
                }
                else
                {
                        if( (Buffer=sysmem( Size, 0 )) == NULL )
                        {
                                tsterror("Can't allocate memory");
                        }
                        else
                        {
                                read(Path,Buffer,Size);
                                if( fixmod( Buffer ) )
                                {
                                        tsterror("Can't attach module");
                                }
                                else
                                {
                                        printf("loaded at %x\n\r",Buffer);
                                        fflush(stdout);
                                }
                        }
                }
                close(Path);
        }
```

```
}

tsterror( string )
char *string;
{
      printf("%s error %d\n\r",string,errno);
      fflush(stdout);
}


/* This routine checks along the command line looking for the    */
/* re-direct arrows < and > and for concurrent process flag &     */

int doargs()
{
      char *name;
      char *ptr;
      char arg[32];
      int n;
      FILE *fp;

      n = 1;
      while( (ptr=getarg(Buffer,arg,n++)) != NULL )
      {
            switch(arg[0])
            {
                  case '&' :     coproc = 1;
                              break;
                  case '>' :     name = &arg[1];
                              fp = fopen(name,"w");
                              if( fp == NULL )
                              {
                                    tsterror("Can't re-direct output");
                                    return(0);
                              }
                              setbuf(fp,NULL);
                              Out_Path = _paths[fileno(fp)];
                              out = fp;
                              break;
                  case '<' :     name = &arg[1];
                              fp = fopen(name,"r");
                              if( fp == NULL )
                              {
                                    tsterror("Can't re-direct input");
                                    return(0);
                              }
                              setbuf(fp,NULL);
                              Inp_Path = _paths[fileno(fp)];
                              in = fp;
                              break;
            }
      }
      return(1);
}


/* This function extracts an argument from a string. The args           */
/* are separated by tabs or spaces and the input line can end with      */
/* 0 or 13. The required argument is coppied into the buffer pointed    */
/* to by arg and is zero terminated.                                    */

char * getarg( string, arg, count )
char *string;
char *arg;
int count;
{
      string = clearwhite( string );
      while( count )
      {

      while((*string!=32)&&(*string!=9)&&(*string!=13)&&(*string!=0))
                  string++;
```

```

		if( (*string==13) || (*string==0) )
		{
			return(NULL);
		}
		else
		{
			string = clearwhite( string );
			--count;
		}
	}
	while((*string!=32) && (*string!=9) && (*string!=13) &&
(*string!=0))
		*arg++ = *string++;
	*arg = 0;
	return(string);
}


char *clearwhite( string )
char *string;
{
	while( (*string==9) || (*string==32) )
		string++;
	return( string );
}


/* This routine checks that to character arrays are the          */
/* same regardless of the case of the alpha characters in the    */
/* two strings.                                                  */

cmpnam( s1, s2 )
char * s1;
char * s2;
{
	register char c1;
	register char c2;
	do
	{
		c1 = *s1++;
		c2 = *s2++;
		if( (c2>='A') && (c2<='Z') )
			c2 += ('a'-'A');
	}
	while( (c1 != 0) && (c2 != 0) && (c1 == c2) );
	if( (c1 == 0) && (c2 == 0) )
		return(0);
	else
		return(-1);
}


mdir()
{
	struct md **mdirglob;
	struct md *mdir;

	mdirglob = (struct md **) 0x80408;
	mdir = *mdirglob;
	fprintf(out,"\r\n Address |  Size   | Module Name |  Type    |
Memory");
	fprintf(out,"\r\n=====================================================
=");
	while(1)
	{
		ShowPage(mdir);
		if( (mdir=mdir->next) == NULL )
			break;
	}
	fprintf(out,"\r\n");
	fflush(out);
```

```
}

ShowPage(mdir)
struct md *mdir;
{
        int n;
        struct moddef *module;
        char *string;
        for(n=0; n<30; n++)
        {
                if( (module = mdir->modules[n].module) != NULL )
                {
                        string = (char *) module + module->name;
                        fprintf(out,"\r\n %06x  |  ",module);
                        fprintf(out,"%6x |  ",module->size);
                        fprintf(out,"%-13s|  ",string);
                        fprintf(out,"%-8s|",types[module->type]);
                        module->header = 0;
                        if( module->header )
                        {
                                fprintf(out,"  Rom");
                        }
                        else
                        {
                                module->header = 0x4afc;
                                fprintf(out,"  Ram");
                        }
                }
        }
}

proc()
{
        int n;
        struct pd *desc;
        pdt *pdtable;
        pdt **pdtptr;
        struct moddef *mod;
        pdtptr = (pdt **)0x80424;
        pdtable = *pdtptr;
        fprintf(out," PID |  Module Name |  Status   |  Signal | Sleep   |
Death \r\n");
        fprintf(out,"==================================================
===\r\n");
        for( n=0; n<64; n++)
        {
                if( (desc=(*pdtable)[n]) != NULL )
                {
                        if( (mod = desc->module) == 0 )
                                fprintf(out,"%4d | %-13s|",n,"  raw code");
                        else
                                fprintf(out,"%4d | %-13s|",n,(char *)mod + mod-
>name);
                        if( desc->status == 1 )
                                fprintf(out," Sleeping |");
                        else if( desc->status == 2 )
                                fprintf(out," Running  |");
                        else
                                fprintf(out," Waiting  |");
                        fprintf(out," %7d | %6d |",desc->signal,desc->sleep);
                        if( desc->death == 0xffff )
                                fprintf(out," none\r\n");
                        else
                                fprintf(out,"%5d\r\n",desc->death);
                }
        }

        fflush(out);

}
```

Appendix 4 : The PC Analysis Program Listing

```
#include <stdio.h>
#include <string.h>
#include <graph.h>
#include <math.h>
#include <stdlib.h>
#include <pgchart.h>

#define ON              1
#define OFF             0
#define SUCCESSFUL      0
#define UNSUCCESSFUL    1
#define NO_OF_POINTS    50

typedef enum {FALSE, TRUE} boolean;

char * get_outname( char * );
char * get_name( char * );
void case_convert( char * );
void input_file ( char *, char *, char * );
char * get_patient_file( char * );
char * get_date( char * );
int calc_no_of_weeks( int, int, int, int, int, int );
float calc_weight_bearing( char *, int );

FILE *infile, *outfile;


main()
{
char *temp, *inname, *outname, *name, *temp_outname;
char in_name[13];
char out_name[13] = "";
char pat_name[40] = "";
char *char_array_pointer;
char pat_file[40] = "";
char temp_out_name[13];
char temp_name1[40];
char temp_name2[40];
char temp_name3[40];
char temp_name4[40];
char patient_notes[2000];

int hour[24], body_mass=0, i, j, k, input, flag1, flag2, flag3, flag4,
flag5, legs_monitored, event_level, n, input_value, outcome;
int no_of_weeks, year_end, month_end, day_end, year_start, month_start,
day_start, year_new, year_cur, month_new, month_cur, day_new, day_cur;
char input_char;
double sum, sq_dev;
float weight_mean, weight_variance, weight_std_dev, duration_mean,
duration_variance, duration_std_dev;
int cur_read, cur_write, day_ob, month_ob, year_ob;
char hospital_no[20];
char leg_broken;
char fracture_type[40], fracture_pos[40], fracture_treat[40];
float hours[24], weight_bearing[NO_OF_POINTS], week_no[NO_OF_POINTS];
float temp_float;
chartenv env;

char far *hour_name[24] =
{
       "00", "01", "02", "03", "04", "05", "06", "07", "08", "09",
       "10", "11", "12", "13", "14", "15", "16", "17", "18", "19",
       "20", "21", "22", "23"
};


/* Initialisation */

/* Not knowing the type and age of PC which might in the future execute */
/* this programme, the graphics mode with the lowest common denominator */
/* has been chosen (CGA).  The black and white mode was chosen for its  */
/* increased resolution over the colour modes.                          */

_setvideomode(_HRESBW);

inname = "";
outname = "";
name = "";


/* This programme uses the following directories for the storage of its */
/* files: '\patients', '\data', '\analysis'.  The following code checks */
/* for whether they are present on the c: drive, and if not (ie this is */
/* the first time that the programme has been executed on this          */
/* computer), they are created.                                         */

/* First print the list of directories from the root into the file      */
/* called 'temp.dat'.                                                   */

system( "dir c:\\ /A:D /B > temp.dat" );

/* Next search through this file comparing each directory name with     */
/* DATA, ANALYSIS, and PATIENTS, recording the matches found.           */

infile = fopen( "temp.dat", "r" );
flag1 = OFF;
flag2 = OFF;
flag3 = OFF;
while ( fscanf( infile, "%s", temp_name1) != EOF ) {
      if ( strcmp( temp_name1, "DATA" ) == 0 )
            flag1=ON;
      else if ( strcmp( temp_name1, "ANALYSIS") == 0 )
            flag2=ON;
      else if ( strcmp( temp_name1, "PATIENTS" ) == 0 )
            flag3=ON;
      }
fclose( infile );


/* Finally for any that a match was not found, create it.       */

if ( flag1 == OFF )
      system( "mkdir c:\\data" );
if ( flag2 == OFF )
      system( "mkdir c:\\analysis" );
if ( flag3 == OFF )
      system( "mkdir c:\\patients" );


/* Enter the main part of the programme, which as an infinite loop will */
/* never be exited from (except when the programme execution is         */
/* terminated).                                                         */

while (1) {
      if ( strcmp( outname, "" ) != 0 )
            strcpy( temp_out_name, outname );

      else {
            if ( strcmp( inname, "" ) == 0 )
                  strcpy( temp_out_name, "" );
            else
                  strcpy( temp_out_name, get_outname( inname ) );

            }

      temp_outname = temp_out_name;
      outname = temp_out_name;


      /* The following is the root or main menu. */
```

```

        _clearscreen(_GCLEARSCREEN);
        _settextposition(1,5);
        printf("Current data file: %s",inname);
        _settextposition(2,5);
        printf("Current analysis file: %s",outname);
        _settextposition(3,5);
        printf("Current patient name: %s",pat_name);
        _settextposition(5,20);
        printf("1: Change any of above details");
        _settextposition(7,20);
        printf("2: Analyse data, storing results in %s",temp_outname);
        _settextposition(9,20);
        printf("3: Display analysis");
        _settextposition(11,20);
        printf("4: Examine patient's history");
        _settextposition(13,20);
        printf("5: Delete a patient's files");
        _settextposition(15,20);
        printf("6: Exit");

        _settextposition(20,20);
        printf("Please input a number between 1 and 6: ");
        scanf("%d",&input);


        /* Selecting option '1' allows the operator to change any of the*/
        /* above name details via various sub-menus.                    */

        if (input==1) {
              flag1=OFF;
              while ( flag1==OFF ) {
                    _clearscreen(_GCLEARSCREEN);
                    _settextposition(1,5);
                    printf("Current data file: %s",inname);
                    _settextposition(2,5);
                    printf("Current analysis file: %s",outname);
                    _settextposition(3,5);
                    printf("Current patient name: %s",pat_name);
                    _settextposition(5,20);
                    printf("1: Change data file name");
                    _settextposition(7,20);
                    printf("2: Change patient name");
                    _settextposition(9,20);
                    printf("3: Return to main menu");

                    _settextposition(20,20);
                    printf("Please input a number between 1 and 3: ");
                    scanf("%d",&input);


                    /* Having selected option '1', the operator can */
                    /* access other options to aid in the selecting */
                    /* of a new data file name.  These are to list  */
                    /* the data files not yet analysed, and/or list */
                    /* those already analysed.                      */

                    if (input==1) {
                          flag2=OFF;
                          while( flag2==OFF ) {
                                _clearscreen(_GCLEARSCREEN);
                                _settextposition(1,5);
                                printf("Current data file: %s",inname);
                                _settextposition(2,5);
                                printf("Current analysis file:
%s",outname);
                                _settextposition(3,5);
                                printf("Current patient name:
%s",pat_name);
                                _settextposition(5,20);
                                printf("1: Change data file name");
                                _settextposition(7,20);
```

```
                printf("2: List data files not analysed");
                _settextposition(9,20);
                printf("3: List analysed data files");
                _settextposition(11,20);
                printf("4: Return to the previous menu");

                _settextposition(20,20);
                printf("Please input a number between 1 and 4: ");
                scanf("%d",&input);


                /* When selecting the           */
                /* following option, the        */
                /* operator inputs the date of  */
                /* the monitoring session he    */
                /* wishes to access the data of.*/
                /* If a patient name has not yet*/
                /* been specified the operator  */
                /* is also asked to input one.  */
                /* From all this information,   */
                /* the name of the required data*/
                /* file is constructed and the  */
                /* accessed.                    */

                if ( input==1 )
                      {
                      /* The following function performs most */
                      /* of the file name construction. */

                      input_file( temp_name2, pat_name, pat_file );


                      /* 'temp_name2' is OFF only if the */
                      /* inputted patient name was not valid. */

                      if ( strcmp( temp_name2, "OFF" ) != 0 ) {
                            strcpy( temp_name1, "DAT" );
                            strcat( temp_name1, temp_name2 );

                            strcpy( temp_name2, temp_name1 );
                            temp_name2[9] = '0';
                            temp_name2[10] = '0';
                            temp_name2[11] = '0';


                            /* List the unanalysed data file*/
                            /* names in 'temp.dat', and then*/
                            /* check to see that the data */
                            /* file name constructed exists */
                            /* among these. */

                            system( "dir dat*.* /B > temp.dat" );

                            infile = fopen( "temp.dat", "r" );
                            flag3=OFF;
```

```
                                                  while ( fscanf( infile, "%s",
temp_name3 ) != EOF ) {
                                                        if ( strcmp(
temp_name2, temp_name3 ) == 0 )
                                                              flag3=ON;
                                                        }
                                                  fclose( infile );

                                                  if ( flag3 == OFF ) {
                                                        /* Check to see whether
the constructed */
                                                        /* data file name
exists for the        */
                                                        /* analysed data files
(ie those stored */
                                                        /* in the '\data'
directory.            */

                                                        system( "dir
c:\\data\\dat*.* /B > temp.dat" );
                                                        infile = fopen(
"temp.dat", "r" );
                                                        flag4=OFF;
                                                        while ( fscanf( infile,
"%s", temp_name3 ) != EOF ) {
                                                              if ( strcmp(
temp_name1, temp_name3 ) == 0 )
                                                                    flag4=ON;
                                                              }
                                                        fclose( infile );

                                                        if ( flag4==OFF )
                                                              printf("\nThe
inputted data file '%s' does not exist !! ",temp_name1);
                                                        else
                                                              goto
The_unmentionable_command;
                                                        }      /* Although
using a 'goto', no danger of stack overloading because */
                                                              /* the 'if'
statement's opening bracket is cancelled by the 'else' */
                                                  else {          /*
statement's closing bracket. */

                                                        /* The file is not
analysed yet (so has '.000'   */
                                                        /* as its suffix).
Therefore rename the file    */
                                                        /* the patient number
suffix.                  */

                                                        strcpy( temp_name3,
"rename " );
                                                        strcat( temp_name3,
temp_name2 );
                                                        strcat( temp_name3, " "
);
                                                        strcat( temp_name3,
temp_name1 );
                                                        system( temp_name3 );

                                                        /* The following code
is executed for whether    */
                                                        /* the data file name
has or has not been        */
                                                        /* analysed.
*/

                          The_unmentionable_command:          strcpy(
in_name, temp_name1 );
                                                        inname = in_name;
```

```
            printf("\nThe inputted data file '%s' is accepted.",inname);

            /* Now generate the analysis file name, and     */
            /* check for whether an analysis file exists    */
            /* with the same name.  */

            strcpy( temp_name3, "AN" );
            for ( i=0; i<9; i++ )
                temp_name3[i+2] = temp_name1[i+3];
            temp_name3[i+2] = 0;

            system( "dir c:\\analysis\\an*.* /B > temp.dat" );
            infile = fopen( "temp.dat", "r" );

            flag3=OFF;
            while( fscanf( infile, "%s", temp_name4 ) != EOF ) {
                if ( strcmp( temp_name3, temp_name4 ) == 0 )
                    flag3=ON;
                }
            fclose( infile );


            /* If not, then print a message to remind the   */
            /* operator to analyse the data file.           */

            if ( flag3==OFF ) {
                printf("\nThe corresponding analysis '%s' file does not exist.",temp_name3);
                printf("\nThe user must analyse the data file first.");
                printf("\nTo do so, the data file must be in the current directory.");
                }
            else {
                strcpy( out_name, temp_name3 );
                outname = out_name;
                printf("\nThere is a corresponding analysis file, '%s'.",outname);
                }

            }

        }

    printf("\n\nPress a key to continue.");
    getch();
    }


/* List the data files not yet      */
/* analysed by printing the ones*/
/* on the screen from the           */
/* current directory, as they       */
/* haven't been moved to '\data'*/
/* directory yet.                   */
```

```
                                        else if (input==2) {
                                              system( "dir dat*.* /B | more" );
                                              getch();
                                              }


                                        /* By printing the data files in the
'\data' directory, the     */
                                        /* analysed files are printed.
*/

                                        else if (input==3) {
                                              system( "dir c:\\data\\dat*.* /B |
more" );
                                              getch();
                                              }

                                        else if (input==4)
                                              flag2=ON;

                                        else {
                                              printf("\nInput range is from 1 to
3. Please try again.");
                                              getch();
                                              }

                                        }

                                  }


                            /* By selecting option '2', the operator can    */
                            /* change the patient name to another; list the */
                            /* names of the patients having been monitored; */
                            /* input details of a new patient for storage.  */

                            else if (input==2) {
                                  flag2 = OFF;
                                  while ( flag2==OFF ) {
                                        _clearscreen(_GCLEARSCREEN);
                                        _settextposition(1,5);

                                        if ( strcmp(get_name(pat_file),
"unsuccessful") )
                                              printf("Current patient name:
%s",get_name(pat_file));
                                        else
                                              printf("Current patient not
specified.");

                                        _settextposition(3,20);
                                        printf("1: Change current patient name");
                                        _settextposition(5,20);
                                        printf("2: List patients");
                                        _settextposition(7,20);
                                        printf("3: Input details of a new
patient");
                                        _settextposition(9,20);
                                        printf("4: Return to the previous menu");

                                        _settextposition(20,20);
                                        printf("Please input a number from 1 to 4:
");
                                        scanf("%d",&input);


                                        /* The first option having      */
                                        /* been selected, the operator  */
                                        /* is asked to input the patient*/
                                        /* name, whose letters are all  */
                                        /* converted to lower case      */
                                        /* except the first for each    */
```

```
                                /* word which is converted to   */
                                /* upper.  The name is then     */
                                /* compared to the name stored  */
                                /* in every patient file and if */
                                /* there is a match then the    */
                                /* patient name is accepted.    */

                                if ( input==1 ) {
                                      printf("\nWhat is the new patient's
name? : ");
                                      scanf("%s %s", temp_name1,
temp_name2);
                                      case_convert( temp_name1 );
                                      case_convert( temp_name2 );
                                      strcat ( temp_name1, " " );
                                      strcat ( temp_name1, temp_name2 );

                                      strcpy( temp_name3,
get_patient_file( temp_name1 ) );
                                      if ( strcmp( temp_name3,
"unsuccessful") ) {
                                            strcpy( pat_name, temp_name1
);
                                            strcpy( pat_file, temp_name3
);
                                            printf("\nPatient name
accepted.");
                                            strcpy( inname, "" );
                                            strcpy( outname, "" );
                                            }
                                      else
                                            printf("\nPatient name does
not exist !!");

                                      }


                                /* The second option having     */
                                /* been selected, the names of  */
                                /* all the patients which have  */
                                /* been monitored are displayed */
                                /* in three columns on the      */
                                /* screen.  Each patient file is*/
                                /* accessed in turn and the     */
                                /* patient name displayed.      */

                                else if ( input==2 ) {
                                      system( "dir c:\\patients\\patient.*
/B > temp.dat" );
                                      infile = fopen("temp.dat","r");

                                      i=0;
                                      while ( fscanf(infile, "%s",
temp_name1) != EOF ) {
                                            i++;

                                            strcpy( temp_name2,
"c:\\patients\\" );
                                            strcat( temp_name2,
temp_name1 );
                                            strcpy( temp_name1,
temp_name2 );

                                            outfile =
fopen(temp_name1,"r");
                                            fscanf(outfile, "%s
%s",temp_name1,temp_name2);
                                            fclose(outfile);

                                            strcat( temp_name1, " " );
                                            strcat( temp_name1,
temp_name2 );
```

```

                                          /* The following lines  */
                                          /* display three columns*/
                                          /* of names.            */

                                               if( (i%4)==0 )
                                                    i=1;
                                               if( ((i%2)==0) || ((i%3)==0)
)

     printf("%25s",temp_name1);
                                               else

     printf("\r\n%25s",temp_name1);


                                               }

                                          fclose(infile);

                                          }


                                     /* Selecting the third option   */
                                     /* allows the operator to input */
                                     /* the details of a new patient.*/
                                     /* The operator inputs the      */
                                     /* patient name which is        */
                                     /* compared to all the patient  */
                                     /* names already stored and is  */
                                     /* only accepted if no match    */
                                     /* occurs.                      */

                                     else if ( input==3 ) {
                                          _clearscreen(_GCLEARSCREEN);

                                          printf("What is the new patient's
name? : ");
                                          scanf("%s %s", temp_name1,
temp_name2);
                                          case_convert( temp_name1 );
                                          case_convert( temp_name2 );
                                          strcat( temp_name1, " " );
                                          strcat( temp_name1, temp_name2 );
                                          system( "dir c:\\patients\\patient.*
/B > temp.dat" );
                                          outfile = fopen("temp.dat","r");
                                          flag3=OFF; flag4=OFF;
                                          while( (flag3==OFF) && (flag4==OFF)
) {
                                               if ( fscanf(outfile,
"%s",temp_name2) != EOF ) {
                                                    strcpy( temp_name3,
"c:\\patients\\" );
                                                    strcat( temp_name3,
temp_name2 );
                                                    strcpy( temp_name2,
temp_name3 );

                                                    infile =
fopen(temp_name2,"r");
                                                    fscanf(infile,"%s %s",
temp_name3, temp_name4);
                                                    fclose( infile );

                                                    strcat(temp_name3, "
");
                                                    strcat(temp_name3,
temp_name4);
                                                    if ( strcmp(temp_name3,
temp_name1) == 0 ) {
                                                         printf("\n%s
already exists !!", temp_name1);
```

```
                                    flag3 = ON;
                                    }
                                }
                            else
                                flag4=ON;
                            }

                        /* Execute the following lines only
if no match */
                        /* has occurred.
*/

                        if ( flag3!=ON ) {
                            rewind( outfile );
                            input=0;
                            while( fscanf(outfile, "%s",
temp_name2) != EOF ) {
                                for ( i=0; i<3; i++ )
                                    temp_name3[i] =
temp_name2[i+9];

                                temp_name3[i] = 0;
                                i = atoi(temp_name3);
                                if ( i > input )
                                    input = i;

                                }

                            input += 1;

                            temp_name3[0] =
(input/100)+48;
                            temp_name3[1] = ( (input-
((temp_name3[0]-48)*100))/10 ) + 48;
                            temp_name3[2] = ( input-
((temp_name3[0]-48)*100)-((temp_name3[1]-48)*10) ) + 48;
                            temp_name3[3] = 0;

                            strcpy( pat_file,
"c:\\patients\\patient." );
                            strcat( pat_file, temp_name3
);
                            strcpy( pat_name, temp_name1
);
                            infile = fopen( pat_file, "w"
);
                            fprintf( infile, "%s\n",
temp_name1 );

                            flag3=OFF;
                            while( flag3==OFF ) {
                                printf("\n\nWhat is the
patient's date of birth?\n");
                                printf("Day: ");
                                scanf("%d",&input);
                                if ( (input>0) &&
(input<32) )
                                    flag3=ON;
                                else
                                    printf("\nThe
range is from 1 to 31. Please try again.\n");
                                }
                            fprintf( infile, "%d ", input
);

                            flag3=OFF;
                            while( flag3==OFF ) {
                                printf("Month: ");
                                scanf("%d",&input);
                                if ( (input>0) &&
(input<13) )
                                    flag3=ON;
```

```
                          else
                               printf("\nThe
range is from 1 to 12. Please try again.\n");
                          }
                       fprintf( infile, "%d ", input
);

                       flag3=OFF;
                       while( flag3==OFF ) {
                          printf("Year (eg.
1970): ");
                          scanf("%d",&input);
                          if ( (input>1900) &&
(input<2000) )
                               flag3=ON;
                          else
                               printf("\nThe
range is from 1900 to 2000. Please try again.\n");
                          }
                       fprintf( infile, "%d\n",
input );

                       flag3=OFF;
                       while( flag3==OFF ) {
                          printf("Hospital
Number: ");
                          scanf("%s",temp_name4);
                          flag3=ON;
                          }
                       fprintf( infile, "%s\n",
temp_name4 );

                       flag3=OFF;
                       while( flag3==OFF ) {
                          printf("Right or Left
leg fractured (R/L): ");
                          fflush( stdin );

    scanf("%c",&input_char);
                          if ( (input_char=='r')
|| (input_char=='l') )
                               input_char -=
32;        /* put into upper case */
                          if ( (input_char=='R')
|| (input_char=='L') )
                               flag3=ON;
                          else
                               printf("\nInput
either R or L. Please try again.\n");
                          }
                       fprintf( infile, "%c\n",
input_char );

                       flag3=OFF;
                       while( flag3==OFF ) {
                          printf("Fracture type:
");
                          scanf("%s",temp_name1);
                          case_convert(
temp_name1 );
                          flag3=ON;
                          }
                       fprintf( infile,"%s\n",
temp_name1 );

                       flag3=OFF;
                       while( flag3==OFF ) {
                          printf("Position of
fracture: ");
                          scanf("%s",temp_name1);
                          case_convert(
temp_name1 );
```

```
                           flag3=ON;
                           }
                    fprintf( infile,"%s\n",
temp_name1 );

                    flag3=OFF;
                    while( flag3==OFF ) {
                           printf("Fracture
treatment: ");
                           scanf("%s",temp_name1);
                           case_convert(
temp_name1 );
                           flag3=ON;
                           }
                    fprintf( infile, "%s\n",
temp_name1 );

                    flag3=OFF;
                    while( flag3==OFF ) {
                           printf("Patient Body
Mass: ");
                           scanf("%d", &input);
                           if ( (input<0) ||
(input>120) )
                                  printf("Input
range is from 0 to 120 kg..  Please try again.\n");
                           else
                                  flag3=ON;
                           }
                    fprintf( infile, "%d\n",
input );

                    printf("\nInput the date when
fracture occurred.\n");
                    flag3=OFF;
                    while( flag3==OFF ) {
                           printf("Day: ");
                           scanf("%d", &input);
                           if (
(input<1)||(input>31) )
                                  printf("Input
range is from day 1 to 31 of the month.  Please try again.\n");
                           else
                                  flag3=ON;
                           }
                    fprintf( infile, "%d ", input
);

                    flag3=OFF;
                    while( flag3==OFF ) {
                           printf("Month (1-12):
");
                           scanf("%d", &input );
                           if (
(input<1)||(input>12) )
                                  printf("Input
range is from month 1 to 12 of the year.  Please try again.\n");
                           else
                                  flag3=ON;
                           }
                    fprintf( infile, "%d ", input
);

                    flag3=OFF;
                    while( flag3==OFF ) {
                           printf("Year (eg.
1993): ");
                           scanf("%d", &input);
                           if (
(input<1992)||(input>1994) )
                                  printf("Input
range is from 1992 to 1994.  Please try again.\n");
```

```
                                                    else
                                                           flag3=ON;
                                                    }
                                              fprintf( infile, "%d\n",
input );

                                              }

                                       fclose(infile);
                                       fclose(outfile);
                                       }


                                 /* Selecting the fourth option returns the
operator to  */
                                 /* the previous menu.
*/

                                 else if ( input==4 )
                                       flag2 = ON;

                                 else
                                       printf("\nInput range is from 1 to
4. Please try again.");


                                 if( flag2==OFF ) {
                                       printf("\n\nPress a key to
continue.");

                                       getch();
                                       }

                                 }
                          }

                    /* Selecting the third option returns the operator to
*/
                    /* the root or main menu.
*/

                    else if (input==3)
                          flag1=ON;


                    else {
                          printf("\nInput range is from 1 to 3. Please try
again.");

                          getch();
                          }

                    }
             }


       /* Selecting this option analyses the currently specified data   */
       /* file.  This occurs only if a data file and patient name are   */
       /* specified.  An analysis file is created for the storage of    */
       /* the analysis results.  The operaor also has the opportunity   */
       /* input notes of the monitoring session which are also stored   */
       /* in this file.                                                 */

       else if (input==2) {
             strcpy( temp_name1, "c:\\data\\" );
             strcat( temp_name1, inname );
             if( ((infile=fopen(inname,"r"))==NULL) &&
((infile=fopen(temp_name1,"r"))==NULL) ) {
                    printf("\nCurrent input file does not exist !!");
                    getch();
                    }
             else if ( strcmp( pat_name, "" ) == 0 ) {
                    printf("\nNo patient name specified !!");
                    getch();
                    }
             else {
                    _clearscreen(_GCLEARSCREEN);
                    printf("Analysing data file and writing results to
%s\n",outname);
                    for ( i=0; i<24; i++ )
                          hour[i]=0;
                    fscanf(infile,"%d",&legs_monitored);
                    fscanf(infile,"%d",&event_level);
                    outcome = 0;
                    input_value=0;
                    sum = 0;
                    n = 0;
                    fscanf(infile,"%d",&input_value); /* This is outside so
can check if any data events are in file (unlikely but possible) */
                    while ( input_value != 999 ) {
                          hour[input_value] += 1;
                          for ( i=0; i<3; i++ )
                                outcome =
fscanf(infile,"%d",&input_value);
                          sum += input_value;
                          n++;
                          for ( i=0; i<3; i++ )
                                outcome =
fscanf(infile,"%d",&input_value);

                          fscanf(infile,"%d",&input_value);
                          }

                    strcpy( temp_name1, "c:\\analysis\\" );
                    outname = out_name;
                    outname = get_outname( inname );
                    strcat( temp_name1, outname );
                    outfile = fopen(temp_name1,"w");

                    fprintf(outfile,"%s\n",pat_name);
                    fprintf(outfile,"%d\n",legs_monitored);
                    fprintf(outfile,"%d\n",event_level);

                    for ( i=0; i<24; i++ )
                          fprintf(outfile,"%d ",hour[i]);
                    fprintf(outfile,"\n");

                    weight_mean = sum/n;
                    fprintf(outfile,"%f\n",weight_mean);

                    rewind(infile);
                    input_value = 0;
                    sq_dev = 0;
                    duration_mean = 0.0;
                    fscanf(infile,"%d",&input_value);
                    fscanf(infile,"%d",&input_value);

                    fscanf(infile,"%d",&input_value);
                    while ( input_value != 999 ) {
                          for ( i=0; i<3; i++ )
                                fscanf(infile,"%d",&input_value);
                          sq_dev += (input_value-weight_mean)*(input_value-
weight_mean);

                          fscanf(infile,"%d",&input_value);
                          duration_mean += input_value*256;
                          fscanf(infile,"%d",&input_value);
                          duration_mean += input_value;

                          fscanf(infile,"%d",&input_value);
                          fscanf(infile,"%d",&input_value);
                          }

                    weight_variance = sq_dev/n;
                    weight_std_dev = sqrt(weight_variance);
                    fprintf(outfile,"%f\n",weight_variance);
                    fprintf(outfile,"%f\n",weight_std_dev);

                    duration_variance = 0.0;
                    duration_mean /= n;        /* mean hour for all events
*/

                    rewind(infile);
                    fscanf(infile,"%d",&input_value);
                    fscanf(infile,"%d",&input_value);

                    fscanf(infile,"%d",&input_value);
                    while ( input_value != 999 ) {
                          for ( i=0; i<4; i++ )
                                fscanf(infile,"%d",&j);

                          j *= 256;
                          fscanf(infile,"%d",&input_value);
                          j += input_value;
                          duration_variance += (j-duration_mean)*(j-
duration_mean);

                          fscanf(infile,"%d",&input_value);
                          fscanf(infile,"%d",&input_value);
                          }

                    duration_variance /= n;

                    duration_std_dev = sqrt( duration_variance );

                    fprintf(outfile,"%f\n",duration_mean);
                    fprintf(outfile,"%f\n",duration_variance);
                    fprintf(outfile,"%f\n",duration_std_dev);

                    flag1=OFF;
                    while ( flag1==OFF ) {
                          printf("\nInput the next appointment date in
weeks from today (or 0 if discharged): ");
                          scanf("%d",&input);
                          if ( (input<0) || (input>52) )
                                printf("\nThe input range is from between
0 and 52 weeks.  Please try again.");
                          else
                                flag1=ON;
                          }
                    fprintf(outfile,"%d\n",input);


                    /* The patient notes are stored in the patient_notes
*/
                    /* array before being written to the file.
*/

                    printf("\nDo you wish to record some notes in the
analysis file (Y/N): ");
                    fflush(stdin);
                    scanf("%c",&input_char);
                    if ( (input_char=='Y') || (input_char=='y') ) {
                          printf("\nType in the details, then press RETURN
to insert them into the analysis file.\n");
                          fflush(stdin);
                          i=0;
                          input_char = getch();
                          while( input_char != 13 ) {     /* 13 signifies a
carriage return */
                                putch(input_char);
                                patient_notes[i++] = input_char;
                                input_char = getch();
                                }
                          patient_notes[i] = 0;

                    /* Have to edit the 'patient_notes' array for    */
```

```
                        /* deletes.  A delete is indicated by ASCII 8.  */
                        /* Therefore use two indices into the           */
                        /* patient_notes array; one for the current read*/
                        /* position, the other for the write position.  */
                        /* For each iteration through the loop the read */
                        /* position character is written to the write   */
                        /* position character, there being no change in */
                        /* the patient_notes array when both the read   */
                        /* and write indices point to the same place.   */
                        /* When a delete is encountered, the read index */
                        /* is incremented, and the write index is       */
                        /* decremeneted so that the previous character  */
                        /* will be overwritten so deleteing it.         */

                                cur_read = 0;
                                cur_write = 0;
                                for ( cur_read=0; patient_notes[cur_read]!=0;
cur_read++ ) {
                                        while( patient_notes[cur_read]==8 ) {
                                                cur_read++;
                                                if ( cur_write>0 )
                                                        cur_write--;
                                                }

                                        patient_notes[cur_write] =
patient_notes[cur_read];
                                        cur_write++;

                                        }

                                patient_notes[cur_write] = 0;
                                fprintf(outfile,"%s\n",patient_notes);

                                }

                        /* Finally the analysed data file is moved from the
*/
                        /* current directory to the '/data' directory.
*/

                        fclose(infile);
                        strcpy( temp_name1, "copy " ); /* moving data file into
DATA directory */
                        strcat( temp_name1, inname );
                        strcat( temp_name1, " c:\\data" );
                        system( temp_name1 );
                        strcpy( temp_name1, "del " );
                        strcat( temp_name1, inname );
                        system( temp_name1 );

                        fclose(outfile);
                        fflush(stdin);
                        }

                fclose(infile);

                }


        /* Selecting option 3 allows the operator to view the analyses   */
        /* of the currently selected analysis file.                      */

        else if (input==3) {
                flag2=OFF;
                while( flag2==OFF ) {
                        _clearscreen(_GCLEARSCREEN);
                        _settextposition(1,5);
                        printf("Current data file: %s",inname);
                        _settextposition(2,5);
                        printf("Current analysis file: %s",outname);
                        _settextposition(3,5);
                        printf("Current patient name: %s",pat_name);
```

```
                    _settextposition(5,20);
                    printf("1: Display analyses for '%s' file",outname);
                    _settextposition(7,20);
                    printf("2: Return to the previous menu");

                    _settextposition(20,20);
                    printf("Please input a number from 1 to 2: ");
                    scanf("%d",&input);


                    if( input==1 ) {
                          strcpy( temp_name1, "c:\\analysis\\" );
                          strcat( temp_name1, outname );
                          if ( (outfile = fopen(temp_name1,"r"))==NULL ) {
                                printf("\nCurrent output file does not
exist !!");
                                getch();
                                }
                          else {
                                fscanf(outfile,"%s
%s",pat_name,temp_name1);
                                strcat( pat_name, " " );
                                strcat( pat_name, temp_name1 );

                                strcpy( temp_name1, get_patient_file(
pat_name ) );
                                strcpy( pat_file, temp_name1 );

                                infile = fopen( pat_file, "r" );
                                fscanf( infile, "%s", temp_name1 );
                                fscanf( infile, "%s", temp_name1 );
                                fscanf( infile, "%d %d %d", &day_ob,
&month_ob, &year_ob );
                                fscanf( infile, "%s", hospital_no );
                                fscanf( infile, "%s", temp_name1 );
                                leg_broken = temp_name1[0];
                                fscanf( infile, "%s", fracture_type );
                                fscanf( infile, "%s", fracture_pos );
                                fscanf( infile, "%s", fracture_treat );
                                fscanf( infile, "%d", &body_mass );
                                fclose( infile );

                                strcpy( out_name, get_outname( inname ) );

                                temp_name4[0] = out_name[2];
                                temp_name4[1] = out_name[3];
                                temp_name4[2] = '/';
                                temp_name4[3] = out_name[4];
                                temp_name4[4] = out_name[5];
                                temp_name4[5] = '/';
                                temp_name4[6] = '9';
                                temp_name4[7] = out_name[6];
                                temp_name4[8] = 0;

                                fscanf(outfile,"%d",&legs_monitored);
                                fscanf(outfile,"%d",&event_level);
                                for ( i=0; i<24; i++ )
                                      fscanf(outfile,"%d",&hour[i]);
                                fscanf(outfile,"%f",&weight_mean);
                                fscanf(outfile,"%f",&weight_variance);
                                fscanf(outfile,"%f",&weight_std_dev);
                                fscanf(outfile,"%f",&duration_mean);
                                fscanf(outfile,"%f",&duration_variance);
                                fscanf(outfile,"%f",&duration_std_dev);
                                n = 0;
                                for ( i=0; i<24; i++ )
                                      n += hour[i];


                                _clearscreen(_GCLEARSCREEN);

                                _settextposition(1,1);
```

```
                                        printf("Patient name: %s",pat_name);

                                        _settextposition(1,60);
                                        printf("Date: %s",temp_name4);

                                        _settextposition(2,25);
                                        printf("Total No. of events = %d",n);

                                        _settextposition(2,52);
                                        printf("Body Mass = %d",body_mass);

                                        _settextposition(3,50);
                                        printf("Weight Mean = %.3f",weight_mean);

                                        _settextposition(4,50);
                                        printf("Weight Variance =
%.3f",weight_variance);

                                        _settextposition(5,50);
                                        printf("Weight Std. Dev. =
%.3f",weight_std_dev);

                                        _settextposition(7,40);
                                        printf("Weight Bearing = %.0f%% of Body
Mass",(weight_mean/body_mass*100) );

                                        _settextposition(3,25);
                                        printf("Time Mean = %.2f",duration_mean);

                                        _settextposition(4,25);
                                        printf("Time Variance =
%.2f",duration_variance);

                                        _settextposition(5,25);
                                        printf("Time Std. Dev. =
%.2f",duration_std_dev);

                                        _settextposition(2,1);
                                        printf("D.O.B.:
%d/%2d/%d",day_ob,month_ob,(year_ob-1900));
                                        if( (month_ob/10) == 0 ) {
                                              if ( (day_ob/10)==0 )
                                                    _settextposition(2,(1+10));
                                              else
                                                    _settextposition(2,(1+11));

                                              printf("0");
                                              }

                                        _settextposition(3,1);
                                        printf("Hospital No.: %s", hospital_no );

                                        _settextposition(4,1);
                                        strcpy( temp_name1, "Leg Fractured: " );
                                        if ( leg_broken=='R' )
                                              strcat( temp_name1, "Right" );
                                        else
                                              strcat( temp_name1, "Left" );
                                        printf("%s",temp_name1);

                                        _settextposition(5,1);
                                        printf("Fracture Type: %s",fracture_type);

                                        _settextposition(6,1);
                                        printf("Position of Fracture: %s",
fracture_pos);

                                        _settextposition(7,1);
                                        printf("Fracture Treatment: %s",
fracture_treat);

                                        for ( i=0; i<24; i++ )
                                        hours[i] = (float) hour[i];

                                _pg_initchart();
                                _pg_defaultchart( &env, _PG_COLUMNCHART,
_PG_PLAINBARS );


                                strcpy( temp_name3, "Events Throughout Day
(event level = " );
                                temp_name2[0] = ((event_level/10)+48);
                                temp_name2[1] = 0;
                                strcat( temp_name3, temp_name2 );
                                temp_name2[0] = (event_level-
((event_level/10)*10)+48);
                                temp_name2[1] = 0;
                                strcat( temp_name3, temp_name2 );
                                strcat( temp_name3, " kg. )" );
                                strcpy( env.maintitle.title, temp_name3 );
                                env.maintitle.justify = _PG_RIGHT;
                                strcpy( env.yaxis.axistitle.title, "No of
Events" );
                                strcpy( env.xaxis.axistitle.title, "Hour
of Day" );
                                env.chartwindow.border = TRUE;
                                env.chartwindow.x1 = 0;
                                env.chartwindow.y1 = 60;
                                env.chartwindow.x2 = 639;
                                env.chartwindow.y2 = 199;
                                _pg_chart( &env, hour_name, hours, 24 );

                                getch();
                                fclose(outfile);

                                }

                        }


                else if( input==2 )
                        flag2=ON;

                else
                        printf("\nInput range is from 1 to 2.  Please try
again.");


                if( flag2==OFF ) {
                        printf("\n\nPress a key to continue.");
                        getch();
                        }

                }


        }


    /* Selecting option 4 enables the operator to view the          */
    /* patient's history through another sub-menu.  If a patient    */
    /* name is not specified when selecting this option, then the   */
    /* operator has the option to input one which is then validated,*/
    /* or return to the root menu by typing 'go back'.              */

    else if (input==4) {
        _clearscreen(_GCLEARSCREEN);
        _settextposition(1,5);

        if ( strcmp( pat_name, "" ) == 0 ) {
                printf("\nNo patient name has been specified.");
                flag1=OFF;
                while ( flag1==OFF ) {
                        printf("\nInput the patient's name, or enter 'go
back' to return to the previous\nmenu: ");
```

```
                                        scanf("%s %s", temp_name1, temp_name2);
                                        case_convert( temp_name1 );
                                        case_convert( temp_name2 );
                                        strcat( temp_name1, " " );
                                        strcat( temp_name1, temp_name2 );

                                        if( strcmp( temp_name1, "Go Back" ) == 0 )
                                              break;

                                        system( "dir c:\\patients\\patient.* /B >
temp.dat" );
                                        outfile = fopen( "temp.dat", "r" );
                                        flag2=OFF;
                                        flag3=OFF;
                                        while( (flag2==OFF) && (flag3==OFF) ) {
                                              if ( fscanf( outfile, "%s", temp_name2 )
!= EOF ) {
                                                    strcpy( temp_name3, "c:\\patients\\"
);

                                                    strcat( temp_name3, temp_name2 );
                                                    strcpy( temp_name2, temp_name3 );
                                                    infile = fopen( temp_name2, "r" );
                                                    fscanf( infile, "%s %s", temp_name3,
temp_name4 );

                                                    fclose( infile );
                                                    strcat( temp_name3, " " );
                                                    strcat( temp_name3, temp_name4 );
                                                    if ( strcmp( temp_name3, temp_name1
) == 0 ) {
                                                          strcpy( pat_file, temp_name2
);

                                                          strcpy( pat_name, temp_name3
);

                                                          flag2=ON;
                                                          flag1=ON;
                                                          }
                                                    }
                                              else {
                                                    flag3=ON;
                                                    printf("\n\nThe inputted patient
name '%s' has not been found.",temp_name1);
                                                    }

                                              }

                                        fclose( outfile );

                                        }

                                  }

                            if ( strcmp( pat_name, "" ) != 0 ) {
                                  flag1=OFF;
                                  while( flag1==OFF ) {
                                        _clearscreen( _GCLEARSCREEN );
                                        _settextposition(1,5);
                                        printf("Current patient name: %s",pat_name);
                                        _settextposition(4,10);
                                        printf("For the above patient:");
                                        _settextposition(6,14);
                                        printf("1: List the dates of the recorded
monitoring sessions.");
                                        _settextposition(8,14);
                                        printf("2: Examine the notes from the monitoring
sessions.");
                                        _settextposition(10,14);
                                        printf("3: Display a graph of patient's weight-
bearing progress up to date.");
                                        _settextposition(12,14);
                                        printf("4: Return to the previous menu.");

                                        _settextposition(20,14);
```

```
                                printf("Please input a number between 1 and 4:
");
                                scanf("%d",&input);


                                /* Selecting option 1 lists the dates   */
                                /* of the monitoring session already    */
                                /* recorded for this patient.  All the  */
                                /* analysis file names with this patient*/
                                /* number as their suffix are written to*/
                                /* 'temp.dat' file and then iteratively */
                                /* read and the date extracted from the */
                                /* file name and then printed on the    */
                                /* screen.                              */

                                if ( input==1 ) {
                                        for( i=0; pat_file[i]!=0; i++ ) ;  /*
Getting the patient number by reading the patient filename */
                                        for( j=3; j>-1; j-- ) {
                                                temp_name2[j] = pat_file[i];
                                                i--;
                                                }

                                        strcpy( temp_name1, "dir
c:\\analysis\\an*." );
                                        strcat( temp_name1, temp_name2 );
                                        strcat( temp_name1, " /B > temp.dat" );

                                        system( temp_name1 );
                                        outfile = fopen( "temp.dat", "r" );
                                        while( fscanf( outfile, "%s", temp_name1 )
!= EOF ) {
                                                strcpy ( temp_name2, get_date(
temp_name1 ) );
                                                printf("\n%s",temp_name2);
                                                }

                                        }


                                /* Selecting option 2 displays the      */
                                /* notes taken after each monitoring    */
                                /* session of the patient.  The same    */
                                /* code as for option 1 is used, but    */
                                /* there is the addition that each      */
                                /* analysis file is accessed and the    */
                                /* notes read in character by character */
                                /* into the patient_notes char array.   */
                                /* When the character 32 is encountered */
                                /* (which signifies a carriage return)  */
                                /* then the patient_notes array is      */
                                /* displayed on the screen as string.   */

                                else if ( input==2 ) {
                                        for( i=0; pat_file[i]!=0; i++ ) ;  /*
Getting the patient number by reading the patient filename */
                                        for( j=3; j>-1; j-- ) {
                                                temp_name2[j] = pat_file[i];
                                                i--;
                                                }

                                        strcpy( temp_name1, "dir
c:\\analysis\\an*." );
                                        strcat( temp_name1, temp_name2 );
                                        strcat( temp_name1, " /B > temp.dat" );

                                        system( temp_name1 );
                                        outfile = fopen( "temp.dat", "r" );
                                        _clearscreen(_GCLEARSCREEN);

                                        while( fscanf( outfile, "%s", temp_name1 )
!= EOF ) {
```

```
                                        strcpy ( temp_name2, get_date(
temp_name1 ) );
                                        printf("\n\n%s",temp_name2);

                                        strcpy( temp_name3, "c:\\analysis\\"
);
                                        strcat( temp_name3, temp_name1 );

                                        infile = fopen( temp_name3, "r" );

                                        fscanf( infile,"%s %s", temp_name2,
temp_name3 );

                                        for( i=0; i<26; i++ )
                                              fscanf( infile, "%d", &j );
                                        for( i=0; i<6; i++ )
                                              fscanf( infile, "%f",
&weight_mean );
                                        fscanf( infile, "%d", &j );

                                        strcpy( patient_notes, "" );

                                        fscanf( infile, "%s",
patient_notes);
                                        for( i=0; patient_notes[i]!=0; i++ )
; /* This is to find out starting position for next word (stored in
variable i) */
                                        fscanf( infile, "%c", &input_char );
                                        while( input_char != 0 ) {
                                              patient_notes[i] =
input_char;
                                              fscanf( infile, "%c",
&input_char );
                                              i++;

                                              if( input_char < 32 )
                                                    input_char=0;

                                              }
                                        patient_notes[i] = 0;

                                        printf( "\n%s",patient_notes);

                                        fclose( infile );

                                        getch();

                                        }

                                  }


                              /* By selecting option 3 a graph of      */
                              /* weight-bearing over time              */
                              /* post-fracture is displyed.  Each      */
                              /* analysis file for the patient is      */
                              /* again accessed and the %age           */
                              /* weight-bearing value calculated using*/
                              /* the calc_weight-bearing function.     */
                              /* The week no. and corresponding %age   */
                              /* weight-bearing value are stored in    */
                              /* week_no and weight-bearing arrays.    */
                              /* These are used to print the graph.    */

                              else if( input==3 ) {
                                    _clearscreen(_GCLEARSCREEN);

                                    strcpy( temp_name3, get_patient_file(
pat_name ) );
                                    strcpy( pat_file, temp_name3 );

                                    infile = fopen( pat_file, "r" );
                                    fscanf( infile, "%s", temp_name2 );
                                    fscanf( infile, "%s", temp_name2 );
                                    fscanf( infile, "%d %d %d", &day_ob,
&month_ob, &year_ob );
                                    fscanf( infile, "%s", hospital_no );
                                    fscanf( infile, "%s", temp_name2 );
                                    leg_broken = temp_name2[0];
                                    fscanf( infile, "%s", fracture_type );
                                    fscanf( infile, "%s", fracture_pos );
                                    fscanf( infile, "%s", fracture_treat );
                                    fscanf( infile, "%d", &body_mass );
                                    fclose( infile );

                                    infile = fopen( pat_file, "r" );
                                    for( i=0; i<12; i++ )
                                           fscanf( infile, "%s",temp_name2 );
                                    day_start = atoi(temp_name2);
                                    fscanf( infile, "%s %s",temp_name2,
temp_name4 );
                                    fclose(infile);
                                    month_start = atoi(temp_name2);
                                    year_start = atoi(temp_name4);
                                    year_start -= 1990;

                                    outfile = fopen( pat_file,"r" );
                                    for( j=0; j<11; j++ )
                                           fscanf(outfile, "%s", temp_name1);
                                    body_mass = atoi( temp_name1 );
                                    fclose( outfile );

                                    for( i=0; pat_file[i]!=0; i++ ) ;
                                    temp_name1[2] = pat_file[--i];
                                    temp_name1[1] = pat_file[--i];
                                    temp_name1[0] = pat_file[--i];
                                    temp_name1[3] = 0;

                                    strcpy( temp_name2, "dir
c:\\analysis\\an*." );
                                    strcat( temp_name2, temp_name1 );
                                    strcat( temp_name2, " /B > temp.dat" );
                                    system( temp_name2 );
                                    infile = fopen( "temp.dat","r" );
                                    i=1;
                                    week_no[0] = 0.0;
                                    weight_bearing[0] = 0.0;
                                    while( fscanf(infile,"%s",temp_name2) !=
EOF ) {
                                           year_cur = temp_name2[6]-48;
                                           month_cur = ((temp_name2[4]-
48)*10)+(temp_name2[5]-48);
                                           day_cur = ((temp_name2[2]-
48)*10)+(temp_name2[3]-48);
                                           no_of_weeks =
calc_no_of_weeks(year_start,month_start,day_start,year_cur,month_cur,day_cu
r);

                                           week_no[i] = (float) no_of_weeks;
                                           weight_bearing[i] =
calc_weight_bearing(temp_name2,body_mass);
                                           i++;
                                           }

                                    fclose( infile );
                                    j = i;

                                    for( ; i<NO_OF_POINTS; i++ ) {
                                           week_no[i] = 99999.9;
                                           weight_bearing[i] = 99999.9;
                                           }

                                    flag3=OFF;
                                    while( flag3==OFF ) {
                                        flag3=ON;
                                        for( i=0; i<49; i++ )
                                             if( week_no[i] > week_no[i+1]
) {
                                                  temp_float =
week_no[i];
                                                  week_no[i] =
week_no[i+1];
                                                  week_no[i+1] =
temp_float;

                                                  temp_float =
weight_bearing[i];
                                                  weight_bearing[i] =
weight_bearing[i+1];
                                                  weight_bearing[i+1] =
temp_float;

                                                  flag3=OFF;
                                                  }
                                        }



                              _pg_initchart();
                              _pg_defaultchart( &env, _PG_SCATTERCHART,
_PG_POINTANDLINE );

                              strcpy( temp_name1, "Patient name: " );
                              strcat( temp_name1, pat_name );
                              strcpy( env.maintitle.title, temp_name1 );
                              env.maintitle.justify = _PG_RIGHT;

                              strcpy( env.subtitle.title, "Weight-
bearing as a Percentage of Body Weight" );
                              env.subtitle.justify = _PG_RIGHT;

                              strcpy( env.yaxis.axistitle.title, "%age
Body Weight" );
                              strcpy( env.xaxis.axistitle.title, "Weeks
from Fracture" );

                              env.chartwindow.border = TRUE;

                              _pg_chartscatter( &env, week_no,
weight_bearing, j );

                              getch();

                              }


                         /* Selecting option 4 returns the operator to
*/
                         /* the root menu.
*/

                         else if ( input==4 )
                              flag1=ON;


                         else
                              printf("\nThe range is from 1 to 4.
Please try again.");


                         if( flag1==OFF ) {
                              printf("\n\nPress a key to continue.");
                              getch();
                              }

                         }
```

```

                        }

                }


        /* Selecting option 5 enters the operator into a sub-menu       */
        /* allowing him to delete a patient's records from the disk (the*/
        /* patient, data and analysis files).                           */

        else if (input==5) {
                flag1=OFF;
                while( flag1==OFF ) {
                        _clearscreen(_GCLEARSCREEN);
                        _settextposition(1,5);
                        printf("Current patient name: %s",pat_name);
                        _settextposition(4,9);
                        printf("1: Delete current patient's records and tidy
other files accordingly.");
                        _settextposition(6,9);
                        printf("2: List patients on record (number of
monitoring sessions in brackets).");
                        _settextposition(8,9);
                        printf("3: Change current patient name.");
                        _settextposition(10,9);
                        printf("4: Return to the previous menu.");

                        _settextposition(20,14);
                        printf("Please input a number between 1 and 4: ");

                        scanf("%d",&input);


                        /* By selecting the first option, the operator  */
                        /* deletes all the files associated with the    */
                        /* current patient name.  This is a dangerous   */
                        /* but important option, for doing this manually*/
                        /* is too time intensive since all the          */
                        /* subsequent patient numbers and their         */
                        /* associated files have to be decremented so   */
                        /* that the program does not run out of unused  */
                        /* patient numbers.                             */

                        if( input==1 ) {
                                if( strcmp( pat_name, "" ) == 0 ) {
                                        printf("\nNo patient name specified!!");
                                        getch();
                                        }

                                else {
                                        /* Get total number of patients */

                                        system("dir c:\\patients\\patient.* /B >
temp.dat");
                                        infile = fopen("temp.dat","r");
                                        i=0;
                                        while( fscanf(infile,"%s",temp_name1) !=
EOF )

                                                i++;
                                        fclose(infile);
                                        itoa( i, temp_name3, 10);

                                        /* Get number corresponding to patient
name (j) */


                                        for( j=0; j<4; j++ )    /* gets patient
number */
                                                temp_name3[j] = pat_file[j+20];

                                        j = atoi( temp_name3 );

                                        /* All the files associated with*/
                                        /* this patient number are now   */
                                        /* deleted.                      */

                                        strcpy( temp_name1, "del c:\\data\\dat*."
);

                                        strcat( temp_name1, temp_name3 );
                                        system( temp_name1 );

                                        strcpy( temp_name1, "del
c:\\patients\\patient.");

                                        strcat( temp_name1, temp_name3 );
                                        system( temp_name1 );

                                        strcpy( temp_name1, "del
c:\\analysis\\an*." );

                                        strcat( temp_name1, temp_name3 );
                                        system( temp_name1 );


                                        /* All the patient nunmbers      */
                                        /* higher than the one deleted   */
                                        /* are now iteratively renamed   */
                                        /* with a decremented suffix.    */

                                        for( k=(j+1); k<=i; k++ ) {
                                              itoa( k, temp_name3, 10 );
                                              if( k<10 ) {
                                                    temp_name4[0] = '0';
                                                    temp_name4[1] = '0';
                                                    temp_name4[2] = 0;
                                                    strcat( temp_name4,
temp_name3 );
                                                    }

                                              else if( k<100 ) {
                                                    temp_name4[0] = '0';
                                                    temp_name4[1] = 0;
                                                    strcat( temp_name4,
temp_name3 );
                                                    }
                                              else
                                                    strcpy( temp_name4,
temp_name3 );


                                              strcpy( temp_name3, temp_name4 );

                                              itoa( (k-1), temp_name2, 10 );
                                              if( (k-1)<10 ) {
                                                    temp_name4[0] = '0';
                                                    temp_name4[1] = '0';
                                                    temp_name4[2] = 0;
                                                    strcat( temp_name4,
temp_name2 );
                                                    }

                                              else if( (k-1)<100 ) {
                                                    temp_name4[0] = '0';
                                                    temp_name4[1] = 0;
                                                    strcat( temp_name4,
temp_name2 );
                                                    }
                                              else
                                                    strcpy( temp_name4,
temp_name2 );


                                              strcpy( temp_name2, temp_name4 );

                                              strcpy( temp_name1, "rename
c:\\patients\\patient." );

                                              strcat( temp_name1, temp_name3 );
                                              strcat( temp_name1, " patient." );
                                              strcat( temp_name1, temp_name2 );
```

```
                                       system( temp_name1 );

                                       strcpy( temp_name1, "dir
c:\\data\\dat*." );
                                       strcat( temp_name1, temp_name3 );
                                       strcat( temp_name1, " /B > temp.dat"
);
                                       system( temp_name1 );
                                       infile = fopen( "temp.dat" ,"r" );
                                       while( fscanf(infile, "%s",
temp_name4) != EOF ) {
                                              temp_name4[9] = 0;
                                              strcpy( temp_name1, "rename
c:\\data\\" );
                                              strcat( temp_name1,
temp_name4 );
                                              strcat( temp_name1,
temp_name3 );
                                              strcat( temp_name1, " " );
                                              strcat( temp_name1,
temp_name4 );
                                              strcat( temp_name1,
temp_name2 );
                                              system( temp_name1 );
                                              }
                                       fclose( infile );

                                       strcpy( temp_name1, "dir
c:\\analysis\\an*." );
                                       strcat( temp_name1, temp_name3 );
                                       strcat( temp_name1, " /B > temp.dat"
);
                                       system( temp_name1 );
                                       infile = fopen( "temp.dat", "r" );
                                       while( fscanf(infile, "%s",
temp_name4) != EOF ) {
                                              temp_name4[8] = 0;
                                              strcpy( temp_name1, "rename
c:\\analysis\\" );
                                              strcat( temp_name1,
temp_name4 );
                                              strcat( temp_name1,
temp_name3 );
                                              strcat( temp_name1, " " );
                                              strcat( temp_name1,
temp_name4 );
                                              strcat( temp_name1,
temp_name2 );
                                              system( temp_name1 );
                                              }
                                       fclose( infile );

                                       }

                                 strcpy( pat_name, "" );
                                 strcpy( pat_file, "" );
                                 strcpy( out_name, "" );
                                 outname = out_name;      /* otherwise for
some reason outname points to the string value of the total number of
patients (ie. well done to Microsoft for another bug-free product) */
                                 strcpy( in_name, "" );

                                 }



                           }


                    /* Selecting option 2 displays all the patient   */
                    /* names currently on record, with the number of*/
                    /* monitoring session s which have occurred in   */
                    /* brackets after each name.  For this, the      */
                    /* number of data files for each patient is      */
                    /* counted.                                      */

                    else if( input==2 ) {
                            _clearscreen(_GCLEARSCREEN);
                            system( "dir c:\\patients\\patient.* /B >
temp.dat" );
                            infile = fopen("temp.dat","r");
                            i=0;
                            while ( fscanf(infile, "%s", temp_name1) != EOF )
{
                                    i++;

                                    strcpy( temp_name2, "c:\\patients\\" );
                                    strcat( temp_name2, temp_name1 );
                                    strcpy( temp_name1, temp_name2 );

                                    for( j=0; j<4; j++ )     /* gets patient
number */
                                            temp_name3[j] = temp_name1[j+20];

                                    outfile = fopen(temp_name1,"r");
                                    fscanf(outfile, "%s
%s",temp_name1,temp_name2);
                                    fclose(outfile);

                                    strcat( temp_name1, " " );
                                    strcat( temp_name1, temp_name2 );


                             /* Gets the number of data files for    */
                             /* this patient, storing result in j.   */
                             /* Assume that there are no unanalysed */
                             /* data files.                          */

                                    strcpy( temp_name2, "dir c:\\data\\dat*."
);
                                    strcat( temp_name2, temp_name3 );
                                    strcat( temp_name2, " /B > temp.dat" );
                                    system( temp_name2 );
                                    outfile = fopen( "temp.dat", "r" );
                                    j=0;
                                    while( fscanf(outfile,"%s",temp_name3) !=
EOF )
                                            j++;

                                    fclose(outfile);
                                    itoa( j, temp_name3, 10 );

                                    strcat( temp_name1, "(" );
                                    strcat( temp_name1, temp_name3 );
                                    strcat( temp_name1, ")" );

                                    if( (i%4)==0 )
                                            i=1;
                                    if( ((i%2)==0) || ((i%3)==0) )
                                            printf("%25s",temp_name1);
                                    else
                                            printf("\r\n%25s",temp_name1);

                                    }

                            fclose(infile);

                            }


                    /* This option was included to aid the          */
                    /* operator, for if the patient name needed to  */
                    /* be changed to the one to be deleted then the */
                    /* operator would otherwise have to traverse    */
```

```
            /* through many menus to get to the one where   */
            /* he would be able to change the patient name. */

            else if( input==3 ) {
                printf("\nWhat is the new patient's name? : ");
                scanf("%s %s", temp_name1, temp_name2);
                case_convert( temp_name1 );
                case_convert( temp_name2 );
                strcat ( temp_name1, " " );
                strcat ( temp_name1, temp_name2 );

                strcpy( temp_name3, get_patient_file( temp_name1
) );
                if ( strcmp( temp_name3, "unsuccessful") ) {
                    strcpy( pat_name, temp_name1 );
                    strcpy( pat_file, temp_name3 );
                    printf("\nPatient name accepted.");
                    strcpy( inname, "" );
                    strcpy( outname, "" );
                    }
                else
                    printf("\nPatient name does not exist
!!");

                }


            /* Selecting option 4 returns the operator to the root
*/
            /* menu.
*/

            else if( input==4 )
                flag1=ON;


            else
                printf("\nThe range is from 1 to 4.  Please try
again.");


            if( flag1==OFF ) {
                printf("\n\nPress a key to continue.");
                getch();
                }


            }

        }


    /* Selecting option 6 exits the program by breaking from this    */
    /* loop, for there is no code (except to reset the video mode to*/
    /* what had been previously selected) in the main function      */
    /* afterwards.                                                   */

    else if (input==6) {
        break;
        }


    else {
        printf("\nThe range is from 1 to 6. Please try again.");
        getch();
        }


    }

_setvideomode(_DEFAULTMODE);

```

```
}


/* This function is used to calculate the %age weight-bearing from the  */
/* inputted analysis file name and patient body mass.  The analysis file*/
/* is accessed and the session's average weight-bearing value obtained. */
/* This is divided by the inputted patient's mass and multiplied by 100 */
/* to obtain the %age weight-bearing.                                   */

float calc_weight_bearing( char *file_name, int body_mass )

{
float weight_bearing;
int i;
char temp_str[50];
FILE *fptr;

strcpy( temp_str, "c:\\analysis\\" );
strcat( temp_str, file_name );

fptr = fopen( temp_str,"r" );
for( i=0; i<29; i++ )
      fscanf( fptr, "%s", temp_str );

weight_bearing = atoi( temp_str );
weight_bearing /= (float) body_mass;
weight_bearing *= 100.0;

return( weight_bearing );

}


/* The following function is used to calculate the number of weeks      */
/* post-fracture.  The inputs are the date of the fracture              */
/* ( '.._start' ) and the date post-fracture ( '.._end' ).  The         */
/* intervening number of weeks is calculated by first calculating the   */
/* intervening number of days, and then converting this to weeks.  If   */
/* there are 4 days or over remaining, then this is rounded up to an    */
/* extra week.
*/

int calc_no_of_weeks(int year_start,int month_start,int day_start,int
year_end,int month_end, int day_end)

{
int no_of_weeks=0,i,day_month_start=0,day_month_end=0;
int days_month[] = { 31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31 };

no_of_weeks = (year_end-year_start)*52;

for( i=0; i<month_start; i++ )
      day_month_start += days_month[i];
for( i=0; i<month_end; i++ )
      day_month_end += days_month[i];
day_month_end = day_month_end-day_month_start;

day_month_end += day_end-day_start;

if( (day_month_end%7) > 3 )
      no_of_weeks++;

no_of_weeks += day_month_end/7;

return( no_of_weeks );

}


/* This function is used to obtain the date from an inputted data or    */
/* analysis file name.  The date is returned in the standard            */
/* day/month/year format.                                               */
```

```

char * get_date( char *file_name )

{
static char date[10];
char temp_str[15];
int i;

strcpy( temp_str, file_name );
strcpy( date, "" );

if ( temp_str[0]=='A' )
      i=2;

else if ( temp_str[0]=='D' )
      i=3;

else
      strcpy( date, "ERROR" );


if( date[0] != 'E' ) {
      date[0] = temp_str[i++];
      date[1] = temp_str[i++];
      date[2] = '/';
      date[3] = temp_str[i++];
      date[4] = temp_str[i++];
      date[5] = '/';
      date[6] = '9';
      date[7] = temp_str[i++];
      date[8] = 0;
      date[9] = 0;
      }

return( date );

}


/* This function returns the patient file name corresponding to the     */
/* inputted patient name.  Each patient file is opened in turn and the  */
/* stored patient name compared to the one inputted until a match is    */
/* found, the file name being then returned.                            */

char * get_patient_file( char *patient_name )

{
char static patient_file[40];
char temp_name1[40], temp_name2[40], temp_name3[40], temp_name4[40];
int flag=OFF, i;
FILE *fptr1, *fptr2;

system( "dir c:\\patients\\patient.* /B > temp.dat" );
fptr1 = fopen( "temp.dat", "r" );
while( fscanf( fptr1, "%s", temp_name1 ) != EOF ) {
      strcpy( temp_name2, "c:\\patients\\" );
      strcat( temp_name2, temp_name1 );
      strcpy( temp_name1, temp_name2 );
      fptr2 = fopen( temp_name1, "r" );
      fscanf( fptr2, "%s %s", temp_name3, temp_name4 );
      fclose( fptr2 );
      strcat( temp_name3, " " );
      strcat( temp_name3, temp_name4 );

      if ( strcmp( temp_name3, patient_name ) == 0 ) {
            strcpy( patient_file, temp_name2 );
            flag=ON;
            }

      }

if ( flag==OFF )
```

```
        strcpy( patient_file, "unsuccessful" );

fclose( fptr1 );
return( patient_file );

}


/* This function is called when changing the data file being accessed.  */
/* The date is requested with each value being validated as reasonable. */
/* If a patient name is not specified then this is also requested and  */
/* the data file name constructed.                                      */

void input_file( char *file_name, char *pat_name, char *pat_file )

{
int i, flag1, flag2, flag3, flag4, input;
static char temp_name[40];
char temp_name1[40], temp_name2[40], temp_name3[40];
char temp_name4[40], temp_name5[40], temp_name6[15];

strcpy( temp_name, "" );
strcpy( file_name, "" );
flag1=OFF;
while ( flag1==OFF ) {
        printf("\nInput date of the monitoring session:\nDay of month: ");
        scanf("%d",&input);
        if ( (input>0) && (input<32) )
                flag1=ON;
        else
                printf("\nThe range is from 1 to 31. Please try again.\n");
        }
temp_name1[0] = input/10+48;
temp_name1[1] = input-((input/10)*10)+48;
temp_name1[2] = 0;
strcat( temp_name, temp_name1 );

flag1=OFF;
while ( flag1==OFF ) {
        printf("Month: ");
        scanf("%d",&input);
        if ( (input>0) && (input<13) )
                flag1=ON;
        else
                printf("\nThe range is from 1 to 12. Please try again.\n");
        }
temp_name1[0] = input/10+48;
temp_name1[1] = input-((input/10)*10)+48;
temp_name1[2] = 0;
strcat( temp_name, temp_name1 );

flag1=OFF;
while ( flag1==OFF ) {
        printf("Year (eg. 1993): ");
        scanf("%d",&input);
        if (input>1991)
                flag1=ON;
        else
                printf("\nThe range is from 1993 onwards. Please try
again.\n");
        }
temp_name1[0] = input-1990-((input-1990)/10)*10+48;
temp_name1[1] = 0;
strcat( temp_name, temp_name1 );
strcat( temp_name, "." );

strcpy( temp_name1, pat_name );

if ( temp_name1[0] == 0 ) {      /* ie. temp_name1 = "" */
        printf("\nInput patient name in the following format. ");
        printf("\nPatient Name ('first name' 'second name'): ");
        scanf( "%s %s", temp_name1, temp_name2 );
        case_convert( temp_name1 );
        case_convert( temp_name2 );
        strcat( temp_name1, " " );
        strcat( temp_name1, temp_name2 );
        }

system( "dir c:\\patients\\patient.* /B > temp.dat" );
outfile = fopen("temp.dat","r");
flag1=OFF;
while( (fscanf(outfile, "%s", temp_name2) != EOF) && (flag1==OFF) ) {
        strcpy( temp_name6, temp_name2 );
        strcpy( temp_name3, "c:\\patients\\" );
        strcat( temp_name3, temp_name2 );
        strcpy( temp_name2, temp_name3 );
        infile = fopen(temp_name2,"r");
        fscanf( infile, "%s %s", temp_name3, temp_name4 );
        fclose( infile );
        strcat( temp_name3, " " );
        strcat( temp_name3, temp_name4 );

        if ( strcmp(temp_name3, temp_name1) == 0 )
                flag1=ON;

        }
fclose( outfile );

if ( flag1==ON ) {
        printf("\nPatient name accepted.");
        temp_name2[0] = temp_name6[8];
        temp_name2[1] = temp_name6[9];
        temp_name2[2] = temp_name6[10];
        temp_name2[3] = 0;

        strcat( temp_name, temp_name2 );
        strcpy( pat_name, temp_name1 );

        strcpy( pat_file, "C:\\PATIENTS\\PATIENT." );
        strcat( pat_file, temp_name2 );

        }

else {
        printf("\nThe inputted patient name '%s' does not exist in the
records.",temp_name1);
        strcpy( temp_name, "OFF" );
        }

strcpy( file_name, temp_name );

}


/* This function is called after every name inputted, for it converts   */
/* the case of that name.  All its letters are converted to lower case  */
/* except the first which is converted to upper case.                   */

void case_convert( char *name )

{
int i;

while( *name<65 )        /* in case any spaces before text in input string
*/
        name++;

if ( *name>90 )          /* put first character in upper case */
        *name -= 32;
name++;

for ( i=0; *name!=0; i++ ) {
        if ( (*name<91) && (*name>64) )
```

```
                *name += 32;     /* if any letters upper case, put in lower
case */
        else if ( *name==32 ) {
                while( *name==32 ) /* incase 2 or more spaces in between names
*/
                        name++;
                if ( *name>90 ) /* put first character in upper case */
                        *name -= 32;
                else if ( *name==0 ) /* in case a space at end of names */
                        break;
                name++;
                }
        else
                name++;

        }

}


/* This function obtains the patient name by accessing the inpuuted     */
/* patient file name.                                                   */

char * get_name( char *file_name )

{
int i;
FILE *file;
static char string[] = "unsuccessful";
static char patient_name[40];
char tmp[40];

if ( (file = fopen(file_name,"r")) == NULL )
        return(string);
else {
        fscanf(file,"%s",patient_name);
        fscanf(file,"%s",tmp);
        strcat( patient_name, " " );
        strcat( patient_name, tmp );
        fclose(file);
        return(patient_name);
        }

}


/* This function returns the analysis file name from the inputted file  */
/* name stub.                                                           */

char * get_outname(char *inname)

{
FILE *file;
float a=0.1;
char *outname;
static char tmpstr[13];

tmpstr[0] = 'A';
tmpstr[1] = 'N';
tmpstr[2] = inname[3];
tmpstr[3] = inname[4];
tmpstr[4] = inname[5];
tmpstr[5] = inname[6];
tmpstr[6] = inname[7];
tmpstr[7] = inname[8];
tmpstr[8] = inname[9];
tmpstr[9] = inname[10];
tmpstr[10] = inname[11];
tmpstr[11] = 0;
tmpstr[12] = 0;

outname = tmpstr;
```

```
return( outname );

}
```