

Thesis

A CLINICAL AND BIOMECHANICAL STUDY  
OF CAST-BRACE TREATMENT OF FRACTURES  
OF THE FEMORAL SHAFT

submitted by

Douglas Wardlaw

M.B., Ch.B. (Edinburgh), F.R.C.S. (Edinburgh)

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# C O N T E N T S

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## ABSTRACT

This thesis reviews fracture treatment from early history to the beginning of the First World War; and treatment of fractures of the femoral shaft from then to the present day. A detailed review of the knowledge of fracture healing in relation to fractures of the femoral shaft is undertaken, with a look at the clinical implications which provide a strong argument for cast-bracing. Other factors such as multiple injuries, financial aspects, the recovery of quadriceps function and the different materials and methods are reviewed. The background of the biomechanical aspects are discussed also. Early cast-bracing of fractures of the femoral shaft is shown to be clinically, physiologically and biomechanically a sound method of treatment.

The clinical study reviews retrospectively the treatment of these fractures by traction alone and by traction and cast-bracing of the first year of treatment during the years 1974 and 1975; and the experience of cast-bracing in the Orthopaedic Unit during 1976 and 1977. The first year's experience of a prospective study is also reviewed. The less than good results are correlated with any problems or errors in the technique so that they may be avoided in future. The biomechanical study evaluates the off-loading characteristics of the cast-brace during stance in patients with/...

## ABSTRACT (Continued)

with femoral fractures alone and aged less than 50 years; in those with multiple injuries, and those aged over 50 years. To do this, strain gauged transducers were applied to the cast at the fracture level where it was circumferentially split, and to the hinges at the knee. They measured respectively the load transfer between the two portions of the thigh cast, and the thigh cast as a whole, and the below-knee cast; and by subtraction from the total limb load, the skeletal force at the fracture level, and the knee.

The clinical results compare favourably with other forms of treatment and with other reports of treatment by early cast-bracing. Fractures at all levels were treated successfully and the management of the multiply injured patient was enhanced. The results of the biomechanical study show that the load carried by the two portions of the thigh cast, and the thigh cast as a whole, was proportionately high at first and stabilised at from 20 to 50% of body weight. The effects of age and concomitant injuries is elucidated.

The biomechanical stability achieved by the brace allows early mobilisation and controlled active motion of the limb with a graded increase in load as union progressed which must be due to a physiological feed-back mechanism.

The/...

ABSTRACT (Continued)

The physiological environment stimulates earlier union and recovery of soft tissue and joint function. The hospital service benefits financially, and the patient, physically, socially and financially.

CHAPTER 1

INTRODUCTION

## INTRODUCTION

The concept of cast-bracing or fracture bracing is not new and was applied to the treatment of non-union of fracture of the femoral shaft by an American Surgeon from Philadelphia (Smith 1851 and 1855). He called his device, which had an ischial support, thigh lacer, knee and ankle hinges, a prosthesis because it enabled his patients to walk on their limbs. To his surprise, their fractures united and they were able in most cases to discard their "prostheses".

It seems that fracture treatment passed through what might be termed "dark ages", when immobilisation of the fractured bone, the joint above and below the fracture and very often the patient himself was the dogmatic principle. This resulted in general wasting of the patient's muscles, the partial dissolving of his bones, and depression in his morale. Preventive therapy in the form of physiotherapy of various sorts, prevented completely wasted muscles and stiff joints being the outcome of conservative treatment, often after a prolonged period of rehabilitation. On the other hand, internal fixation enabled the mobilisation of limb and patient at an earlier stage but it always had its attendant hazards. Infection following surgical treatment of a fracture can lead to unnecessary and prolonged disability, amputation or even death.

It/...

It was not until the early 1950's that reports of early ambulation in the conservative methods of fracture treatment, increasingly showed superior overall results to other forms of treatment. Long leg walking casts, and the below-knee cast of Sarmiento were first used. The cast-brace technique in the treatment of femoral shaft fractures, has all the advantages of internal fixation without its disadvantages, and all the advantages of conservative treatment without its disadvantages. In a nutshell, it is a non-invasive technique and allows rehabilitation of the patient whilst the fracture is uniting, producing in many instances the most desirable result of an extremity fracture. A limb capable of nearly full function as soon as the fracture is united.

Cast-brace treatment was introduced into the Grampian Region in 1973 by the late Mr. George Hay, then Consultant Orthopaedic Surgeon, Stracathro Hospital, Brechin, Angus. He and Mr. David Begg, Senior Orthotist, also of Stracathro Hospital applied the first ever cast-brace in Scotland, if not, in the United Kingdom or even Europe. It proved to be a success and after that, all patients with fractures of the femoral shaft, admitted to Stracathro, were so treated. At about that time, the oil industry, together with other factors, began to have its impact on the Orthopaedic Unit. The pressure on beds increased so that ways of increasing patient turn-over were looked for. Almost simultaneously, a two year survey of femoral shaft fractures, which were treated/...

treated at that time by continuous traction in a Thomas splint, showed the bed occupancy to be 8%. Thus, in the latter months of 1974, cast-braces were applied to cases of fracture of the femoral shaft to allow their earlier ambulation and discharge from hospital. The technique of application used at first was basically that described by Mooney, Nickel, Harvey and Snelson (1970) and has been modified since as experience was gained. In early 1976, it was decided to carry out a review of cast-brace treatment practiced in the Unit up to the end of 1975 and compare it to a similar group of patients treated by continuous traction. This was done retrospectively, and was the subject of a paper (Wardlaw 1977).

The clinical advantages of cast-bracing were clear, but scepticism remained. How did the brace function? I determined to find out, and discussed the possibility of carrying out a study of the biomechanics of the cast-brace. A small pilot study was carried out to assess the off-loading characteristics of two patients in a cast-brace during stance and demonstrated that further study was worthwhile. A sum of money was obtained from the Grampian Health Board to initiate this, and, to enable more sophisticated equipment to be used, a further grant was obtained from the Scottish Home and Health Department. Thus, on 1st January, 1978, a prospective clinical and biomechanical study was commenced.

Meanwhile, during the years 1976 and 1977, cast-bracing/...

bracing continued to be practiced, the braces being applied mainly by Senior Registrars and, on occasion, Registrars working in the Unit. I have now carried out a retrospective study of these patients and complete clinical data on a prospective series of patients treated during the year 1978 is now available.

The prospective study together with further biomechanical studies continues and will hopefully yield further results which are not within the scope of this thesis.

CHAPTER 2

HISTORICAL REVIEW OF FRACTURE TREATMENT  
PRE-WORLD WAR 1

# HISTORICAL REVIEW OF FRACTURE TREATMENT

## PRE-WORLD WAR I

The first record of fractures is in the Smith papyrus which dates back to 3,000 B.C. (Meade 1968). Archeological finds in the Nubian desert have produced accounts of forearm fractures (Garrison 1929), and a forearm fracture treated with a splint of strips of wood held together with twine was found in a mummy by Smith in 1908 (Castiglioni 1958). Garrison observed that there is a reference in Ezekiel, chapter thirteen, to the use of a roller bandage to treat a fracture of the forearm, and that in Susruta, the discussion on fractures lists crepitus as a characteristic sign.

Hippocrates (460-370 B.C.) is credited with describing the oldest method of traction for fractures of the femoral shaft. He also differentiated between simple and open fractures, and described his method of applying bandages. Celsus gave accurate instructions for setting fractures and recommended splints and bandages hardened with a mixture of wax and starch. After union of the fracture had occurred, he urged frequent exercise (Castiglioni 1958). The ancient Egyptians used stiffened linen for splinting, Hippocrates used bandages "smeared with cerate and resin", Rhazes (born A.D. 865) used lime and white of eggs and Cheselden (1688-1752) used rags dipped in the white of eggs mixed with a little wheat (Meade 1968). Percival Pott in 1769/...

1969 enunciated, what was long thought an important principle in fracture treatment, that in splinting fractures, the joint above and below the fracture must be immobilised (Monro 1935).

The properties of plaster of Paris were known in ancient Egypt, India and Arabia. It was first used in building and (exactly when is not known) was used in the splinting of fractures. The Oxford English Dictionary states that the first reference to the term was in a poem written in 1462, and that the name is derived from the material first prepared from the gypsums of Montmartre, Paris (Cameron 1961). In 1816, Hubenthal was using equal parts of plaster of Paris and ground-up blotting paper. In 1828, Keyl and Kluge in Berlin used plaster of Paris applied to the limb which was placed in a box containing the plaster. In 1852, Matthysen, a Dutchman, used plaster bandages and, in 1894, Korsch used plaster directly to the skin. In America, Samuel St. John saw the advantages of plaster and recommended splitting the plaster. He placed a layer of cotton wool between the skin and the cast. Samuel Cooper recognised that immobilisation following a fracture lead to stiff joints especially when soft tissue damage was severe and the fracture near the joint, whilst Hugh Owen Thomas (1834-91) recognised that immobilisation of a healthy joint does not lead to ankylosis. Thomas first made patients with lower limb fractures walk in their apparatus by converting his splint to an ischial bearing walking/...

walking caliper fixed to the patient's shoe (Monro 1935). Lucas-Championniere in 1879 considered a moderate degree of deformity a small price to pay for absence of joint stiffness (Lucas-Championniere 1907). Krause in 1887 used walking plasters applied to the tuber ischii for the early ambulation of femoral fractures, the patient remaining in bed for two days afterwards to allow the plaster to dry. In 1893 he reported 98 fractures of the lower limb and found the healing time shortened by this method. Korsch in 1893 reported the use of a plaster incorporating the ring of a Thomas knee splint in the top of the plaster to give counter-traction against the ischial tuberosity. He pointed out that when the plaster is removed the patient is able to walk at once without it and joint stiffness quickly disappears. Guitard in 1903 wrote on the ambulatory treatment of lower limb fractures in walking plasters. With the added advantages of radiography, Lorenz Bohler during the 1914-18 War, applied the "functional treatment" of a walking plaster (Monro 1935).

Meanwhile in 1827 Rodgers appears to have been the first to use open reduction and wire suture fixation, but it was not until improvements in the results of surgery brought about by the concepts of antisepsis and asepsis that such procedures gained acceptance and, up to the time of Arbuthnot Lane, wire sutures, screws and Parham bands were used. Lane's plates proved more stable, and he advocated their use to restore the skeleton to normality and thus allow/...

allow early recovery of function. External skeletal fixation was first used by Bennet in 1870 and Parkhill (1898) reported his experience, whilst in Europe, Lambotte wrote about it in 1913.

The first account of extension is in Hippocratic writings, where a traction bed was described for immediate reduction and permanent extension. Celsus said that in fractures with shortening, "it behooved immediately to extend that limb". The first treatise devoted entirely to fracture treatment by mechanical means was by Oribasius (325-403 A.D.) and first translated into a modern language (French) in the sixteenth century. He described a screw-traction set attached to a narrow wooden bed and devised multiple pulley systems which were not improved upon until Russell did so in 1924 (Meade 1968). Guy de Chauliac, in 1350, described continuous traction for treating "fractures of the thigh" (Chauliac 1350, Wallner 1969). McCurdy (1923) presents the evolution of fracture treatment as he sees it, mentioning the various methods of internal fixation aimed solely to oppose the bone ends, and describes in some detail reduction and traction methods for fractures of the femoral shaft. Skin traction with adhesive plaster was first mentioned in 1740 by Cheselden and was used throughout the nineteenth century, the limbs often resting on what look very like the Thomas splints of today. Other forms of splintage are also described, and various designs of fracture beds illustrated including the so-called Balkan frame which was a development of the First World War.

Peltier/...

Peltier (1968) in his paper "A Brief History of Traction", completes the picture. Malgaigne (1806-1865), the author of the first comprehensive work on fracture treatment, credits Guy de Chauliac (1350) with the introduction of continuous isotonic traction. Early in the nineteenth century, Desault's splint was commonly used and in the United States, Physic's modification was popular. Hamilton's tables listed 83 patients with fractures of the shaft of the femur of which only nine were considered to have had a perfect result. Suspension and traction were combined by Nathan Smith in 1831. His splint was modified by his son and this was further modified by Hodgen in 1865. The final modification was especially useful for gunshot injuries and saw considerable service in the First World War.

Adhesive plaster was first effectively used by Crosby about 1850 and the method became known as Buck's extension. The complications and poor results of skin traction stimulated Steinmann in 1907 to develop a method of applying traction to the femur by means of two pins driven into the femoral condyles, and later his through-and-through pin technique. In 1909, Kirschner introduced his method of using wires of small diameter. Finally, Pearson's tongs for applying skeletal traction to the femoral condyles, along with his knee-flexion piece, was widely used by the allied armies of the First World War.

The treatment of fracture non-union was a problem.  
John/...

John Hunter in 1791, when confronted with a man with non-union of a fracture in the proximal part of his femur, instructed him to "walk upon crutches and press as much on the broken thigh as the state of the parts would admit with a view to rouse the parts to action by forcing them by a species of necessity to strengthen the limb". The fracture united rapidly allowing the man to walk with a cane in two months. Smith (1851) first reported the use of a "prosthesis" for non-union of fracture of the femoral shaft, having used similar "prostheses" for tibial fractures and found it to work (Smith 1848). According to Smith (1855), "In the ordinary treatment of fractures, nature furnishes the bond of union and, therefore, but little aid is required from the surgeon - rest and the apposition of the fragments being sufficient to enable her to accomplish the cure. But, when she has failed in the performance of this important action, surgery has always been ready to step forward and interfere, and, in some instances, has done so with a rudeness that has terminated either in the loss of the limb or the life of the patient". He goes on to describe these surgical insults. Local stimulants such as caustics, liniments and plasters either applied to the skin or directly to bone as was the case with tincture of iodine which was injected, and the introduction of a seton. Resection of the bone ends was an extremely risky procedure and electricity, galvanism and acupuncture were tried. The overall picture was summed up very nicely by Dehne (1972). "Imagine/...

"Imagine the times. Wilhelm Roentgen was still a gleam in his father's eye at best, Lister had not yet started washing his hands, and bone surgery was almost uniformly fatal. Open injuries were still uncommon. Splints and bandages were all that were available for treatment of fractures, and yes - the contemporary breakthrough of medicine - Dr. Physic's gentle lavages. The patients washed away in pools of pus, afflicted by hectic and racking fevers. Dr. Smith stood them up in his artificial limbs (braces), their strength and appetites returned, their infections subsided, and the bones healed on top of it, 'Gesundgehen'". 'Gesundgehen' was the term used in the German literature for Smith's walking therapy and practiced by Dehne (1903) for the treatment of non-unions.

Before Lister, compound fractures of the femoral shaft were treated by thigh amputation and, if not, then death resulted from sepsis or gangrene. During the American Civil War, the mortality was very high and, in most cases, amputation was done; and during the Russo-Japanese and Boer Wars, the mortality and amputation rate were reduced due to the principles of asepsis. No further improvements occurred until half-way through the First World War with better organisation of medical services and the introduction of wound excision or debridement (Sherman 1924).

CHAPTER 3

HISTORICAL REVIEW OF TREATMENT OF FRACTURES OF  
THE FEMORAL SHAFT DURING THE FIRST WORLD WAR  
AND BETWEEN THE WARS

HISTORICAL REVIEW OF TREATMENT OF FRACTURES OF  
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AND BETWEEN THE WARS

During the First World War, the record shows a total of 5,138 compound fractures of the femur with a mortality of 23% and a permanent disability of 50% in 48% of cases (Soto-Hall and Horwitz 1946). In the British Army, the death rate for all fractures of the femoral shaft reaching the Casualty Clearing Stations in 1914 was 80% and, in the Casualty Clearing Stations was 50%. In 1918, the death rate was about 15%. The Thomas splint was first used in large quantities in April 1917 at the Battle of Arras. The immediate result was a reduction in mortality in the Casualty Clearing Stations to 15.6%. At the same time, special operating teams were rushed to any point in the line where a push was on. The thorough excision of dead and damaged tissue was practiced from about that time with a resultant drop in mortality from sepsis and gas gangrene. The result of specialisation was a drop in the death rate in base hospitals to about 2% and secondary haemorrhage was practically abolished' (Jones 1920). An attempt was made to justify the setting up of special femur hospitals but during the post war period, fracture of the shaft of the femur was a relatively rare event.

The policy of radical wound excision followed by traction in a Thomas splint was strongly supported (Bulkley and/...

and Sinclair 1919, Hurley and Weedon 1919). The latter authors reported 170 cases during the latter six months of 1917. The wounds received were 1½-7 days old and were treated by excision and drainage within forty-eight hours of admission. Their mortality was 38%. They advocated early massage and simple movements. A few wounds remained septic and their non-union rate was 1%. To allow ambulation, walking calipers were widely used once union had taken place (Jones 1920, Sherman 1924, Hurley and Weedon 1919).

The problem of dressing wounds prompted some developments. The Balkan frame to allow suspension of the limb in a Thomas splint was designed by Blake in 1915 (McCurdy 1923). A double Thomas splint to allow dressing of posterior wounds without upsetting the leg in traction was developed (Alexander 1919). Hepburn (1919) first described delayed primary suture of wounds, practiced in the later stages of the War.

Temporary internal fixation with plates or bands was tried (Brown and Brown 1918) in the belief that the incidence of infection was reduced by opposing the bone ends. External support was of course also necessary and the plates and bands removed at about four weeks. This practice was also described by Sherman (1924).

The overall evidence suggested that the optimum method at that time was wound excision, usually leaving it to granulate, followed by skeletal traction with tongs or calipers via the lower femur, and the leg resting on a Thomas/...

Thomas splint. A Pearson's knee flexion piece allowed early muscle activity with knee mobilisation. When the fracture was solid enough, ambulation in a walking caliper splint was allowed. By this method, the total recovery time was reduced with a decrease in total disability and mortality (Jones 1920 and Sherman 1924). Cook (1924) reviewed 116 compound fractures of the shaft of the femur in which the wounds had been treated by the various methods of the time in civil practice. There were five deaths from septicæmia or gas gangrene, six secondary and five primary amputations. He noted that the implantation of metal delayed healing by six times.

Hey-Groves (1918) reported a series of 16 patients with non-union following gunshot fractures of the femur. He emphasised the role of movement in fracture healing referring to Lucas-Championniere. However, rather than allow mobility by external bracing, he operated on these fractures by a variety of methods. He used plates step-cut operations, bone grafts, intramedullary ivory or tibial bone pegs and even, in three cases, intramedullary metal tubes or rods. There were three deaths, two from the operation itself and one from infection with gas gangrene. In 1919, Ryerson reported the use of intramedullary splints made of beef bone obtained from a butcher. It was shaped to the appropriate size and then boiled before use. External support was also necessary.

The problem of the stiff knee following compound femoral/...

femoral fractures was discussed by Alexander (1919). The trauma, infection and disuse led to muscle being bound down to the fracture site and replaced by fibrous tissue. He advised repeated manipulation of the knee and physiotherapy during the recovery phase. He recognised the pathology and how it might be minimised. In civilian practice after the War, conservative methods of treatment were widely used and few advocated internal fixation, and then only for specific indications. In the United States of America, the technique of applying a plaster spica to the fractured limb was first described by Eliason (1918). He applied the spica with the patient on a special traction frame with the hip and knee in thirty degrees of flexion, the frame also being incorporated in the cast. He felt it allowed easier nursing of the patient.

Metcalf (1919) studied the application of war lessons to Civil Practice and reasoned that they were applicable. He felt that the so-called Buck's method would become obsolete in preference to skeletal traction. Peckham (1921) advised treatment by leg traction and counter-traction fixed to both ends of the bed, Sherman (1924) felt that war lessons in the treatment of compound fractures should not be lost and if plates were used, they should be removed at four to five weeks. He advocated conservative methods. Henderson (1921) reported a series of 30 closed fractures of the femoral shaft treated conservatively and stated that 28 patients were "cured". He also describes a/...

a mixed series of mal unions, delayed unions and non-unions in which 76% of those operated on and 93% treated conservatively were "cured".

In 1922, Bennet described his operation for "lengthening of the quadriceps tendon" for patients with a stiff knee following fracture of the femoral shaft and, at a time when the Thomas splint method of traction was widely established, Russell (1924) introduced his traction method. Campbell and Speed (1924) meanwhile advised conservative methods with spica cast fixation and were enthusiastic about early massage and mobilisation but stressed care be taken lest union was not sound. They thought that non-union was due chiefly to mal position and that rarely was open reduction indicated when autogenous graft should be used for fixation. Shipley (1924) described a large series of fractures treated mainly conservatively and pointed out that Sherman's plates were much stronger than Lanes. Stern (1927) wrote about compound fractures and showed that internal fixation increased the risks of infection and delayed healing, thus prolonging the morbidity. In 1926, Albee described how a segment of dead bone was removed and shaped to act as an internal splint in an infected fracture of the lower shaft of the femur. The sequestrum was subsequently removed when the fracture had healed. Wilmoth (1928) discussed the problem of mal alignment in the conservative treatment of femoral shaft fracture and stressed that following early closed reduction and/...

and elevation, early mobilisation, massage and active motion would reduce the disability. Mercer (1929) reported six femoral shaft fractures, four of which were treated by internal fixation. One patient died due to surgery and in another patient, a plate broke necessitating a further operation for a bone graft. There were no infections.

During the 1930's, it seems that the treatment of choice was traction. Various modifications of skeletal traction methods are described (Mathews 1931, Rush and Rush 1932, Codorniu 1935). Lee and Veal (1933) reported a series of fractures treated by Russell traction and obtained anatomical restoration of the fracture in 70% of cases. They stressed that the patient and apparatus should be regularly checked and repositioned immediately if it became disarranged. Lawry (1935) describes the physics of Russell traction and Selig in 1938 described the complication of peroneal nerve palsy due to the method. In 1939, Rush and Rush described their method of inserting a small intramedullary pin through the greater trochanter for the treatment of subtrochanteric and proximal third shaft fractures of the femur.

Mansfield (1941) reviewed a small series of 15 patients and compared a group treated by closed methods to one treated surgically with screws, wires or plates. The surgically treated group were discharged in half the time of those treated by closed methods and returned to work in two-thirds of the time. This was a small group of patients but demonstrated/...

demonstrated the potential of sound internal fixation. Watson-Jones and Coltart (1943) reported a large series of 142 fractures of the femoral shaft treated mainly by immobilisation. He concluded that the causes of delayed union were interrupted immobilisation, distraction at the fracture site, infection, persistent angulation, too early weight bearing and severe trauma with consequent damage to the blood supply of the fragments. In 1944, Burns and Young reviewed a series of patients treated by early knee movements. These results showed that, given a good position, the fractures healed in the presence of motion eliminating the need for rehabilitation. Charnley (1944) analysed the use of traction methods from the mechanical standpoint and, using a Thomas splint as a model, tried to rationalise them for the best treatment of the whole patient. Also, in 1944, Thomson reported his quadriceps-plasty to improve knee function. It was developed from Bennet's operation and attempts to deal with the pathological changes present following conservative treatment for fracture of the femoral shaft.

Kuntscher (1940) changed the whole approach to fracture treatment using his intramedullary nail which was strong enough and had enough fixation to allow early mobilisation of the patient and early hospital discharge and return to duty. Unfortunately, this method of treatment is not without serious risk to the patient.

CHAPTER 4

HISTORICAL REVIEW OF TREATMENT OF FRACTURES OF  
THE FEMORAL SHAFT DURING THE SECOND WORLD WAR  
AND THE NINETEEN FIFTIES

HISTORICAL REVIEW OF TREATMENT OF FRACTURES OF  
THE FEMORAL SHAFT DURING THE SECOND WORLD WAR  
AND THE NINETEEN FIFTIES

The ravages of war continued to supply material in the form of compound fractures for the further development of techniques in fracture treatment, each new technique being the product of necessity in dealing with vast numbers of severely injured men. Each war had its different circumstances in which medical services had to be administered. During the latter part of the First World War, men received their initial treatment near the front and were then transferred to base hospitals. The Second World War saw the introduction of closed intramedullary fixation by Kuntscher (1940) using his V-shaped and clover leaf nails which, despite the development of many varied designs of nail, has withstood the test of time and is still widely used today throughout the world, perhaps due to the fact that it combines strength with relative lightness. This revolutionised fracture treatment at the time and was used to treat the German war wounded enabling their early return to duty. According to Carr and Turnipseed (1953), Kuntscher reported that Ehrlich (1943) was the first to use intramedullary fixation in compound fractures and Heim (1943) to use it in compound wounds incurred in battle. Kuntscher (1940) refers to Muller-Meernach (1933) who introduced lamellar nails into the medullary cavity by the direct approach and obtained good results. After the fracture united/...

united, the nail could not be removed which Kuntscher felt should be done in young patients after three months or more. He felt that by not exposing the fracture, there was no risk of infection. In the pre-antibiotic era, in 132 nailings, there were nine wound infections, all of which healed, and one deep infection; that is, a deep infection rate of less than 1%. He felt that anatomical reduction was important for stability to allow early muscle activity and movement and, therefore, comminuted fractures were unsuitable. He also advised that the nail should be removed after a minimum time of three months because he foresaw that secondary bone changes would eventually occur leading to mechanical weakening of the bone. He saw the value of intramedullary nailing in pathological fractures to enable patients to go home and that it did not really matter whether or not their fractures united. The method was first seen by non-German surgeons among hospitalised German prisoners of war in France in 1945.

Stimson (1947) reports her experience in the British Army in the Italian campaign. Primary wound excision was carried out in the field and the wounded were then transferred to base hospitals where they received their definitive treatment, along conservative lines, and most of their rehabilitation. There was no rush to send the men back to Britain because of the lack of trained specialist medical personnel at home and lack of facilities. On the other hand, Hampton (1946) reported his experience in the United/...

United States Army where medical services were "centralised". The aim was to get the wounded into a fit enough state to withstand transfer to the zone of interior which meant back to the United States. To this end, internal fixation was carried out and transfer was possible at six weeks as opposed to twelve weeks in patients treated by conservative means. He appreciated the dangers of internal fixation, even when delayed, but it was felt that the benefits outweighed the disadvantages. Wire loop fixation, screws and plates were used. Overall, 77% of fractures solidly healed with or without the fixation device still in place. No mention was made of functional recovery. In the China/Burma campaign, gunshot fractures of the femoral shaft treated by traction-suspension, gave a healing rate of 96% (Brav and Fitts 1946). Winant (1949) stated that during the early years of the war, compound fractures were treated in plaster of Paris spica casts and dressings but, with the advent of delayed primary closure - the same procedure as delayed primary suture (Hepburn 1919) - this treatment was discarded for skeletal traction. He advised skeletal traction through a supracondylar pin and early knee motion. The traction was maintained until union of the fracture when weight-bearing with a brace and crutches was permitted. Eighteen of a total of 68 patients required operation for bone grafting with or without internal fixation. There were eight delayed unions, six with gross loss of bone substance, three/...

three refractures and one mal union.

McKeever (1945) reported the management of 47 patients treated in the United States of America by many surgeons whom he referred to as "a median cross section of the surgical talent of the nation". Twenty-three patients were treated by traction, 17 by plate fixation and seven with external skeletal fixation. Complications in these treated by traction were minimal. There were nine serious complications including five infections in those treated by plating and, almost all of those treated by external skeletal fixation, had serious complications. He therefore advised surgery only when muscle interposition is present. Funsten and Lee (1945) assessed the healing time in 71 adults treated by traction and traction and spica cast. Clinical and radiological union were assessed to be similar in the two groups. Seventy-five per cent of those treated by traction and cast were united at 24 weeks.

Gill (1947) reported an improved rotating stirrup for use in skeletal traction which allowed easier knee motion. The stirrup rotated on the fixation piece to the Steinmann pin. Charnley (1947) assessed the relationship of knee movement to the healing fracture and concluded that recovery of knee motion depended on quick healing of the fracture when there was little scarring of the quadriceps. With delayed union, he said that callus is scanty and scar tissue plentiful with consequent quadriceps tethering and poor knee motion. He was doubtful if mechanical movement would/...

would prevent this occurrence. Sturrock (1954) felt that delayed union and non-union were due to muscle interposition. Delorme, West and Shriber (1950) showed that progressive resistance exercises were beneficial early in the recovery phase after immobilisation followed by heavy resistance exercises later.

Outside Germany, medullary nailing of fractures of the femoral shaft rapidly spread. Soeur (1946) from Brussels reported 55 fractures treated by intramedullary nailing, 23 of which were treated by the closed method which he recommended. Fractures of the proximal, middle and proximal part of the distal third were treated and he advocated its use in pseudarthroses, femoral shortening and pathological fractures but advised against its use in compound fractures. Lauritzen (1949) of Sweden, reported its use in 63 femoral shaft fractures. He observed that delay in operating of two weeks or more did not retard the development of callus and felt that operating on compound fractures was advantageous. Additional fixation was used in 11 patients in the form of a plaster of Paris spica cast in four and circlage wire in seven patients. Deep infection occurred in two patients and two patients died from fat embolism following surgery. He stressed the importance of surgical expertise. Bohler and Bohler (1949) from Austria reported Kuntscher's method of intramedullary nailing in a large series of patients and discussed the relative merits of open and closed nailing. They said that closed nailing/...

nailing had two great advantages in that infection was almost completely avoided and stability was better. They thought it the best treatment for transverse closed fractures, open fractures and most osteotomies and non-unions of the femur, only if suitable equipment was available, and that fixation should be firm enough to allow the patient to walk without external support when the wound had healed at two to three weeks. Thus, joint stiffness and muscle atrophy are avoided. Watson-Jones, Adams, Bonnin, Burrows, King, Nicoll, Palmer, Vom Saal, Smith, Trevor, Vaughan-Jackson and Le Vay (1950) reviewed the difficulties and complications of both the closed and open methods. They pointed out the dangers of the closed method as they saw them, enumerating 12 in all and recommended the direct approach with open reduction of the fracture, advising that only transverse proximal fractures were suitable. McLaughlin, Gaston, Neer and Craig (1949) reported the use of two plane plate fixation of 63 femoral shaft fractures and, despite 17 patients having restriction of knee motion and two cases of osteomyelitis, they still advocated the technique. Peterson and Reeder (1950) reported dual slotted plate fixation of fractures of the femoral shaft and advocated its use in cases where internal fixation was definitely indicated for mal position, non-union or mal union or where open reduction and internal fixation is the treatment of choice. Street (1950) compared medullary nailing, dual plating and skeletal traction for fractures of/...

of the femoral shaft in a small group of 20 patients and found little difference in the healing time but the total disability was greater in those treated conservatively.

Brav and Jeffress (1952) compared equal groups of 21 patients treated by traction suspension and intramedullary nailing. They showed that intramedullary nailing had great advantages regarding period of recumbency, hospitalisation time, quality of bone healing and functional results. They felt that intramedullary nailing was indicated in selected cases and that the advantages off-set the risks and a contraindication was subtrochanteric fracture. All patients operated on were given prophylactic penicillin and were grafted with autogenous iliac bone. A year later, (Brav 1953) an expanded series was reported with 11 notable complications in 65 patients whilst Bohler (1951) reported the results of nailing of 95 selected fresh fractures. Additional external support was required in 18 of 23 patients considered to have unstable fixation. The complications arising from the last two series were many. Death, infection, non-union, refracture, bone resorption due to electrolytic action between the nail and accessory fixation, rotatory mal alignment, distraction of fragments, shortening, angulation, knee stiffness and bending, fracture or migration of the nail. Lottes (1953) enumerated 13 complications which may occur with any type of open reduction of fractures of the femoral shaft and a total of ten which were peculiar to intramedullary nailing.

The Korean War again produced large numbers of compound fractures/...

fractures of the femur due to gunshot wounds. During the Second World War, conservative management had given excellent results in terms of wound healing, but the ultimate functional results, with knee stiffness and muscle wasting, left a lot to be desired. The logical progression, therefore, was to use intramedullary nail fixation of these fractures along with thorough wound excision and early mobilisation at three to four weeks post surgery. Wounds were left open if necessary and it was shown that in such circumstances, wounds would heal and fractures unite. However, only small numbers were reported and the problem of persisting infection remained in some patients (Brav and Jeffress 1953, Carr and Turnipseed 1953).

As far as intramedullary nailing was concerned, the honeymoon period was over. In Britain, the Commonwealth and America, depending on the local circumstances, two schools of treatment developed. Those who treated fractures of the femoral shaft conservatively, trying to minimise the disadvantages and using internal fixation only for specific indications; and those who treated them by internal fixation primarily. When an intramedullary nail was the fixation device used, then the open method was much preferred, certainly in Britain.

Hartmann and Brav (1954) studied the problem of refracture in 18 patients, 14 of whom had been treated by traction, three by intramedullary nailing which were due to the nails being removed too early, and one patient by a plaster/...

plaster of Paris spica cast. Twelve of the patients had early refracture and six occurred during rehabilitation. Six of the fractures had been compound. In those treated by conservative means, aetiological factors were; lack of patient co-operation in three, a further three patients fell whilst wearing a ring topped caliper, two had flexion deformities at the hip and severe knee stiffness with muscle atrophy was present in others. Two-thirds were considered to have been unavoidable. The subsequent treatments included a plaster of Paris spica cast in four, intramedullary nailing with bone grafting in six and traction suspension in eight patients. Ten patients were totally unable to return to work, five were severely depressed, two had renal stones and one had gluteal atrophy. The main aetiological factors were considered to be poor muscles and stiff joints following prolonged immobilisation. They recommended that in those patients treated by intramedullary nailing, that the nail should be removed after a minimum of one year. Lewis (1958) devised a step-cut osteotomy with intramedullary fixation, bone grafting, circumferential wiring or interfragmentary screws and plaster of Paris immobilisation when indicated. Twelve out of 17 fractures united with an average of 68 degrees of knee motion. Shoe raises of up to two and a half inches were often required. Marshal (1958) described three-sided plate fixation of fractures of the femoral and tibial shafts. This required very wide exposure/...

exposure and of 16 femoral fractures, complications included two cases of mal union, one deep infection, one wound haematoma and one refracture.

Finally, the era of the motor car was ushered in by Ritchey, Schonholtz and Thompson (1958) who described the "dash board femoral fracture" where the energy of a head-on collision was absorbed by the bone when the knee struck the dash board causing a grossly comminuted fracture of the femoral shaft. This fracture was also often associated with dislocations and fracture dislocations of the hip and injuries to the knee. They advised that safety be considered in the construction of roads and cars and the wearing of seat belts.

CHAPTER 5

THE MODERN ERA IN THE TREATMENT OF FRACTURES  
OF THE FEMORAL SHAFT

THE MODERN ERA IN THE TREATMENT OF FRACTURES  
OF THE FEMORAL SHAFT

In 1961, Dehne, Deffer and Hall first described non-operative treatment of the fractured tibia by immediate weight-bearing using a long leg walking cast with the knee in extension. "Our method of treating the fractured tibia arose from the simple premise that the severe complications resulting from surgery can only be eliminated by foregoing open reduction". The method was initiated in 1950 in United States Army personnel at the 98th General Hospital in Munich. A consecutive, unselected series of 270 fractures were treated, 30 were compound and 17 had associated fractures of the femoral shaft with or without other injuries which were treated by traction until union of the femoral fracture. All the fractures united with minimal shortening, though five patients in whom the fibula had healed with consequent delay in union of the tibia had osteotomy of the fibula performed and three patients had phemister-type of bone grafts. There were three refractures. Ninety-two per cent of patients had full functional recovery in an average time of five months. The results clearly supported the use of ambulatory methods of treatment of tibial fractures.

Sarmiento (1967) showed that tibial fractures could be treated by early ambulation in a below-the-knee plaster of Paris cast which incorporated at the proximal end, the patellar/...

patellar tendon bearing configuration of a below-the-knee amputation prosthesis. It was applied at about two weeks after initial treatment in a long leg cast. He reported a selected series of tibial fractures treated in this way with an average healing time of 14.5 weeks. In 1970, he reported a further series of fractures treated by a below-the-knee brace with ankle hinges attached to the patient's shoes. The average overall healing time was 15.5 weeks. He recommended that the patellar tendon bearing configuration of the cast be firmly moulded around the patellar tendon and into the popliteal fossa with the quadriceps relaxed. The distal portion of the cast should be firmly moulded over the malleoli and may be trimmed in front and behind to allow free ankle movements. He pointed out that the patients thus continue to use their muscles normally while the fracture is uniting, thus eliminating the need for rehabilitation.

The next significant advance was when Brown and Urban (1969) showed that compound fractures of the tibia, with extensive skin and soft tissue damage, unite and that the soft tissues heal with early ambulation and without the need to skin graft in most cases. Most were gunshot injuries incurred in Vietnam. Once again, war provided the impetus for further development in fracture care by providing large numbers of seriously injured men. Fifty-seven of 63 cases had no major disability. The average shortening which could be attributed to early weight-bearing/...

bearing was one millimetre. Wounds were only dressed if and when the patient required a plaster change. Four patients had persistent drainage after cast removal and their injuries were caused by a high velocity missile in two and prior internal fixation at another hospital in two. Three of these healed after consolidation of their fractures and only one patient, who had prior internal fixation, had a persistent low grade osteomyelitis.

Meanwhile, Godfrey (1961) reviewed the late results of compound fractures of the femoral shaft incurred in battle. One hundred and eighty-one had been treated by traction, and 171 by internal fixation. He assessed them for persistent infection, angulation, extent of hospitalisation, disability award, and present status, and concluded that internal fixation should be reserved for the exceptional case and delayed until the evidence of sepsis had disappeared.

Ernst Dehne (Dehne 1969) wrote an excellent review article on the functional treatment of fractures of the tibial shaft. It was he, as a Colonel in the United States Army, who initiated early weight-bearing for tibial fractures, and it was his enthusiasm as chief of the Orthopaedic Service at Brooke General Hospital, Fort Sam, Houston, Texas, that rubbed off on to Lieutenant Colonel Joseph H. Moll. Moll reasoned that factors which facilitate union of tibial fractures treated by weight-bearing ambulation should be applicable to fractures of the femoral shaft./...

shaft. Initially, a walking spica with a carefully moulded ischial seat was used and this metamorphosed to a quadrilateral thigh bearing cast-brace which allowed both hip and knee motion (Scully 1974). The principle was taken, like Sarmiento's walking plaster, from prosthetics where above-knee amputees were fitted with a total contact quadrilateral thigh bearing socket which had an ischial weight-bearing seat. The quadrilateral shape was moulded round the root of the limb and compress the soft tissues. Moll (1973) reported the first 178 patients with 184 fractures with remarkable results. The thigh portion was carefully moulded in its upper part to a quadrilateral shape compressing the soft tissues of the thigh, and had an ischial seat. The technique was introduced into Brooke General Hospital in 1966 and was applied at six to eight weeks after fracture. Since 1968, cast application and weight-bearing was started in the early period after injury. Most fractures were open gunshot injuries that had been treated initially with thorough wound excision and tibial pin skeletal traction. They were received at three to six weeks and placed immediately into a cast-brace. Some patients were admitted directly to the hospital, in which case, their casts were applied within the first three weeks. X-rays were taken to check alignment of the cast, which was wedged if necessary. Knee hinges were applied either at the same time or after several days of walking and the cast trimmed round the knee to allow knee motion. Knee swelling occurred in 10%/...

10% of patients and settled with short periods of recumbency and wrapping. Extensive open wounds did not preclude the walking cast treatment and drainage regularly ceased. Four patients required sequestrectomy and skin grafting and only one patient continued to have drainage after his fracture had healed. Fractures at all levels were treated. Only two fractures failed to unite and this was due to muscle interposition. Obese patients with conical thighs produced technical problems, but were successfully treated. One patient objected to the weight of the cast and abandoned it before her fracture united. It was treated by intramedullary nailing. The average healing time in 77 closed fractures was 5.5 months with no non-unions and all with satisfactory knee function; whilst the average healing time in 107 open fractures was 7.5 months with three non-unions and 13 patients with unsatisfactory knee function. Fifteen of the open fractures had angulation greater than ten degrees, two of which underwent osteotomy and internal fixation. Early walking in a cast-brace was shown to be feasible, was acceptable to patients, improved functional results and had proved valuable in the treatment of severe compound femoral fractures with bone loss. Scully (1974) reported a further series of patients treated at Brooke General Hospital during the following four years. Again, the majority of patients were Vietnam casualties, and many of the patients had severe associated injuries, 108 patients with 114 femoral fractures were treated and 13 patients had ipsilateral/...

lateral tibial fractures. He felt that fractures ideally suited to the quadrilateral thigh bearing cast-brace were comminuted fractures of the middle three-fifths of the shaft, and transverse fractures in the same situation, with end-on apposition. Average time to healing with mature callus was 27 weeks; average shortening was half an inch. Seventy-five of the knees had more than 90° of flexion. Considering that most of the fractures were open, severely comminuted and complicated by loss of bone substance and often with severe soft tissue, vessel and nerve injuries, the results are impressive.

Another group of workers initiated a similar technique in 1966 and applied it to fractures of the tibial plateau and distal shaft of the femur (Mooney, Nickel, Harvey and Snelson 1970). The cast-braces were applied after the acute phase, using similar prosthetic principles with brace joints at the knee, and adjustable plastic quadrilateral brims, contoured to fit the root of the limb. Other materials were used in the fabrication of the brace, but none compared with plaster of Paris for ease of fabrication. The brace was applied in stages, first the thigh portion, then the below-the-knee portion and finally the brace hinges. They felt that polycentric joints offered no advantages over unicentric joints and positioned them two centimetres posterior to the mid-line in the sagittal plane and opposite the adductor tubercle. The joints were held in place with hose clips until fixed in position with/...

with plaster of Paris. A canvas boot was worn because it protected the plaster of Paris from soiling and allowed free movement of the limb during the swing phase without the need for a raise on the opposite shoe. The brace was not ischial bearing and was usually worn for six to eight weeks. Radiographs were taken after application of the brace and if alignment was lost then the brace was wedged. Patients were told that the brace would be removed when they could take full weight on the injured leg. They found that varus developed in treating upper third fractures and so only middle and distal third fractures were treated of which 70% were in the distal third. One hundred and fifty patients treated by cast-bracing were compared to a control group of 50 patients treated by a hip spica cast. The cast-braces were applied when the fracture was stable. The mean traction time was 7.3 weeks, the mean time in a brace was 7.2 weeks and the mean time to union was 14.5 weeks and all fractures united without complication and a good functional recovery was obtained. In those treated by spica cast, the mean traction time was 8.7 weeks, the mean cast time was 16 weeks and the mean time to union was 24.7 weeks and six patients had either a non-union or refracture. Forty-two per cent of those treated by cast-brace had greater than  $90^{\circ}$  of knee motion on removal of their braces at 14.5 weeks.

Connolly, Dehne and Lafollette (1978) reported their results in 143 fractures of the femoral shaft treated by a method/...

method of cast-bracing which differed from Mooney, Nickel, Harvey and Snelson (1970) only in that it did not incorporate the plastic quadrilateral top. They also treated upper third fractures and if varus angulation developed, then the cast was either wedged or a pelvic band with a hip hinge applied or even a hip spica to abduct the leg in relation to the pelvis and proximal fracture fragment. Thirty fractures in the series were open, of which eight were infected prior to application of the cast-brace and all healed. In six cases, the cast-brace was applied after bone-grafting for non-union following failed treatment using other methods, and a further 11 patients had residual knee stiffness following a previous fracture to the same limb. In three-quarters of the patients, the braces were applied during the first to the fourth weeks after injury. There were three refractures and one non-union. Of the remaining 133 fresh fractures, 69 were united by 14 weeks and able to take their full weight on the injured limb and all were united at six months. Thirteen per cent of patients had shortening of two centimetres or more. Nine proximal third fractures and four middle third fractures had either medial or lateral angulation. Only seven patients of those with fresh fractures and without previous knee stiffness had less than 90° knee flexion. Immobilisation of the ankle did not result in any restriction of ankle movements. In 20 patients with ipsilateral tibial fractures, all united save one that had been/...

been treated by plate fixation in another hospital and resulted in an infected non-union. Two patients with ipsilateral tibial plateau fractures did not recover 90° of knee flexion. Overall, the complications were three cases of refracture treated successfully by re-application of a cast-brace, and one non-union which required operative treatment. Pulmonary embolism occurred on four occasions, two when patients were in traction and two following application of their cast-braces. All were treated by anticoagulation and continued mobilisation. The writers concluded that besides the benefits pointed out by other writers, that the greatest effect is on the patient as a whole.

Brown and Preston (1975) reported a series of 76 fractures in 73 patients. The majority of these fractures were in the middle and distal thirds. Sixty-eight satisfactory results were obtained. The average time in traction was 4.7 weeks, the average hospital stay 5.8 weeks and the average treatment time 15.3 weeks. Their results supported the use of a cast-brace.

Vieyera (1972) reported 102 casualties from Vietnam using Moll's method of cast-bracing. Eighty-four per cent of cases attained 90° knee flexion. The complications included non-union (1.9%), mal union (5.8%) and pressure sores (4.9%). A high rate of union, high patient morale, shortened hospital stay, ease of management of concomitant injuries, absence of operative infections/...

tions and low incidence of complications were seen to be the advantages. Hackethorn, Burkalter, Donley and Bailey (1975) reported a further series of 156 fractures in 151 patients of which 131 were gunshot injuries. There were seven delayed unions and two non-unions treated by internal fixation and bone grafting. Complications included varus angulation in proximal third fractures treated early in the series. There were three cases of chronic osteomyelitis and no deaths.

Meanwhile, Scudese, Hamada and Awitan (1970) reported a multiple percutaneous pin technique of external skeletal fixation of femoral fractures which incorporated a thigh cylinder plaster. Good results were obtained but the method had complications. Snowdowne (1973) and Adair (1976) successfully used a long leg plaster technique to allow early ambulation where the thigh part of the cast was moulded into a quadrilateral shape by applying an external box to shape the plaster.

Published literature began to show that treatment of fractures of the femoral shaft by traction and cast-brace, had great advantages over conservative treatment and eliminated many of the disadvantages (Mital and Banadio 1974, Schweigel and Gropper 1974 and Wardlaw 1977). Similarly, there were advantages over operative treatment where the disastrous consequences could be eliminated (Weiss 1976), Sweating under the plastic quadrilateral top proved to be a problem (Bossley 1976 and Wardlaw, in Press), and plastic hinges were used by some authors (Albertson/...

(Albertson, Griffith and Lafollette 1976, and Bossley 1976). Mital and Cashman (1976) reported the use of cast-bracing in children, Brown and Sprague (1976) reported its use in the early management of fractures of the tibial plateau, and Meggit, Broom and Ross (1975) reported its use in fractures of the proximal tibia and distal femur.

Colley and Roper (1978) reported their experience in the use of a vitrathene cast-brace fabricated from a plaster-cast of the limb. Hardy, White and Williams (1979) treated 79 fractures by early cast-bracing and assessed them for shortening occurring after application of the brace. They found that more than two centimetres of shortening occurred most often when the brace was applied within two weeks of injury or after six weeks in comminuted middle third fractures. The last finding is at variance with all other series. Deyerle and Patterson (1974) and Crotwell (1978) reported the use of a thigh lacer which was suspended from a waist band. Selected patients with fractures at all levels were treated successfully.

Throughout the 1960's, the controversy between traction alone and internal fixation of fractures of the femoral shaft continued. Traction was the method that had withstood the test of time. The advantages and disadvantages were outlined by Anderson (1963). Proctor (1962) followed the practice of Perkins (1953). He felt that the repair should be a functional one rather than a radiological/...

radiological one and treated the fracture functionally on a fracture bed, only taking an x-ray after 12 weeks. Of 41 patients, there were two refractures and infection of the Steinmann pin track occurred in 15% of cases. Excellent results were obtained. Usdin (1967) compared Perkin's method of traction, to Thomas splint traction and intramedullary nailing. Perkin's traction had the best overall results with far fewer stiff knees than either of the two other methods. Nichols (1963) showed that closed methods need not result in a wasted thigh and stiff knee, whilst open methods continued to have their disasters. Dencker (1965)(a) reviewed 1,003 fractures in 992 patients and showed that there was little to choose between intramedullary nailing and traction methods as far as assessing the good and excellent results were concerned. Comparing the complications of treatment of the two methods, however, shows them in a different light. In those treated by closed methods, infection of the pin or wire track occurred in 3% when the traction was through the tibial tubercle and 9% when through the lower femur when a stiff knee may also result. That was the morbidity due to treatment. When open methods of treatment were used, the morbidity due to fracture treatment included five mid-thigh amputations which became necessary as a result of infection when closed fractures were converted to open ones by surgery. Seven deaths in the series were directly attributable to the surgery of internal fixation. Many papers were written on the management/...

ment of sepsis following intramedullary fixation of fractures of the femoral shaft (McAusland and Eaton 1963, McAusland 1968, Wilson 1966).

Dencker (1965)(b) found in a series of 400 fractures that for closed fractures treated by internal fixation the infection rate was 6% and for open fractures the figure rose to 21%. For open fractures treated conservatively, the figure was 3%. He also found in a series of 435 fractures treated by intramedullary nailing that technical problems occurred in 14% (Dencker 1965(c)).

In recent years, the closed method of intramedullary nailing has once again been in vogue, but the complications and morbidity of treatment persist (Rascher, Nahigian and Maeys 1972, Clawson, Smith and Hausen 1971).

Eriksson and Hovelius (1979) reported 16 cases treated by Ender nailing. The time to mobilisation varied from two to 16 weeks and two patients required reoperation. One nail had to be removed (for an undisclosed reason) once the fracture had united.

Thus, cast-brace treatment for fractures of the femoral shaft appears to be a real advance in management.

CHAPTER 6

THE BIOLOGY OF FRACTURE HEALING IN RELATION  
TO FRACTURES OF THE FEMORAL SHAFT

THE BIOLOGY OF FRACTURE HEALING IN RELATION  
TO FRACTURES OF THE FEMORAL SHAFT

General Considerations

From the foregoing chapters, it will be evident that a discussion of the processes of bone repair must be considered in the light of the soft tissue injury and indeed the patient as a whole. The skeleton, muscles and joints of the lower limbs comprise a lever system which moves the body by various methods and speeds from one place to the next, and at the same time supporting it. In a normal individual, the musculo-skeletal system has the capacity to adjust itself to functional demands. The stimulus of exercise produces an increase in blood supply by means of an increased cardiac output and muscle vascular bed; and an increase in oxygen carrying capacity of the blood by means of hyperventilation. The metabolic processes of the muscle are also adjusted, and the muscle fibres hypertrophy and the number of motor end-plates increase (Hansel and Hildebrandt 1964). The mechanical effect of muscle activity on bone causes remodelling and appropriate strengthening of the tubular bones by alterations in their architecture (Antmann 1971). These changes of course are entirely dependent on the patient's or person's willingness or capability to bring them about through the control of his central and peripheral nervous system.

Certain/...

Certain changes occur during immobilisation. The loss of the trophic stimulus of the nervous system on muscles causes muscular wasting which, in turn, and with other factors such as the loss of the effect of gravity, causes osteoporosis. There is also loss of the action of the muscle pump with consequent venous stasis. Renal calculi may develop due to the increased calcium output in the urine from bone breakdown. Some cartilage degeneration and intra-articular adhesions may occur but provided certain movements are carried out either actively or passively, ligaments do not undergo contracture and joints are capable of full recovery of function.

An uncomplicated fracture of the shaft of the femur is a common major injury and will be accompanied by a variable amount of soft tissue damage and bleeding into the limb. The importance of rapid resuscitation in the form of appropriate amounts of intravenous fluids and blood to provide rapid recovery from shock and prevent its complications such as renal failure, brain damage and death, has been stressed by many authors over the years.

The injury itself causes muscle spasm often with overriding of the fragments and manipulation under anaesthesia is performed during muscle relaxation followed by the application of skeletal traction to overcome the spasm and hold the bone in alignment and pulled out to length. The patient soon learns that muscular contraction is followed/...

ed by pain at the fracture site with painful muscle spasm, and so he avoids it. Individual psychological reaction to this varies depending on the person's personality, previous experiences, the presence of other injuries and severity of local injury. The patient, under supervision of the physiotherapist, may rapidly gain voluntary muscle control to perform static quadriceps exercises but, on the other hand, this may take a very long time. Thus, the variability of recovery of neurological control may play a role in the duration of disability and ultimate recovery. This subject is interestingly discussed by Dehne (1969). The immediate effect of immobility and reflex inhibition of muscular contraction, is the rapid development of inactivation atrophy which is characterised by a decrease in muscle fibre diameter, diminution of myoneural junctions and increase in interstitial connective tissue and fat. No degeneration of muscle fibres occurs (Hansel and Hildebrandts 1964). However, muscle when damaged is replaced by fibrous tissue and no regeneration occurs.

#### Local Changes in the Healing of a Fracture

Smith (1855) discussed this subject in his paper with reference to the development of non-union. Unlike muscle, bone heals not by scar tissue but by reconstitution of the damaged area to something like its original form, and the process/...

process is clearly much more complicated. The knowledge we have of what happens is based almost entirely on experiments performed on different species of laboratory animals under a variety of experimental conditions especially in the mechanism of production of the fracture.

#### The blood supply to bone

Normally, the cortex of long bones is supplied mainly through the medullary system, the flow being centrifugal with only a small peripheral contribution from the periosteum (Brooks 1971). The anatomy and anastomoses of the system are such, however, that following a fracture and a change in the haemodynamic state, an extraosseous blood supply develops from the surrounding soft tissues by way of the periosteum (Rhineland 1974, Trias and Fery 1979). This function regresses in the later stages of the healing process with the recovery of the medullary blood supply. Damage to the medullary blood supply due to a medullary nail causes most of the diaphysis to become avascular and stimulates the periosteal blood supply (Trueta and Cadavias 1955, Gustito, Nelson, Hanrel and Moe 1964). There is associated marked proliferation of the periosteum and laying down of the periosteal callus.

#### Phase of inflammation

Following a fracture there is bleeding from the bone ends and damaged soft tissues, and a clot forms. Vasodilation occurs in the soft tissues with the usual changes of acute inflammation, and the exudation of plasma and leucocytes/...

leucocytes (Wray 1964). Polymorphs, histiocytes and mast cells soon make their appearance, and the clearing up of debris begins (Lindholm, Lindholm, Linkko, Paasimaki, Isokaanta, Rossi, Antio and Tammineu 1969). Increased cell division begins at about eight hours reaching a maximum in 24 hours. It starts in the periosteum and surrounding tissues, extending throughout the whole length of the injured bone. Within a few days this generalised activity declines and becomes localised to the area round the fracture where it remains above normal levels for some weeks (Tonna and Cronkite 1961). The ends of the broken bones are dead for a variable distance, and this occurs due to the anatomical arrangement and anastomotic connections of compact bone (Ham 1930). They can therefore play only a passive role in the repair process.

#### The periosteum

McEwan (1912) stated that the periosteum was no more than a limiting membrane and that the cells responsible for new bone formation arose from the surface of the bone. The periosteum is now regarded as having two layers, an outer fibrous one and an inner cambial layer which contains spindle-shaped cells termed osteoprogenitor cells (Young 1962) to distinguish them from the osteoblasts to which they give rise, osteoblasts having lost their power of cell division. These cells are present on all bone surfaces and when the periosteum is stripped from the bone it takes with it some of these cells. Mullholland and Pritchard (1959)/...

(1959) and McClements, Templeton and Pritchard (1961) showed that when a segment of bone is excised, leaving the periosteal tube, it may regenerate a new bone.

The development of osteogenic repair tissue

So-called organisation of the fracture haematoma now occurs. It is invaded by blood vessels with the laying down of fibrous tissue with collagen fibres and matrix which subsequently becomes mineralised forming the woven bone of provisional callus. There is a front of cell division which advances from both sides of the haematoma leaving behind it more mature tissue joining the callus to the bone fragments. Areas of cartilage are often present especially peripherally and they are ossified by endochondral ossification. Cartilage is more prominent where movement is permitted (Roux 1895, Anderson 1965, Sarmiento, Schaeffer, Beckerman, Latta and Enis (1977) and a low oxygen tension is also a factor in its formation (Girgio and Pritchard 1958, Bassett and Herrman 1961). It appears that if callus outgrows its blood supply, cartilage fills the gaps because it is less demanding of oxygen and when the blood supply catches up, then endochondral ossification takes place.

Meanwhile, in the medullary region, the vascular response is much slower (Gotman 1961). Union by medullary callus is the method of union in cancellous bones, and it also forms in varying amounts in tubular bones. McKibbin (1978) showed that when the fracture is offset, medullary callus/...

callus may unite with the periosteal callus of the opposite fragment. Ham (1969) describes a zone of two encircling collars of callus arising from the periosteum. They start in the angle between the raised periosteum and bone and advance towards each other until they meet. Successive layers are then laid down until the haematoma is organised. Pritchard (1963) describes the osteogenic blastema which he says arises from the inner cambial layer of the periosteum and the medullary cavity and invades the fracture haematoma. Besides the osteoprogenitor cells arising from the outer bone surface or bone marrow (Owen 1972), another possible source of osteogenic cells is from previously uncommitted fibroblasts present in the surrounding soft tissues as first suggested by Leriche and Policard (1928). Osteogenic induction, the formation of bone and non-specialised cells in extra-skeletal sites by a variety of inducing agents has been demonstrated (Urist and McLean, Chalmers, Gray and Rush 1975). Thus, it may be that given the appropriate stimulus that such fibroblasts which cannot be distinguished morphologically from osteoprogenitor cells may gain access via the altered bone circulation following fracture. Trueta (1966) suggested that such cells arose from the vascular endothelium whilst Friedenstein (1968) showed that cells with osteogenic potential in marrow may have access to the general circulation. Clinically, in the treatment of adult fractures of the femoral shaft, the radiological picture seen is/...

is usually that of diffuse ossification across the fracture gap (Figure 1), whilst other fractures show mainly periosteal callus following an intact piece of periosteum (Figure 2).

Once union has taken place, consolidation, which is a radiological term, takes place, when radiologically bony trabeculae are crossing the fracture callus and fracture line from one fragment to the next. This is of course a remodelling process whereby histologically the callus is converted into cortical bone with Haversian systems. First the osteoclasts ream out a tunnel in the dead bone end down which a blood vessel follows bringing osteoblasts. If it happens that the bone ends are touching, then the osteoclastic "cutter head" may drive directly into the opposite fragment and this is analogous to the process called primary bone union. Thus the dead bone ends are revascularised and the callus incorporated into the bone, a process dependent to a large extent on mechanical factors (Bourne 1971). Thus, the dead bone may serve for a time as a splint or anchorage point for new bony trabeculae (Ham 1969) and according to Wolff's law, it may be incorporated or eroded according to the needs of the new structure.

#### Factors Controlling Fracture Healing

A fracture treated other than by internal fixation must be subjected to movement. Charnley (1970) stressed that/...

that the critical step in obtaining union of a fracture is the development of an intact bony bridge and for this to happen, the system must become immobile momentarily. Once this has occurred, the system must thereafter be protected from undue stress until the callus is strengthened by the progress of union.

#### Factors influencing the development of external callus

A mass of callus external to the bone is best fitted to achieve the purpose of immobilisation of the fragments (Charnley 1970). This happens when callus spreads from one fragment to the other, but this process does not go on indefinitely because following amputation, the bone end becomes inert. This is because its response is dependent on another fragment which is missing in an amputation but not in a fracture (McKibbin 1978). External callus is absent when the bone is rigidly fixed, and when movement occurs, periosteal callus develops (Schenk and Willinegger 1967). Thus, the presence or movement of one fragment to another is necessary for the development of external callus. If part of the periosteum is intact, as it often is, then a periosteal bridge develops between the fragments (Figure 3(a)). However, if they are not intact, then the two collars of callus advance till they join and continuity is established. Ham (1969) postulates, in what McKibbin (1978) terms the "cellular contact theory", that if the developing collars are excessively separated by the interposition of soft tissues or a long segment of dead/...

dead bone, then contact cannot occur and non-union will result. Philips and McKibbin (1976) studied fractures that for some reason could not possibly unite and they noted in every case that there was a 'primary callus response' which underwent involution if no contact was made within two weeks. The periosteum could never be reactivated by removing the inhibiting agent such as interposed muscle. Thus, there appears to be two phases in the development of external callus, namely, the 'primary callus response' (Figure 3(b)) and the phase of 'external bridging callus' (Figure 3(c)) when the participation of induction mechanisms seems most likely (McKibbin 1978).

#### Possible humeral agents

Osteogenic induction has been previously mentioned. It is the induction of bone formation in extra-skeletal sites, and such inducing agents have been identified. Even bone transplants separated from the surrounding tissues by a millipore membrane can induce bone in vivo (Goldhaber 1961) which strongly suggests that some inducing agent exists. The exclusion of the fracture bone ends by silastic caps does not effect the formation of external callus (Church and Young 1965) so that if a humeral agent is involved in the formation of external callus, it must presumably be liberated not from the injured bone itself, but from the products of the primary response (McKibbin 1978). It is possible, however, that in the last experiment the fracture haematoma would be formed/...



formed beneath the cap and a humeral agent absorbed from this into the general circulation. Whether there is a locally acting humeral agent, or one acting through the general circulation has still to be elucidated.

#### Mechanical factors and bioelectric phenomena

Experimental fractures in rat tibiae and fibulae showed that callus had no strength until five days post fracture, and there was a rapid build-up in strength to approximately 80% compared to a normal bone at 20 days post fracture (Wray 1965, McKeown, Lindsay, Harvey and Howes 1932) and at 80 days post fracture the callus was stronger (Wray 1963). Sarmiento, Schaeffer, Beckerman, Latta and Enis (1977) examined fracture healing in rat femora and compared two groups, one treated by immobilisation in a plaster spica and one by early weight-bearing. There were histological and radiological differences in the mechanical properties by the second week which became even greater by the eighth week post fracture. Functional weight-bearing accelerated healing and improved the strength of the healing bone. Tissue culture experiments showed that the differentiation of fibroblasts was influenced by tension and compression forces (Bassett and Herrman 1961). Fukada and Yasuda (1957) demonstrated that mechanical deformation of bone gave rise to electrical potentials; positive potentials on the tension side, and negative potentials on the compression side. These facts, added to the fact that electronegativity favours bone formation,/...

formation, and vice versa (Bassett, Pawluk and Becker 1964), suggest very strongly that compression forces or even intermittent compression, as would occur with muscle contraction, must be beneficial to the osteogenic processes. Bassett and Becker (1962) demonstrated the generation of electrical potentials by bone and Becker, Bassett and Bachman (1964) related the electrical activity to the molecular structure and showed that collagen fibrils became aligned perpendicular to the direction of current. A diagram was constructed suggesting how mechanical stress might cause appropriate structural changes in bone and thus explain Wolff's law. Friedenberg and Brighton (1966) found that when a fracture occurred, the broken ends became electro-negative but Lokietek, Pawluk and Bassett (1974) suggested that such potentials arose from injured muscles and were largely artefactual. However, it may be that injury in all tissues produces a negative potential. Finally, Bassett, Pawluk and Pilla (1974) have shown that fracture healing can be accelerated by means of small electrical stimuli induced in the limb by means of a pulsed electromagnetic field and, similarly, chronic non-union caused to heal (Bassett, Mitchell, Norton and Pilla 1978). Direct stimulation of the fracture site by means of implanted electrodes have also been used to produce the same effects (Friedenberg, Roberts, Didision and Brighton 1971, Brighton, Friedenberg and Mitchell 1977).

Thus, there appears to be a mechanism whereby muscular activity/...

activity and weight-bearing induce potentials in bone and perhaps fracture callus which in turn are responsible for the orderly laying down of new matrix and bone or conversely its removal, thus bringing about necessary structural changes to adapt to a changing mechanical environment.

#### Effect of blood flow and oxygen tension

Linked to the fact that activity causes the appropriate changes in the strength of normal bone by remodelling and also callus perhaps in a similar way, is the fact that appropriate changes in oxygen tension and blood flow to the tissues must take place for both bone remodelling and healing processes. Sim and Kelly (1970) showed that when remodelling of bone is taking place, there is an increase in blood flow and oxygen uptake. The influence of oxygen concentration along with mechanical factors as demonstrated by Bassett and Herrmann (1961) in vitro appears to be applicable therefore in the natural state because muscular activity produces an increase in blood supply to the limb generally and thus provides an increase in bone blood flow and oxygen carriage to the tissues.

#### Medullary callus

Whilst medullary callus may take part in the early stages of fracture healing as in the primary callus response of external callus, there also appears to be a slower, later response which is not inhibited by stability. In an unfixed fracture, early stability is produced by external/...

external callus. When external callus is inhibited by rigid internal fixation by plating, then the earliest form of union is by medullary callus, and appears to form without any intermediary stage of fibrocartilage (Anderson 1965, Olerud and Danckwardt-Lilliestrom 1971, Rhinelanders 1974). In a fracture treated by an intramedullary nail, medullary callus is inhibited and there is always a periosteal reaction with peripheral callus. McKibbin (1978) demonstrated that in fractures such as a rib where a large bony defect is filled with fibrous tissue, then the defect will be gradually bridged by medullary callus. The rib is well splinted by tissues to its neighbours and so controlled rhythmic movements must take place during the phases of respiration, and thus either mechanical or humeral influences may play a part in this process. Mulholland and Pritchard (1959) showed that cauterisation of the bone ends greatly diminishes the ability to bridge a fracture gap when the activity of the surrounding tissues may interfere by interposing fibrous tissue. Perhaps some factor has been destroyed. When fibrous tissue is excluded by joining the fracture ends with a polythene tube, much greater gaps can be bridged.

However, the process of repair by medullary callus is much like the 'osteogenic blastema' of Pritchard (1963) and given suitable circumstances, can replace interposed fibrous tissue by a slow process of replacement. Again, the presence of the opposite fragment, and controlled movement/...

ment, are the two factors known to be present, and may operate through bioelectric mechanisms, because it is very unlikely that a humeral mechanism could operate for such a prolonged period.

#### Primary bone healing

When a fracture of a cortical bone is fixed by a compression plate such that the two fragments are rigidly held together, then primary bone union occurs. The dead bone of the fracture ends is not, as was initially expected, resorbed, but is recanalised by new Haversian systems traversing the fracture directly. Very often there are small gaps on the opposite side from the plate which become filled by bone whose blood supply arises from the periosteum. This bone provides the bridge to allow new Haversian systems to cross the gap (Anderson 1965, Olerud and Dankwardt-Lilliestrom 1968 and 1971, Rahn, Gallinaro, Baltensperger and Perran 1971). Bone necrosis under compression has not been found to be a problem, and large avascular segments rigidly fixed do not collapse and are gradually revascularised (Olerud and Dankwardt-Lilliestrom 1971). It is not known if the stability of the bone/fixation device system has a biological effect. Friedenbergl and French (1952) demonstrated that moderate compression, at pressures of 12-18 lbs. per square inch, stimulated union, whereas excessive pressures caused delayed union.

These healing processes of bone have been summarised by McKibbin (1978) (Figure 4).

Clinical/...

## Clinical Implications

### Non-union

Smith in 1855 considered factors in the development of non-union and felt that excessive uncontrolled movement be the greatest contributing factor. Wray (1965) considered that factors operating in the early stages, before callus had developed much strength, were important and this perhaps is consistent with the idea of primary callus response and external bridging callus in that undue interference may well result in the bridge failing to meet in the middle. Yamagishi and Yoshimura (1955) demonstrated that the application of shearing forces to fractures in the early stages of healing produced a high incidence of non-union. Clinically, two factors are consistently referred to in the literature as a cause of non-union. The first is severe trauma which must be associated with greater damage to the blood supply to the fragments and possibly delay in vascularisation of the fracture callus. Greater areas of dead bone will take longer to be revascularised. Delayed union is inevitable and any external interference may upset delicate healing mechanisms. Any form of internal fixation inevitably interferes further with the blood supply. The second factor is muscle interposition. Here, it is not only the presence of the interposed muscle that is a factor, but also it is not difficult to imagine how the muscle might become obliquely placed in relation/...

relation to the other structures in the limb. In such a situation, muscular contraction shearing forces would be produced thus further increasing the likelihood of non-union.

#### Effects of continuous traction

Traction initially allows healing by external callus and once cessation of movement at the fracture has occurred, protects the callus from excessive forces until union has occurred. There is no interference with the healing process. However, prolonged immobilisation causes osteoporosis of bone and the callus so formed is mechanically weaker than that formed under conditions of early weight-bearing (Sarmiento, Schaeffer, Beckerman, Latta and Enis 1977). Clinically, delayed union, non-union and refracture are common problems especially if the patient has also been immobilised in a spica cast (Mooney, Nickel, Harvey and Snelson 1970, Schweigel and Gropper 1974, Seimon 1964, Suiter and Bianco 1971, Kaufer 1972, Sletten, Gustilo, Miller, Hamel and Kleven 1971).

#### Internal fixation

In fractures treated by means of an intramedullary nail, the medullary blood supply is totally destroyed, medullary callus is inhibited and, despite the switch to periosteal supply that accompanies any fracture, widespread avascularity of the cortex is present. Healing is by periosteal callus and proliferation of the periosteum occurs throughout the entire shaft and is greatest at the fracture/...

fracture site. This stage peaks at about three months and then subsides as the cortex becomes revascularised. At about six months, when the fracture is radiologically united, patchy areas of necrosis persist (Gustilo, Nelson, Hamel and Moe 1964). The result is delayed union and cortical remodelling throughout the whole length of the diaphysis. It is interesting to note that Kuntscher (1940) foresaw this possibility and advised removal of the nail to prevent long term changes in the bone structure. Internal fixation with vitallium and stainless steel plates produces significant weakening of the bone at the site of the plate. This is because the plate carries a certain amount of the load through the bone which may be as much as 30% with a corresponding reduction in strength of the bone itself. Thus, there is a very real danger of refracture following removal of the plate. There is pronounced cortical thinning beneath the plate and this is most marked on the cortex immediately beneath the plate than on the opposite cortex (Woo, Akeson, Coutts, Rutherford, Dotty, Jemmott and Amiel 1976). There is also a persistence of woven bone at the fracture site (Uhthoff and Dubuc 1971). However, these effects can be diminished by using plates of composite materials which allow bending stresses to be transferred to the bone by virtue of their flexural rigidity being less than metal plates (Bradley, McKenna, Dunn, Daniels and Stratton 1979).

Kuntscher/...

Kuntscher (1940), though he later changed his views (Kuntscher 1958), considered that his intramedullary nail prevented bending and shear stresses at the fracture site, but allowed controlled compression of the fragments by virtue of the action of the patients own muscles, and the ability of the fracture fragments to slide on the nail. Thus union was enhanced. Certainly this has recently been borne out when comparing intramedullary nailing to plating without compression (Sedel, Christel, Dewas, de Charentenay and Leray 1980). Finally, with regard to delayed internal fixation, there appears to be no scientific basis for this, and the published evidence is conflicting and confusing (Smith and Sage 1957, Smith 1959, Charnley and Guindy 1961, Lam 1964, Smith 1964).

#### Functional Fracture Bracing or Cast-Bracing

The development of a callus bridge and the cessation of movement has been discussed already. Once this stage is reached then protection of the fracture callus from excessive forces will result in healing of the fracture. It appears from clinical results that a cast-brace can provide this environment and, at the same time, gain the benefits of muscle action, controlled compression of the fracture callus, and thus possibly speedier healing of the fracture. It has been shown by Connolly and King (1973) by cineradiographic techniques, that cessation of movement/...

movement need not have occurred before applying a cast-brace. A pistonning action of the bone ends was often present on weight-bearing and stopped by the sixth week approximately in all patients, and all the fractures united. Thus, the brace appeared to control the forces to which the fracture was applied, thus enhancing union and preventing the adverse effects of immobilisation and internal fixation on fracture healing.

CHAPTER 7

THE ARGUMENT FOR CAST-BRACING

## THE ARGUMENT FOR CAST-BRACING

Before the last decade, treatment of fractures of the femoral shaft in the United Kingdom consisted of predominantly conservative treatment, internal fixation only being used for specific indications. The use of internal fixation in an open fracture or in the presence of infection was to be abhorred. However, the influence of the Swiss school in Europe (Muller, Allgower and Willenegger 1965), who developed sound biomechanical principles in the operative treatment of fractures, spread to Britain where its principles and practice have been enthusiastically taken up by a few centres. It very soon became apparent that the sophisticated implants and instruments could not be used without very careful training (Hamblen 1977). They stressed the importance of adequate resuscitation before surgery and could see no point in delaying surgery after the patient's condition was stable. They advocated the use of a double compression plate to stabilise the fracture, one being placed on the anterior surface, and one on the lateral surface. In the femur this produces the most biomechanically stable bone/implant system. If intramedullary nailing was preferred, then the direct or open method was advocated with the closed method only being advocated, quite rightly, in centres with the necessary equipment.

The Commonwealth countries, until recently, tended to follow/...

follow the British school, whilst in the United States, internal fixation tended to be much more widely practiced, due partly to economic factors but also the threat of litigation by a more demanding population of patients played a part. It seems that at times it was more important to be able to stand up in court and show a radiograph of an anatomically reduced fracture with the metal work involved, rather than have a functionally normal individual whose radiograph, to the uneducated eye, looked badly reduced. The functional results of cast-bracing appear to be so good without the hazards of internal fixation. It has already been shown that the biological arguments for cast-bracing are sound. The clinical arguments are equally sound.

### Conservative Treatment

#### Advantages

Conservative methods of treatment for fractures of the femoral shaft all involve traction initially (Paterson 1961). The Thomas splint (Scott 1961, Usdin 1967) and Russell traction (Anderson 1967) are mainly used, and involve immobilisation of the limb and the patient for three months, approximately, before mobilisation in hospital and discharge, at about four months (Wardlaw 1977, Sletten, Gustilo, Miller, Hamel and Kleven 1971). In the United States of America, the period in traction is often followed/...

followed by the application of a plaster spica to allow earlier discharge from hospital (Scott 1961, Kaufer 1972, Carr and Wingo 1973) and it was also used as further protection following discharge from hospital in patients treated by traction alone (Schweigel and Gropper 1974, Sletten, Gustilo, Miller, Hamel and Kleven 1971, Stryker, Fussel and West 1970, Ramey 1960).

The Chinese have integrated some of their traditional methods with modern medicine and devised an excellent traction system that allows early active mobilisation in bed (Hsien-Chih, Ying-Ch'ing and T'ien-Yu 1964). Perkin's method of traction also allows early knee movements and uses the thigh muscles under traction to act as a splint (Usdin 1967, Proctor 1962). Ricker, Bajema and Bagg (1971) developed a modification of the Thomas splint with a Pearson knee flexion piece allowing active knee function. It also had an adjustable foot piece that acted as a 'lively' splint. The approximate time to union by traction methods is 17 weeks (Wardlaw 1977). Following discharge from hospital, or removal of the spica cast, a prolonged period of out-patient rehabilitation and physiotherapy is required (Nichols 1963, Rokkanen, Slatis and Vankka 1969). The main advantage of conservative treatment is that no operation is required.

#### Disadvantages

Muscle wasting, osteoporosis and knee joint stiffness are often the end result of conservative treatment (Patterson/...

(Patterson 1961, Stryker, Fussell and West 1970) but this tends to improve over a two year period such that, eventually, results are comparable to other forms of treatment such as internal fixation (Dencker 1965(a), Hayes and Saer 1962). Knee stiffness present after several years can be improved by quadriceps-plasty (Scott 1961, Nicoll 1963, Hesketh 1963, O'Brien 1964).

Infection of the pin track occurs in 3% to 9% of cases depending on whether the traction is through the tibia or lower femur (Dencker 1965(a)). Delayed union and non-union are rare when dynamic forms of traction are used (Proctor 1962, Hsien-Chih, Ying-Ch'ing and T'ien-Yu 1964, Usdin 1967) but the incidence of these complications and of refracture added together has been as high as 39.4% in any one series with prolonged immobilisation in a spica cast (Sletten, Gustilo, Miller, Hamel and Kleven 1971). Pressure sores in the cast may also be a problem and an incidence as high as 11.6% has been reported (Kanfer 1972) and shortening may also occur (Scott 1961).

### Operative Treatment

Apart from the Swiss school or the Association for the Study of Internal Fixation (A.S.I.F.), surgeons on the whole have favoured the use of intramedullary nails in the treatment of fractures of the femoral shaft in preference to plates. This is because two plates in different planes are/...

are necessary to ensure biomechanical stability which is essential if the advantages of internal fixation are to be gained (Muller, Allgower and Willenegger 1965). A wide exposure of the fracture is necessary for the application of the plates and Grant, Shaffan and Herbsman (1970) felt that only carefully selected fractures in carefully selected, co-operative patients were suitable. Direct exposure of the fracture site increases the risks of infection and if stability is not achieved then supplementary treatment in the form of skeletal traction, or a plaster spica is necessary. Thus, the patient has been subjected to an operation that has been of very dubious benefit to him.

The same arguments hold for intramedullary nailing. The most suitable fractures for intramedullary nailing are transverse or short oblique fractures of the middle and upper thirds of the femoral shaft, as classified after Dencker (1965(a)). However, exponents of the closed nailing technique now advise that comminuted fractures and fractures of the shaft from a point just distal to the greater trochanter to ten centimetres proximal to the knee joint are suitable (Brown, Nahigian and Rascher 1971), whilst others (Winqvist, Hansen and Clawson 1977) felt that a point two centimetres distal to the lesser trochanter to the same point distally were suitable. The reason that these fractures are now suitable is that there is no dissection of the soft tissues so that there is greater inherent stability.

However/...

However, most authors who advocate closed intramedullary nailing use a device known as a femoral distractor which is applied to the leg, pulling distally on the leg against the ischial tuberosity, distracts the fragments, and holds the bone out to length. Operation may be deferred until the patient has been resuscitated, or until the next operating list. There is no manipulation of the fracture, so that in transverse or short oblique fractures with a soft tissue periosteal bridge as described by Charnley (1970), the bridge must be destroyed to allow reduction of the fracture thus increasing the trauma at the fracture site. Some authors actually advise distraction of the fragments by one centimetre prior to surgery (Rascher, Nahigian and Macys 1972). When reduction cannot be achieved by closed methods then a small secondary incision is necessary to obtain reduction. To overcome the problem of breaking and bending of the nail, it is advocated that the medullary canal be reamed out with a flexible power reamer until it will accept a nail of from 12 to 20 millimetres diameter (Clawson, Smith and Hansen 1971, Rascher, Nahigian and Macys 1972). Clearly, such treatment of the bone together with the presence of the nail must adversely affect the bone structure. Antibiotics are sometimes given prophylactically (Clawson, Smith and Hansen 1971). Segmental fractures have been treated successfully by the closed method (Winqvist and Hansen 1978).

The/...

The discussion as to whether early or delayed operation enhances or delays union goes on. Warmbrad, Weiss and Yelton (1975) found in a series of 233 fractures treated by nailing that the overall non-union rate was 5.2% and for 73 early nailings it was 6.8%. Clearly, further discussion on this subject is futile, and it is difficult to see how interference can possibly be other than harmful to the osteogenic processes. Thus, operation may be carried out at the time of injury or some two to three weeks afterwards.

#### Advantages

Rigid internal fixation allows early mobilisation, early discharge from hospital, and rehabilitation is permitted whilst the fracture is uniting (Cloke 1965, Clawson, Smith and Hansen 1971, Wickstrom and Corban 1967, Kamdar and Arden 1973, Rothwell and Fitzpatrick 1978). Rothwell and Fitzpatrick (1978) showed that 77% of patients could return to work in less than four months post fracture. A second operation is often required to remove the implant as advised by Kuntscher (1940) (Warmbrod, Weiss and Yelton 1975, Wickstrom and Corban 1967). There is no doubt that an operation affects the blood supply to the bone and consequently delays union of the fracture.

#### Disadvantages

Delayed union is inevitable with intramedullary nailing, and those patients who have been allowed to return home, and to work at an early date did so because of the rigidity of their internal fixation and the strength of the implant.  
As/...

As we have seen with bone plates, the bone weakens by an amount which is equal to the strength of the plate. Similar changes must occur with an intramedullary nail. The delayed union rate and non-union rate has been as high as 9.7% and 3.0% respectively for open intramedullary nailing (Savastano and Cadena 1971). Warmbrod, Weiss and Yelton (1975) had a non-union rate of 5.2% and Takase, Nemura, Kataoka, Harada and Nakamura (1960) had a non-union rate of 13.2%. Obrien (1964) reported a non-union in a child treated by nailing. Also, the refracture rate can be as high as 3% (Savastano and Cadena 1971).

No discussion of implant surgery is possible without reference to infection, a subject entirely lacking in a discussion of conservative methods of treatment. Open methods of treatment by repute have a higher incidence of deep infection than closed methods. An examination of a selection of series of fractures treated by open nailing (Table 1) and closed nailing (Table 2) despite the use of antibiotics in some series suggests strongly that this is the case. Again, reference to Kuntscher (1940), in his original article, he suggested that this was the case. He had a deep infection rate of 1.0%.

The treatment of chronic infection following internal fixation of fractures of the femoral shaft has been the subject of many papers (McAusland 1968, Wilson 1966, Jeffrey 1966, Kostuik 1971, Weber and Hirtzman 1964). Essentially the treatment is to leave the nail in position if /...

if possible until union has occurred, carrying out any operation that may be necessary to remove sequestra or drain pockets of pus. At the same time, infection must be controlled with appropriate antibiotics. Sometimes infection cannot be controlled and to save the patient's life amputation must be carried out (Kandar and Arden 1973). Chronic sinuses often persist. Weber and Hirtzman (1964) reported the outcome of deep infection in 35 patients. Eighteen patients were cured, seven had intermittent drainage and ten had amputation performed. Kostuik (1971) reported 30 patients with infected fractures and over a five year period each patient had on average six operations. This may have been a relatively small infection rate in a large series, but the end result for these patients was prolonged morbidity with considerable mental, physical and economic hardship. One patient required an amputation and three had persistent sinuses.

Death has occurred as a result of the surgery of internal fixation. Dencker (1965(a)) reviewing 1,003 patients found that seven deaths were attributable to the surgery of internal fixation, and five patients required thigh amputation for infection occurring in closed fractures infected at surgery. Such complications are totally unacceptable. Mukopadhaya and Verma (1972) showed that operating on infected compound fractures, and fixing them with a medullary nail so that ambulation can be commenced, can be beneficial.

It/...

It is now quite clear that closed medullary nailing has reached a high level of excellence in some centres (Winguist, Hansen and Clawson 1977, Rothwell and Fitzpatrick 1978). Such expertise is only attained by learning and by practice, usually making a few mistakes in the process.

There continues to be many reports of problems incurred. Lottes and Key in 1953 enumerated 13 complications which may occur during an operation for any type of internal fixation:

1. Surgical shock
2. Death
3. Failure of reduction
4. Fever
5. Haemorrhage
6. Infection
7. Thrombosis, phlebothrombosis and pulmonary embolism
8. Fat embolism
9. Deformity and mal union
10. Distraction at the fracture site
11. Delayed union and non-union
12. Excessive callus formation
13. Stiffness of joints

A surgical scar to some people is unsightly and may therefore be described as a complication of surgical treatment and a wound haematoma may occur, adding numbers 14 and 15. To be fair, 3, 7, 8, 9, 10, 11, 12 and 13 may occur with conservative management.

Ten/...

Ten complications peculiar to the surgery of intramedullary nailing are also enumerated, and many have been cited as complications encountered by other authors:

1. Nail of improper length or diameter (Rascher, Nahigian and Macys 1972).
2. Nail cutting out of cortex or nail splitting (Winquist and Hansen 1978, Brown, Nahigian and Rascher 1971).
3. Breaking of guidepin.
4. Additional comminution (Clawson, Smith and Hansen 1971).
5. Splitting of the shaft of the femur (Brown, Nahigian and Rascher 1971).
6. Pain and swelling of knee (Kamdar and Arden 1973).
7. Bending or breaking of nail (Rothwell and Fitzpatrick 1978, Patterson and Scott 1975, Savastano and Cadena 1971, Takase, Nomura, Kataoka, Harada and Nakamura 1960).
8. Bursa over end of nail (Davies 1957).
9. Pain in hip.
10. Migration of nail (Belder 1968).

A further complication is loss of rotatory control of the fracture leading to rotatory mal alignment (Winquist, Hansen and Clawson 1977). Its significance was assessed by Mayfield (1974) who deduced that in conjunction with shortening of more than two centimetres, the patient had a limp. The injection of methyl methacrylate into the medullary/...

medullary cavity around the nail has been advocated to allow early ambulation in the debilitated patient (Stubbs, Mathews and Sonstegard 1975). It is due to nailing of comminuted fractures and fractures of the distal part of the shaft, and leads to failure of the implant to do its job. Some authors do not seem to regard this as a failure of surgery and place the leg post operatively in balanced traction until there is radiological evidence of early union (Rascher, Nahigian and Macys 1972).

Further operations are often necessary for non-union, infection, delayed union and for removal of the nail. Ramey (1960) advised the use of iliac bone grafts to enhance union when performing open nailing of femoral fractures - thus necessitating a second wound with its possible complications.

Many series comparing closed treatment with internal fixation have been carried out and all are agreed that the advantages of internal fixation over operative treatment are; early mobilisation and discharge from hospital. Some patients return earlier to work and a stiff knee is less of a problem. Some authors feel that despite these advantages, the risks are too great and advise conservative treatment (Godfrey 1961, Patterson 1961, Scott 1961), and others feel that the advantages of internal fixation outweigh the disadvantages (Stryker, Fussel and West 1970, Patterson and Scott 1975); whilst others remain uncommitted (Hayes and Saer 1962). Rokkanen, Slatis and Vankka (1969) found that whilst/...

whilst angular deformity was a problem with conservatively treated fractures, rotatory mal alignment was equally a problem in nailed fractures.

### Cast-Brace Treatment

The basic concepts and techniques of application of the cast-braces are described by Mooney, Harvey, Nickel and Snelson (1970), Moll (1973) and Connolly, Dehne and Lafollette (1973) and have already been discussed in chapter five of this thesis.

#### Advantages

Cast-brace treatment means a period of in-patient immobilisation and traction for one to six or more weeks, and after application of the cast-brace, early mobilisation and discharge from hospital is made possible. Rehabilitation occurs whilst the fracture is uniting. After discharge from hospital, usually little physiotherapy is required, and a high degree of rehabilitation is attained by the time of removal of the brace and fracture union. The average time to union with this form of treatment is approximately 14.5 weeks (Moll 1973, Mooney, Nickel, Harvey and Snelson 1970 and Connolly, Dehne and Lafollette 1973). No operation is required.

#### Disadvantages

Skin reaction to the plastic quadrilateral brims has been a problem easily surmounted by not incorporating them in/...

in the cast or fabricating a brim of plaster of Paris (Bossley 1976, Wardlaw, in Press). Soft tissue swelling of the knee has been noted, but is not a problem and elevating the leg for short periods, causes it to quickly subside (Moll 1973). Pressure sores also occur (Vieyra 1972) but with good basic plaster technique, can easily be avoided. Of the many series now published, only one author (Hardy, White and Williams (1979)) found shortening, occurring after application of the brace, to be a problem. Angulation occurring after application of the brace has occurred in some series (Hackethorn 1975) and has been corrected by wedging the cast, adding a waist band with a hip hinge, or a hip spica (Mooney, Nickel, Harvey and Snelson 1970, Connolly, Dehne and Lafollette 1973). All these disadvantages are of a minor nature.

There are three inter-related disadvantages, however, common to all forms of treatment so far described, but their occurrence in patients treated by cast-bracing so far seems to be rare. Mital and Banadio (1974) had one case of refracture out of 75 patients treated. Wardlaw (1977) reported 34 cases treated with one non-union which was treated by plate and bone grafts. Connolly, Dehne and Lafollette (1973) out of 133 cases reported, had three cases of refracture treated successfully by reapplication of a cast-brace and one non-union which required operative treatment. Vieyra (1972) reported a series of 102 casualties from Vietnam and had a 2% incidence of non-union./...

union. Hackethorn, Burkalter, Donley and Bailey (1975) treated 156 compound fractures of which 131 were caused by high velocity gunshot wounds. They had seven cases of delayed union and two non-unions which were treated by internal fixation and bone grafting. Three patients had chronic osteomyelitis due to their original injury. There are no recorded cases of bone infection due to treatment by traction and cast-bracing. Colley and Roper (1978) successfully treated three patients who were suffering from non-union following failed treatment by other methods. Similarly, Connolly, Dehne and Lafollette (1973) treated six patients successfully. Going back in time more than 120 years, Smith used a method that differed only in the materials used to construct his prosthesis. The complications of surgical treatment during his time were the same as they are today. Only the severity and frequency of these complications is diminished, but not for the unfortunate minority who suffer from them.

Schweigel and Gropper (1974) and Mooney, Nickel, Harvey and Snelson (1970) compared a series of patients treated by traction and cast-bracing with patients treated by traction and spica cast, and Wardlaw (1977) compared patients treated by traction and cast-bracing to those treated by traction alone. It was shown that cast-bracing had all the advantages of conservative forms of treatment without their disadvantages. Weiss (1976) reviewed/...

reviewed the results of 169 patients treated by Kuntscher nailing and compared them to 34 patients treated by traction and cast-bracing. He found that cast-brace treatment had the advantages of intramedullary nailing without its disadvantages, but preferred to use an intramedullary nail for fractures of the proximal third.

Lesin, Mooney and Ashby (1977) described the early application of an "off-the-shelf" cast-brace. In selected patients, they used an adjustable polythene thigh section attached by plastic hinges to a plaster of Paris below-knee section in conjunction with skeletal traction using a roller traction technique. Patients were thus able to mobilise in bed whilst on traction.

Thus, on the whole, cast-brace treatment for fractures of the femoral shaft has the advantages of both closed and open treatment and avoids their disadvantages.

CHAPTER 8

OTHER FACTORS FOR CONSIDERATION IN THE  
MANAGEMENT OF PATIENTS WITH FRACTURES OF THE  
FEMORAL SHAFT

OTHER FACTORS FOR CONSIDERATION IN THE  
MANAGEMENT OF PATIENTS WITH FRACTURES OF THE  
FEMORAL SHAFT

When considering the overall management of a patient with a fracture of the femoral shaft, other factors must be taken into account. In the light of these factors, the management programme should be carefully planned before any definitive treatment is undertaken. Thus, the optimum use can be made of hospital resources available so that the patient may be returned to his environment with the best possible chance of full recovery. Concomitant injuries, social and economic circumstances, recovery of muscle and joint function in the limb, and the material available to aid the surgeon in his task, are important.

Concomitant Injuries

Patients with multiple concomitant injuries pose a major therapeutic emergency. The first essentials are to ensure a patent airway and the rapid replacement of circulating volume and thus adequate perfusion of vital organs. A satisfactory urinary output should be maintained. Meanwhile, thorough assessment of the injuries enables decisions to be made with regard to priorities in treatment. Life threatening situations such as an acute extradural haematoma, flail chest or intra-abdominal catastrophe may require/...

require to be immediately dealt with, during which time adequate splintage of orthopaedic injuries must be maintained. The patient's subsequent condition may affect the definitive orthopaedic management.

From the orthopaedic point of view, ipsilateral fractures of the lower limb often pose difficult problems in their management (Hayes 1961, Omer, Moll and Bacon 1968). The death rate after arrival at hospital in a series of patients with ipsilateral fractures of the tibia and femur has been as high as 13%. Many reviews have approached the problem differently. Murdoch (1961) suggested that the femur should be treated by an intramedullary nail, for easier management and better knee function. Gibson (1960) showed that even patients with severe head injuries could, in the majority of cases, be treated conservatively. McBryde and Blake (1974) assessed 81 patients, mostly treated conservatively and found that 22 patients required a total of 41 delayed operations. Thirty-seven per cent of fractures had delayed or non-union and there were 15 amputations. Sixty per cent of patients had a permanent disability.

Winston (1972) on the other hand, showed that conservative treatment of these fractures was a safe and reliable method whereby satisfactory results can be obtained in most cases. It has been shown, however, that internal fixation can produce better functional results (Ratcliff 1968, Gilquist, Reiger, Sjodal and Bylund 1973, Karlstrom/...

Karlstrom and Olerud 1977). The patients can usually be mobilised and discharged from hospital at an earlier date. Infection, however, still poses a major problem and Kavacs, Richard and Miller (1973) showed that the incidence of infection following operative treatment of fractures in patients with multiple trauma is much greater than patients with a single fracture. In the face of this, internal fixation is still advocated.

The association of knee and hip injuries in patients with fractures of the femoral shaft is well known, as is the difficulty of examining these joints clinically. Pedersen (1968) advised internal fixation of the femur with an intramedullary nail and then examination of both knees under anaesthesia. Bernstein and Meyers (1975) suggested that for a hip/shaft combination of fractures that the hip should be fixed, whilst in knee injuries the shaft of the femur should be fixed. On occasion difficulty in reduction of a dislocated hip necessitates internal fixation of the femur. Sadler (1975) showed that in patients with fractured patellae that whether the patella was removed early or later did not influence the functional result, but compound fractures of the patella warranted patellectomy.

Moll (1973), Scully (1974) and Connolly, Dehne and Lafollette (1973) showed that conservative management of these fractures and the early application of a cast-brace enabled excellent functional results to be achieved without/...

out the risks of internal fixation. In spite of this, Fraser, Hunter and Waddell (1978) on reviewing a large series of 222 patients retrospectively, concluded that intramedullary nailing of the femur combined with either rigid external fixation of the tibia or cast-bracing was the advised treatment. Connolly, Dehne and Lafollette treated eight patients with ipsilateral tibial fractures, two of which had been internally fixed at another hospital, with excellent results, apart from one of the patients who had received internal fixation of his tibia. He had a chronic osteomyelitis persisting after removal of his plate. The evidence strongly suggests that conservative treatment of both bones followed by early mobilisation in a cast-brace produces excellent functional results.

### Financial Aspects

Fracture of the femoral shaft nowadays is mainly caused by road traffic accidents (Dencker 1965(a)). The different forms of management impose differing burdens, financial and otherwise, on different parts of the hospital service.

Mital and Banadio (1974) compared conservative management, internal fixation and treatment by early cast-bracing and noted that the major part of the cost to the patient was in terms of hospitalisation time. Patients treated/...

treated operatively, spent one month in hospital, and those treated by early cast-bracing spent two months, whilst those patients treated by conservative methods spent, on average, nine months in hospital. Carr and Wingo compared the costs of a group of patients treated by traction and spica cast with a group treated by internal fixation with a medullary nail. The management of the complications of each form of treatment including delayed union, non-union and infection, plus financial loss due to absence from work, were included in the costing. On that basis, they found that the cost to the patient was 28% greater by traction alone. Schweigel and Gropper (1974) compared patients treated by traction and cast-bracing to patients treated by traction and spica cast and found that those treated by cast-bracing were discharged from hospital on average 66 days earlier and had recovered function more quickly without complications. The spica group had a complication rate of 10% non-union, 5% refracture and 2.5% delayed union. Not only can patients be discharged from hospital and make a full functional recovery more quickly, they can, if their work allows it, return to gainful employment (Wardlaw 1977, Colley and Roper 1978).

Clearly, factors other than hospitalisation time are important. With regard to the National Health Service, any increase or decrease in burden on hospital beds, physiotherapist's time, not to mention the time spent by the surgeon/...

surgeon and other staff involved, tends to be absorbed or otherwise by the department concerned with minimal additional costs to the service. This, of course, only happens within certain limits, but it makes real costing of different methods of treatment difficult. In terms of savings in hospital bed time, clearly, there is a cost saving with cast-bracing and in allowing the earlier return of function and return to work, the patient may also benefit financially.

### The Recovery of Quadriceps Function

Assessment of the functional recovery of the quadriceps, following fracture of the femoral shaft, until recently, consisted entirely of measurement of the circumference of the thigh along with the patient's subjective feeling of pain or discomfort, if any (Dencker 1965(a)). In 1972, Damholt and Zdravkovic reported a series of 75 patients with 77 fractures who had been assessed for recovery of quadriceps function. All but a few of the patients had been treated with an intramedullary nail inserted by the direct approach (the 'open' method). Fifty-seven patients were assessed for recovery of isometric strength, and 53 for recovery of dynamic endurance of the quadriceps muscles in the fractured leg compared to the good leg. Heebøl-Nielson in 1964 showed that, in normal individuals, there was a difference in physiological/...

gical strength of from five to 11 per cent between symmetrical muscle groups. There was a tendency for right-sided muscle groups to be stronger than the symmetrical left sided ones but this was not significant. In the light of this Damholt and Zdravkovic (1972) classified a difference of greater than 15% reduction in strength of the fractured leg compared to the good leg, to be pathological. They found that two-thirds of the patients had an abnormally reduced strength of their quadriceps. It was increased in patients whose fractures had taken greater than one year to unite. A simple test to measure dynamic endurance and isometric strength was described.

Danckwardt-Lilliestrom and Sjogren (1976) reported the results of measurement of muscle isometric strength recovery in patients with fractures of the femoral shaft treated by open medullary nailing. They found that even in young patients, the isometric strength of the knee extensors and possibly also the knee flexors was still significantly reduced two to six years after the operation. Mal-rotation affected the recovery of muscle power. Hip abduction appeared to be reduced on both legs following the operation but reduction was greater on the affected side.

Zdravkovic and Damholt (1978) reported a series of 24 patients treated by the closed method of intramedullary nailing followed up at two to six years following surgery. They found that the isometric strength and dynamic endurance/...

ance were significantly decreased by five per cent compared to the unaffected leg, and that there was poor correlation between thigh circumference and strength. The decrease in isometric strength and dynamic endurance after indirect nailing was less than that found in their previous investigation of fractures of the femoral shaft treated by direct nailing.

There have been no studies carried out following treatment by traction alone or by traction and cast-bracing.

### A Review of Materials and Methods

Most published articles on the management of fractures of the femoral shaft by traction and cast-bracing describe the use of plaster of Paris for fabrication of the brace (Moll 1973, Scully 1974, Connolly, Dehne and Lafollette 1973, Wardlaw 1977). This is because no other material was available that had the ease of fabrication of plaster of Paris. No new application technique needed to be learned (Mooney, Nickel, Harvey and Snelson 1970). Unicentric metal hinges were also favoured by these authors and by many others. Mooney, Nickel, Harvey and Snelson (1970) and Scully (1974) felt that polycentric joints had no advantage over unicentric ones. Colley and Roper (1978) reported the use of a vitrathene brace which was fabricated from a plaster cast of the leg. It had unicentric metal hinges. Schwiegel and Gropper (1974) described/...

described the use of sand-splint in the fabrication of their casts and obtained good results. Bossley (1976) and Albertson, Griffith and Lafollette (1976), however, favoured the use of polypropylene hinges because, they said, there was no expertise needed to align them, and they appeared to have equally good results. Moll (1973) favoured leaving the Steinmann pin in place until after the brace had been applied, and a check radiograph taken showing a satisfactory position of the fracture. He then removed the pin. Moll (1973) tried, in some patients, to leave the foot free but these patients developed pressure sores around the ankle caused by the plaster cast-brace slipping distally. Connolly, Dehne and Lafollette (1973) suspended the cast from the tibial Steinmann pin which was left in place, and this enabled the ankle to be freed. If the pin subsequently became loose, then it could be removed and the cast suspended in another way such as extension of the cast over the ankle and foot. Clearly, several methods of application of the technique are available, but the use of plaster with metal hinges and incorporating the foot is by far the most practiced and well proven method.

CHAPTER 9

BACKGROUND OF THE BIOMECHANICAL ASPECTS  
OF CAST-BRACING

## BACKGROUND OF THE BIOMECHANICAL ASPECTS OF CAST-BRACING

In early 1976, it became apparent in our unit that cast-bracing was producing excellent clinical results. On reviewing the literature available at that time, it was found that certain parameters in the biomechanics of the cast-brace had already been studied. The author was unable to find a study, however, to measure the off-loading capability of a cast-brace.

Connolly and King (1973) measured rotation between the two fracture fragments by means of an electrogoniometer attached between two pins inserted into the proximal fragment by means of the greater trochanter and the distal fragment by means of the lateral femoral condyle. They then measured patients after reduction of their fracture whilst in traction in bed, then in bed after application of a cast-brace and finally when ambulant in the cast-brace. They showed that rotation was greatest in bed on traction when the limb was relatively fixed in position by the traction apparatus. It was least, lying in bed with a cast-brace when the limb was free to move with the patient, and was slightly higher on weight-bearing in the cast-brace but less than when in traction in bed. This was true in middle and lower third fractures. In proximal third fractures, however, rotation was greatest when weight-bearing and least when the patient was lying in bed in a cast-brace. They also/...

also studied the behaviour of fractures in patients in a cast-brace using cineradiography. Many types of fractures were studied, and they showed that some fractures pistoned approximately 0-2 centimetres on weight-bearing, and during the swing phase of gait returned to their resting positions. This phenomenon was least in distal fractures and stopped when the fracture became stable, at any point from one to eight weeks post injury. Transverse or short oblique fractures were considered least stable but in those patients a brace was applied at an earlier date after injury. They concluded that cast-brace application was most suitable for fractures in the middle and proximal thirds of the shaft, and that weight-bearing in a cast-brace permitted controlled motion of the fracture fragments. Thus healing was promoted by the formation of periosteal callus.

Murdoch (1976) demonstrated in patients with a Syme's amputation wearing a conventional prosthesis, that only a proportion of weight is in fact carried by the end of the stump. Weight transference took place at the skin/prosthesis interface over its whole length. The author believed that a similar weight transference took place in a cast-brace.

Encouraged by these findings, a small pilot study was performed to assess the off-loading characteristics of a cast-brace. Two patients were studied using strain-gauged metal hinges to measure the axial force passing through/...

through each hinge during stance. A set of bathroom scales acted as a force plate and measured the load the patient was applying to the limb. The patient was encouraged to take as much weight as he or she felt comfortable on the limb during each test. In this way, the proportion of load being applied to the limb and through the brace at the knee level was measured during static weight-bearing. Measurements were taken in the early stages of mobilisation and at each out-patient visit until union had occurred and the brace was removed. This demonstrated that in both these patients, in the early stages of weight-bearing, the percentage of limb load which was transferred into the brace was high in the early stages and appeared to decrease progressively as union proceeded. These results have now been published (Pratt 1976, Bowker, Pratt, Wardlaw and McLauchlan 1978).

Since that time further results have come to light and further work has been done. Mooney (1974) found that off-loading into the whole brace was 50% in the early stages and that it rapidly fell off to 10-20%. He did not give details of his experimental methods and referred to Mooney and Harvey (1970). Scully, in 1974, felt that all femoral fractures tended to develop lateral angulation and that the brace, in fact, functioned in such a way that this was prevented by means of a three point fixation technique. No experimental evidence was produced to support this idea. Meggit, Broom and Ross (1975) described a/...

a hinged walking plaster for fractures above and below the knee on which they had carried out biomechanical investigations using hinge mounted strain transducers. They showed the load sparing mechanism of the brace to be 25-50%. Finally, Dewar (1977) reported the results of measurements carried out via transducers at the fracture level throughout the gait cycle. Three measurements were carried out in two patients. In the first patient at the beginning and end of treatment and the second patient at the beginning only of treatment. They deduced that at the fracture level, 20% of the load was being borne by the brace.

Hardy and Baddeley (1979) measured pressures generated in the thigh muscles before and after application of a cast-brace and between the cast and skin, and Hardy (1979) measured pressures between the cast and skin in patients with cast-braces. It was shown that muscle pressure was increased in a normal subject following application of a brace and significant skin/cast pressures were generated. There appeared to be a large margin of error by their method.

Clearly, a more detailed biomechanical study was indicated, and an experimental method was devised which will be described in detail in a later chapter of this thesis.

CHAPTER 10

MATERIAL AND METHOD

## MATERIAL AND METHOD

### Clinical Study

The clinical study was carried out in three separate parts. An attempt was made by the author to personally review all the patients. To eliminate any bias in classifying the results, it was decided before starting the study, to use the classification of Dencker (1965(a)) and this is summarised in Figure 5. During the second part of the study, however, it became clear that the majority of the patients were in the good or excellent category, and so these results were further subdivided into 'good' and 'excellent'. Those patients with full knee motion, thigh circumference equal to or greater than the opposite thigh, no thigh discomfort, and fracture angulation of less than ten degrees were classed as excellent.

The shaft was defined as starting five centimetres distal to the most distal prominent point of the lesser trochanter and ended distally five centimetres proximal to the adductor tubercle, as measured on available radiographs. The shaft was then divided equally into thirds, the fracture level assessed accordingly and classed as proximal, middle or distal third (Figure 6). The fracture type was also assessed from radiographs and classified according to Dencker (1965(a)). Angulation was measured directly from radiographs in both the A.P. and lateral planes./...

planes. Connolly, Dehne and Lafollette (1973) showed that a fair degree of antero-posterior angulation could be accepted without affecting the clinical result, and in this study, angulation in the antero-posterior plane was not noted unless it was greater than the angulation in the medio-lateral plane. All patients with fresh fractures of the femoral shaft treated in the Orthopaedic Unit, Aberdeen Royal Infirmary, from 1st January, 1974 to 31st December, 1978, are included in this study. A proforma was made out for ease of documentation (Table 3). One further item was added, and that was time of return to work.

#### PART ONE

Patients admitted between 1st January, 1974 and 31st December, 1975, were the subject of a retrospective study. An attempt was made personally to review all these patients, but for various reasons, only three-quarters of the patients were seen personally and the information concerning the other patients taken from the case notes. Cast-bracing was introduced into the main Orthopaedic Unit towards the end of 1975, with the result that all but four of the patients treated in 1974 were treated by traction alone and the majority of patients in 1975 were treated by traction and cast-bracing, a few being treated by internal fixation used for specific indications.

For the purposes of this study the patients were divided into the following groups.

- 1./...

1. Those treated by traction alone.
2. Those treated by traction and cast-bracing.
3. Those treated in other ways.

Using the above criteria, there were 56 fractures of the femoral shaft in 1974 which occurred in 55 patients, one case being bilateral. In 1975, 42 fractures of the femoral shaft were treated in 41 patients. This included one bilateral case and three refractures.

Of the 56 fractures treated in 1974, 48 were treated by traction alone, four were treated by traction and cast-brace and four were treated in other ways. In 1975, 42 fractures were treated, ten by traction alone, 30 by traction and cast-bracing and two in other ways. The first bilateral case was treated by traction alone and the second by traction and cast-bracing. Thus, the total treated by traction over the period was 58 and 34 were treated by traction and cast-bracing and six in other ways (Table 4).

Of the 58 patients treated by traction alone, two died shortly after admission as a result of multiple injuries. Eight patients were discharged to other Centres at an early stage in their treatment and were lost to follow-up. A further eight were old ladies and three of them died in hospital after the fracture had united and the others were not followed up because they lived at a considerable distance from the hospital. Of the remaining 40 patients, two were discharged to other Centres when their fractures were firm enough for them to be mobilised without weight-bearing./...

bearing. This left 38 patients available for review.

Of the 34 fractures treated by cast-brace, three were lost to follow-up because they were discharged to other Centres after application of the cast-braces. The group of fractures treated in other ways all had specific indications for the particular method of treatment. Thus the number of patients available for study were 38 in the traction alone group, and 31 in the traction and cast-bracing group (Table 5).

#### Technique of application

The materials required for the application of a cast-brace are shown in Figure 6. They are fracture cast stocking (a), piece of stockinette (b), plaster wool (c), six inch (15 cms.) plaster of Paris bandages, about 12 on average (d), polythene quadrilateral tops split laterally (e), bicentric hinges (f), alignment jig (g), plate benders (h), jubilee or hose clips (i) and finally a small allen key to fit the hinge screws (k). The alignment jig, jubilee clips, plate benders and screw driver are re-usable items. The dicentric hinges, fracture cast stocking (available in many sizes to fit long thin or short fat legs) and polythene quadrilateral brims (available in three sizes, right and left) are disposable components. The technique used was basically that described by Mooney, Nickel, Harvey and Snelson (1970). Our Senior Orthotist first applied the braces until the junior orthopaedic staff became competent to do so.

At/...

At first, no sedation was used for any of the patients on application of the cast-brace, but it became obvious that sedation was necessary. Ten to twenty mgs. of intramuscular Valium usually produced enough relaxation of the patient. The Steinmann's pin was removed and dressings applied to the pin sites (Figure 8). A cast-brace stocking was applied, which should be long enough to pass just beyond the groin without too much stretching (Figure 9). A piece of stockinette was then applied over the knee covering about four inches above and four inches below the knee; and wool was applied around the head of the fibula to protect the lateral popliteal nerve and also from the toes to just above the malleoli. Apart from these areas, the plaster must be in total contact. The quadrilateral socket was applied as high as was comfortably possible and seated firmly around the root of the limb. The thigh part of the cast was then applied. During this time, traction must be maintained on the femur by an assistant, gripping the limb just below the knee with the knee flexed (Figure 10). An x-ray was taken to check the alignment of the femur (Figure 11). Once this part was hardened, the traction could be released. A below-knee cast was then applied with the foot plantigrade (Figure 12). The hinges were applied preferably using a jig to align them. First, a cross was marked centred on the patella. In the normal individual, the transverse line marks the knee axis. The hinges were bent to the required shape using plate benders and attached to/...

to the jig (Figure 13). They were then centred on the cross previously marked, and held in position by the jubilee clips, care being taken that the thigh cast has not slipped distally (Figure 14). Some turns of plaster were then applied and allowed to harden. The knee stockinette was cut circumferentially and folded back to "finish off" the cast around the knee (Figure 15). The cast was strengthened particularly between the lower end of the hinges and the ankle. The screw driver and allen key were necessary for the jig attachment and locking screws on the hinges respectively. The patient rested in bed for two days to accustom himself to the cast and this allowed the plaster to harden fully (Figures 16 and 17). The patient was then mobilised with crutches by a physiotherapist and the nursing staff until he or she could confidently walk on their own. With this technique, no cast needed renewal due to breakage.

Cost of items used at present day prices inclusive of V.A.T.

Re-usable items:-	alignment jig	£40.25
	jubilee clips (per pair)	4.60
	plate benders (per pair)	28.75
		<hr/>
	<u>Total cost of re-usable items:-</u>	<u>£73.60</u>
Consummable items:-	cast stocking	£18.97½
	polythene quadrilateral brim	16.85
	bicentric hinges	18.51½
	plaster of Paris bandages (approx.)	<u>5.00</u>
	<u>Total cost of consummable items:-</u>	<u>£59.34</u>

The/...

The cost of smaller plaster room items used will perhaps round off the cost per cast-brace to £60.00. These are the present day prices quoted by S. H. Camp and Company Ltd., East Portway, Andover, Hampshire, SP10 3NL.

## PART TWO

This covers the period from 1st January, 1976 until 31st December, 1977. All patients were assessed retrospectively by the author. This showed the continuing use of cast-bracing as practised in the Orthopaedic Unit. The technique of cast-bracing being used gradually changed. The plastic quadrilateral top is no longer incorporated into the brace. These tops are a direct copy of the quadrilateral top of an above knee prosthesis, with a flared brim and ischial seat. Both these features are unnecessary in a cast-brace which is not ischial-bearing. The flared brim often caused trouble in the groin and over the ischial tuberosity. This, combined with a tendency for the skin to sweat under the plastic, meant that the brim often had to be trimmed back or on a rare occasion the brace temporarily removed. This difficulty has been entirely overcome by making the thigh portion of the cast entirely of plaster of Paris, using the plastic brim to mould the upper part of the cast into a quadrilateral shape, to maintain rotational control of the fracture. At first this was held by hand (Figure 18) and then using a jubilee clip (Figure 19). The braces were applied by a registrar or senior registrar usually with two assistants, and/...

and on occasion our Senior Orthotist applied a brace. Twenty milligrams of oral Diazepam given one hour before application is now used for sedation and application of the brace takes approximately 30 minutes. The decision when the brace was to be applied was taken by the Consultant in charge of the patient. This was usually when the fracture was "sticky" and was assessed clinically when the fracture did not shorten on release of traction, but when some angulatory motion may still be present. Radiologically, early callus was usually visible. The time at which this stage was reached varied greatly with each fracture and was not necessarily related to the type of fracture.

### PART THREE

On 1st January, 1978, a prospective study was set up. The time of application of the brace was considered by this time to be approximately three to four weeks, when the fracture had reached enough stability to allow the application of the brace and subsequent mobilisation without much discomfort. Plaster continued to be used in the fabrication of the brace until the latter part of 1978 when crystona was used. This is a new water activated material which has the ease of application of plaster of Paris. No new technique need be learned. It retains many of the good characteristics of plaster of Paris in that it 'breathes' and reduces the weight of the cast by a third. It does not deteriorate in water and is acceptable to patients. The patient may mobilise after one hour. This part deals with patients admitted to the Unit during 1978.

The application technique now used is as described below./...

### Prescription

A walking knee-hinge long leg cast-brace using support from the ankle-foot section.

### Application technique

With the leg in fixed traction on a Thomas splint, the patient reclines at  $45^{\circ}$  seated on a low plinth. Manual traction is maintained by an assistant. The Steinmann pin and Thomas splint are removed and dressings applied to the pin holes. The fracture cast stocking is rolled on (Figure 20) and held in position by a shoulder strap. Three pieces of stockinette are positioned at the top of the thigh, above and below the knee, and are used for finishing off the cast. Plaster wool is applied at the level of the head and neck of the fibula and from the toes to just above the malleoli (Figure 21). The assistant grips the leg, the left hand maintaining traction and the right hand simply steadies the leg in the most comfortable position of knee flexion, usually about  $20^{\circ}$ . Crystona is then applied round the thigh from just above the patella, to the rest of the limb, well into the groin. The stockinette is folded over the ends and the quadrilateral top former applied. While the cast is hardening, it is moulded with an anterior bow to ensure correct alignment (Figure 22). A check x-ray should be taken, and alignment corrected if necessary by wedging. The below-knee cast is then applied with the foot plantigrade, and finished off with the stockinette and the cast stocking. A cross on the patella/...

patella marks the centre and level of the knee axis (Figure 23). The hinges are contoured using plate benders and centred using the jig (Figure 24). They should be positioned two-thirds of the way from anterior to posterior and may be held in position using jubilee clips (Figure 25). The four inch Crystona bandages suffice to fix the hinges above and below the knee, and the cast stocking is folded down. The sole of the cast is strengthened with a slab of Crystona and a plastazote sole applied as a buffer. Finally, the cast is strengthened, if felt necessary, between the lower end of the hinge and the ankle (Figure 26). Figure 27 shows the patient mobile and ready for discharge and Figure 28 the range of knee flexion possible in the cast.

Cost of items now used at present day prices inclusive of V.A.T.

Re-usable items:-	alignment jig	£24.49½
	set of six quadrilateral brims	101.08½
	jubilee clips (set of 3)	4.14
	plate benders (per pair)	28.75
		<hr/>
	<u>Total cost of re-usable items:-</u>	<u>£158.47</u>
Consummable items:-	cast stocking	£18.97½
	bicentric hinges	25.30
	Crystona bandages (approx)	20.00
		<hr/>
	<u>Total cost of consummable items:-</u>	<u>£64.27½</u>

In/...

In this costing, the items, alignment jig, jubilee clips and bicentric hinges were obtained from Chas. A. Blatchford and Sons Ltd., Lister Road, Basingstoke RG22 4AH. The hinges obtainable from S. H. Camp and Company Ltd., are approximately seven pounds cheaper. Thus, the cost per cast-brace will be approximately £65.00.

#### Multiple injuries

The clinical data collected on all patients treated by cast-bracing from its introduction in 1974 until 31st December, 1978 was put together, and the influence these injuries had on patient management, especially with reference to cast-bracing, was assessed.

#### Quadriceps function

This study measured the recovery of quadriceps function in patients treated by cast-bracing. It was carried out by sending a small explanatory note to all patients treated by cast-bracing, which requested them to come at an appointed time and date. One hundred and forty six patients, according to records, still lived in the area. Patients over the age of 70 years and those who had a history of cardiac and/or respiratory failure, were not sent for. Seventy-one patients were able to attend of whom 54 had femoral fractures alone, and 17 had concomitant lower limb injuries. The patients with femoral fractures alone are the subject of this study because the numbers in the other group were too small for conclusions to be drawn.

The/...

The method of study was similar to Damholt and Zdravkovic. In our study the isometric strength was measured with the patient seated with his spine vertical with the entire thigh fully supported and with a freely hanging lower leg with the knee flexed at  $90^{\circ}$ . The patient was fitted with a special boot which was attached by means of an inextensible cord to bathroom scales. He or she was carefully instructed in the procedure and asked to extend the lower leg using maximum possible force. In this manoeuvre, there was minimal movement of the foot so that the recorded strength on the scales was isometric. The boot was then transferred to the other foot and the procedure carried out again. The dynamic endurance was measured with the patient seated in the same position. He was then carefully instructed to lift his leg to the extended position and thereafter in a given rhythm to extend the leg to the same level. The first time that the fixed level could no longer be reached, the test was stopped. Knowing the length of the lower leg, the load attached and the number of elevations of the lower leg, it was possible to calculate the dynamic endurance. After resting for a period, the test was then carried out on the other leg.

From the difference between the two, the affected leg was compared to the normal leg and the difference calculated and expressed as a percentage increase or decrease with respect/...

respect to the good leg. Patients with a diminished strength in the fractured leg compared to the good leg had results expressed as a positive difference. In some cases, no difference was present and when the affected leg proved to be stronger than the normal leg, this was expressed as a negative difference.

### Costing

The cost per cast-brace has been presented, and a more detailed costing per patient will be discussed later.

## Biomechanical Study

### Material

Femoral shaft fractures admitted to the Orthopaedic Unit, Aberdeen Royal Infirmary, after 1st January, 1978 are included in the prospective study of the management of these fractures by traction and early cast-bracing. Some of these patients were fitted with a standard cast-brace with modified hinges to allow biomechanical measurements to be carried out. To minimise any variables, the author applied the braces in those undergoing the biomechanical studies, the other braces being applied by other members of the orthopaedic staff. The first 60 cases with fresh fractures were studied. Three patients had to be excluded, leaving 57 patients. Of these, 30 patients had femoral fractures alone and were aged 50 or under and are grouped separately. The resulting spread of patients is shown/...

shown in Table 6. The other 27 patients were assessed separately for the effect of concomitant injuries and aging on their recordings and recovery. The measurements were carried out as soon as the patient was able to walk post bracing, at one week post bracing and at three to four weekly intervals thereafter until the fracture was deemed to be clinically and radiologically united.

### Method

The force transfer patterns between the cast and the limb during walking must be very complex. As a first stage it was decided to measure axial fracture, knee and limb loadings during static weight-bearing. It was not possible to measure the load at the fracture site directly, so the thigh portion of the cast was split circumferentially at the fracture level and the load transfer between the two portions was measured ( $f_1 + f_2$ ). By subtracting this value from the known limb load ( $L$ ) the assumed load acting through the fracture ( $f$ ) was obtained. This figure represented the total load carried not only by the fracture, but also by the surrounding soft tissues. The contribution of the soft tissues to axial load carriage is likely to be minimal, and thus the whole of the calculated load was taken to be acting through the fracture. The load transfer through the hinges at the knee level ( $K_1 + k_2$ ) was also measured to obtain the total load transfer into the thigh portion of the cast (Figure 29). To make these measurements/...

measurements, each hinge was modified to allow strain gauge transducers to be mounted on the proximal hinge arm at the fracture level and at the distal hinge arm (Figure 30). The hinges were thus specially modified for each patient depending on the fracture level. Figure 31 shows the details of the force measuring apparatus at the knee level and the arrangement at the fracture was similar. The two sections of each hinge arm were joined by a back plate and a blanking plate. For measurements to be taken, the blanking plates were removed and replaced by the transducers which were gauged to respond to axial force (Figure 32). The back plate maintained alignment of the hinge arms during the change over manoeuvre. The total limb load was measured by the force plate gauged to measure axial force (Figures 33 and 34) and incorporated into a wooden platform. Output from the force plate and transducers were simultaneously recorded on a U. V. Oscillograph. Measurements were taken at each out-patient visit (Figure 35). The patient was encouraged to put as much weight on the fractured limb as he or she felt comfortable and then lift the leg clear of the force plate. At least seven such measurements were obtained and the average calculated. The patient was weighed wearing the brace and the brace was weighed after removal. At each out-patient session, clinical data of the patient's progress was also noted.

The/...

The application of the strain gauges was carried out as described by Pratt, Bowker, Wardlaw and McLauchlan (1979), and the construction of the force plate and adaptation of the hinges carried out under the supervision of David J. Pratt.

Some of the 57 patients in the Biomechanical Study were admitted during 1979 and are part of the continuing clinical study. Only their relevant clinical details are given. Twenty-seven of these patients had their braces applied using Crystona. Finally, a number of the patients either had fractures too near the knee or too near the proximal end of the shaft to allow the cast to be split at the fracture level.

CHAPTER 11

RESULTS

## RESULTS

### Clinical Study

#### PART ONE

The patients available for study have already been discussed in the preceding chapter. Of the 58 patients treated by traction alone, and the 34 treated by traction and cast-bracing; 38 and 31 respectively were available for review. The six patients treated in other ways are mentioned to show the complications encountered.

The sex ratio was approximately 3:1 as in most other large series. Two-thirds of the fractures were due to road traffic accidents and the distribution in the main study groups is comparable (Table 7). The distribution of the type of fracture is also comparable in the two groups (Table 8) taking in all fractures.

In the study group, the level of the fracture is evenly distributed between the two groups (Table 9). Eleven fractures were compound, six in the traction group and five in the traction and cast-brace group. The age distribution in the study group is as shown. More than half the fractures in the two groups occurred in the second and third decades. The average age in the group treated by traction alone was 40 years and by traction and cast-bracing, 34 years (Table 10).

Here/...

Here are two examples of treatment. An 18 year old girl fell off her horse whilst show jumping and sustained a closed short oblique fracture of the upper third of the shaft of her femur (Figure 36). It was treated by traction for four weeks and a cast-brace for eight weeks. The final result is shown in Figure 37. A 23 year old man sustained, in a car crash, a compound short oblique fracture of the middle third of the shaft of the femur (Figure 38). He was treated by traction in a Thomas splint initially and a cast-brace was applied at five weeks. The fracture was united at 15 weeks (Figure 39).

A large number of concomitant injuries were present in many of the patients (Table 11). None of these injuries, however, proved to be a contra-indication to cast-bracing. As pointed out by Connolly, Dehne and Lafollette (1973), the application of the cast-brace may well facilitate the nursing care of the severely ill patient with a femoral fracture. Other fractures in the same limb were treated simultaneously by a cast-brace. The method was especially applicable to tibial fractures, and three patients in the cast-brace group had tibial fractures in the same limb.

A girl aged 19 was involved in a car crash and sustained severe burns of the face, right arm and right thigh. Her skeletal injuries included a comminuted fracture of the lower third of her right femur and a fracture of the same tibia and fibula (Figure 40). At eight weeks, a cast-brace was applied (Figures 41 and 42). The femoral fracture was united/...

united at 14 weeks (Figure 43) and so was the tibial fracture.

The complications of treatment are listed in Table 12. There were no cases of infection in either of the main groups. There were two cases of delayed union in the traction group, one fracture took 40 weeks to unite. The other fracture had secondary internal fixation carried out by means of a Kuntscher nail and cancellous bone grafts, because there was no evidence of union 13 weeks following fracture.

There were two cases of non-union. One occurred in the traction alone group and presented 18 months after his fracture and about ten months after discharge from hospital with a fibrous non-union. A cast-brace was applied to see if Smith's treatment of 125 years ago would be successful. The fracture united after 16 weeks treatment in a cast-brace. The second case of non-union occurred in a patient treated in a cast-brace in which the knee hinges were badly placed such that attempted flexion at the knee caused flexion at the fracture site. Though in this case there were other factors which contributed to his non-union, there was no doubt that the cast-brace played a part. His case will be discussed in detail in the section on multiple injuries. There were three cases of refracture in the traction group and these were all treated successfully by subsequent cast-bracing.

Neither/...

Neither thrombo-embolism nor fat embolism is a reflection on treatment because they occurred when the patients were on traction. One patient developed a drop foot whilst on traction in a Thomas splint and this later recovered. Vascular damage was present in neither of these groups. However, vascular damage did occur in one patient and, because of it, he had internal fixation carried out followed by vascular repair but this proved unsuccessful and he subsequently required an amputation due to distal ischaemia. Amputation was necessary in a second patient for infection secondary to internal fixation of a mid shaft femoral fracture with an intramedullary nail. Two deaths occurred in old people and were due neither to the injury nor to the treatment.

Knee swelling occurred in patients treated by cast-brace. It occurred because of the fact that the soft tissues in the region of the knee were relatively unsupported compared to the rest of the limb which was totally encased in plaster. It was usually well controlled by the use of a fracture stocking and in only three patients had it either been recorded in the notes or been troublesome. One patient developed gross knee swelling due to the fact that his fracture stocking was too wide a fit and was not supporting his knee. He was re-admitted to hospital, his cast-brace was split in the thigh portion and after the knee swelling had subsided, a new cast-brace was applied.

One/...

One patient in the group treated by traction alone developed angulation of  $15^{\circ}$  whilst in traction. Increased angulation at the fracture site occurred after application of the cast-brace in seven patients. Two of the fractures were middle third and five were proximal third fractures. The angulation was five degrees or less in four of the fractures and of the other three fractures, two were upper third fractures where the increased angulation was  $15^{\circ}$ , and the third was a greatly comminuted middle third fracture and is discussed. It was sustained by a 30 year old man in a car crash who, on admission, was drunk and for two or three days following admission, was extremely confused due to delirium tremens. He was an unco-operative patient and his fracture became angled by  $17^{\circ}$  in the traction and was present on application of the cast-brace at 12 weeks. The angulation increased to  $25^{\circ}$ . He refused further treatment and his fracture became united in this position.

The final angulation of the fractures in each group is shown in Table 13.

Union was said to have occurred in the following circumstances. In those treated by traction alone, it was either when the surgeon stated in the notes that union had occurred or when full weight-bearing without crutches was allowed. In those treated by cast-brace, it was when the cast-brace was removed. On these criteria, the average time to union in those patients treated by traction alone was 17 weeks and in those patients treated by traction and cast-/ $\dots$

cast-brace was 14.4 weeks. The average time of cast-brace application was 6.5 weeks and the average time in a cast-brace was 8.9 weeks. The average time of discharge from hospital in those patients treated by traction alone was 15.3 weeks and in those treated by traction and cast-brace was 8.2 weeks.

The time of final assessment of each patient was noted and in those treated by traction alone, the average was 16.4 months and in those patients treated by cast-brace was seven months. The results obtained are shown in Table 14. In those patients treated by traction alone, 16.3% yielded good or excellent results, 16% satisfactory results, 8% poor results and 13% very poor results. In those treated by cast-brace, 78% yielded good or excellent results, 16% satisfactory results, 3% poor and 3% very poor results.

#### PART TWO

In 1976, 44 fractures of the femoral shaft were treated in 42 patients and in 1977, 64 fractures were treated in 61 patients. In 1976 there were two bilateral cases and in 1977, one patient fractured the same bone twice, the second time in a drunken brawl five months after his first fracture had united. The other two patients were both treated conservatively initially and during the early period of exercises in hospital, they sustained refractures which were successfully treated by cast-bracing.

In/...

In 1976, nine patients were treated in other ways, four died of multiple injuries, and five fractures in four patients treated by cast-bracing were lost to follow-up, leaving 27 fractures in 26 patients available for review (Table 15). Three of these patients were treated secondarily by cast-bracing after a period of treatment by traction of 13 weeks, 14 weeks and 18 weeks, leaving 24 fractures in 23 patients treated by early cast-bracing available for review. In these patients, the average time of applying the cast-braces was 6.3 weeks after fracture, the average time to discharge 7.7 weeks, the average time in a cast-brace 8.5 weeks, with an average time to union of 14.7 weeks (Table 16).

In 1977, 17 patients were treated in other ways, one patient treated by cast-bracing was lost to follow-up, two patients were treated by internal fixation then cast-bracing, and 44 patients were treated by early cast-bracing (Table 15). One of the latter group was an old man whose fracture united but he was otherwise ill and later died in hospital. Of these 43 patients, the average time of cast-bracing was five weeks after fracture, and the average time in hospital was 7.4 weeks. There were two old ladies who, for social reasons, were unable to go home for 17 and 18 weeks, and if they are excluded, then the average time in hospital was seven weeks. The average time in a cast-brace was 9.3 weeks and the average time to union was 14.3 weeks (Table 16).

The/...

The time of application of the brace ranged from the day of fracture to ten weeks after it. By far, the majority of braces were applied between the third and sixth week. The range of time to union was from nine to 21 weeks. Of the patients treated in other ways, some were transferred to other hospitals in traction in a Thomas splint and others did not have a cast-brace applied because of frailty or the state of the skin. Nevertheless, quite a number of patients were suitable for cast-bracing and did not have cast-braces applied. Perhaps this simply reflects the reluctance of the individual orthopaedic surgeon in taking up a new technique.

Fourteen of the fractures treated by cast-bracing were open. The average age of the patients was 35 years, the range being 16 to 89 years. The level of the fractures is shown in Table 17. All x-rays were examined and there was no evidence of shortening occurring in any of the patients due to telescoping of the fracture following application of the brace.

Many of the patients had other injuries and on occasion the application of a cast-brace was used to facilitate the nursing care of the ill patient. An example of this is the previously mentioned old man who later died in hospital. He was aged 87 years and had lost his left leg during the First World War. He managed very well with an old-fashioned type of prosthesis until he fell causing an oblique fracture of the shaft of the/...

the right femur. He was placed on skeletal traction on a Thomas splint but, within a week, developed bed sores on the sacrum due to the immobility imposed on him by the Thomas splint (Figure 44). He also had ischaemic ulceration of the lower leg (Figure 45). A cast-brace was applied and suspended on the Steinmann pin so that the lower leg could be given frequent dressings and he could be nursed from side to side (Figure 46).

Information was available on 24 of the patients of time of return to work. A number of patients were out of work or had retired. Of the 24 patients, the average time of return to work was 20.8 weeks, the range being ten weeks to 51 weeks. Younger patients were able to return to work more quickly and patients who had sedentary jobs or were self-employed also returned to work more quickly.

The results are summarised on Table 18. The good or excellent results were further subdivided into "good" and "excellent" as previously described. In 1976, 66.7% excellent results were obtained, 8.3% good results, 12.5% satisfactory and 12.5% poor results. In 1977, 67.4% excellent results were obtained, 20.9% good results, 4.7% satisfactory, 2.3% poor and 4.7% very poor results.

Eleven results were in the categories satisfactory, poor and very poor and their case histories are summarised in Tables 19 and 20. The age of these patients varied from 18 to 89 years, the oldest patient being the only female/..

female of the group. Seven fractures were comminuted, three were transverse or short oblique, and one was a long oblique fracture. Seven fractures were in the proximal third, three in the middle third, and one in the distal third of the femur. Five fractures were open. In seven of the patients, the classification was due to the fracture being angulated greater than  $15^{\circ}$  at the time of final assessment. The angulation was present in traction and throughout management in two patients, increased or developed after application of the brace in two patients and increased or developed during the first month following removal of the brace in three patients. Of the remaining four patients, one had a knee extension lag of  $18^{\circ}$ , another persistent thigh discomfort and a limp and the last two developed non-union and required internal fixation with bone grafting. The last two patients both had upper third fractures and their cast-braces were loose from the day they were applied. This was stated by both patients who also said that it was possible to pass the hand down inside the cast almost to the knee.

### PART THREE

During the year 1978, 73 patients with 74 fractures of the femoral shaft were admitted to the Orthopaedic Unit, one case being bilateral. Fifty fractures in 49 patients were treated by traction and cast-bracing, and were available for review. Six patients were lost to follow-up and one patient/...

patient died before her fracture united. The last patient warrants special mention. She was a previously fit, overweight 76 year old lady who fell whilst crossing a wall, sustaining a short oblique middle third fracture of the shaft of the left femur. This was treated by skeletal traction in a Thomas splint. After three weeks, she developed bullous pemphigoid for which she was treated with steroids and local dressings. Despite this treatment, the skin problems persisted over the pressure areas and, to aid nursing, a cast-brace was applied at almost five weeks post fracture, when the fracture remained completely mobile and no callus was visible on x-ray. An indwelling catheter was inserted. She seemed to be progressing well when at nine weeks post fracture she developed gram negative septicaemia from which she recovered with very intensive management. At 14 weeks, she continued to be well and there was no sign at all of callus on x-ray. She was treated by open intramedullary nailing and, at operation, no sign of callus was present at all, and no muscle interposition was present. She again progressed well until 17 weeks post fracture when she developed a vaginal discharge and was found to have a rectovaginal fistula. She collapsed suddenly and died one week later. Post mortem examination revealed that there was still no evidence of union at the fracture site, rectal ulceration with a rectovaginal fistula, lung abscesses, acute pancreatitis with pancreatic abscesses, peptic ulceration/...

ation and nephrocalcinosis. She was felt to have died from acute pancreatitis where the signs were suppressed by steroids.

Two patients were treated by internal fixation and cast-bracing. Both were upper third fractures. One patient, an overweight 28 year old girl with fat thighs, was treated by traction initially and was started on anti-coagulant treatment by an overenthusiastic junior, three days after admission. She developed a haematoma in her thigh despite anticoagulants being stopped. At five weeks it was decided to apply a cast-brace on the next appointed day, and three days later, was found to be pyrexial because the haematoma had become infected. The cast-brace was not applied and she was instead taken to the operating theatre where the abscess was drained. Antibiotics were given and the infection was cured. Delayed union was the outcome and at 19 weeks, under antibiotic cover, the fracture was treated by direct intramedullary nailing and bone grafting. A cast-brace was applied two weeks later to give added protection and to provide rotatory control of the fracture. The second patient was treated by open intramedullary nailing because a good position of the fragments could not be obtained by manipulation under anaesthesia. Unfortunately, a rotational deformity developed, and, under heavy sedation, some correction of the deformity was obtained, and a cast-brace applied to maintain it. Even so, he had an external rotation deformity of  $25^{\circ}$  at fracture union.

Thirteen/...

Thirteen patients were treated in other ways. Two patients were transferred to other hospitals at an early stage whilst still in traction. One patient's x-rays were lost and notes were inadequate. Two patients were confined to wheel chairs, one a paraplegic and the other a mental defective. Two patients died during treatment, one a senile lady seven weeks post fracture and two days after her cast-brace had been applied; and the other in his early twenties from the result of a severe head injury after ten weeks of traction. Two patients had comminuted fractures of the upper third of the shaft extending to the intertrochanteric region, and another had a transcervical fracture, as well as a lower third fracture of the shaft of the same femur. These three patients were treated by traction until their fractures united. Of the remaining three patients, one was a feeble old man treated by traction alone, one was a patient who had fractured the same femur for the third time in a motor cycle accident, each time being slow to unite, and was treated by intramedullary nailing. The last patient suffered multiple injuries and certain stipulations were placed on the patient's management by the person in charge of the case, that it was impossible to apply a proper cast-brace. He was therefore excluded from the trial patients.

Two patients died within a few days of admission due to multiple injuries.

Patients treated by traction and cast-bracing

Of/...

Of the 49 patients, 11 were female and 38 were male. Seven of the fractures were compound. The average age of the patients was 33 years, the age range being 13 to 96 years (Table 22), against the average age for all the patients which was 35 years.

Two patients had their braces applied after 15 weeks in traction with delayed union. One was an obese man in his sixties who had generalised atherosclerosis. His fracture eventually united at 41 weeks and at one year, he was returned to his original state. He was classified as a good result. The other patient was a 78 year old diabetic lady who was almost blind. She had sustained a grossly comminuted fracture of the whole lower third of her femoral shaft extending into the knee joint. She went home after 17 weeks in hospital, and her fracture united after 12 weeks in a cast-brace. In spite of her severe injury, she had a good result. This left 48 fractures in 47 patients treated by early cast-bracing available for review.

Of those patients reviewed, four-fifths of the fractures were caused by road traffic accidents (Table 23). The spread of fracture type is given on Table 24 and the fracture level on Table 25. Many of those fractures classified as middle third fractures were greatly comminuted fractures over a length of the shaft and therefore may have involved either the proximal or distal thirds also.

Excluding the two patients whose cast-braces were applied at 15 weeks, the average time of application of the brace/...

brace was 4.7 weeks and the average time of discharge from hospital was 6.2 weeks. The range of brace application is shown in Table 26. The average time in a cast-brace was 9.8 weeks and the average time to union was 14.5 weeks (Table 27). One patient with a transverse proximal third fracture developed a non-union. His fracture was slightly overdistracted initially in traction. A cast-brace was applied at six weeks when there was still some mobility at the fracture site. He became very mobile and at 15 weeks got drunk and fell down a flight of stairs. The inner hinge was bent through  $90^{\circ}$  with the force of the fall, and he complained of some discomfort at the fracture site. X-ray did not show a definite refracture (Figure 47). However, the fracture became painlessly mobile and the position changed. Some three months later, in spite of continued immobilisation in the cast-brace, an 'elephant's foot' type of non-union was developing (Figure 48). When his brace was removed 36 weeks following injury, his fracture was painlessly mobile. Intra-medullary nailing and bone grafting was carried out. Two weeks later, he was found to have a severe external rotation deformity. Manipulation under anaesthesia to correct this and the application of a cast-brace to control rotation was performed. The fracture subsequently united and a good result was obtained. However, for the purposes of this thesis, it was classified as a very poor result.

The results of these patients are shown in Table 28. This/...

This Table also shows the results of all patients treated by traction and cast-bracing since its introduction in 1974, and they are shown together for comparison. Two patients were actually better off as a result of their treatment. Both were elderly ladies. One had advanced osteo-arthritis of the hip with a severe adduction deformity. Her fracture was intentionally allowed to angulate on application of her cast-brace so that the apparent shortening was eliminated. She was pleased that her walking was better, though she still had a painful hip. The second patient had a painful arthritic knee with a varus deformity and walked with two sticks. She sustained a lower third fracture in a fall. Her fracture was again intentionally allowed to angulate, correcting the deformity. She was subsequently able to walk without pain in her knee or a limp and she used only one stick.

Of the remaining 41 patients, 29 had excellent and 12 good results. Three of the good results were due to shortening of four centimetres, and the remainder were due to thigh wasting of one centimetre which could confidently be expected to recover fully in time to give 35 excellent results; three of these nine patients having fracture angulation of 10 to 15°. The satisfactory results were due to shortening secondary to very severely comminuted fractures in two and fracture overlap in one patient.

The/...

The average follow-up time for these patients was seven months, the range being three to 14 months. Two patients were still under review. All but six patients were able to resume their previous activities. Some of these were old people who went home, others had no jobs or were students. Twenty-seven patients returned to their previous jobs in an average of 22 weeks. One man resumed supervisory work at six weeks until fit for heavy work, and one young farm worker resumed manual work at eight weeks following fracture whilst wearing his cast-brace. Three patients were unable to resume their prior occupations and sought lighter work.

#### Multiple injuries

During the period of study, 277 patients with 282 fractures were treated in our Unit. Eight patients died of multiple injuries (Table 29). One hundred and one patients with 102 fractures were treated in other ways. Four were treated by internal fixation and cast-bracing leaving 164 patients with 168 fractures treated by traction and cast-bracing. A number of patients were lost to follow-up and three patients in 1976 and two in 1978 were treated at a late stage by cast-bracing, leaving 147 fractures in 144 patients treated by early cast-bracing available for review. The patients treated by cast-bracing in 1974 and 1975 have been grouped together.

#### Results

The/...

## Results

The following groups of patients have been examined (Table 31). Patients with femoral fractures alone totalling 49, those with femoral fractures and other major limb injuries, totalling 77, and those with femoral fractures, major limb injuries and abdominal and/or thoracic injuries totalling in this series 18.

Fifty-three patients had head injuries ranging from minor head injuries requiring 24 hours observation, to closed head injuries, where the patients were confused, restless and disorientated for periods of several days and subsequently recovered. Many of this group also had facial injuries and one had a skull vault fracture. Patients with this type of injury are spread throughout the preceding three groups. In this context, it is worth noting that there were seven patients who suffered from varying degrees of fat embolism, one of the patients required ventilation for a period of two days. Many of these patients also had severe facial injuries such as depressed zygomatic fractures, Le Fort fractures and mandibular fractures which required appropriate treatment. One patient aged 76 had multiple injuries and six months after his accident, having made an excellent recovery from these injuries, complained of a painful neck. Although initial x-rays of his cervical spine were normal, x-rays at this time showed an Atlanto-axial subluxation.

Nine/...

Nine patients had chest injuries. The majority of these had lung contusion with rib fractures. However, one patient had a haemopneumothorax, one had a simple pneumothorax and a third had a flail segment with lung collapse requiring repeated bronchoscopy. His management was further complicated by a depressed zygomatic fracture and a displaced mandibular ramus fracture. During repeated bronchoscopies, his femoral fracture developed muscle interposition which subsequently proved to be a bar to union with cast-bracing, and at 41 weeks this fracture was quite ununited and was treated by a plate and bone grafts. He subsequently went on to make a good recovery. He is the patient in Part One who had a very poor result.

Thirty-seven patients had major upper limb injuries. Seven patients had serious abdominal injuries, ranging from renal contusion to three patients who required laparotomy. Eleven patients had pelvic fractures, one had a major pelvic ring disruption without bladder or urethral damage. There were 46 major lower limb injuries in the same leg, and 26 injuries were present in the opposite leg. Many of these injuries occurred in the same limb of the same patient (Table 32).

Table 33 shows the breakdown of limb injuries. There was one patient with bilateral femoral shaft fractures each year. One patient had fractures of both tibiae. At five weeks, one limb was treated by cast-brace and the other by a Sarmiento type of below-knee cast.

A/...

A 38 year old man, driver of a car involved in a head-on collision was admitted with multiple injuries (Figure 49). He had been unconscious but had no skull fracture. He had multiple contusions with abdominal tenderness, a closed comminuted fracture of his right femur, a compound stellate fracture of his right knee and a fracture dislocation of his right talus. He also had a compound fracture of the mid shaft of his left radius and ulna, a laceration of the dorsum of his left hand with division of the extensor tendons. He was resuscitated, the compound wounds and fractures were dealt with and the right leg placed in a below-knee equinus plaster. His femoral fracture was treated with skeletal traction. A cast-brace was applied at six weeks with the right foot in equinus, and a similar raise in the other shoe. He was able to walk with elbow crutches at first, his left arm being in a long arm plaster. He was discharged from hospital at eight weeks and the cast-brace was removed at 15 weeks. He subsequently had a good result.

Eleven patients had tibial fractures and six patients had severe knee injuries in the same limb (Table 34). In those with tibial fractures, six had excellent, two good, two satisfactory and one poor result. In those with knee injuries, four had excellent, one a good and one a satisfactory result. The poor result was a patient who had an acromio-clavicular subluxation of the left shoulder, a mid shaft femoral fracture and a segmental tibial fracture. He/...

He was treated by traction for five weeks. At fifteen weeks, his femoral fracture was united, but the tibial fracture required bracing for a further six weeks. Two months later, he fell when he was drunk refracturing the proximal tibial fracture with minimal displacement. Six months after this incident his result was assessed. He had five centimetres of shortening of the leg, but otherwise had a good result. The satisfactory result in the patient with a knee injury was one who had a dirty compound wound of a mid femoral shaft fracture with an avulsion of the tibial spine with minimal displacement. His final result showed a fixed flexion deformity of a few degrees of his knee with an antero-medial instability. Table 28 shows the results of all femoral shaft fractures treated by cast-bracing. Of the six poor results, three had femoral fractures alone, one had a femoral fracture with multiple rib fractures and lung contusion. The second had a fracture of the third, fourth and fifth metatarsals and a severely comminuted lower tibial fracture involving the ankle joint on the same side, and the third patient had a minor closed head injury, minor rib fractures, a shoulder dislocation, a segmental fracture of the tibia and fibula of the other leg with an undisplaced fracture of the opposite femoral condyle. In these patients, the other injuries had no bearing on the outcome of the result. Of the four very poor results, only one patient had multiple injuries and these were - facial lacerations with a depressed/...

sed right zygoma and a fracture of the right mandibular ramus, multiple rib fractures, with a flail segment and lung contusion requiring bronchoscopy on three occasions for lung collapse. He did not require ventilation. He also had a fracture of the same ankle and a transverse fracture of the upper third of the opposite tibia and fibula. The patient initially had a good reduction of his femoral fracture, but following four anaesthetics, one initial one and three subsequent bronchoscopies, his femoral fracture became displaced so that the proximal fragment spiked through the quadriceps muscle. It subsequently proved impossible to reduce this and though he may be regarded partly as a brace failure, there was certainly muscle interposition present and this came about as a result of his other injuries. Once again, he is the patient in Part One who had a very poor result.

#### Quadriceps Function

This concerns 54 patients without concomitant lower limb injuries. Ten of the patients were female, and 44 were males. The average age of both males and females was similar; 27.5 years for females and 27.5 years for males. The age range was from 13 to 70 years. The spread of the fracture type is shown in Table 35 and fracture level in Table 36. In fact, 54 patients were able to carry out the isometric strength tests and 53 patients the dynamic endurance tests. One patient declined to perform the dynamic endurance test because of recurring/...

recurring pain in the knee. Two of the patients in the dynamic endurance tests stopped at a very early stage because of pain in the knee in one patient, and pain in the thigh in the other and both of them had a percentage difference of greater than 50%.

Patients with no difference in strength between the two limbs are shown as zero (Table 37). Patients with a positive difference in fact had a decrease of isometric strength in the affected limb compared to the normal limb and patients on the negative side of the scale had an increase of strength compared to the normal limb. Greater than 15% difference was considered to be pathological. This terminology was used by Damholt and Zdravkovic and therefore, the author presents the results in the same way so that comparisons may be made. With regard to the isometric strength results, 31% had a decrease in isometric strength of more than 15% compared to the normal limb. In the dynamic endurance studies, 45% had a decrease of greater than 15% compared to the normal limb.

It was felt that the isometric strength is a more sensitive measurement because it was easily reproducible, whereas, in the dynamic endurance test, it seemed that, on occasion, patients lost interest and stopped before the limit of endurance was reached.

On comparing isometric strength to fracture level, middle third fractures appeared to do best with 50% of both upper and lower third fractures having a decrease in strength/...

strength outwith the normal range. Dynamic endurance compared to fracture level gave an even spread and no definite conclusions could be made (Table 38). On comparing isometric strength and dynamic endurance to the type of fracture, it was felt that no firm conclusions could be drawn (Table 39). On comparing isometric strength to fracture angulation, there was a tendency for the more severe degrees of angulation to be in the pathological range. A similar picture was present on comparing dynamic endurance to angulation (Table 40). On comparing isometric strength to time to union of the fracture, two patients had fractures taking more than 20 weeks to unite and they were both in the pathological range. Similarly, with regard to dynamic endurance, the same picture was present. Otherwise, there was an even spread of patients in both groups (Table 41).

None of the patients had knee instability and five patients out of 54 patients had knee flexion which had not returned to normal. The average decrease in isometric strength was 18.4% and the average decrease in dynamic endurance was 36%. Six of the fractures were compound and in those the average decrease in isometric strength was 16.6% and the average decrease in dynamic endurance was 35.9%. Table 42 shows a comparison of results with Damholt and Zdravkovic where fractures were treated by direct nailing. The significant figures are in the first column. In the isometric strength estimation, in fractures treated by direct nailing, 63% of patients were in the pathological range/...

range and in patients treated by cast-bracing, the figure was 31.5%. Similarly, in the dynamic endurance studies the patients treated by cast-bracing performed significantly better, 45% of patients treated by cast-bracing being in the pathological range compared to 58.5% in patients treated by nailing (Table 42). Comparing results to Zdravkovic and Damholt's paper in which patients were treated by the indirect nailing technique, there is really little difference between the two groups of patients (Table 43). Table 44 shows the mean decrease in isometric strength compared to the type of treatment used. In the direct nailing technique mean decrease was 30.6%. In the indirect nailing technique the mean decrease was 10.5%. In the cast-bracing technique the mean decrease was 11.4%. Table 45 shows the decrease in dynamic endurance compared to treatment. In those treated by direct nailing it was 33%, indirect nailing 12.2% and cast-bracing 15.4%. It should be pointed out at this stage that in both these studies there was a certain amount of patient selection because patients with greatly comminuted fractures are not suitable for nailing methods of treatment. Therefore, these groups must be selected. In the patients treated by cast-bracing, the whole spectrum of fractures can and have been treated.

#### Costing

As previously discussed, an accurate costing for patients/...

patients treated by the National Health Service is very difficult to achieve. The author attempted, on several occasions, to obtain figures from Grampian Health Board to enable him to estimate in some way the cost effectiveness of cast-bracing. It was evident that with the increase in admissions to the Orthopaedic Unit without any increase in resources whatsoever, that the freeing of hospital beds by the use of cast-bracing played a major role in enabling the Unit to cope with the situation.

At last, the October 1979 issue of Tempo, the staff newspaper of the Grampian Health Board, surprisingly provided the necessary information. The cost per patient week for Aberdeen Royal Infirmary was, for the year ended 31st March, 1979, £397.57. A calculation, taking into account the saving to the hospital board in not having to provide the extra beds that would have been necessary, had cast-bracing not been used, was possible. No account is taken in the saving on out-patient visits, General Practitioner visits, physiotherapists' time or indeed the saving to the patient himself in being fit for work at an earlier date than he would have been.

Thus, the costing for 141 patients with 144 fractures of the femoral shaft treated by early cast-bracing and whose discharge from hospital was not delayed for social reasons; and taking the average time in hospital of patients treated by continuous traction, and the average overall time of patients treated by early cast-bracing, the cost of a cast/...

cast-brace being estimated at £60 each using "Camp" hinges, then the cost is as follows:-

Number of patient weeks saved	= average patient
Week saving per patient (8.1) x 141	= 1142.1
<u>Saving to Grampian Health Board</u>	
1142.1 x £397.57	= £454,064.69
-Cost of 144 cast-braces (144 x £60)	= 8,640.00
	<hr/>
	= <u>£445,424.69</u>

### Biomechanical Study

#### Patients with femoral fractures alone and aged under 50 years

Thirty patients are in this group (Table 46). The average time in traction was 31.6 days and the average time in a cast-brace was 54.9 days giving an average time to union of 86.5 days (12.4 weeks). Initially, the average limb loading was 39.9% of body weight, and at union in all cases the limb loading was over 90% with an average of 98.1%.

The patients were sub-divided into three groups depending on the level of their fracture, and the data from each group analysed separately. Figure 50 shows the data from the force plate. The total load taken on the cast-braced limb is expressed as a percentage of body weight and plotted against the time post-injury. The cross hatched area shows the envelope of the individual data points on either side of the/...

the Linear Regression Line, which is the "best fit" straight line through the points. For each of the three groups, statistical tables showed that there was an excess of 99.9% certainty that the data could be represented by the single straight line. All the patients showed a progressive increase in weight-bearing on the cast-braced limb from the time of fitting of the brace to the time of clinical and radiological union. At this point in time, the percentage of body weight taken on the limb was over 90% in all cases, over 95% in 24 cases and 100% in 20 cases (Tables 6 and 46).

Typical sets of results obtained from the transducers mounted at the fracture level, knee level and the force plate, together with the corresponding skeletal loadings obtained by subtracting the transducer readings from the total limb load are shown in Figure 51. Patients with fractures of the proximal middle and distal thirds are represented. All the load values are expressed as a percentage of body weight and are plotted against time post fitting of the cast-brace. The graph of the force plate readings shows a progressive increase in limb load with advancing fracture union. The transducer readings at the fracture and knee levels gradually increase in the early stages and stabilise. In all three cases, except for the early stages in the patient with the lower third fracture, there was an order of magnitude of the transducer readings from the fracture level, to the knee level to the limb load/...

load as measured by the force plate. The skeletal loadings similarly have an order of magnitude from the knee level, to the fracture level, to the limb load, and the values obtained for these gradually increase with progressive fracture union. In the upper third fracture, the initial limb load (L) carried was 16.4% of body weight, 11.6% of body weight being off-loaded through the whole thigh portion of the brace ( $k_1 + k_2$ ) as measured by the transducers at the fracture level, and 5.2% of body weight transmitted through the transducers at the fracture level ( $f_1 + f_2$ ) indicating the off-loading into the proximal thigh portion. The off-loading into the distal thigh portion therefore  $[(k_1 + k_2) - (f_1 + f_2)]$  equals 6.4% of body weight. Similarly, in the middle third fracture, the initial limb load was 34.4% of body weight, the proximal off-loading being 7.6% and the distal off-loading being 6.1% body weight. In the distal third fracture, the initial limb load was 40.9% body weight and the proximal and distal off-loading was 36.2% and -8.6% body weight respectively. This demonstrates that the direction of load transfer need not necessarily be from the limb to the cast but can also go in the reverse direction. In all patients, the off-loading into the brace increased with increasing limb load and then stabilised at a certain level which is different in every case. This level has been defined as the maximum off-loading capability of each brace/patient system.

Thus/...

Thus a diagram of the main avenues of force transfer may be constructed (Figure 29). The measurement of the force plate equals the force applied to the limb (L). The off-loading capability of the brace at the fracture level is given by the transducer readings ( $f_1 + f_2$ ) and subtraction from the total limb load (L), gives the force across the fracture. The transducer readings at the knee can be similarly treated to give the off-loading of the thigh portion of the cast-brace ( $k_1 + k_2$ ) and the skeletal force at the knee level  $[L - (k_1 + k_2)]$ .

With reference to Table 46, six of the fractures were compound. At the time of brace removal, 18 knees had attained  $100^\circ$  or more of knee flexion, a further six knees  $90^\circ$  to  $99^\circ$ , leaving six knees with less than  $90^\circ$  of flexion. Of the latter six knees, four of the patients had compound fractures. All patients were shown knee extension and flexion exercises by the physiotherapist before discharge from hospital and only three patients required further out-patient physiotherapy.

The ratio of the total of the absolute values of the outside to the inside transducers was calculated for each patient as follows:

Total of absolute values of outside transducer readings

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Total of absolute values of inside transducer readings

The mean of the ratios for each patient was then calculated and was 0.98.

Patients/...

Patients with other injuries and aged over 50 years

This group consisted of 27 patients with 28 fractures of the femoral shaft (Tables 6 and 47). Seventeen patients were under 50 years of age and had concomitant upper and lower limb injuries which may have affected mobilisation; and ten patients were aged over 50 years. Five of them had femoral fractures alone, two had femoral fractures with other major injuries, and one 73 year old patient was an extremely brittle diabetic who developed pressure sores on her heels and calf which refused to heal. Her fracture united, but she subsequently required an above-knee amputation due to diabetic vascular disease. One patient was treated with an intramedullary Kuntscher nail and a cast-brace was applied to aid rotatory control. The last patient was an old lady whose brace was applied after 15 weeks. The last two patients have been described already in the Clinical Study.

Taking all 27 fractures treated by early cast-bracing as a group, the average time in traction was 37.1 days and the average time in a cast-brace was 76.9 days with an average time to union of 114 days (16.3 weeks). The last patient (Case 58) had her brace applied at 15 weeks and the fracture was united at 30 weeks.

The patients were again divided into groups depending on the level of their fracture and since there was one bilateral case, then the results of 28 fractures are plotted. Figure 52 shows the Linear Regression Lines for these groups/...

groups with the cross hatched areas showing the envelope of the individual data points. All three of these Lines are at least 95% significant and two are 99% significant. The majority of patients showed a progressive increase in weight-bearing on the cast-braced limb from the time of fitting of the brace to the time of union of their fractures. Of the 17 younger patients with 18 femoral fractures, the average of the initial limb loadings was 46.9% of body weight, and in the ten patients greater than 50 years of age, it was 38.1%; whilst at union the same figures are respectively 91.7% of body weight and 60.4% of body weight. The overall average limb loading in this group was 43.8% initially and 80.1% at union.

In the younger group, six patients (35.1%) were taking 100% of body weight on the affected limb, 11 (64.7%) more than 90% and a further three patients 80-90% with three less than 80% of body weight. In patients over 50 years of age, the limb loading at union was 100% body weight in one, 80-90% in two, 70-80% in one, 60-70% in two, 50-60% in two and 40-50% in two patients.

Case 34 did not have a measurement taken at union. He was a 45 year old man with a comminuted upper third fracture who also had an ankle injury. To allow a free ankle, the Steinmann pin was left in position, and a plastic hip hinge applied to control rotation. When he returned to have his brace removed it was, for technical reasons, not possible to carry out a measurement.

In/...

In six cases, there was an initial drop in percentage weight taken on the limb. Five of them had other major limb fractures and the other patient (Case 38) was particularly reluctant to use his limb following discharge from hospital despite regular encouragement to do so and despite having a healing clavicular fracture combined with a traumatic rotator cuff lesion of the same shoulder causing pain and stiffness. The hinges in his brace were also noted to be placed anteriorly so that knee flexion was impeded. Needless to say, by the time of union of his fracture, he had a poor range of knee motion with wasted muscles and required physiotherapy. Of the other five patients, one (Case 47) who also had a fractured anterior tibial spine with minimal displacement, had his cast-brace applied at four weeks. At seven weeks post fracture he was going home from a Disco having had a drink and fell over on his crutches developing pain at his fracture site. He was readmitted and x-ray showed no displacement of his fracture. The pain settled and after a few days he was mobilised. The reading at this point showed a drop in the percentage weight borne on the limb. The final reading was 84.7% body weight. A man in his 20's had bilateral femoral shaft fractures (Cases 35 and 36). The fracture on the right was a grossly comminuted upper third fracture and that on the left was a slightly comminuted middle third fracture. His cast-braces were applied at five weeks. His mobilisation was slow initially and/...

and on the second day of walking he developed pain at both fracture sites. X-rays showed that he had developed an increased angulation of from  $6^{\circ}$ - $12^{\circ}$  on the left and of from  $8^{\circ}$ - $21^{\circ}$  on the right. The situation was explained to him but he was unwilling to have anything further done. He was kept on bed rest for a period of ten days and then gradually mobilised. This is reflected in his transducer readings in that from the initial measurements his readings dropped and then rose again to be 82% on the left and 87% on the right at time of union. An 18 year old had a greatly comminuted fracture involving the middle and part of the upper third femur with a compound fracture of the tibia and fibula of the same leg and a fractured scaphoid (Case 46). He was treated initially by skeletal traction and a below knee padded plaster. His cast-brace was applied at five weeks. Initially he was very reluctant to weight-bear and his transducer loadings went down initially rising again to almost 100% at time of cast-brace removal and fracture union at 24 weeks post fracture. It is interesting to note in this patient that at 20 weeks, i.e. four weeks before union, his cast-brace thigh portion was split and his fracture examined and found to be still partially mobile to varus and valgus stress. At this point he was willing to bear 90% of weight on his limb. The final two patients both had injuries affecting the other limb. One (Case 40) had a slightly comminuted middle third fracture of his right femur with a tear of the/...

the medial collateral ligament of the same knee. There was also an undisplaced fracture of the medial femoral condyle of the other knee. The patient's accident happened at sea and he was taken first to an island hospital and some three to four days later, was transferred to our Unit. He was treated by Steinmann pin traction for the femoral fracture and simultaneous immobilisation for the collateral ligament tear. The other leg was treated by traction and early knee mobilisation. He progressed satisfactorily and at four weeks, a cast-brace was applied. He was gradually mobilised after and was able to partially weight-bear on his other leg. The final patient (Case 45), aged 21 years, had a compound greatly comminuted middle third fracture with severe muscle damage and skin loss to the anterior aspect of his mid thigh. He also had a fracture of the opposite mid shaft of the tibia and fibula. He required skin grafting to his thigh and at six weeks, a cast-brace was applied to the left leg and a Sarmiento type of below-knee cast to the other leg. From his initial recording the weight borne on his cast-brace leg went down and then rose to approximately 100% at time of union at 15 weeks.

In the majority of patients similar patterns of recordings with respect to percentage off-loading above and below the fracture, and the thigh portion of the cast as a whole, were obtained. They were similar in all respects to patients with femoral fractures alone (Figure 52). In those/...

those six patients who had a drop in recordings, there was a corresponding drop in fracture level, and knee level recordings.

Generally, patients with concomitant injuries, and patients over 50 years of age were slower to mobilise. Lower limb injuries in the same leg did not appear to affect the general mobility of the patient, because the other lower limb and both upper limbs were available to off-load the fractured leg, as is the situation with femoral fractures alone. The mobilisation of the fractured limb, however, was slower than in patients with femoral fractures alone, as was the rate of increase of weight-bearing on the limb (Figure 53). Patients with opposite limb injuries who experience excessive discomfort on initial weight-bearing on the fractured leg may subsequently bear less weight for a period until fracture healing has progressed. An injury to just one of the other three limbs tended to impair the ability to off-load the cast-braced limb. The force diagram drawn from patients with femoral fractures alone (Figure 29) can be similarly drawn from patients with concomitant injuries and patients over 50 years of age. Seven of the patients had less than  $90^{\circ}$  of knee flexion at the time of brace removal and of these, four had less than  $80^{\circ}$ . One patient (Case 32) had delayed union with knee flexion of  $70^{\circ}$  and another (Case 38) was generally reluctant to use his limb despite encouragement to do so. The patient with  $50^{\circ}$  of knee flexion (Case/...

(Case 48) had an extremely comminuted femoral fracture with a four centimetre portion lying transversely and evidence of chondromalacia patellae. The last patient, who had  $70^{\circ}$  of knee flexion, had a lower third femoral fracture and a fracture of the upper tibial shaft five centimetres from the knee. Eleven of the patients required out-patient physiotherapy.

The ratios of the outside to the inside transducer readings was also calculated for the two main groups. In the young patients with concomitant injuries, the ratio was 1.11, and in those patients over 50 years of age, it was 1.2.

Finally, for all patients in the study whose casts were split circumferentially, the mean percentage of thigh cast load carried by the brace at the fracture level was calculated. This gave the mean percentage loading of the proximal portion of the thigh cast compared to the thigh cast as a whole. This included all middle third fractures totalling 29, 13 of the 15 proximal third fractures and nine of the 14 distal third fractures. The percentage loads thus calculated were 50.4% for proximal third fractures, 68.4% for middle third fractures and 59.2% for distal third fractures. Two of the patients with middle third fractures actually consistently had a reverse loading pattern, and their values were 120.8% and 133.6% respectively. If they are excluded, then the value for the 27 remaining middle third fractures was 64%.

CHAPTER 12

DISCUSSION

## DISCUSSION

For the application of a cast-brace, it is essential that the principles of the biomechanics and application of the technique are understood. Close attention to detail and practice in the application of the technique gives good and excellent results in most cases. An analysis of the clinical and biomechanical results presented in this thesis demonstrate this.

### Clinical Aspects

Part One of the study compares a group of patients treated by continuous traction alone to a group treated by traction and cast-bracing. Basically, it compares the old established standard method of treating femoral shaft fractures to a technique that was introduced and taken up in the Orthopaedic Department without any one person having had previous knowledge and expertise. It has been shown that these two groups which comprised similar number of patients in each group, also had similarities with regard to fracture aetiology, type, level and age distribution of patients. Patients with multiple injuries were present in both groups also. With regard to complications related to treatment, in those treated by traction alone there were two cases of delayed union, one with non-union and three of refracture compared to those/...

those patients treated by traction and cast-bracing where there was one case of non-union. An increase in angulation after application of the cast-brace occurred in seven patients. In four of the patients, however, this was minimal. Despite this increase in angulation, the final angulation in the group treated by traction and cast-bracing was generally better. Certainly on comparing the percentages of the two groups which were fairly similar in numbers, the overall results were considerably better (Table 14). When examining these results, one must also bear in mind the fact that the time of final assessment related to time of injury in those patients treated by traction alone was on average considerably greater (16.4 months) than those treated by traction and cast-brace (seven months). Accepting the limitations in the definition of union in the two groups, the fractures in patients treated by cast-bracing unite more quickly and this is in keeping with the general rehabilitation of these patients which starts essentially when the cast-braces are applied. At the time of fracture union, patients treated by cast-bracing have already obtained a fairly advanced degree of recovery of muscle function and joint motion whilst those patients treated by traction alone are only just beginning to mobilise the knee and recover muscle function. On mobilisation in a cast-brace, patient morale received a tremendous boost. The prospect, especially for young people spending three to four months in hospital, most of it in a hospital bed, is extremely demoralising. I discussed with my senior colleagues/...

colleagues the possibility of carrying out a prospective double blind study comparing traction alone with traction and cast-bracing. There was unanimous agreement that such a trial was unnecessary and impractical because of the very obvious benefits shown to the patient and hospital service by this retrospective study.

Part Two of the clinical study served to demonstrate very nicely how the technique of femoral fracture bracing described in this thesis fares when used in a busy Orthopaedic Unit where the braces are applied by a mixture of staff of varying degrees of knowledge and expertise in the application of the technique. It was also interesting to note that over this two year period, that despite universal agreement, as to the obvious benefits of the technique, that some patients who were very suitable for cast-bracing were not having cast-braces applied. These patients were almost all under the care of one consultant and this simply reflected the reluctance of the individual consultant in taking up a new technique. Despite this, the average time of application of the braces has been reduced from 6.5 weeks in the initial study to 6.3 weeks during 1976 and five weeks during 1977 and there is a corresponding reduction in time to discharge from hospital. A critical look at the 11 satisfactory, poor and very poor results shows that the reason for the classification was marked angulation in seven of the fractures, the development of non-union in two, persistent thigh discomfort and a limp in one and an extension lag of the knee in/...

in the other (Table 19). Eight of the fractures were proximal third, three were middle third and one distal third, and five of the fractures were open. The two very poor results were clearly technical failures of cast-bracing because the cast-braces were loose and were not performing their proper function. The old lady in her 80's who had an extension lag of the knee of  $18^{\circ}$  otherwise had an excellent result and the 18 year old who, following a comminuted compound proximal third femoral fracture with a fracture of the same tibia and fibula, had a persistent thigh discomfort and a limp, otherwise had a good result. He was a poorly motivated patient. The seven other patients all had marked angulation and had it not been for the angulation, would have produced four excellent, two good and one satisfactory results. In only two of the patients did the angulation increase whilst wearing the brace and therefore in this group of 70 patients, there was an increase in angulation in only two patients following application of the brace. In four patients, angulation developed or increased after removal of the brace and clearly these fractures had not consolidated in the brace and had therefore obviously been removed too early. In these patients, the braces were removed at 13 weeks, 14 weeks, 21 weeks and 22 weeks. Two of the fractures were greatly comminuted, one was compound transverse and the other was a compound, greatly comminuted fracture. Clearly these are fractures which are/...

are caused by very severe trauma and therefore one would expect the soft tissue damage and the blood supply to the fracture fragments to be more severely compromised. Such fractures should be treated with caution on removal of the brace. In two middle third fractures, and one proximal third fracture, angulation of greater than  $15^{\circ}$  was accepted in traction and was present on application of the cast-brace.

During Part Three of the clinical study, by far the majority of the cast-braces were applied by the author who by this time had obtained considerable experience of the application of the technique. The braces were applied on average earlier than in previous years the corresponding reduction in hospital stay for the patients. Thirty-nine of the 48 patients treated by cast-bracing and available for review had their braces applied from three to five weeks post injury (Table 26). One patient with bilateral femoral shaft fractures had an increase in angulation following application of his braces and was previously described in the biomechanical study (Page 140). In retrospect it was noted that the upper parts of the thigh sections of his braces were not as snug as they could have been. Perhaps the author was more intent on the placement of the hinges and transducer mountings. The result was good on the left side and poor on the right side due to the angulation. As far as other parameters were concerned, the results were excellent.

Reference/...

Reference to Table 28 shows that the proportion of good or excellent results improved each year with experience and with recognition of the factors which were contributing to failure of the technique. In the less than good results the technical errors in the application of the technique have been responsible in many cases. These were the development of angulation after application of the brace, a loose thigh section, mal position of the hinges and too early removal of the brace.

The development of angulation is, almost certainly, due to the thigh section of the cast slipping distally during the application of the brace before it is finally fixed in position by the below-knee section and the knee hinges. Once the "sticky" phase of fracture healing has been reached, shortening of the bone by overlapping of the fracture fragments does not tend to occur, but rather angulation or an increase in angulation of the fracture occurs. This increase in angulation is usually in a varus direction but in two patients, occurred in a valgus direction. Therefore, it would appear that if any angulation at all is present, then accommodation for a loose cast-brace will occur by an increase in the angulation in the same direction as that already present. Shortening of varying degree occurs following the initial injury due to the bone and soft tissue damage (Figures 36, 38, 40 and 49). This is corrected by manipulation, and held by traction until the fracture is sticky. If the brace is applied before/...

before the fracture is sticky, then shortening may occur without angulation. In 1976, this happened to one patient with a muscular thigh who came from Canada, when his brace was applied at five weeks. It was decided to operate on this patient rather than reapply the brace, and at operation, he was found to have muscle interposition. He was not included in the cast-brace group because other factors rather than purely clinical ones were involved in the decision to use internal fixation.

A shoulder strap attached to the upper end of the thigh stocking by means of orthotic clips prevented the thigh section slipping distally during the application of the cast-brace and thus overcame this difficulty. A loose thigh section need not lead to angulation. It means, however, that the thigh is not enclosed in a skin tight cast, and that the fracture is therefore not protected from excessive rotatory angulatory and longitudinal stresses. It is instead subjected to excessive stresses leading to non-union.

Some further points should also be made with regard to application of the brace. The thigh portion of the brace is applied firmly but not with excessive pressure over a fracture cast sock such that it is in firm contact at all points. By the time of application of the brace, the fracture haematoma has resolved, a large amount of muscle wasting has occurred and no limb oedema is present because the limb had previously been elevated in a Thomas splint/...

splint whilst in traction. It is the author's estimation that in most cases, maximum muscle wasting and resolution of the fracture haematoma has occurred at two and a half to three weeks. Clearly, this depends on the severity of fracture and associated injuries. Application of a brace from this point onwards, therefore, will ensure a snug skin tight fit throughout the treatment period. Any brace which is loose is therefore a technical failure. The development of a loose thigh section following application of a cast-brace in the circumstances described does not occur in the author's experience and from a physiological point of view, is highly unlikely to occur. With mobilisation and activity, there will be a generalised increase in cardiac output, a reversal of the negative calcium balance due to immobilisation and an increased calcium uptake into bones. The neurological stimulus to the muscle causes a reversal of the inactivation atrophy (Hansel and Hildebrandts 1964) and in turn the mechanical effect of muscle on bone causes remodelling and appropriate strengthening of the tubular bones by alteration in their architecture (Antmann 1971). The increased demands of muscle and bone together with an increased cardiac output are part of the recovery process. The muscle fibres which have atrophied and been replaced by fat and interstitial connective tissue, hypertrophy with an increase in motor end plates and the fat and extra interstitial connective tissue disappears (Hansel and Hildebrandts/...

Hildebrandts 1964). Thus one would logically expect the thigh to tend to bulge out at the brace rather than the brace become loose. Part of the continuing study into the biomechanics and other parameters of fracture bracing, involves imaging of femoral fractures by nuclear magnetic resonance. This is in its early stages at present and so far is showing that the thigh volume remains unchanged throughout the treatment period, that the muscle heavily infiltrated by fat changes to functionally active muscle and that characteristic changes occur in the fracture callus throughout union and consolidation of the fracture.

Mal position of the hinges in one patient, whose fracture was at a disadvantage due to muscle interposition, led to the hinges applying undue angulatory stress to the fracture. Thus the importance of correct placement of the hinges.

It was also thought at first that the plastic hinges did not need such careful positioning, but in fact they do. The use of plastic hinges does not lead to easier or quicker application of a cast-brace. Plastic hinges were used in only a few braces. It was observed that on weight-bearing that they tended to buckle in a medio-lateral direction and it was difficult to give adequate clearance at the knee to prevent chaffing of the skin. Considerable force is necessary to bend these hinges and the force must be overcome by the thigh muscles using the femur as a lever arm. A proportion of the energy must be taken/...

taken up therefore by the fracture and in certain circumstances this may be disadvantageous. Finally, plastic hinges do not have a fixed axis of bending which is considered by some an advantage. When the distal fragment of the fractured bone is short then the fracture will inevitably be close to the lower end of the cast so that on knee flexion angulatory stresses may be imparted to the fracture. Uniaxial or bicentric metal hinges, on the other hand, ensure that flexion only occurs in the axis of the knee. Very little force at all is necessary to cause these hinges to bend. The use of plastic hinges has been given up completely in our Unit.

Increased angulation occurred during the first month following removal of the brace in four patients. The first patient, of 20 to 30 years of age, had a spastic diplegia and sustained a greatly comminuted fracture of the upper third of his femoral shaft. His cast-brace was applied at four weeks and removed at 14 weeks. Following removal of his cast-brace, valgus angulation increased from  $7^{\circ}$  to  $24^{\circ}$  as the fracture consolidated. The patient noted no difference. The second patient was in the same age group and had a compound upper third fracture. His cast-brace was applied at six weeks and removed at 13 weeks when his fracture was felt to be solidly united. A few degrees of anterior angulation was present and this increased over the following month to  $28^{\circ}$ . The third patient was an 18 year old boy with a comminuted middle third fracture./...

fracture. On x-ray his fracture appeared to have been over-distracted in traction. His cast-brace was applied at six weeks and removed at 16 weeks when he was able immediately to fully weight-bear on the leg. When he returned to out-patients one month later, he had felt some thigh discomfort and noted a lump on the outside of his thigh. X-ray showed that he had developed  $17^{\circ}$  of varus angulation. It did not increase further and otherwise he had an excellent result. The fourth patient was a man in his 40's with a greatly comminuted compound proximal third fracture. Angulation of  $8^{\circ}$  was accepted in traction and on application of a cast-brace at nine weeks, this increased to  $18^{\circ}$  following cast-brace application. The position was accepted and the brace removed at 22 weeks following fracture. During the following month, there was a further increase in angulation to  $28^{\circ}$ .

Thus besides technical failure in the application of the brace, other factors such as over-distraction of the fracture during traction and muscle interposition, are factors which may contribute to failure of treatment. Over-distraction of the fracture may have been a factor in the development of non-union in the patient with the very poor result in Part Three of the study (Figure 47). It is clearly safer to leave the brace on for too long rather than to remove it prematurely.

All fractures of the femoral shaft may be treated by this technique without the use of a pelvic band and hip hinge./...

hinge. In the early years, three patients with upper third fractures had a pelvic band and hip hinge applied. All three of the patients were found to be loosening the pelvic band when it suited them. One patient alone had a minimal increase in fracture angulation and many patients since then with upper third fractures had been treated successfully. Thus it is clear that in the majority of upper third fractures, a pelvic band is unnecessary. A pelvic band may subsequently be added to the cast to aid angulatory or rotatory control of upper third fractures. It is now the author's experience that a pelvic band is only necessary for upper third fractures who have pain on mobilisation despite snugly fitting quadrilateral-shaped upper thigh sections. This appears to be due to loss of rotatory control in a short fragment. The pain is abolished by application of a pelvic band which is made simply of rolls of 8" plaster bandage or Crystona fitted snugly over the iliac crests on top of a piece of orthopaedic felt and a reversed knee hinge attached and centred at the tip of the greater trochanter.

Hardy (1979) suggested over-distraction of the fracture followed by early application of a cast-brace incorporating a hip hinge in  $20^{\circ}$  of abduction whilst maintaining strong traction. It has been previously pointed out in this thesis that over-distraction can only be obtained by completely disrupting all periosteal connections between the fragments and appears to be a contributory/...

tory factor to the development of non-union. The results presented in this thesis show in contrast that the position of the fracture during traction was generally maintained on application of the cast-brace and that over-distraction may lead to delayed union or non-union.

It seems logical therefore that the optimum position of the fracture should be obtained immediately by manipulation under anaesthesia after admission to hospital. This position should be maintained until the fracture is "sticky" when application of a cast-brace using the technique described can be safely carried out. Thus, with careful technique, excellent and good results should be obtainable in almost every case.

The results obtained in this study compare favourably with already published work. Mooney, Nickel, Harvey and Snelson (1970) treated 150 fractures of the lower third of the femur and the mean traction time was 7.3 weeks, the mean cast time was 7.2 weeks and the mean time to union was 14.5 weeks. It is remarkable that this compares almost exactly to the time of union as estimated in this study. In Part One it was 14.4 weeks, in Part Two it was 14.7 weeks in 1976 and 14.3 weeks in 1977 and finally in Part Three it was 14.5 weeks in 1978. Connolly et al (1973) treated 130 fractures at all levels of the shaft of the femur and, using a modification of Dencker's classification, achieved 107 (82%) good results, 21 (16%) satisfactory results and two (2%) poor results. In some of the/...

the upper third fractures, varus angulation developed and was controlled by use of a pelvic band and hip hinge. Sixty-nine fractures were united by 14 weeks and all were united by six months. Collie and Roper (1978) treated 70 patients by femoral bracing. On average they were in hospital for 8.1 weeks, spent 5.9 weeks in traction and a further 9.9 weeks in a brace, with a total treatment time of 15.8 weeks. In this series, a pelvic band was also used to correct varus angulation.

There are no contra indications to cast-bracing for femoral shaft fractures as classified. The incidence of complications is low. Complications such as skin sweating, plaster sores and angulation can be eliminated by good technique. Skin sweating occurs in relation to plastics and this problem was eliminated by using the plastic quadrilateral top to simply shape the proximal thigh section of the brace whilst the plaster or Crystona hardened. Plaster and Crystona are absorbent materials and also allow the skin to breathe. The application of a good layer of wool to protect the malleoli, heel and foot and also around the fibular head, together with good plaster technique, have eliminated the problem of plaster sores. Skin chafing may also occur around the proximal end of the thigh section if proper care is not taken in this area. Should it become necessary to trim the cast in the groin or buttock, then this should be done by rolling back the cast sock and trimming the cast only so that the cast stocking can/...

can then be rolled back over the rough plaster edges to give skin protection.

The reasons for the development of non-union have already been discussed. Delayed union, however, occurred in one patient in the prospective study whose fracture took over 33 weeks to unite. He was a man in his 50's with a comminuted upper third fracture sustained during a fall from a considerable height.

Infection is not a complication of this technique. From the clinical point of view, this is the major advantage over internal fixation. Although one's incidence of infection is low, for the individual patient who develops this complication, the result is disastrous.

Part One of this study showed that cast-bracing enhanced union of fractures of the femoral shaft and this is also borne out by the low incidence of delayed union overall. The physiological factors responsible are presumably the same as those which govern the normal recovery processes of muscle and bone, and the increased mechanical stimulus to the healing fracture produces mechanically stronger callus (Sarmiento, Schaeffer, Beckerman, Latta and Enis, 1977). The development of non-union in the four patients described can be attributed to technical failure.

The application of a cast-brace may also aid the nursing care of patients with femoral fractures both in debilitated patients (Figure 46) or the multiply injured (Figure 49).

Multiple/...

### Multiple Injuries

As has been shown in this study and in other studies (Moll 1973, Connolly, Dehne and Lafollette 1973, and Scully 1974), the use of cast-bracing in the multiply injured patient is beneficial. It goes without saying that treatment of severe head, chest and abdominal injuries takes priority over limb injuries. Operative treatment causes further unnecessary trauma to an already severely traumatised patient. Therefore, conservative management of fractures is advised after the priority injuries have been dealt with. A cast-brace is applied during the recovery phase or after the patient has recovered from abdominal, chest or head injuries, when early mobilisation may take place. Other major limb injuries do not preclude cast-bracing which enhances the management of these injuries, especially injuries in the same limb. The results experienced in this study in patients with ipsilateral tibial fractures and knee injuries compare very favourably with the reviews carried out by others (Moll 1973, Scully 1974, Connolly, Dehne and Lafollette 1973, and Fraser, Hunter and Waddell 1978).

### Quadriceps Function

In assessing the results of quadriceps function, one should remember that the majority of our patients do not get out-patient physiotherapy. The patient has not been subjected to iatrogenic trauma in the form of operative treatment of the fracture. The patients in this study were/...

were also unselected by the Surgeon so that a spectrum of all the fractures of the femoral shaft were treated in contrast to the studies of Damholt and Zdravkovic (1972) and Zdravkovic and Damholt (1978) in which the fractures were undoubtedly selected as suitable for intramedullary nailing.

When analysing individual patients, the factors found to be responsible for an overall decrease in muscle function were angulation of the fracture with comminution, open fractures and delayed union. All these factors are inter-related. The more severe fractures are associated with a greater degree of soft tissue damage, which is mostly to the periosteum and muscle, and consequently a greater degree of circulatory damage. These fractures are therefore often compound and liable to delayed healing. A greater degree of muscle damage means that less healthy muscle will remain. These fractures also tend to be more unstable leading more often to greater final angulation of the fragments. There was no correlation between the recovery of isometric strength and dynamic endurance in the same patient. Specific exercises tend to promote recovery of a specific function or improvement in function in muscle. Perhaps therefore this simple test may allow a specific exercise programme to be prescribed for patients.

The results in this study are better than in patients treated by direct nailing. This is ascribed to the fact that the operative technique causes further trauma to the soft tissues, especially muscle and periosteum. This, in turn, /...

turn, leads to increased muscle damage, fibrous tissue replacement and adhesion formation with consequent decrease in active muscle bulk and increased mechanical impairment. The direct lateral approach to the femur not only interferes with blood supply to the muscle locally but also divides the nerve supply to the muscle posterior to the incision with resultant loss of functional muscle. Functional muscle is also lost due to the inevitable scarring which results from the incision.

The results are at least as good as a selected series of patients treated by the indirect nailing technique in which there is minimal added soft tissue trauma, though the trauma to the bone may be relatively great. The results in patients treated by cast-bracing are achieved without this added trauma to the bone which may lead to delayed union, non-union and bone infection.

#### Financial Aspects

The financial saving to the National Health Service has been shown in simple monetary terms to be considerable. With the advent of the oil industry there has been a 40% increase in major trauma from road traffic and industrial accidents over the four years up to 1978 and this is reflected in the increased number of fractures of the femoral shaft admitted during 1978. In spite of this, the Orthopaedic Department has been able to function without an increase in beds. Clearly in these circumstances, the saving in bed time produced by cast-bracing has allowed the/...

the Orthopaedic Service to continue to function without an increase in beds which would have meant further expense by the Grampian Health Board. There is also a considerable reduction in the amount of physiotherapy required and the earlier return to work means a saving to the country in terms of reduced sickness benefit and lost work. There are also clearly financial benefits to the patient in that he may return to work and full earning capacity at an earlier date. Many patients who have been self-employed and therefore have had an incentive to return to work have done so, at least on a part-time basis, whilst wearing their braces.

#### Psychological and Social Benefits

There are also considerable psychological and social benefits in that the patients on discharge from hospital can return to a near normal life. One young man of 18 years went to a Disco shortly after discharge from hospital. On his way home, he tripped and fell and developed pain at the fracture site. Two friends brought him to the hospital and an x-ray did not show evidence of refracture. However, he was admitted overnight for observation and the following day, mobilised and went home. His fracture united uneventfully. Another young male patient was involved in a car crash two weeks after being married. His cast-brace was applied at three and a half weeks and during the application procedure he asked whether it would damage his fracture to have sexual intercourse whilst wearing/...

ing his cast-brace. He was told that such a question had not been posed and advised that he could do whatever he felt able to do. On returning to out-patients following discharge from hospital, he assured the author that normal sexual activity was possible whilst wearing a cast-brace.

A final point is concerning toilet. Occasionally, the upper end of the brace in the groin region becomes soiled. This has not necessitated removal of the brace before union has occurred. The absorbent nature of plaster of Paris and Crystona is clearly beneficial.

#### The Physiology of Rehabilitation

The application of a cast-brace permits rehabilitation whilst the fracture is uniting such that the majority of patients have 100<sup>0</sup> or more of knee flexion on removal of the brace and they are able to fully weight-bear on the injured limb, usually requiring at most one stick as a walking aid. Most patients with fractures of the femoral shaft are fit, young individuals, who do not take kindly to lying in bed for prolonged periods. For them, as for others, their morale is lifted greatly on mobilisation in a cast-brace. Once the initial physical and mental shock of the injury has passed, most patients are keen to become active again. When they see fellow patients becoming mobile in a cast-brace, they soon become keen to do the same. Many patients on going home, return to work especially when their occupation is a sedentary one. Self-/....

Self-employed patients often return to work whilst wearing the brace and some patients who had manual jobs such as farming went back to work. Perhaps sensibly most manual workers are not encouraged to go back to work until they are fit to do so. Once the patient becomes active, the next stage is that he is looking forward to removal of the brace. A few patients, however, require constant encouragement and pushing to recover function more quickly. Others are slow to mobilise due to the severity of their injuries. These patients were fortunately relatively few in number and required out-patient physiotherapy.

A number of patients, on the other hand, are able to walk totally unaided and very often without a sign of a limp immediately on removal of their braces.

Cast-bracing thus allows early mobilisation and rehabilitation whilst the fracture is uniting so that a minimal further rehabilitation period is necessary before full recovery.

The physiological environment provided, allows recovery of normal physiology of bone and soft tissues and thus recovery of function. Cast-bracing has indeed been shown to have the advantages of conservative treatment without its disadvantages and the advantages of internal fixation without its disadvantages.

#### Biomechanical Aspects

It is quite clear from the clinical results that cast-/...

cast-bracing works and that fracture union and rehabilitation is enhanced. When the biomechanical study was envisaged, there were no published reports of the off-loading capability of a cast-brace. Clearly, the movement and stresses applied to the fracture site had to be limited to allow union to progress whilst at the same time withstanding the stresses of muscle function and activity in walking. The object of the biomechanical study was to assess the off-loading capability of the brace and to assess as far as possible the stresses at the fracture site. At that point in time Connolly and King (1973) had demonstrated the pistonning effect of the fracture on load bearing in the early stages of fracture healing which ceased with progression of union. They also demonstrated that a degree of rotatory control was imparted by the brace. Murdoch (1976) demonstrated in patients with Syme's amputation wearing a conventional prosthesis that weight transference took place at the skin prosthesis interface throughout its whole length. Since then, other work has been reported showing that a degree of off-loading occurred into the brace (Mooney 1974, Meggit, Broom and Ross 1975, and Dewar 1977). This study clearly demonstrates that there is a pattern of off-loading into the brace and a pattern of fracture loading throughout union.

Throughout the treatment period, each patient was encouraged to take as much weight as he or she felt comfortable/...

fortable on the injured limb. The initial limb loading had a wide variation and rose progressively until clinical and radiological union. It did not relate solely to the state of fracture union and appeared to relate more to the patient's reaction to injury and treatment. Figure 51 shows that the skeletal loading at the fracture and knee levels gradually increase in parallel with total limb load whilst the transducer readings, indicating the proportion of load borne by the brace at the fracture and knee levels, stabilise at a certain level in all cases. This is the maximum off-loading capability in each brace/patient system, and the value varied from 20-50% of body weight. Before this point is reached, when the total limb load is relatively low, the proportion of load borne by the brace at the fracture and knee levels is high. As the limb load increases, the load borne by the brace also increases until the maximum off-loading capability is attained. Beyond this point the further increase in limb load is borne solely by the fracture.

It is also clearly demonstrated that bracing occurs in fractures at all levels in the limb (Figure 51). This capacity depends on the snugness of fit of the brace rather than the level of the fracture. Several of the braces have been split longitudinally and opened up by a few millimetres. This produced a significant reduction in transducer readings in every case.

In the very high proximal third fractures and low distal/...

distal third fractures, it was not possible to split the cast circumferentially. Therefore, the values obtained of the percentage proximal thigh cast loading (or upper fracture fragment off-loading) of the whole thigh cast are not truly representative for proximal and distal third fractures (Table 48). There does, however, tend to be a graded off-loading of the proximal thigh section, depending on the fracture level, there being least for proximal third fractures with higher values for middle and distal third fractures (Table 48).

In patients with concomitant injuries, the loading pattern was essentially the same. In the patients previously described who had an initial fall in limb loading, this could be ascribed to the fact that their ability to off-load the cast-braced limb was impaired and that perhaps initially they had been over-loading the limb. Patients over 50 years of age, especially those over 70 years, loaded the limb less, perhaps due to the fact that their balance was impaired and therefore they depended more on their walking aid which was usually a Zimmer.

Clearly, the fracture callus is capable of bearing a graded increase in load and stress according to the state of union. There appears to be a physiological feedback from the fracture site to the patient's central nervous system, monitoring the stress the fracture will withstand. This produces a remarkably constant pattern of load transfer in the braced limb despite widely differing patient personalities/...

personalities and reactions to injury.

Scully (1974) described the cast-brace as functioning as a three point fixation device preventing lateral and anterior bowing of the femur. If this were the case, the cast-brace would be resisting this tendency and this would be reflected in the transducer readings at the fracture level. The inside reading would always be higher than the outside reading if this were the case, and the ratio of the outside to the inside transducer reading would always be less than one. In fact, the tendency is for it to be very close to one. The average ratio for all 58 patients is 1.06. In the controlled situation when the patient is loading the limb, support is being provided over the whole area of skin-cast contact. The brace is therefore functioning as an exoskeleton.

Connolly and King (1973) showed by cine radiography that there was a pistonning of the bone ends at the fracture site in some cases which subsequently stabilised. In this study we did not perform radiography on our patients during static weight-bearing and we cannot say if pistonning occurred. In some patients the braces were applied at a very early stage and it seems reasonable to assume that if pistonning was occurring that this would be reflected in the transducer readings due to the tendency for the thigh to shorten. The volume of the thigh within the brace is kept constant and therefore on "hydraulic" principles the soft tissues in the thigh were compressed/...

compressed within the brace, thus increasing the skin-cast pressure. This led to an increase in the proportion of limb load borne by the brace as reflected in the transducer readings at the fracture level in the early stages. Sarmiento states that in fractures of the tibia and fibula, the interosseous membrane plays a part in preventing shortening. In the thigh as in all limbs, there is a connecting network of musculo-fascial compartments and the muscles and fascial planes are attached to the femur as well as to the deep fascia. This forms a network of "rigging" and closed compartments which must aid in maintaining the alignment of the bone in a limb enclosed in a skin-tight cast. Normal alignment of the fracture is maintained within the brace which is in this way functioning as an exoskeleton. Thus in the very early stages of union where pistonning occurs, shortening is prevented by this "hydraulic system". When stabilisation of the fracture occurs, then the brace acts mainly to minimise longitudinal, rotatory and angulatory stresses.

It is postulated that at a cellular level, with the development of the callus bridge, that the stable "sticky" phase of fracture healing is reached when the callus bridge unites. Thus the brace enables the patient to mobilise, by limiting the amount of movement of the fracture fragments. Superimposed on this, the patient is able to load the limb by bearing some weight and moving his muscles. The amount of loading and stress he or she applies depending/...

ing on the feedback he or she receives from the region of the fracture. The most likely feedback is via the autonomic nerve fibres accompanying the blood vessels in the fracture callus.

In summary, it has been shown that the load through the fracture progressively increases as union proceeds. The brace provides a mechanism whereby the patient can off-load the fracture by a variable amount depending upon the degree of union. From this work and the work of others, it is clear that the cast-brace provides an environment for function in which alignment of the fracture is maintained and longitudinal, rotatory and angular stresses are limited. It is suggested that this is brought about by the brace itself and also by a physiological feedback mechanism whereby there is central nervous system control over the fracture stress throughout union of the fracture. Thus, an optimum functional environment is provided in which union is stimulated and rehabilitation is permitted whilst the fracture is uniting.

### General Conclusions

This thesis has comprehensively reviewed the literature on fracture healing and fracture treatment with special reference to fractures of the femoral shaft. Equally good and excellent results can be obtained by all methods of treatment. This is agreed. What is disputed is/...

is whether any benefits one form of treatment has, weighed against any disadvantages and risks to the patient's well-being, makes it the best form of treatment. Ideally, the object of treatment is to provide the body's natural healing processes with the optimum environment for healing to take place so that the optimum functional result is obtained within the shortest period of time and with the minimum of iatrogenic risks. Cast-bracing or femoral fracture bracing, as it is more correctly called, has the clinical advantages of both conservative forms of management and internal fixation without the disadvantages. As the "Swiss School" or the Association for the Study of Internal Fixation (A.S.I.F.) has applied sound biomechanical principles to the internal fixation of fractures, so femoral fracture bracing applies sound biomechanical principles to the treatment of diaphyseal fractures of the femur. These findings must have application to all diaphyseal fractures and perhaps also fractures involving joints such as the knee or elbow.

With regard solely to femoral shaft fractures, internal fixation performed well in a suitable fracture type produces immediate biomechanical stability, so that the patient can begin mobilisation without delay. However, if the fixation is not biomechanically stable, then mobilisation may be delayed for some weeks until increasing biomechanical stability of the fracture callus plus the implant allows mobilisation. In this situation, increased/...

ed biomechanical stability can be achieved by the application of a femoral fracture brace allowing early mobilisation, and this has been carried out on four patients in this study. All femoral fractures are not "ideal" for treatment by internal fixation, and it is in the more severe fracture types that the blood supply to the fracture fragments is precarious and the soft tissue damage severe. Operative treatment will cause further damage in these fractures thus increasing the likelihood of complications and long term disability. These fractures must be considered ideal for femoral fracture bracing which depends not on an internal support gripping the two main fracture fragments, but gives total contact external support to the whole thigh which is thus contained in a rigid tube which functions as an exoskeleton providing an external shape controlling the position and to a degree the function of the structures of the thigh within. No further muscle damage is inflicted by surgery allowing the full potential of muscle recovery to be achieved. This is borne out by the study of quadriceps function. All femoral shaft fractures can be treated by femoral fracture bracing gaining the advantages of early mobilisation without the risks of an operation.

Of the previous biomechanical studies described, Mooney (1974), Meggit, Broom and Ross (1975), measured only the loads in the hinges at the knee. On the other hand, Dewar (1977) measured only the loads at the fracture level during walking. However, very few measurements were taken/...

taken and the brace used for the biomechanical measurements was not the one the patient was being treated with. Two braces were made, one for treatment and one fitted with transducers for biomechanical measurement. In contrast, in the study described in this thesis, the braces used for treatment were the ones in which the biomechanical measurements were made. These measurements were taken both at the fracture and knee levels. A very large number of measurements were taken at intervals throughout the treatment period so that a composite picture could be built up of the loading patterns throughout union, and their relationships with one another deduced. Perhaps the most significant finding to emerge is that a biofeedback mechanism is active in patients treated by femoral fracture bracing and the patient can decide whether consciously or subconsciously the optimum loading of the fracture at any point in fracture healing and so maximise the rate of healing.

### Summary

A fracture of the femoral shaft is a major limb injury which also damages the surrounding soft tissues. The best programme of management is immediate closed manipulation followed by skeletal traction, and when the fracture is sticky, application of a cast-brace and early ambulation. The best possible position of the fracture should be achieved by manipulation under anaesthesia, and the period of skeletal traction allows the fracture haematoma to resolve. Meanwhile, physiotherapy is begun to minimise the effects of/...

of immobilisation in traction.

The application of a cast-brace should only be undertaken by someone who has an understanding of the principles and application of the technique. All fractures of the femoral shaft may thus be treated, and cast-bracing is ideal for patients with multiple injuries especially those with fractures in the same limb. It may be used to aid the nursing care of some patients.

Biomechanical stability is achieved allowing ambulation without the hazards of internal fixation. A physiological feedback mechanism ensures that the fracture is subjected to graded loading and stress as union proceeds, thereby stimulating union, when the young patient can usually bear his full weight on the limb.

The functional environment allows recovery of the normal physiology of soft tissues and bone, such that rehabilitation takes place whilst the fracture is uniting. Normal recovery of joint and quadriceps function takes place without out-patient physiotherapy in most cases.

The hospital service and the patient enjoy financial benefits and patient morale is boosted with return to near normal activities. On removal of the cast-brace at fracture union, little further rehabilitation is required allowing the early return to work and normal daily living.

#### Further Research

The prospective clinical study of femoral fracture bracing continues not only for fractures of the femoral shaft but also in patients with fractures around the knee and/...

and especially tibial plateau fractures. Both static and dynamic studies of cast-braces applied to normal subjects are in progress together with dynamic studies of patients with fractures of the femoral shaft. These include the study of gait analysis patterns throughout the treatment period, intracast pressure measurements and free body diagram analysis. These studies are in their early stages but confirm the findings of the static biomechanical study presented and discussed in this thesis.