FUNCTIONAL TREATMENT OF TIBIAL FRACTURES WITH A CUSTOM MADE BRACE

Functionele behandeling van tibiafracturen met een brace

Proefschrift

ter verkrijging van de graad van
Doctor aan de Erasmus Universiteit Rotterdam
op gezag van de Rector Magnificus
Prof. Dr. C.J. Rijnvos
en volgens het besluit van het college van dekanen

De openbare verdediging zal plaatsvinden op
woensdag 6 september 1989 om 13.45 uur

door

WILLEM MARIA VAN LEEUWEN

geboren te Laren (N-H)

Promotoren	:	Prof. Dr. B. van Linge
		Prof. Dr. Ir. C.J. Snijders
Overige leden	:	Prof. Dr. J. Jeekel
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Colofon:

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to my parents,
Anne and Fijs.

INDEX

CHAPTER 1

INTRODUCTION

The aim of fracture treatment is rapid bone union with the preservation of perfect function, resulting in the patients' early return to normal daily activities with a minimum of complications.

Many conservative and operative methods are used for the treatment of tibial fractures. Conservative treatment consists of a toe-to- groin plaster cast. Surgically, the fracture can be stabilised with a plate and screws, an intramedullary rod or an external fixation device. All these methods involve serious complications. Impairment of subtalar, ankle and knee function, with severe atrophy of the calf and quadriceps muscles, for instance, are well- recognised problems following a toe-to-groin plaster cast. Deep infection of a tibial fracture, mainly following internal fixation, can be disastrous.

Another treatment is early functional weight-bearing treatment, which was first described by Sarmiento and has the advantages of both the conservative method and operative functional treatment, without major complications.

The advantages of conservative functional treatment are low infection rate, short hospitalisation time and the patients' early return to normal daily activities.
The number of infected non-unions after operative treatment referred from other hospitals to the orthopaedic department at the University Hospital Leiden, motivated us to introduce functional weight-bearing treatment for tibial fractures.
A prospective study was started in 1981 (University Hospital Leiden). It was our aim to investigate

- the hospitalisation time.
- the results of early weight-bearing in a functional brace and shorten the consolidation time.
- a possible correlation between early full weight-bearing and the early, return of the patient to normal activities.

This thesis reports the results of tibial fractures which were treated with a custom-made functional brace.
Patients admitted to the departments of orthopaedic and general surgery at the University Hospital Leiden, to the departments of orthopaedic surgery at the Westeinde Hospital, The Hague and the University Hospital Rotterdam, were studied between 1981 - 1983 and followed-up one year after the initial trauma.

CHAPTER 2

CONTROVERSIES IN FRACTURE TREATMENT

Since the time of Hippocrates, rest and exercise have been the most commonly prescribed forms of non-operative treatment of injuries.
Hippocrates described the use of wax, starch and clay on the bandages to provide support. For splinting and traction of lower limb fractures, he used leather bands wrapped around the leg both above and below the fracture site, with the leg held in extension by four pliable willow rods placed between the bands. He taught that it was especially important for the patient to rest and to lie down ("Bones will not unite if the fragments are allowed to move").
In 350 B.C., Aristotle was the first to emphasize that movement is beneficial to fracture healing. Nowadays, more and more surgeons are starting to believe in this principle.
Ambroise Paré, the sixteenth century French surgeon, believed strongly in the power of nature and advocated rest for the injured limb. Nicolas Andry, the originator of Orthopaedic Iconography and professor of medicine in Paris in the eighteenth century, considered that activity and exercise were a more important means of treatment than rest.
One hundred and thirty years ago, Mathijsen devised a method of making casts by impregnating bandages with plaster of Paris. Since then, many surgeons have used plaster casts without questioning the potential harm that cast immobilisation causes the musculo-skeletal tissues.
Historically, one of the most adamant advocates of rest was Hugh Owen Thomas, who worked in Liverpool in the second half of the nineteenth century. He developed many splints for treating tuberculous joints. For the knee, for instance, he used what is known today as "The Thomas Splint". After a long period of rest in the splint, the arthritis healed and the knee became ankylosed. He later used the splint for femoral fractures. His principle was: "don't expect union of the bones if movement of the fragments is permitted".
Championniere, a French surgeon in the same century wrote that: "splints render joints stiff and often do them irrevocable damage".
Böhler advocated rest. He treated most lower limb fractures primarily with traction. After two weeks, a toe-to-groin plaster was applied.
Watson Jones wrote : "However long it takes, if a fracture is still in the stage of slow union, the essential treatment is to leave it undisturbed and protect it by continued immobility".
Perkins advocated balanced skeletal traction with active motion even for intra-articular fractures.
The A.O. group founded by Muller and Allgöwer, adopted the term fracture disease and appointed that it should include muscle atrophy, osteoporosis, joint stiffness and chronic oedema. They believe in rigid internal fixation of the fracture, allowing early movement of the joints and functional treatment of soft tissues.
Sarmiento developed closed functional treatment, in which the joints below and

above the fracture could be moved during treatment and the fractured limb could function almost normally.
In Toronto, Salter carried out many laboratory experiments with continuous passive movement. He stated that as the immobilisation of joints has been proven to be harmful and as joints are designed to move, we should keep them moving whenever it is feasable to do so. [97]
Current publications on treatment of fractures are becoming more and more concerned with active or passive movement of the joints both above and below the fracture.
This is how fracture treatment is developing.

CHAPTER 3

FRACTURE REPAIR

Fracture healing is one of the most remarkable of all the repair processes in the body, because it does not result in scar formation. The damaged tissue, the bone, is replaced by tissue of an identical kind and is possibly a process of bone regeneration.
Fracture healing has been described histologically as consisting of six phases, which occur in sequence but also overlap to a certain extent:

1. impact
2. inflammation
3. soft callus
4. hard callus
5. fracture line consolidation
6. structural remodelling

1. The stage of impact occurs at the moment of the accident and lasts until there is complete dissipation of all energy. The amount of energy that can be absorbed before failure occurs depends on the volume of the bone, the coëfficient of elasticity and the speed of the force applied.
   The greater the volume of bone, the smaller the coëfficient of elasticity and the greater the speed of the force applied, the greater the amount of energy that can be absorbed before failure occurs.

2. The stage of inflammation corresponds clinically with the onset of pain and swelling. There is disruption of the blood supply, bleeding from the damaged bone ends and from the adjacent soft tissues.
   Haematoma soon forms between the bone fragments. The ends of the broken bone become necrotic. The local soft tissue shows the usual changes of acute inflammation which include increased vascular permeability, vasodilation and the infiltration of inflammatory cells. The first cells to arrive at the fracture site are polymorphonuclear neutrophils. In addition, a loose network of fibrin reticulin fibrils and old collagen fibrils form in the haematoma. Fibroblasts appear next and new collagen is produced in the fracture haematoma.
   Soon the fracture haematoma is replaced by granulation tissue consisting of inflammatory cells, fibroblasts, collagen and invading capillaries. Osteoclasts also appear at an early stage at the fracture site and remove the dead bone. Ingrowth of vasoformative elements occurs, accompanied by a tremendous amount of cellular proliferation.[17]
   The nature of the humoral factors which cause the massive proliferation of osteogenic cells and the infiltration of callus as well as the factors responsible for the inflammatory reaction, are unknown.
   Dekel suggested that one of the reactions of bone and muscles to trauma, is a local increase in the production of prostaglandins. He stated that prostaglandins

may be responsible for the initial proliferation of osteogenic cells, the stimulation of local vasodilatation and the resorption of bone. [32]

3. The soft callus phase

   After the inflammation has subsided, the soft callus stage begins. In this period, a large increase in vascularity and cellularity occurs.

   As mentioned above, the fracture haematoma is invaded by fibrovascular tissue. This tissue replaces the clot and lays down the collagen fibres and matrix which will later become mineralised and form the woven bone of primary callus.

   McKibbin, stated that the formation of external callus can be considered as two separate but interrelated phases [74];

   a The primary callus response, which Sarmiento refers to as adjacent callus. [108] It is formed by a reaction of the injured bone tissue. Soon after impact, a primary callus response takes place, so this response starts in the phase of inflammation. Although primary healing develops rapidly, the ability to bridge gaps is poor, there is a high tolerance of movement as well as of rigidity. The response is short-lived.

   b The bridging external callus or peripheral callus response. This is also a rapid process which involves widespread cellular activity between the fragments and is probably due to the induction of cells from the surrounding tissue. The adjacent tissues play a vital role in this phase, because the blood supply arises from there. External callus formation is suppressed by total rigidity. The primary purpose is the formation of a bridge between the proximal and distal adjacent callus.

   In the soft callus phase, the callus behaves in a rubbery- compliant manner controlling the position of the bone fragments. The adjacent callus, which is formed early after the impact then becomes hard callus, while the bridging callus is still soft.

   This is the phase in which the fracture is sticky. The callus will be broken by anything more than minute movements at the fracture site. The central region, where cartilage and fibrous tissue still remain, can resist compression forces but bending and torsion must be prevented. The soft callus phase lasts 2-3 weeks for both forms.

4. The hard callus phase

   Early in the hard callus phase a thin ring of bone bridges the adjacent proximal and distal regions in the peripheral region of the callus mass. On an X-ray film bony bridge is visible in the periphery that does not appear to be very dense. Vessels invade the central region from the adjacent and peripheral regions. The overall callus structure has become rigid. Clinically, the fracture has healed at the end of this phase.

5. Fracture line consolidation

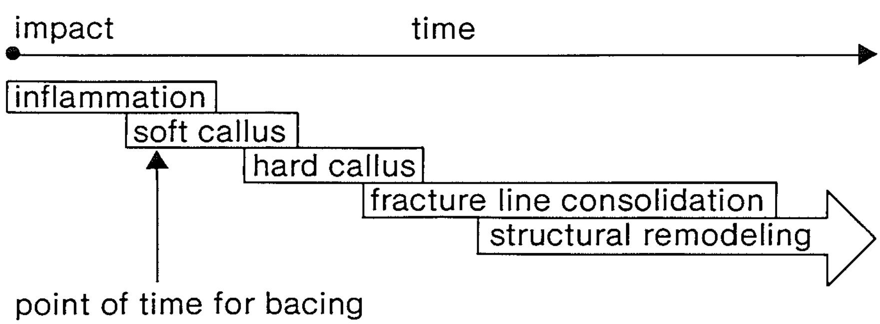
   Fracture line consolidation is characterized by the shrinkage of the central

callus zone and the disappearance of the radiolucent line. The hard callus of the adjacent and peripheral region undergoes remodelling.
The previously soft central callus, becomes hard callus.

6. Phase of remodelling
The stage of remodelling begins after the fracture has healed. It is characterized by callus shrinkage. The fibrous bone slowly develops into lamellar bone; the medullary canal is re-established and the diameter of the fracture gradually decreases until it has resumed its normal width.

Fracture repair by external callus formation is the most rapid of all the processes which have been described in the literature. This process is the quickest way to restore the strength of a fractured diaphysis to its former level. [74]

STAGES OF FRACTURE HEALING



PRIMARY BONE HEALING

This form of fracture healing does not exhibit the same histological stages as those described above. Neither connective tissue nor fibrocartilage play a part in the development of new bone. During rigid and anatomical fixation of a fracture, compression is only exerted on the cortical bone underlying the plate, whereas a small gap remains open after reduction and compression on the contralateral side. In the first stage this gap is filled up via the process of primary bone formation. The second stage, which leads to healing of the bone, is characterized by a longitudinal reconstruction of the fracture site by Haversian remodelling. [116] Thus, internal fixation with a compression plate gives an anatomical reduction and the fracture heals without external callus. [83] In certain cases, primary bone healing consists of bone remodelling only, a process which normally occurs very late in the normal healing process. Protection of the fracture must be maintained for many months. Early weight-bearing is prohibited, because even a minute movement at the fracture site cannot be tolerated. A simple mechanical overload may result in either a fracture of the plate, a shear fracture of a screw, or a screw being torn out of the bone. Movement may also result in the formation of irritation callus. [115]

CHAPTER 4

VASCULARISATION IN THE HEALING OF TIBIAL FRACTURES

The human tibia, like all mature bones, is a tissue which is rich in blood vessels. However, it may present a special problem during fracture healing, because it is only sparsely covered by soft tissue from which the temporary, but essential, extra-osseous blood supply for fracture repair is obtained.
There are three main sources of blood supply to the tibia:

1. the principal nutrient artery
2. metaphyseal and epiphyseal arteries
3. periosteal arterioles

The nutrient artery arises from the anterior aspect of the posterior tibial artery, very close to its origin from the popliteal artery and alsmost directly penetrates the tibialis posterior muscle. It enters a groove on the posterior surface of the tibia and traverses the cortex diagonally, just below the origin of the soleus muscle. The artery in the long subperiosteal groove and osseous canal, is very vulnerable to injury by even a slightly displaced fracture.
When the nutrient artery reaches the medullary canal it divides into an ascending and descending branch.
Brooks stated that the inner diaphyseal cortex is mainly supplied by medullary vessels. Proximally as well as distally there are vascular anastomoses with the metaphyseal and epiphyseal arteries. [18]
The blood supply to the metaphysis (fused with the epiphysis at maturity) is very rich, proximal, and distally. In the proximal metaphysis, blood is supplied by branches from the middle and inferior geniculate arteries, distal to the tibialis recurrens artery.
These vessels are important when the latter is injured, because of the anastomoses with the nutrient artery. [44]

The periosteal vessels are mainly derived from the surrounding soft tissue and the anterior tibial artery, which runs along the anterior aspect of the interosseus membrane. See figure 4.1. [56] The vessels run transversely to the long axis of the bone and supply the outer third of the diaphyseal cortex. If the bone is fractured, the nutrient vessel is often disrupted. However, the periosteal vessels also run transversely to the long axis of the bone and maintain the blood supply to the periosteum on both sides of the fracture line. [70]

It is generally accepted that a rich blood supply is needed for callus formation in fracture healing. Correction osteotomies, for example the valgus upper tibial osteotomy for medial compartment osteo arthritis of the knee, are performed in the metaphyseal area. Because of the rich blood supply and the amount of cancellous bone, early bone union is achieved in nearly all cases. [24,86]

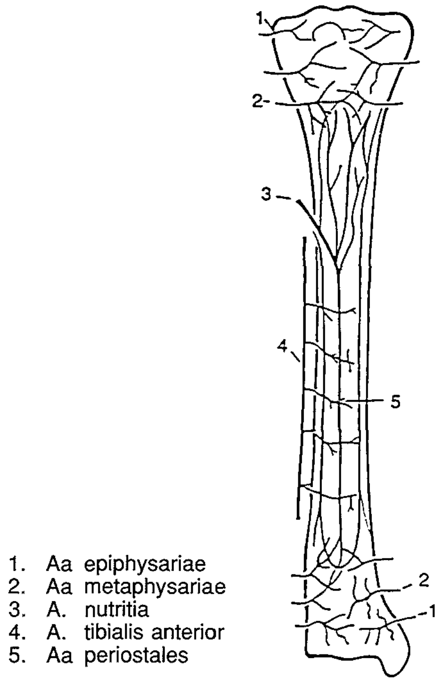


Figure 4.1 Blood supply of the tibia

As was described above in the first weeks after the impact, the inflammation stage, the vessels are hyperaemic. [58] In the same stage, an extra-osseous blood supply develops which is derived from the surrounding soft tissues. Rhinelander observed that the blood supply is at its maximum ten days after the impact, after which it decreases slowly. [92]

What is the role of functional weight-bearing in relation to the blood supply?
When the muscles are contracted, compression of the periosteal veins causes a sudden increase in the intramedullary pressure which ceases when the relevant muscles are relaxed. The pumping action of the muscle which has been shown to be necessary to prevent the loss of bone material, has the same function in fracture healing. [132]
Tondevold showed that during physical excercise the long bones increase their perfusion by fifty to seventy five per cent of the rest value and that this hyperaemia is maintained for nearly one hour after termination of the exercise period. [129]
The extra-osseous blood supply diminishes after about three weeks in a tibial fracture. The pumping action of the calf muscle in functional treatment increases the blood flow and thus enhances the growth of good quality callus.

CHAPTER 5

FUNCTIONAL WEIGHT-BEARING FRACTURE HEALING

Fracture healing is dependent on local and systemic factors.

1. Local factors which may influence fracture healing include both the extent of the injury to the bone and the soft tissue damage. The greater the bone injury in comparison with the soft tissue injury, the more rapid the healing and vice versa. [48]
   The interposition of blood vessels, inadequate reduction, the presence of infection or malignant tissue at the fracture site, play an important role as well. Skiing fractures, which are mainly spiral and are caused by indirect trauma, have a favourable prognosis. [66] There is a correlation between the prognosis and the type of impact which caused the fracture.

2. Mechanical factors may influence fracture healing, either adversely or beneficially. It is a fact that bones are prone to atrophy during prolonged rest periods. General atrophy occurs after recumbency or immobilization and local atrophy is caused by rigid plates fixed on either healthy or fractured bones which is also the same with "stress protection" or "stress shielding" [4,14,51,69,82,87,93,125,130,134,143] Conversely, with greater physical activity, the bone increases in strength and mass. [26,51,62,63,64,85,113,114]
   The repair of a fracture requires the preservation of the elasticity of the bone and of the bone forming tissues which unite the fracture, as well as stability.
   The type of movement most harmful to fracture healing is rotational or shearing stress, which encourages the formation of cartilage and fibrous tissue in the space between the bone ends. Fibrocartilage is laid down in the plane of movement parallel to the fractured surfaces.[12] In the treatment of fractures, rotational and shearing stress must be eliminated either by internal or external fixation.

   The exerion of axial compression on the fracture seems to have a positive influence on healing. [52] However, if the compression across the fracture site is too great, cell necrosis occurs and fracture healing is impaired.

3. Although a constant pressure has no effect on the healing time, it has been established that cyclic loading or functional loading, by full weight-bearing, seems to have a positive effect on the healing time. It is well known that in intact bone, the physiological stimulus that maintains normal osteogenesis is intermittent cyclic deformation.
   In animal models, Panjabi et al have demonstrated that the cyclic loading of fractures in rabbits speeds the rate of healing by twenty-seven per cent, compared to fractures which were fixed in a similar way in compression, but with no change in loading.[87]
   Recent studies in which less rigid and rigid plate fixation are compared, suggest that by allowing a small amount of motion at the fracture site in the axial plane,

the union can take place rapidly and the stress-shielding caused by rigid metallic plates can be diminished. [126,127,133]

Experience with full weight-bearing in a cast or with a functional brace (for the treatment of fractures) has also suggested that function and motion are desirable for osteogenesis as long as the fracture alignment and stability can be satisfactorily maintained. [19,29,30,81,94,98]
A low incidence of non-unions has been reported using functional bracing for the treatment of fractures of the tibia, femur and humerus. [99]
Studies on animal models have supported these clinical findings. They demonstrate that the early periosteal callus which stabilizes fractures of the femur and forearm in rats and dogs, was significantly stronger in animals whose fractures were not immobilized compared to those treated by a cast or rigid internal fixation. [112]
Goodship demonstrated the same effect in the healing of tibial osteotomies in sheep. [41] In one group, rigid external fixation was maintained throughout fracture healing, while in the other group, controlled axial micro-movement was applied. In the group undergoing induced micro-movement, he found early external callus formation at the fracture site and the fracture was significantly more stiff than in the immobilised group.

In a recently fractured extremity, motion occurs at the fracture site when stress is applied. Sarmiento believes that such motion between the fracture fragments assists in producing an environment that is favourable for osteogenis. He suggests that the muscle activity produces intermittent stress, which results in irritation of the injured tissues. This might be the stimulus for the massive invasion of capillaries into the callus observed in non-immobilised fractured extremities.

Dekel stated that constant movement of the bone fragments causes repeated microtrauma to the muscle closely associated with the bone and may result in further prostaglandin production which promotes bone formation. [32] Brighton postulates the hypothesis that early protected weight-bearing leads to the formation of stress-generated potentials in fracture callus, which leads to closely packed collagen bundles. [17] These bundles not only increase the strength of the callus but also enhance mineralization. Allowing micro-movements to take place at the fracture site causes rubbing of the bone fragments against each other, which in turn releases bone determinants. [50]
The exact mechanism of intermittent or cyclic loading on bone repair is not fully understood. It seems very clear, however, that treating fractures using full weight-bearing, gives rise to early callus development with high torsional stiffness, in, or soon after, the phase of inflammation.
The adage is: "Don't heal the fracture to walk, walk the fracture to heal". [128]

CHAPTER 6

THE ROLE OF SOFT TISSUE IN FRACTURE STABILIZATION

Experience with the patellar-tendon-bearing prosthesis (PTB) used after amputations below the knee led to the development of a cast applied below the knee for treating tibial fractures, introduced by Sarmiento et al. [98]
The original idea of the PTB cast was to remove the load from the fracture site during ambulation using a mechanism similar to that of the PTB prosthesis. During clinical application of the PTB cast, however, Sarmiento et al learned from the patients that the greatest pressure was felt over the bulkiest portion of the calf and pressure was rarely felt on the patellar tendon or tibial condyles.
This led to the development of a functional brace for application below the knee. Sarmineto et al measured the load-bearing function of braced tibial fractures using strain gauges. They found that only twenty per cent of the load borne by the limb was transferred to the brace. [65]
Experimental studies on cadaver specimens, conducted by the same researchers, demonstrated the stabilising role of the imcompressible soft tissue mass encapsulated by the brace. [102] (Figure 6.1)

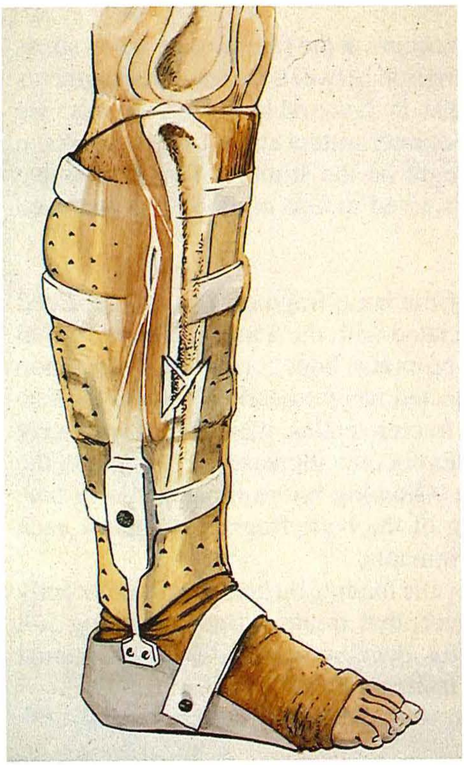


Figure 6.1 The brace fastens snugly around the soft tissue mass

The brace closes firmly around the soft tissue mass. Distally, the muscles are all continuous with the tendons where they cross the talo-crural joint and are tightly held against the bone by the crural ligaments and fasciae. Proximally, only the tendons of the gastrocnemius muscle cross the knee joint.

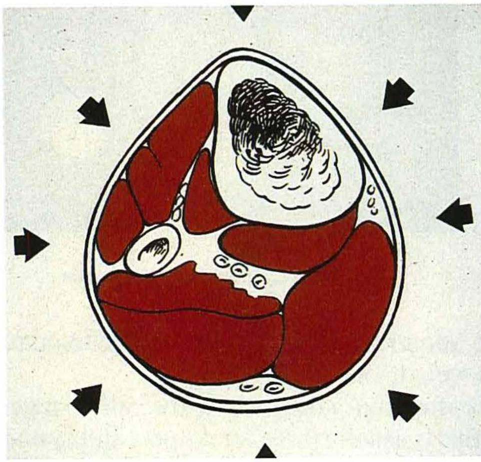


Figure 6.2 The muscles are firmly held by the compression exerted by the brace

Sarmiento et al found that axial loading of soft tissue, compressed in the manner described above (figure 6.2), acts like an incompressible fluid column. According to Pascal's law, an axial load applied to a closed fluid column is transmitted equally in all directions. In this way exceptional shortening of the fracture is prevented. In laboratory work on amputation specimens, they found that the interosseous membrane also plays a major role in the behaviour of the fracture fragments of the fibula and tibia. These specimens were stripped of all soft tissues, with the exception of the interosseous membrane and the periosteum. Under axial loading, the amount of shortening was minimal when the interosseous membrane was intact. In tibial fractures the interossseous membrane is hardly ever disrupted.

Testing oblique fractures in anesthetised patients with and without a brace under axial loading, showed that the amount of displacement was least when the fracture was braced. In both the groups with and without a brace, the bony fragments returned to the initial shortening position after relaxation of the load.
They concluded that the soft tissue acts like an elastic band which makes the fracture ends return to the rest position (Figure 6.3).

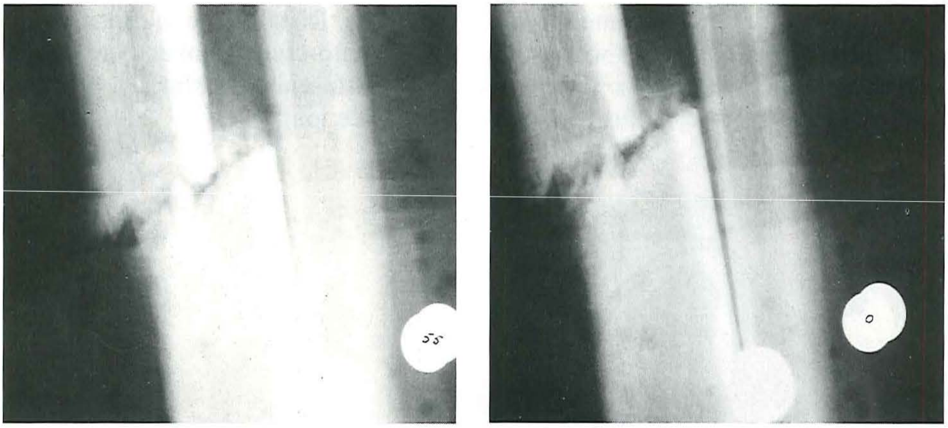


Figure 6.3a the fracture ends in full weight bearing *b the fracture ends in rest position*

In this three-week-old transverse fracture, some callus has developed. The fracture ends return to the rest position after full weight-bearing (=55 kg).
The brace is not applied in the first weeks after injury but early in the callus stage. For closed, mild and moderate fractures, this is usually three weeks post-injury and for open fractures, seven weeks, when the soft tissue has healed. A small amount of callus had already developed and the fracture is "sticky", which is defined as being deformable but not displacable.

In functionally braced fractures, the fracture ends are controlled by the "hydraulic effect" of the brace, the sticky nature of the fracture, the interosseous membrane and the soft tissues.
Biomechanical analyses will show how forces other than axial loading are transmitted by the brace.

CHAPTER 7

BIOMECHANICAL ANALYSIS OF A FUNCTIONAL BRACE, BELOW THE KNEE APPLIED

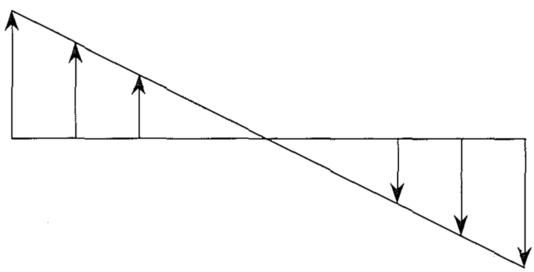
The majority of bones, especially the long bones of the limbs, serve as levers upon which the muscles act to produce movement. During movement, as well as at rest, the bones are subjected to a variety of forces which are primarily the result of muscle action and body weight.
A force is defined as a pull or push. There are three kinds of forces: tensile, compressive and shearing. A tensile force tends to pull an object apart or lengthen it, while a compressive force has the tendency to push an object together or shorten it. A shearing force tends to make one part of an object slide over an immediately adjacent part.
These forces can act separately or in combination with one another. Two parallel forces of equal magnitude but with opposite lines of action constitute a couple. When a couple is applied to an object in a plane perpendicular to its long axis, it produces torsion or twisting, causing one part of the object to be rotated in relation to the other. Application of a couple in a plane parallel to the long axis of the object produces bending, causing perpendicular cross sections to be rotated in relation to each other.
The moment of a force around a point is the product of the force times the distance from that point to the action line of the force. The moment of a couple around any point in the plane of the couple is the product of one of the forces and the distance between them.
Stress is the intermolecular resistance within an object against the action of an outside force which is applied to it. An example of stress in the human body is the internal resistance produced within the bones of the leg as a result of the compressive force applied to them by the body weight when standing erect.

$$\text{Stress}=\frac{\text{force}}{\text{area}}$$

Strain is the change in the linear dimensions of an object, being the result of the application of a force, which may be compressive, tensile or shearing.

$$\text{Strain}=\frac{\text{deformation}}{\text{length}}$$

A concentrically loaded column is subjected to compressive stress and strain throughout the area of its cross section.
If a column is eccentrically loaded it is bent in addition to being compressed. As a result of the bending, tensile stresses and strains are created on the concave side. The magnitude of the stresses and strains is greatest on the surface of the column and decreases towards the center of the column.



The same occurs when a column is subjected to load from the side perpendicular to its long axis.
When a couple is applied to the ends of a column, the ends are twisted or rotated in opposite directions to one other.

When the stresses produced in a material are plotted against the corresponding strains, a stress-strain curve is obtained.
E.g. when a force is applied to a material, it has............

1. an elastic region in which the material returns to its original form or shape after it has been deformed by the load or force;
2. a plastic region, where deformation continues until collapse occurs;
3. a failure point at which the fracture occurs.

The yield point is situated at the transition zone between the elastic region and the plastic region. Should the load or force increase beyond the yield point, causing the load to be borne by the plastic region, then the material will not return to its original shape.
The coëfficient of elasticity is a measure of the stiffness of a material and its magnitude is obtained by dividing the stress by the strain in the elastic region when the curve is a straight line.
In a stress-strain curve, the slope of the curve represents the stiffness of the material. Metal has a steep slope and is thus a stiff material.
Glass, a brittle material, does not have a plastic area, thus the yield point is also the failure point.
The stress-strain curve in bone runs in a somewhat curved fashion in the elastic area which predominates that bone and does not behave in a purely linear elastic fashion.
Long bones are constructed from spongiosa and cortical bone. Cortical bone is

stiffer than spongy bone and is able to endure a higher level of stress but a somewhat lower level of strain before fracture occurs. Both cortical and spongy bone are anisotropic, which means that their mechanical properties are not the same in all directions. The diametrical structure of bone differs from the longitudinal structure, having a variability in strength which is compatible with the direction of the load to be borne during weight-bearing.
The strength and stiffness of bone are greatest in the direction in which the weight is borne.
During the walking cycle, the cortical bone is thus constantly subjected to compressive, tensile and shearing forces either separately or in combination, causing bending and twisting. Cortical bone is able to withstand heavy compressional stress and a smaller degree of tensile. Bone is able to withstand more tensile stress than shearing stress.

When a material is bent, tensile stress appears on the convex side of the neutral axis while on the concave side there is compressive stress and strain. As stated above, there is no stress or strain on the neutral axis. The intensity of the stress is proportional to the distance to the neutral axis of the bone. Thus stress is greatest at the periphery of the bone, decreasing in intensity until the central axis is reached. As bone is symmetrical in form, the intensity of tensile and compressive stress are frequently unequal.
Torsion or twisting stresses are distributed over the entire structure, working in planes that are parallel and perpendicular to the neutral axis.
Three-point bending of the tibia in an anterior direction produces compressive stress on the anterior side and tensile stress on the posterior side. Bone is less able to endure tensile stress and a fracture will occur on the posterior aspect. Through contraction, the triceps surae creates compressive stress and thus helps to prevent the occurence of a fracture to some degree.

If a tibial brace is used to stabilize a fracture, it is important to find out how different loads and forces are received and indeed transmitted from the knee to the foot. Schematically, this question can be answered by means of a free body diagram and via a description of (quasi-)static equilibrium during weight bearing.

1. The brace fastens snugly around the soft tissue mass. By isolating the fractured tibia, the soft tissue and brace from its surroundings, a free body diagram will be obtained. Rectangular coordinate axes are used for the analysis. Figure 3.1 shows all the possible forms of load, which can act proximally and distally to the brace. This involves forces and moments (the double arrows).

   The direction of rotation of the moments can be derived by using the corkscrew rule (Figure 7.1).

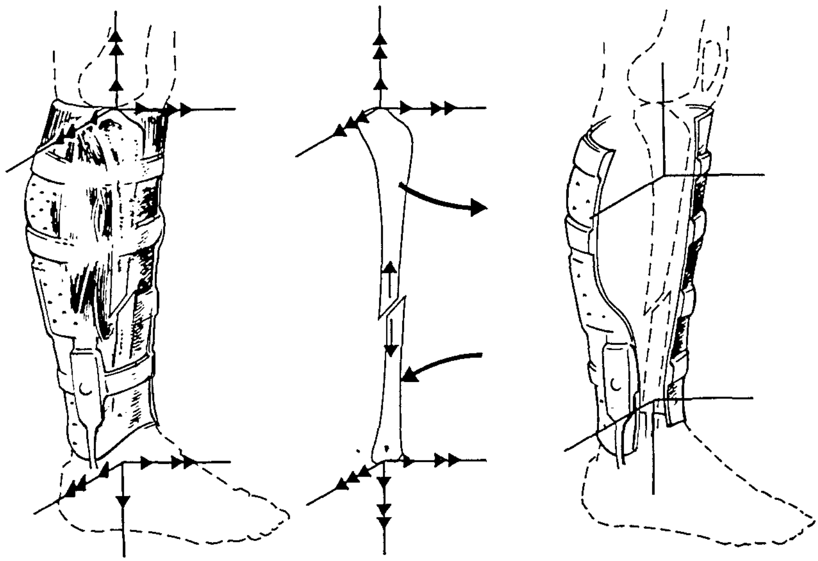


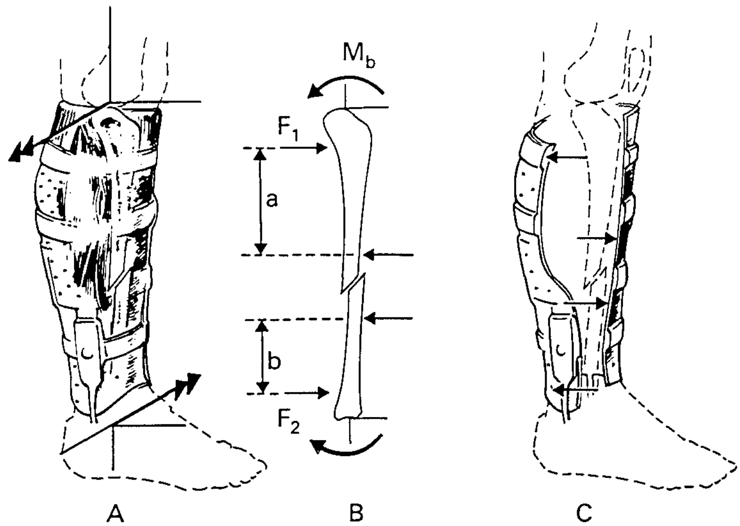
Figure 7.1 All the possible forms of load which can act proximally and distally to the brace

For the biomechanical enhancement of fracture healing, the absence of tensile and shearing stress is essential. The brace must prevent the existence of such stresses by "leading" these loads, as it were, around the fracture.
An exception to this rule is the compression stress in the bone which, within certain limits, is beneficial to the healing of the fracture (Figure 7.1b and 1c)

2. Let us fistly examine the loading by a bending moment, for example, take the moment in the sagittal plane (Figure 7.2).

Mb=the moment in the sagittal plane occuring above the fracture at the level of the knee joint
F_1=the force which is obtained by the compression of the brace on the soft tissue and bone situated proximally to the fracture
F_2= the same force distally to the fracture

The areas of bone on which compressive forces are created depends on the direction of rotation of the couples needed to obtain equilibrium.
The moment on the proximal part of the tibia is schematically presented as follows:
$M_1 = F_1.a$



$M_b = F_1.a = F_2.b$
this applies for any vertical plane

Figure 7.2 the loading of a bending moment Mb in the sagittal plane

a = the distance between the forces forming a couple. For the distal part, the same principle applies, although with the opposite direction of rotation and an assumed distance b. The moment balance can be formulated thus

$Mb = F_1.a = F_2.b.$

Because the forces F_1 and F_2 are delivered through the brace, a bending moment is created which is taken up by the brace. This is valid for a bending moment in any given vertical plane.

3. Tensile forces The fractured tibia stabilized with a brace, is also subject to tensile forces. It is assumed that these are almost totally due to gravity. These forces are borne by tensile stress in the tibio-femoral ligaments and capsulae, the muscles and the brace. The free body diagram in Figure 7.3A demonstrates a schematic picture.

F_2 = the combined weight of the leg and the brace
F_3 = weight of the foot
$F_1 = F_2 + F_3$

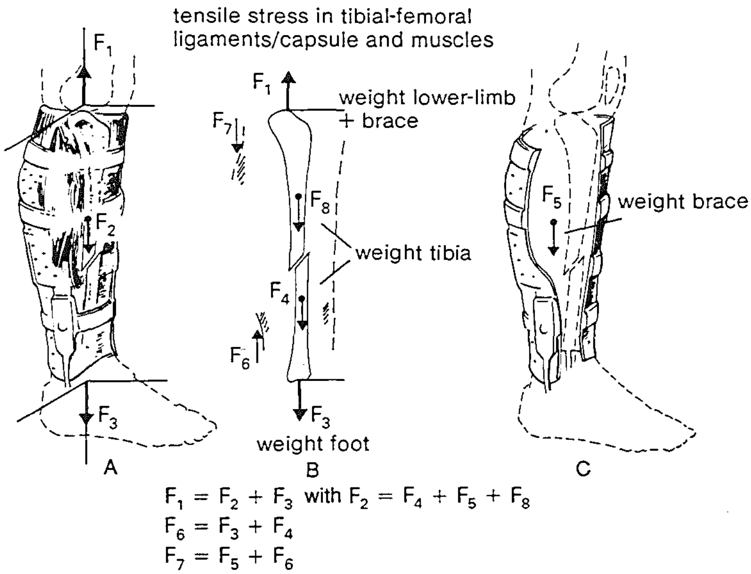


Figure 7.3 Free body diagram of tensile forces

Figure 7.3b shows the free body diagram of the tibia and muscles without a brace and a possible weight-bearing force between the muscles and brace. The brace should be wedge shaped. Because of the conical form of the lower leg, i.e. from distal to proximal from the level of the achilles tendon and from the level of the triceps surae to near the knee joint, but in the opposite direction (proximal to distal), this gives proximally force F_7 and distally F_6 as pressure between the brace and the soft tissue.

F_4 = soft tissue weight and tibial weight distally from the fracture

Comment: Obviously, in principle, each tensile force can be exclusively transferred by the muscles.

F_8 = soft tissue weight + tibia weight proximally from the fracture

F_5 = brace weight

$F_1 = F_2 + F_3$

$F_2 = F_4 + F_5 + F_8$

$F_6 = F_3 + F_4$

$F_7 = F_5 + F_6$

4. Compressive forces.

A compressive force at the level of the knee joint can be transmitted to the foot along several different lines. In practice, forces are transmitted via a combination of lines, although for simplicity, three possible paths are illustrated separately. These are: transition via the muscle mass (Figure 7.4A), through the fracture plane (Figure 7.4B), and via the bony protuberences at the level of the knee joint, (Figure 7.4C).

In Figure 7.4A, it can be expected that owing to the conical form of the brace on the muscle mass, a vertical force F_3 can be exerted. As soon as pressure exists between the brace and muscle mass, friction occurs between the skin and brace which contributes to the transmission of force in the vertical direction.

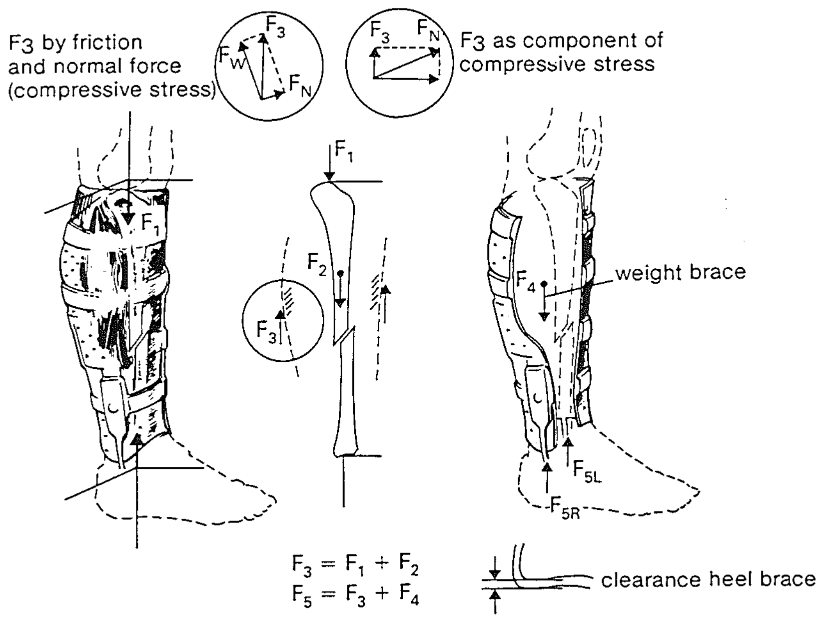


Figure 7.4A transmission of compressive forces via the muscle mass

F_1 = compressive force at the level of the knee joint
F_2 = weight proximal part of the lower leg
F_3 = vertical component of normal force F_n and friction force F_w
F_4 = brace weight
F_5 = resistance of heel shoe

$F_3 = F_1 + F_2$

$F_5 = F_3 + F_4$

In Figure 7.4b it can be assumed that the compressive force is absorbed on the fracture surface. In the case of an oblique fracture, there is, however, a risk of shearing. The function of the brace is to prevent this. At the level of the fracture, the brace can be imagined as forming a broad ring, inside which a hydrostatic pressure is created due to the compression of the muscle mass. This results in radial forces on the fracture fragments which prevent movement of the bone ends. This effect is increased by increasing the number of rings and by using material which is as rigid as possible. This extra degree of rigidity can be achieved by adding a ring at the level of the fracture.

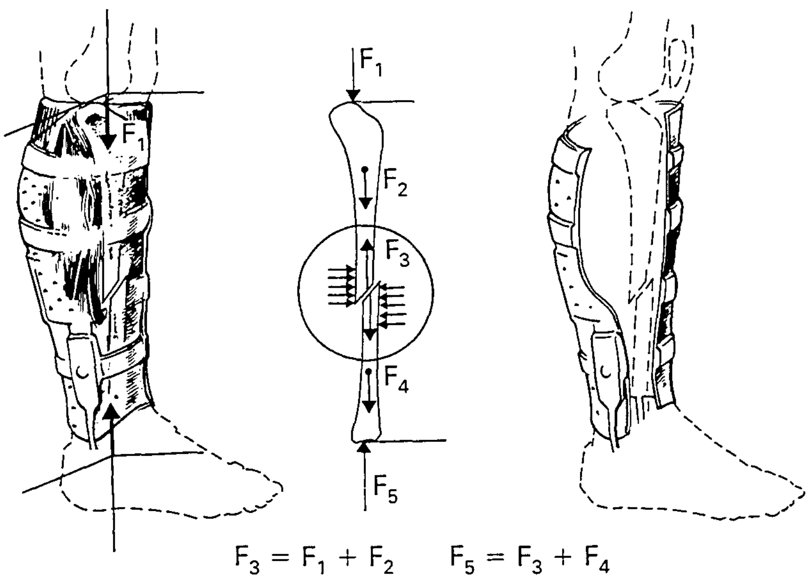
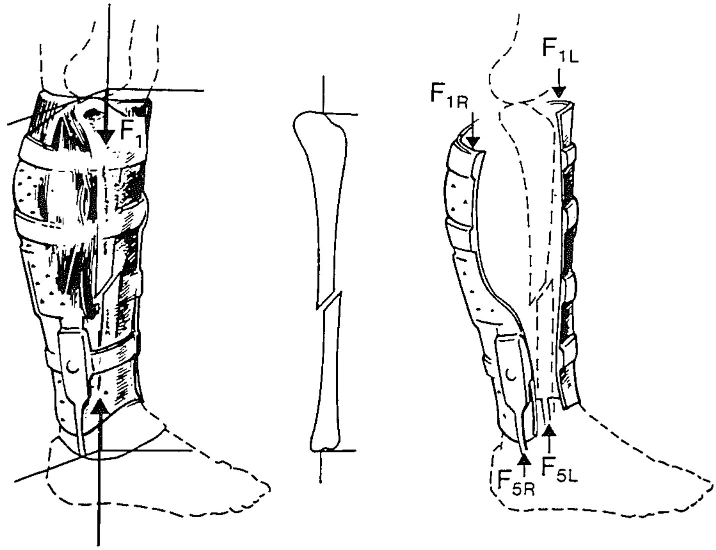


Figure. 7.4b Transmission of compressive forces via the fracture

$F_3 = F_1 + F_2$
$F_5 = F_3 + F_4$

Finally, in Figure 7.4c the entire compressive force is transmitted by the brace. For this reason a snug fit between the brace and the prominences at the level of the knee joint is necessary. The counter force of the shoe heel is also essential.



$$F_1 = F_{1R} + F_{1L} = F_{5R} + F_{5L}$$

Figure 7.4C Transmission of compressive forces by the brace

The bone is now completely free from load. Force F_1 is transmitted directly from the bony prominences of the tibial plateau to the brace.
$F_1 = F_{1R} + F_{1L} = F_{5R} + F_{5L}$

5. To illustrate the action of a transverse force, a force F_1 is applied (see Figure 7.5). Next, a free body diagram of the distal tibia below the fracture line is shown.
   The transverse force F_1 can be translated parallel to itself, approximately in the middle of the bone area, while at the same time introducing moment $M_1 = F_1.c$. Equilibrium with this transverse force can be achieved through the resistant pressure of the brace via the local muscle mass. The moment $M_1 = F_1c$ can be transferred analogous with Figure 7.2A.
   At equilibrium:

   $M_1 = F_1c = F_2.b$
   $M_2 = F_1\ d$

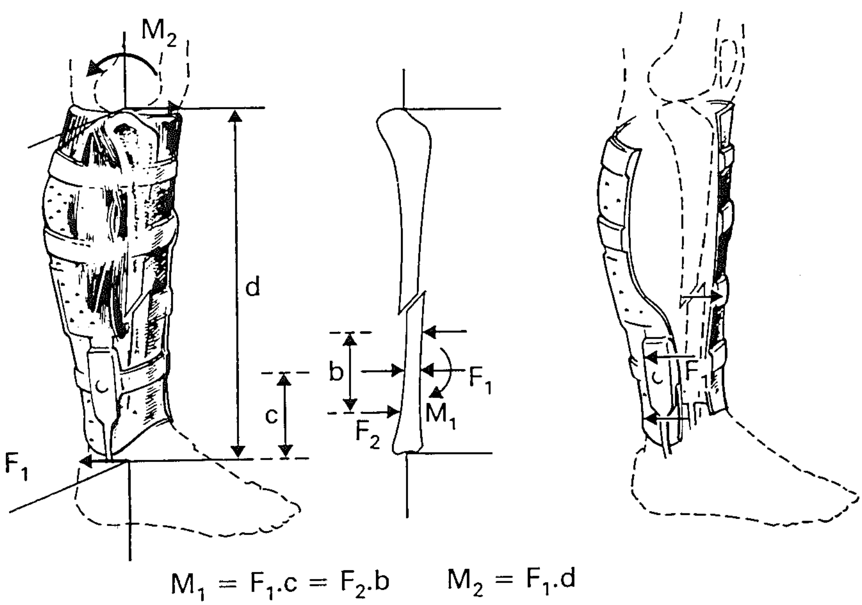


Figure 7.5 A free body diagram of a transverse force below the fracture line

6. The transition of a torque moment can occur along two paths: via the muscle mass or the brace.
   In Figure 7.6a, the free body diagram shows how a torque moment Mw, proximal to the fracture, causes shear stresses in cross sections of the soft tissue.

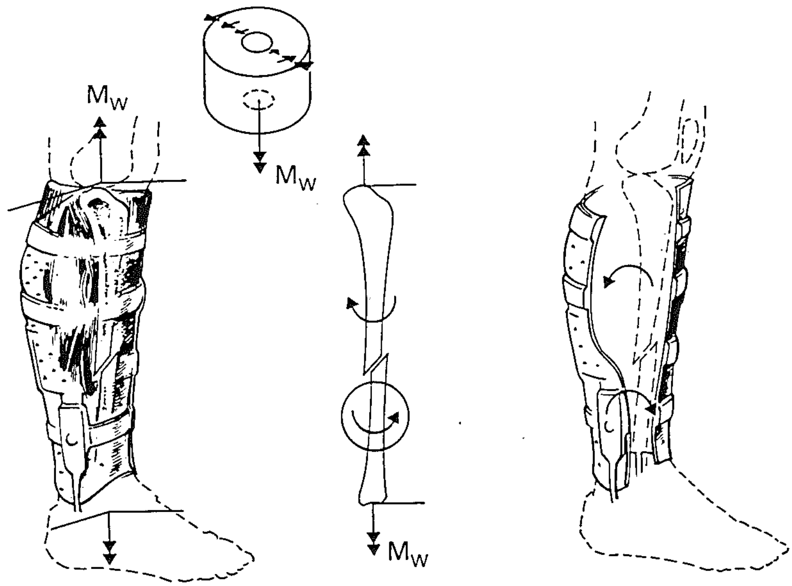
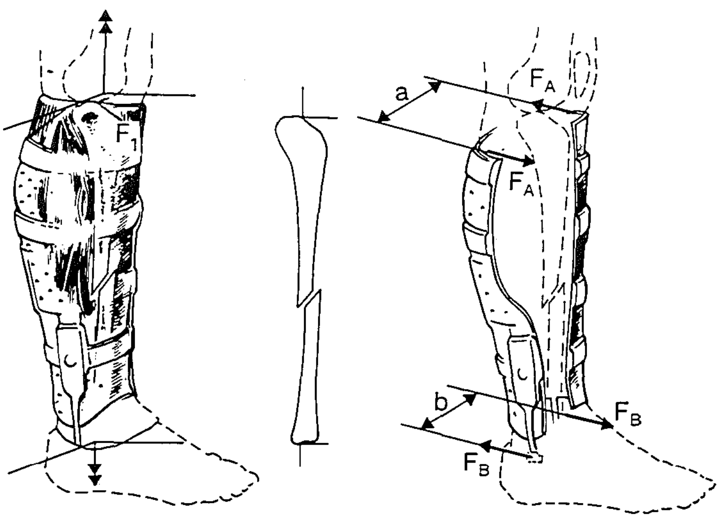


Figure 7.6a Transmission of a torque moment via the muscle mass.

The shear stress is highest at the periphery of the soft tissue mass.
Under the influence of this action, the muscle mass should function as a strong column.

In Figure 7.6b, a torque moment is completely transmitted through the brace.



$$M_W = F_A . a = F_B . b$$

Figure 7.6b Transmission of a torque moment by the brace

The bone is free from load. Moment Mw is transmitted directly from the bony prominences of the tibial plateau through the brace.

$M_w = F_A.a = F_B.b$

To achieve this effect, it is essential that there should be a snug fit between the brace and the bony prominences and a solid connection between the brace and the heel cup.

Finally, in this biomechanical analysis, it is necessary for the brace to be sufficiently strong to take up all the forms of stress and strain occurring during weight bearing. Because of its considerable stiffness, it is possible to prevent deformities at the fracture site.
The present state of our study does not allow for numerical analysis of the different forces and moments mentioned.

CHAPTER 8

BRACE TECHNOLOGY AND TREATMENT

The brace used in this series was a modified Sarmiento brace, made of Orfit. Orfit is an orthopaedic sheet material made of a crystalline polyester with a high molecular weight (HCP). HCP is a versatile engineering plastic with a unique balance of physical properties which qualify it for moulding at moderate temperature. At 55°C, the material softens and becomes transparent. At this stage it is very easily moulded and applied, even when anatomical deformities exist. At room temperature it takes 5 minutes to harden.

When a patient is admitted to hospital with a tibial fracture, the fracture is reduced (if necessary) and after all the appropriate diagnostic measures have been taken to ensure that impending compartment syndromes and/or neurovascular symptoms have been ruled out, the fracture is immobilized in a plaster cast from the foot to just above the knee. This cast is applied while the leg hangs vertically over the end of a table, so reduction can be maintained by gravity. The ankle must be immobilized in a neutral position. After the plaster has hardened, it is finished off with the patient lying in the supine position. Special care should be taken to ensure that there is adequate padding over the malleoli, the back of the heel and the neck of the fibula. The plaster is split anteriorly before the patient leaves hospital, in case there is any further swelling. After two or three days, the split in the plaster is closed with plaster bandages. The patients are allowed to walk with a pair of crutches, i.e. partial weight-bearing. They are instructed to elevate the limb frequently and perform calf and thigh muscle exercises. In most closed fractures of the tibia, the acute symptoms subside rapidly. If the alignment is not accurate it should be corrected by wedging. After two to four weeks the plaster can be removed and a brace can be applied.
Open and closed fractures with severe soft tissue damage require a longer period of immobilisation using plaster or an external fixation device, before bracing. After the initial period (in the soft callus stage, see page 6), the plaster cast is split and the patient is asked to raise the leg. If this is painless and no angulation deformity occurs, the fracture is sticky. If the alignment is acceptable i.e. less than 5 degrees of varus, valgus, apex anterior or apex posterior angulation, the brace can be applied.

Application method
Both legs hang vertically over the end of the table, with ninety degrees of flexion at the knees and the hips. The fractured leg can now easily be compared with the opposite one. Any deformities can be seen and corrected in the brace. Rotation deformities should especially be looked out for.
A stockinette is rolled from the foot across the ankle to above the knee. The length of the limb is measured from the ankle joint to just above the tuberosity of the tibia. The circumference of the leg muscle 5 cm above the malleoli and at the thickest

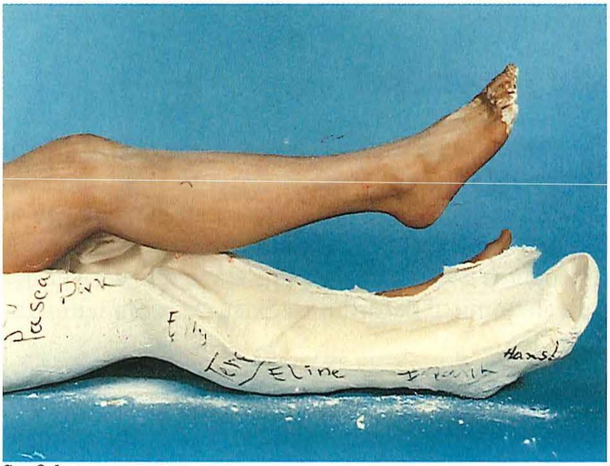


fig. 8.1

fig. 8.2

Figure 8.1 *If the leg can be raised without deformities occurring, the fracture is sticky. The plaster can be removed.*

Figure 8.2 *The brace is applied with both legs dangling at ninety degrees of flexion at the knees, so that deformities can easily be seen*

Figure 8.3 *a stockinette is rolled from the foot to above the knee, the length of the limb and the circumference of the calf muscle are measured*

Figure 8.4 *the piece of Orfit is cut in accordance with the measurements of the leg and heated to 55° until it becomes transparent. The patient holds the sheet proximally on both sides.*

fig. 8.3

fig. 8.4

fig. 8.5

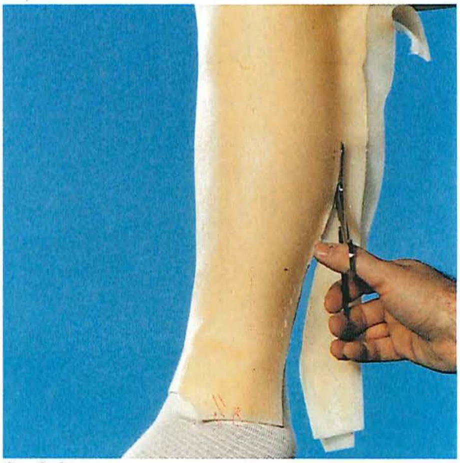


fig. 8.6

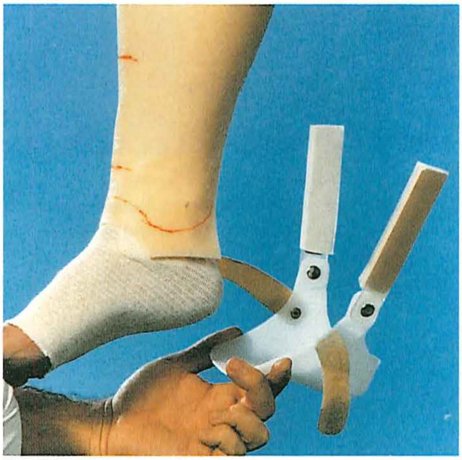


fig. 8.7

fig. 8.8

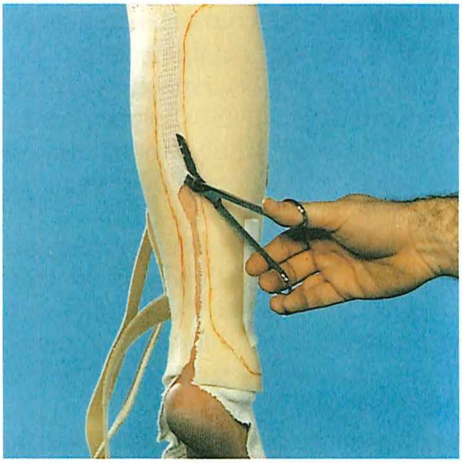


fig. 8.9

Figure 8.5 *The Orfit is wrapped around the leg from anterior to posterior and from distal to proximal. On the posterior border the edges are sealed together.*

Figure 8.6 *Excess material can easily be trimmed off with a pair of scissors*

Figure 8.7 *The appropriate heel cup is placed*

Figure 8.8 *Three self adhesive Velcro-straps are applied on the brace at equal distances*

Figure 8.9 *The brace is removed by splitting the Orfit sleeve on the posterior border and removing a two centimetre strip of Orfit posteriorly.*

Figure 8.10 Proximal and distal trim lines are completed, any rough surfaces are removed, a hundred per cent cotton stockinette is applied and the brace is finished off; anterior view

Figure 8.11 Posterior view of the brace with a gap of two centimeters to maintain compression if muscle atrophy occurs

lined on the Orfit sheet.

The Orfit is cut with a pair of electric scissors after it has been placed in water at approximatley 50°C and heated until it becomes transparent.

The stockinette compresses the soft tissues slightly and protects the skin against the heat of the Orfit sheet. The sheet is removed from the water and dried. The patient holds the sheet proximally on both sides and the Orfit is wrapped around the leg from anterior to posterior and from distal to proximal. On the posterior border of the leg the edges are sealed together. Orfit is moulded firmly around the soft tissues and the reversed pyramidial anterior aspect of the tibia and between the lateral and medial gastrocnemius heads posteriorly.

Distally, the brace is moulded around the malleoli. Anteriorly, the brace is trimmed just above the ankle joint and a space is created for the dorsi-flexors of the foot. Excess overlap of the Orfit posteriorly is removed with a pair of scissors. Any deformities can be corrected at this stage and maintained until the Orfit hardens. The appropriate heel cup is selected, placed on the foot and fastened with a Velcro strap. It is then attached to the brace with Velcro straps.

The brace is removed by splitting the Orfit sleeve on the posterior border. A strip part of the calf are measured and 2 cm are added to these measurements and out of of approximately two centimetres of Orfit is removed posteriorly, so creating a gap between the two sides of the brace. If muscle atrophy occurs during treatment further trimming dorsally has to be done to maintain compression of the soft tissues.

Three self adhesive Velcro strips are applied to the brace at equal distances. By tightening the three strips, beginning distally, the dorsal gap is diminished and the soft tissues are compressed.

Proximal and distal trimlines are completed to allow a full range of movement of the ankle and the knee. Any rough surfaces are removed. The firm moulding around the bony prominences of the proximal tibia, prevents occurence of rotational deformities during treatment. The overlap at the malleoli protects the bony prominences from rubbing against the plastic foot which is inserted during walking and is also necessary to provide rotational stability. A 100% cotton stockinette is used, which absorbs any exudates better, and prevents skin maceration.

Radiological examination is performed while the patient bears weight untill it causes pain. If adequate reduction and alignment are maintained a recording is made of the amount of weight that can be borne before pain occurs. Patients are instructed to use normal socks in the heel cup to prevent maceration of the heel. They also are told to wear sport shoes half a size to large.

They are encouraged to bear as much weight as possible while walking with crutches.

One week after the application of the brace, clinical and radiological examinations are performed. If alignment and reduction are maintained, most patients canbe seen on a three weekly basis. If a slight degree of misalignment has occurred it is possible to improve it by the application of pads to the inner wall of the brace, opposite the apex of the deformity. In such a case, weekly examination of the skin should be carried out.

As soon as the patients are able to walk without crutches, they are instructed how to remove the brace for a daily shower and how to put on the stockinette and the brace.

After application of the brace, patients are given instruction form I and when they can walk without crutches, form number II. They are now allowed to engage in normal daily activities. If, during treatment, any complications occur, it is always possible to discontinue the bracing and choose another form of treatment.

When clinical and radiological consolidation is achieved, the brace is removed.

INSTRUCTION FORM I

1. You have been fitted with a brace. You may bear weight on the leg until you feel pain at the fracture site. It is best to wear sport shoes 1/2 a size too large.
2. From now on, train your thigh muscles twice a day by lifting your stretched leg whilst sitting on the edge of a chair.
3. Move your ankle as much as possible.
4. Change your socks every day so as not to cause irritation to your heel.
5. When you are not walking, put your broken leg up. By putting your toes level with your eyes you will prevent your ankle from swelling.
6. Do not take your brace off before your doctor gives you permission to do so.
7. The brace should be close fitting, but not uncomfortably tight.
8. From now on, your leg will be X-rayed every three weeks to monitor the healing of the fracture.
9. One year after the brace has been removed, you will be called-up for a final examination.

INSTRUCTION FORM II

Taking the brace off

1. Sit down, legs dangling.
2. Loosen velco straps on the heel cup.
3. Undo three velcro straps of the brace.
4. The brace can now be easily taken off.
5. Take off the old cotton stockinette to wash it and put on a new one.
6. After this, put on the brace again.
7. Put on your sock and shoe.
8. Put on the brace and strap the heel cup on using the velcro straps.
9. Strap the brace on, starting with the bottom strap and work your way upwards. The brace should be close-fitting but not uncomfortable.

Important: never stand on your leg without the brace, unless the doctor gives you permission to do so!

CHAPTER 9

FUNCTIONAL TREATMENT OF TIBIAL FRACTURES

From July 1981 to December 1983, 177 patients with a tibial fracture were treated with a functional applied below the knee brace in combination with early ambulation and early weight bearing.

The patients were admitted to the department of orthopaedic and general surgery at the University Hospital Leiden, the Westeinde Hospital in The Hague and the University Hospital Rotterdam.

The patients admitted to the orthopaedic departments with a tibial fracture were treated with a functional brace. The general surgeons at the University Hospital Leiden referred many patients for inclusion in the study. For some of their patients, other methods of treatment had also been used at the beginning of the study.

The selection criteria for functional bracing comprised: fractures with acceptable alignment and shortening after the initial treatment, i.e. shortening of less than 10 mm and a deformity of less than 5 degrees.
Functional bracing was first used at our department for the treatment of minor fractures of the tibia. As more experience was gained, more fractures were treated with this method. The author is aware of the fact that this series is not a consecutive one.

Directly post-trauma, the treatment for a closed fracture of the tibia mainly consisted of reduction and a toe-to-groin plaster cast for 3 weeks. For open fractures, it was external fixation. Functional bracing was never applied on the day of injury.

The treatment methods directly post-trauma are described in the next chapter.

Of the 177 patients, four could not be traced for follow-up and were therefore excluded from the study. Three patients had a simultaneous fracture of the other tibia. For analytical and technical reasons, these cases were interpreted as six separate patients.
In total 176 fractures were studied prospectively by means of detailed clinical and radiological analysis.

During treatment, the amount of weight bearing was accurately measured and any change in the behaviour of the fracture fragments was noted. All patients underwent a clinical and radiological examination. At least twelve months after the initial trauma.

Age and sex distribution

The mean age was 26 years, with a range from twelve to seventy years. As in other series, there were more men involved (74.4 per cent) than women (25.6 per cent).

Right and left distribution

There were 90 fractures of the right leg (51.1 per cent) and 86 of the left leg (48.9 per cent), Figure 9.1.

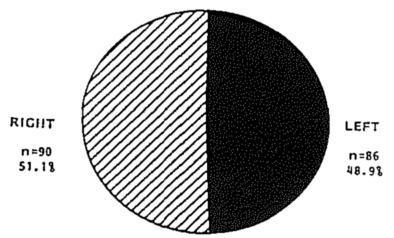


Figure 9.1 right and left distribution

Cause of tibial fracture

The cause of injury in 46.0 per cent was a traffic accident. The percentage of fractures caused by sport (mainly soccer injuries) was also significant (Figure 9.2).

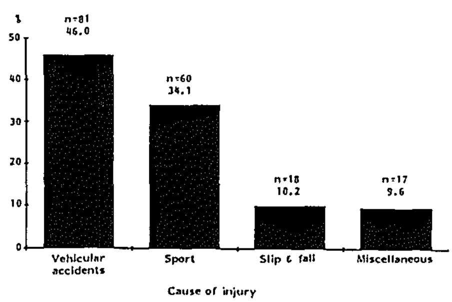


Figure 9.2 cause of injury

Fracture type

The fractures were divided into six types. *Transverse fractures* were defined as fractures in which the fracture line formed an angle of between 70 and 90 degrees with the long axis of the diaphysis; *oblique fractures* had an angle of less than 70 degrees. *Spiral fractures* showed the characteristic feature of a curved fracture line. Fractures with an intermediary fragment larger than half the diameter of the diaphysis were classified as *comminuted.* When the diaphysis was fractured at two separate levels the fracture was classified as a *segmental fracture* (Figure 9.3).

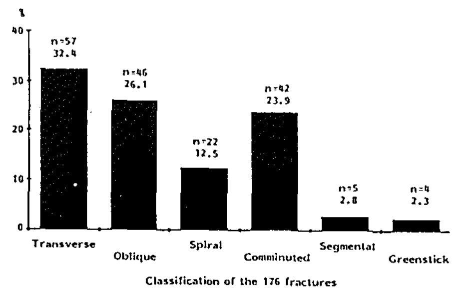


Figure 9.3 classification of the 176 fractures

The tibia was divided into three parts, proximal, middle and distal in accordance with Edwards. Segmental fractures were classified as fractures of the middle third of the tibia. In one case, a spiral fracture ended in the ankle joint and was classified as an intra- articular fracture of the ankle (Figure 9.4).

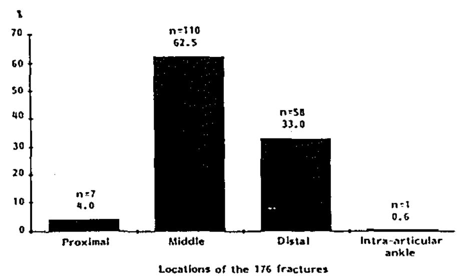


Figure 9.4 locations of the 176 fractures

Closed and open

There were 137 closed and 39 open fractures. The size of the wounds, measured in cm, is shown in Figure9.5.
Fractures were considered to be open fractures when the skin and soft tissue injuries suggested that a fragment of the fracture had been exposed to the external environment.
In first degree open fractures, the skin is pierced from within by a sharp bone fragment and the lesion in the skin is less than two cm2. In second degree fractures, the skin is disrupted and crushed from within with skin damage of two to five cm2 and damage to the soft tissue. Third degree open fractures involve skin wounds of more than 5 cm2 and are often associated with major damage to the soft tissues.

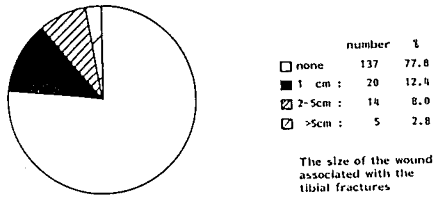


Figure 9.5 the size of the wound associated with the tibial fractutes

Fibular fractures

Isolated tibial fractures may occur from direct trauma. Indirect trauma leads to fractures of both the tibia and fibula. Isolated tibial fractures are mainly the result of low energy trauma. They tend to heal in varus angulation, 123. Nicoll stated that an intact fibula is not prejudicial to union, 84. The locations of the fibular fractures are shown in Figure 9.6.

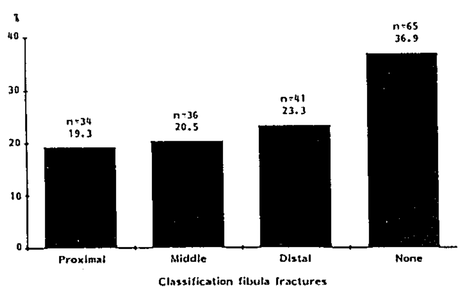


Figure 9.6 classification of the fibular fractures

The relation between the fibular fractures and the tibial fractures is shown in Table 9.1.

Tibial fractures	Fibular fractures percentages	
Transverse	43.8	per cent
Spiral	59	per cent
Oblique	72.9	per cent
Comminuted	78.5	per cent
Segmental	80	per cent
Greenstick	25	per cent

Table 9.1

Shortening

All post-trauma X-rays of the 176 tibial fractures were examined and the initial shortening was measured. The maximum initial shortening was 30 mm, mean shortening was 4 mm (see Figure 9.7).

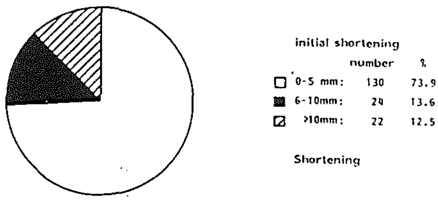


Figure 9.7 initial shortening

After application of the brace, the shortening was measured radiologically, while the patient was partially bearing weight in the limb.
In most patients (98.9 per cent) reduction during the initial treatment produced an acceptable shortening of 10 mm or less (see Figure 9.8).

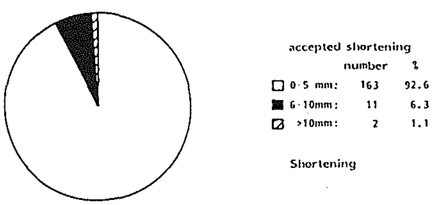


Figure 9.8 accepted shortening

Soft Tissue Lesions

Damage to the soft tissues plays an important role in the healing of a fracture, but it was not really possible to make an objective classification of the soft tissue lesions in closed fractures. We have tried to classify the damage to the soft tissue according to the swelling of the calf muscles.
On admission to the casualty department, the degree of calf swelling was classified as minimal if the circumference of the affected calf was slightly more than the contralateral one. Moderate swelling was defined as a significant difference in the size of both calves. All other swellings were defined as severe (Figure 9.9). Experimental work, relating blood enzyme activity to soft tissue damage will perhaps

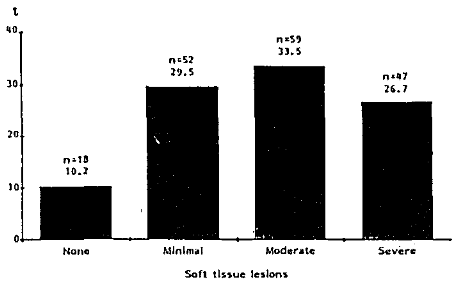


Figure 9.9 soft tissue lesions

enable us to obtain an accurate quantitative measurement of the degree of soft tissue damage.

Dislocation

Large initial displacement is detrimental to the healing of the fracture [83]. Fracture displacement is classified as 0 - 33 per cent, 34 - 66 per cent and 67 - 100 per cent displacement of the diameter of the tibial shaft (see Figure 9.10).
In 94.9 per cent of the fractures, the position was accepted if the displacement was less then 34 per cent of the diameter of the tibial shaft after application of the brace (Figure 9.11).

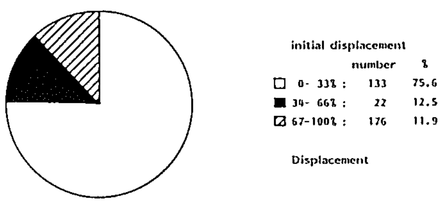


Figure 9.10 initial displacement

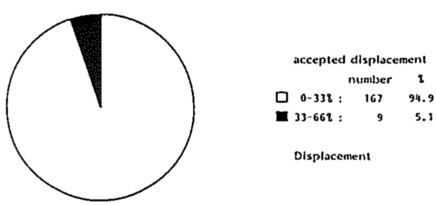


Figure 9.11 accepted displacement

Associated injury

Early functional weight-bearing of tibial fractures in patients with multiple injuries is usually impossible. The associated injuries in this series were mostly minor.

associated injuries	
vertebral fracture	2
pelvic fracture	1
femoral fracture	2
fracture upper extremity	10

Ten patients suffered a significant head injury.

CHAPTER 10

METHODS

Initial treatment

As mentioned above, the brace was never applied on the day of injury. Treatment before the application of the brace was defined as initial treatment. Initial treatment was reduction and a toe-to-groin plaster or calcaneal traction or external fixation (Figure 10.1).

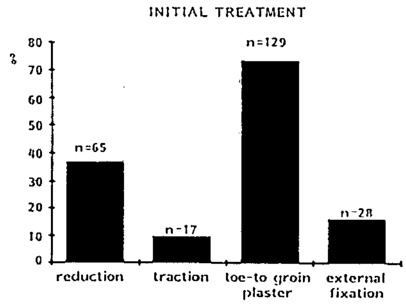


Figure 10.1 Initial treatment

After calcaneal traction a toe-to-groin plaster was applied for an additional two weeks.

Calcaneal traction must not exceed three kg. According to Böhler [12], more than 3 kg of traction causes distraction of the fracture ends, the gap is filled with fibrotic tissue and a delayed or non-union develops. One patient developed a delayed union because of distraction.

Any loss of correction after reduction and during plaster treatment, can be corrected by wedging the plaster. On 18 occasions the initial plaster was wedged.

Application of the custom-made functional brace

After the acute symptoms had subsided, the brace was applied in accordance with the technique described in chapter 8. The average application time of the brace for closed fractures was 26 days after the trauma, with a range from 3 to 84 days (Figure 10.2).

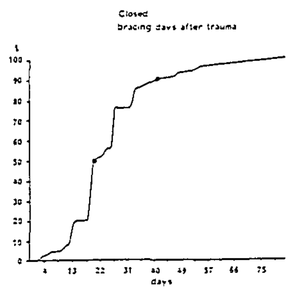


Figure 10.2 cumulative percentage curve of the application time of the brace for closed fractures

In our series, 50 per cent of the patients were braced after 21 days and 90 per cent after 6 weeks.

The average application time of the brace for open fractures was 48 days after the trauma, with a range of 7 to 98 days (Figure 10.3).
In our series 50 per cent of the patients were braced after 6 weeks and 90 per cent after 11 weeks.

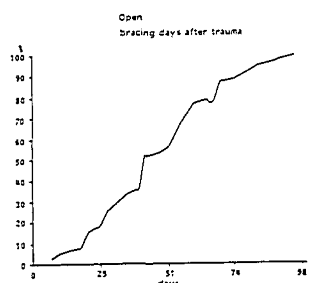


Figure 10.3 Cumulative percentage curve of the application time of the brace for open fractures

Weight-bearing

Immediately after the application of the brace, a record was made of the amount of weight that could be borne before pain resulted (Figure 10.4).
Most of the patients (68.7 per cent) could bear more weight than 25 kg. without pain.

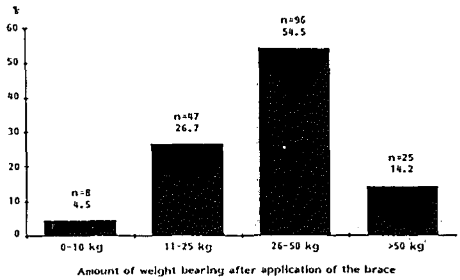


Figure 10.4 amount of weight bearing after application of the brace

After the application of the brace, a scanogram was performed. If there was no change in the appearance of the fracture, the patient was encouraged to put as much weight as possible on the injured leg. A note was made of the time at which the patient could walk, bearing ful weight and walk without crutches.

Patients with closed fractures walked with full weight-bearing at a mean of 7.4 weeks, with a range from 2 to 24 weeks. After 14 weeks, 90 per cent of these patients were walking with full weight-bearing (Figure 10.5).

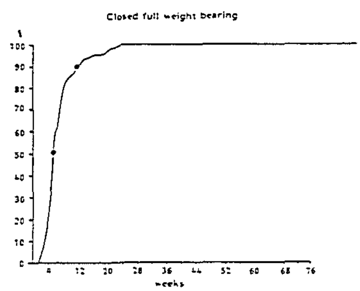


Figure 10.5 cumulative percentage curve of full weight-bearing for closed fractures

Patients with open fractures walked with full weight-bearing at a mean of 12.8 weeks. After 20 weeks, 90 per cent of this group were walking with full weight-bearing (Figure 10.6).

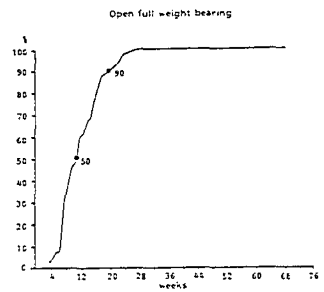


Figure 10.6 cumulative percentage curve of full weight-bearing for open fractures

Figure10.7 shows the cummulative percentage of full weight-bearing for closed and open tibial fractures.

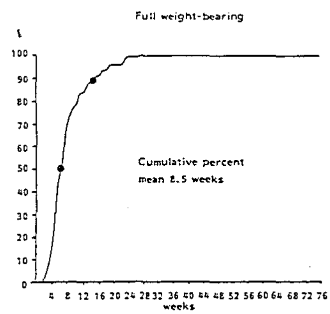


Figure 10.7 cumulative percentage curve of full weight-bearing for the whole series

Average full weight-bearing was accomplished in 8.5 weeks, median full weight bearing in 7 weeks and 90 per cent of all the patients could walk without support with full weight-bearing after 16 weeks.

As soon as the patient no longer suffers discomfort from weight-bearing in the brace, it can be removed for a daily shower.
If the patient can bear full weight, he or she can take part in all normal daily activities, such as riding a bicycle, driving a car, travelling by bus or tram and even taking part in non-contact sports, such as surfing and golf. Most young patients were able to swim and surf with the brace and could go to school on their own. White-collar workers were able to return to work.

Consolidation

Fracture consolidation was assessed on clinical and radiological grounds.

A fracture is clinically consolidated if there is no erythema and swelling at the fracture site and if there is no tenderness when the the fracture ends are tested for stability, by movement, during clinical examination.

Radiologically the fracture is consolidated if:

1) the fracture line in the periphery of the bone has disappeared
2) the soft callus has been replaced by sharp hard callus.If there was radiological as well as clinical consolidation, the patients were allowed to remove the brace. Many patients prefered to retain the brace during long walks or other exercises.

A cummulative percentage curve gives more information about the whole group than frequency distribution curves.

Figure 10.8 shows the cummulative percentage curve of consolidation time for both the open and closed fractures.

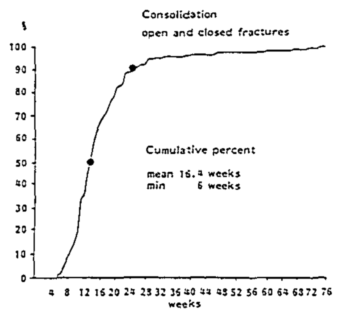


Figure 10.8 cumulative percentage of consoloidation time for the whole series

The average consolidation time for the whole group was 16.4 weeks with a minimum of 6 weeks and a maximum of 48 weeks; 53 per cent of the fractures were consolidated after 15 weeks and 91 per cent were consolidated after 26 weeks.

The non-unions were not included in the analysis of the average consolidation time.

Figure 10.9 shows the cumulative percentage curves of consolidation time for the open and closed fractures separately.

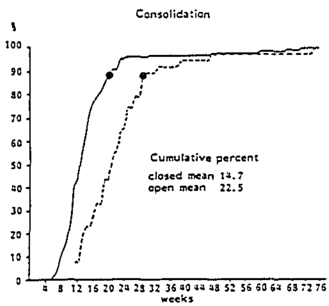


Figure 10.9 cumulative percentage curve for the consolidation time of closed and open fractures separately

The average consolidation time for closed fractures was 14.7 weeks with a range from 6 to 48 weeks. For open fractures, the mean consolidation time was 22.5 weeks with a range from 12 to 48 weeks.
In the group of patients with closed fractures, 54 per cent had healed after 14 weeks and 91.2 per cent after 21 weeks.

It was to be expected that the consolidation time for open fractures would be longer than for closed fractures.
In the group of patients with open fractures, 53.8 per cent had healed after 22 weeks and 98 per cent after 30 weeks.

Comparing cumulative percentage curves in Figures 10.7 and 10.9, it is apparent that full weight-bearing occurs before clinical and radiological consolidation. The cumulative percentage curve for full weight-bearing is further to the left than the one for consolidation.
If a tibial fracture is not treated by intramedullary nailing or a brace, the patient will be treated with a toe-to-groin plaster and will be seriously incapacitated during the healing of the fracture. It is, therefore very important for the patient that the correct time of consolidation should be determined.
After removal of the plaster, a long period of rehabilitation follows before the joints function normally again and atrophy of soft tissue and bone has disappeared.

For patients treated with internal fixation, the correct time of consolidation is important because that is the moment that they will be able to bear full weight without the risk of complications, such as plate fractures.
Patients treated with external fixation also like to know the date on which the pins can be removed. However, for patients treated with an intermedullary nail fixation or a brace, the time of consolidation is not the most important aspect. Both methods of treatment aim at early functional weight-bearing. The patients return rapidly to normal daily activities.

Hospitalization time

Hospitalization time was noted for the open and closed fracture group. Average hospitalization time was 10 days with a maximum of 72 days (Figure 10.10).

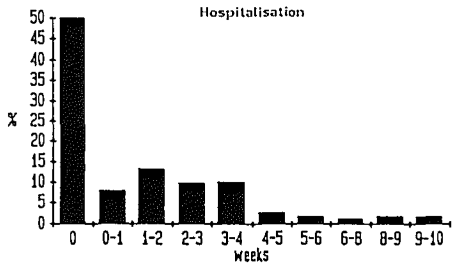


Figure 10.10 hospitalization time of the whole series

Correction of the fracture position after weight-bearing

Correction of the position of the fracture in the brace was necessary in 4 patients. In one case, the brace was removed and a plaster cast was applied after correction of the angulation.

On 4 occasions, a valgus deformity was completely corrected by means of a pad applied inside the brace at the apex of the angulation. Special care must be taken during the application of these pads inside the brace. There is a chance that the patient may develop a pressure ulcer, so weekly skin examination is necessary and the patient should be instructed accordingly.

CHAPTER 11

COMPLICATIONS

During the treatment of tibial fractures, complications are sometimes unavoidable. How serious these complications are, depends on the extent of the external trauma. The degree of soft tissue injury plays an especially important role in the healing of fractures. A complicated grade III fracture of the tibia has more chance of developing a non-union or osteomyelitis than a closed spiral fracture. [66]

The complications can vary from skin irritation, loss of function of the knee, ankle and subtalar joint to non union, chronic osteomyelitis and amputation [9,21,35,43,48,76,79,95,119,137,141].

Prolonged immobilisation of a fractured tibia in a toe-to-groin plaster, is often associated with muscle wasting, knee, ankle and subtalar stiffness, particularly when weight-bearing is avoided for some weeks after the accident.
Rehabilitation constitutes a real problem except in young and active patients. [45]

Despite the progress in medicine,the fear of osteomyelitis has not yet disappeared and the results of osteomyelitis can still be disastrous. Cachexia, sepsis, myocarditis and mental retardation have been reported following osteomyelitis. [23,140]

Long hospitalisation, with multiple operations, can cause disruptions of family and social ties.
Furthermore the complications may have serious financial consequences for the patient and his family. [119]

The incidence of osteomyelitis is increased particularly following limb-saving surgery in serious injuries of the extremities and to some extent by the increased tendency towards open treatment of closed fractures.

The rate of consolidation is often a measure of the success of the treatment which is applied. [5,8,10,11,13,20,28,34,42,51,60,67,71,72, 77,96,117,123,131].

Authors who have reported on fractures treated without internal fixation used the standard definition of clinical union:

- absence of local tenderness
- absence of mobility and pain on stress
- the ability of the patient to commence weight-bearing on the supported leg
- mature bridging callus visible on the X-rays

Authors who have reported on fractures treated by internal fixation relied more on radiological signs for assessing the state of union.

Opinions on what constitutes delayed union and non-union vary within wide limits. Some define a fracture which has not consolidated as a delayed union after 20 weeks and others after 26 weeks. [6,33,66,99,122,141].
We applied the definition according to Sarmiento. Delayed union was diagnosed after 26 weeks in patients in whom no active bone repair was evident on X-rays and in whom movement and pain were present at the fracture side on clinical testing. Non-union was diagnosed if no sign of clinical and radioligical consolidation was seen after 52 weeks.

Non-union of the tibia has long been, and continues to be, a significant clinical challenge. Many varied surgical procedures have been advocated to deal with delayed or non-union of a fracture of the tibia. Bone grafting, with or without internal fixation, has been the standard form of treatment for a definite non-union of the tibia. [38,39,53,62,89,90]
Fibular osteotomy followed by weight-bearing has also been a successful treatment [33].
Recently, electrical biophysical enhancement of fracture healing for the treatment of non-union has been advocated, and the results appear to be highly satisfactory. [16,17,48,121]

In this series, the majority of complications were moderate. The Serious complications to be discussed below are delayed union, non-union and refracture.

Delayed union
Delayed union was observed in 5 fractures (2.8 per cent: 3 closed and 2 open fractures). These healed after fibula osteotomy in 4 patients and in one patient after internal fixation.

Non-union
Three patients (1.7 per cent) developed a non-union. Two fractures were open, one closed.
One middle-aged patient still has a radiological non-union, but he is not experiencing problems with his leg and plays table tennis matches for veterans.

Refractures
In three patients, refracture occured after moderate trauma. In one patient, the fracture was treated with internal fixation.

Less serious complications

Sequestrectomy
One patient, with an open fracture, developed soft tissue infection, which resolved after sequestrectomy.

Thrombo-embolism
The patients received prophylactic treatment against thrombosis (Marcoumar). As in Sarmiento's series, no clinical thrombosis was seen [100]. (It is very likely that early movement of the ankle and knee also plays an important role in avoiding thrombo-embolism).

The complications after conservative treatment with a toe-to-groin plaster for some five months, are well-known.
Prolonged immobilisation of a joint can cause alterations in the cartilage nutrition which may not be reversible and can lead to impairment of joint function.

The complications after internal fixation can be disastrous, because there is no alternative treatment other than reoperation.

In this series of 176 tibial fractures treated with a functional brace applied below the knee and early weight-bearing serious complications only occurred in 6.2 per cent: 1.7 per cent refractures, 2.8 per cent delayed union and 1.7 per cent non-unions.
All but one of these complications healed after fibulotomy, internal fixation, cancellous bone grafting and bracing.
In this series there was no deep infection with osteomyelitis.

Incidental complications

Patient C. 16 years, male

Open, grade one fracture of the right tibia, caused by a traffic accident. Severe pain, moderate swelling at the fracture site.

Fracture type	: transverse with fibular fracture
Fracture level	: middle third
Primary treatment	: external fixation for 8 weeks
Application of brace	: after 8 weeks; weight-bearing 50 kg. for 4 weeks
Full weight bearing	: after 9 weeks
Hospitalization time	: 35 days

Progress

Twelve weeks after the trauma, the brace was removed assuming consolidation of the fracture. There was a small varus angulation.
Eighteen weeks after the trauma, the varus angulation was twelve degrees. This was treated by fibular osteotomy and correction of the deformity by wedging the toe-to groin plaster which was applied for two weeks. After this the original brace was reapplied. At that time, the patient could walk without crutches and with full weight-bearing. After 40 weeks, the brace was removed. Hospitalisation time was 35 days. At follow-up 2 years and 8 months after the trauma, he was free from pain in the right leg, had no oedema, normal function of the ankle and knee and his walking distance was unlimited.
Varus angulation was 5 degrees. Radiological and clinical shortening was less than 3 mm.

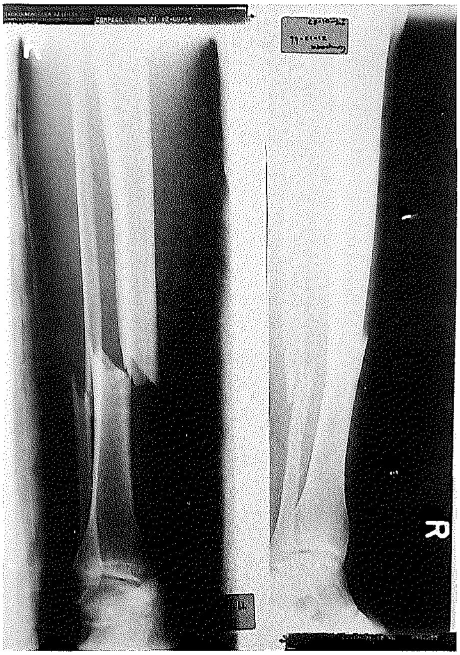
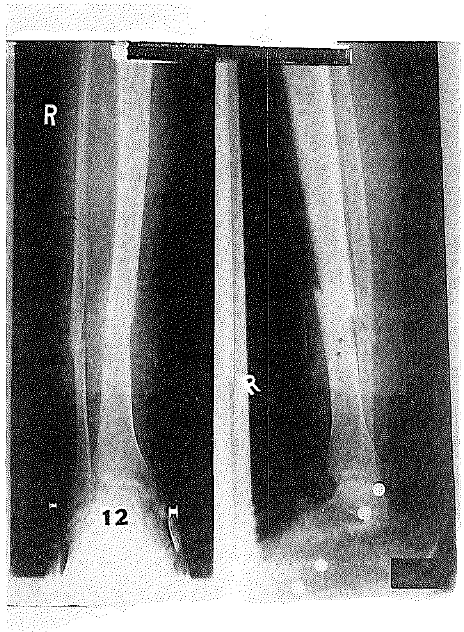
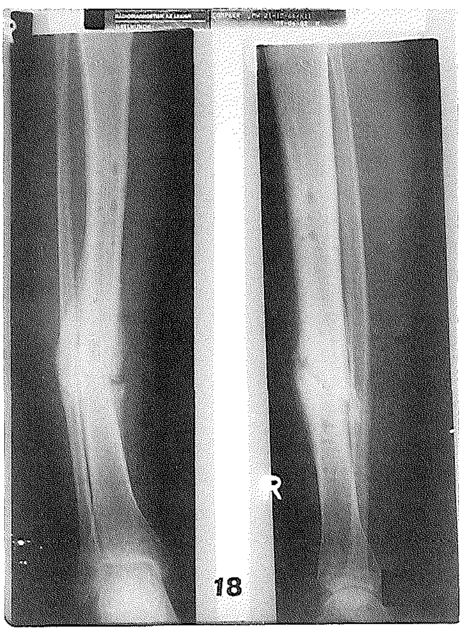


Figure 11.1 a. *transverse fracture, initial treatment with external fixation; brace applied after six weeks*

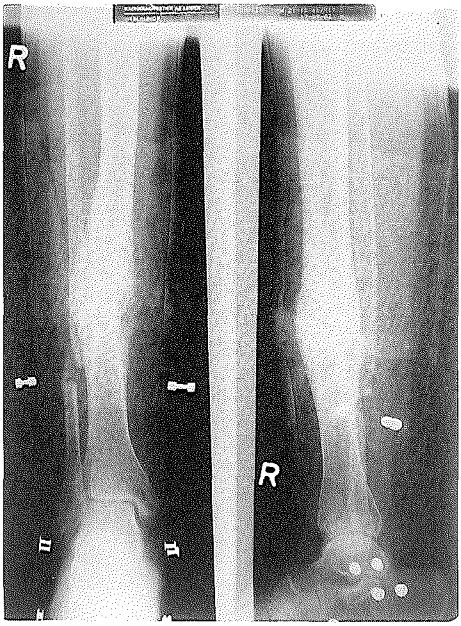


b. *brace removed twelve weeks post-trauma*

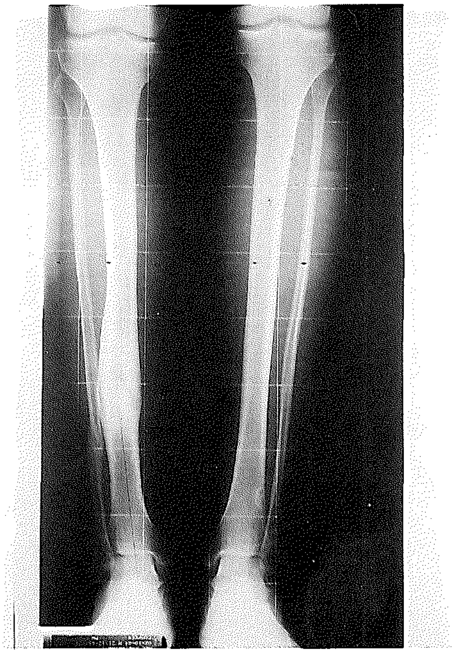


c. *Varus angulation of twelve degrees eighteen weeks post-trauma.*

d. *Correction of the deformity by fibular osteotomy; toe-to-groin plaster applied for two weeks*



e. the fracture in the brace after fibulotomy



f. healed fracture at 40 weeks

Patient B, 18 years, female.

Closed fracture of the right tibia caused by a traffic accident. Severe pain and swelling at the fracture site.

Fracture type	: comminuted with fibular fracture
Fracture level	: middle third
Primary treatment	: traction and toe-to groin plaster
Primary shortening	: 2 cm
Application of the brace	: after 4 weeks, weight- bearing 40 kg.
Full weight-bearing	: after eight weeks.
Hospitalization time	: 27 days

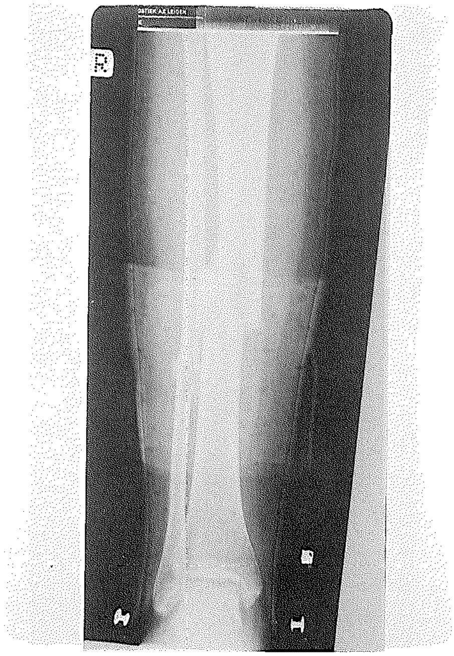
Progress

The patient could walk without crutches and pain, bearing full weight 22 weeks after the trauma. There was no apparent increase in radiological and clinical consolidation at 26 weeks. This was treated by fibular osteotomy and the original brace was reapplied. The brace was removed after radiological and clinical consolidation at 48 weeks. Hospitalisation time was 27 days.

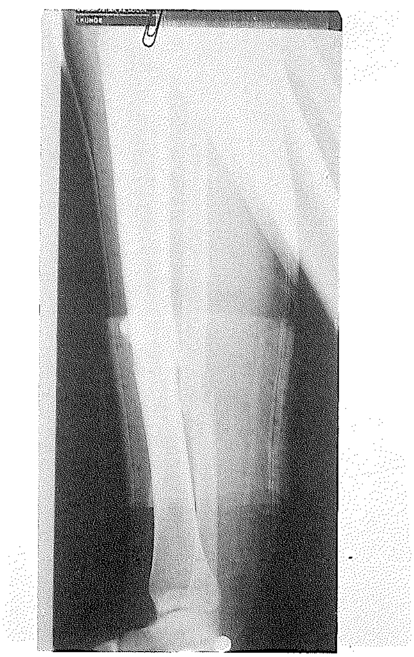
At follow-up, 2 years and 8 months after the trauma, she had normal function of the knee, ankle and subtalar joint. She had no pain or oedema of the leg, her walking distance was unlimited with a normal gait.

Radiologically and clinically there was no angulation and the shortening was 5 mm.

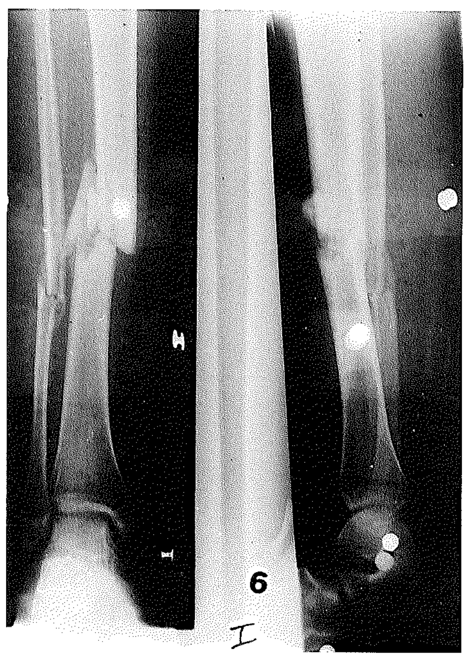
Figure 11.2 a. comminuted fracture of the tibia and fibula



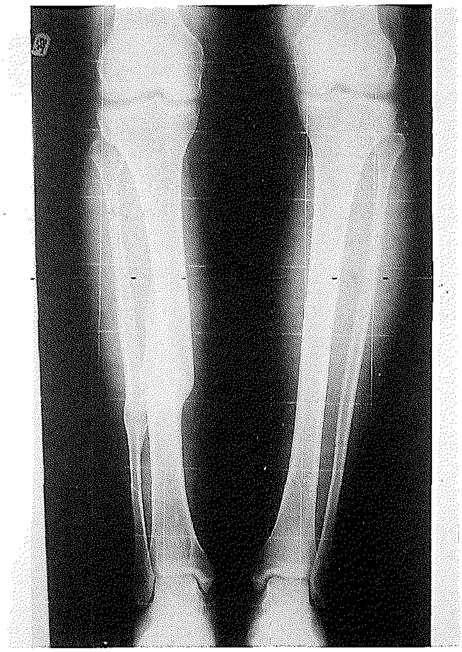
b. application of the brace after 4 weeks, AP view



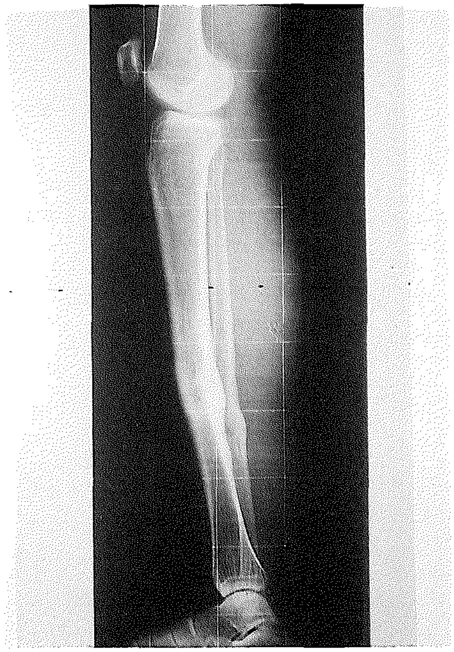
c. lateral view



d. X-rays six weeks after the initial trauma



e. after fibular osteotomy, the fracture healed at 48 weeks



f. lateral view

CHAPTER 12

MALALIGNMENT

Angulation and shortening

The early recognition of unacceptable deformities during the treatment of fractures, demands adequate surgical or non-surgical treatment for correcting the deformities.
A tibial fracture with unacceptable shortening must be lengthened by manipulation, internal fixation, traction or external fixation.
The same applies to unacceptable angulation or rotation.
The initial shortening of a tibial fracture depends on the soft tissue injury. Open fractures usually have a greater amount of initial shortening than closed ones. Closed spiral fractures are rarely complicated by shortening. Transverse fractures are usually stable and have no tendency towards shortening or angulation after adequate reduction.
An oblique fracture, caused by a fall from a height, often suffers from initial shortening, because of stripping of the periosteum and interosseus membrane. In spite of this soft tissue damage, the shortening does not increase further during weight-bearing. Fractures with an unacceptable amount of shortening should be treated by traction, internal fixation or external fixation.
An oblique fracture with unacceptable initial shortening should not be reduced by manipulation, because after weight-bearing and muscle action, the fracture ends return to the initial position. Spiral fractures caused by torsion trauma are fairly stable, because of the small amount of soft tissue injury. They are frequently seen in the lower third of the tibia.

A comminuted tibial and fibular fracture, caused by crush injury, is often associated with soft tissue trauma which does not hamper the intrinsic stability of the fracture, because the soft tissues are not torn away from the bone.

The fractures usually have an acceptable degree of shortening which does not increase after functional weight-bearing.
During conservative treatment of fractures in traction, one should aim for minimal shortening of about 5 mm [12]. Distraction of the fracture often results in delayed union.
If a tibia is shortened by less than 10 mm by overriding of the fragments this is not followed by difficulties with walking,
for example, limping. As stated above in this series, a shortening of less than 10 mm was regarded to be acceptable.

All measurements were obtained by scanography. The patient was placed in front of a cassette containing a single film and both limbs were X-rayed simultaneously, from just above the knee joint to the ankles. All the X-rays were taken while the patient was bearing full weight. The distance between the tibia and the X-ray film taken in this way was 13 cm, so enlargement of the tibia on the X-ray was 6 per cent. The distance between the X-ray plate and the tube was 3 metres. Accurate assessment to within 2 mm was possible using the midpoints of the joint space of the knee and ankle as reference points. The X-rays were taken with 80 kv and 64 mm A.S.

An acceptable amount of shortening of less than 10 mm was found in 96 per cent. During brace treatment, the shortening increased in 10 cases. The final shortening is shown in Figure 12.1. In 3 per cent of the fractures, the shortening before treatment of less than 10 mm increased to 10 mm during brace treatment. The maximum amount of shortening was 15 mm.

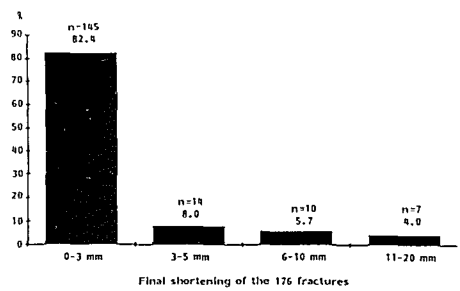


Figure 12.1 final shortening in the whole series

Angulation deformities

Fractures of the lower limb have a tendency to heal in varus position. Fractures of the femoral neck, especially medial adduction fractures, heal in varus which leads to a noticeable difference in leg length, if they are not fixed by means of an operation in valgus position. [139]
Femoral shaft fractures treated conservatively also have a tendency to heal in varus position because of the strong abductor attachment to the greater trochanter and the insertion of the adductors on the medial side of the distal portion of the femur.
The conservative treatment of femoral fractures should therefore be in valgus position. [45,80] A fracture which has healed in varus position is cosmetically unacceptable and leads to a difference in leg length and early knee complaints.
The tibia has varus bowing in the middle third, because of its anatomical standard.

Tibial fractures where the fibula is intact, have a tendency to heal in varus, because during weight-bearing the lateral condyle is supported by the intact fibula, whereas the medial condyle is not. This results in varus moment at the knee. Fractures in the distal part of the tibia sometimes heal with recurvatum deformities. This is often the result of a faulty plaster technique, in which the fracture is reduced and plastered while the knee is in extension. If the horizontal planes through the knee joint and the ankle joint are parallel, arthrosis of the ankle joint is not to be expected.
On the whole, it is assumed that angulation deformities of less than five degrees in the tibia do not lead to functional or cosmetic disability and to ankle arthrosis in future life.
Reynold described five tibial fractures in children which united in fifteen degrees or more of either varus or valgus angulation. All these fractures were in the distal half of the bone and in all the cases the degree of angulation was gradually reduced during the course of remodelling. [91]

Because of the anatomical form of the tibia with varus bowing in the middle third, a small varus deviation will be more difficult to assess clinically than a small valgus deviation.
In this series, therefore, the aim was to achieve a small varus deviation rather than a small valgus one. However, the goal was always anatomical repositioning.

As described above one of the functions of the brace was to absorb the pull push torsion and internal and external curvation transmission and thus prevent their influence on fracture healing.

The varus, valgus, apex anterior and apex posterior angulation deformities which were considered to be acceptable for the open and closed fractures were compared with the ultimate angulation deformities for open and closed fractures.

The final varus, valgus, apex posterior and apex anterior deformities are shown in Figures 12.2, 12.3, 12.4 and 12.5.

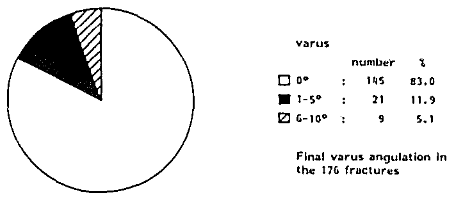


Figure 12.2 *final varus angulation in the 176 fractures*

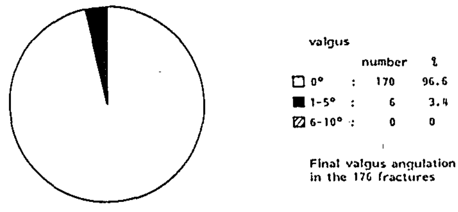


Figure 12.3 *final valgus angulation in the 176 fractures*

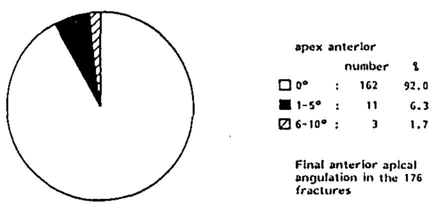


Figure 12.4 *final anterior apical angulation in the 176 fractures*

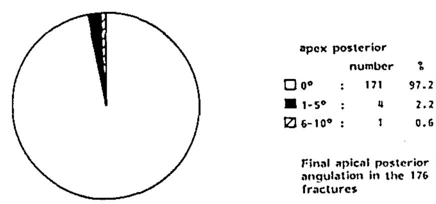


Figure 12.5 *final apical posterior angualation in the 176 fractures*

Closed fractures (n = 137)

Varus:

117 fractures in varus did not alter their position
9 fractures improved
11 fractures worsened: from 0° to 6° varus
from 0° to 10° varus
from 2° to 7° varus
from 6° to 10° varus
In 7 cases the change in position was less than 5° varus.

Valgus:

Valgus angulation did not appear in 130 cases during brace treatment. In one case, the angulation had not consolidated and changed from 2° to 4°. In 6 cases, the position was improved. In three patients the angulation was improved by a pad at the apex of the deformity.

Apex anterior:

In 130 fractures the position was checked. In most cases, the position improved but in 2 there was an increase in angulation of less than 5°.

Apex posterior:

There were no apex posterior deformities.

Open fractures:

The 39 open fractures were also checked to see whether the position of the fracture had changed during bracing.

Varus

In 32 cases the tolerated position was unchanged. It had improved in 3 cases and worsened in 4.
In all cases, the ultimate varus deviation was less than 5°.

Valgus

In 34 cases the position was unchanged, in 4 it deteriorated and in 1 it improved.

Apex anterior

In 33 cases, the position was unchanged and in 6 the position had deteriorated.

Apex posterior

In 37 cases, the position remained the same and in two the position worsened, in one case from 0 to 7°.

In both the open and closed fractures, it was striking that the acceptable degree of varus, valgus, apex anterior and apex posterior positions were preserved by the brace.

CHAPTER 13

FUNCTIONAL RESULTS

After lengthy plaster immobilisation of the joints above and below the fracture, one often sees stiffness of those joints after removal of the plaster. Rehabilitation for these patients usually takes a long time because of atrophy of the calf and femoral muscles.[27] By exchanging the plaster for a brace at an early stage, the joints are only immobilised for a short time. The function of the affected limb remains normal, even during the healing process.

After the fracture had consolidated and the brace had been removed, the knee function of the left and right legs was compared and the difference measured in degrees. Ankle function was measured as well as subtalar mobility. The mobility of the ankle joint was measured while the patient sat with both legs dangling over the edge of the table and while squatting with the heel on the ground. The difference was expressed in degrees.

Subtalar inversion mobility (the movement of the heel medially) and eversion mobility (the movement of the heel laterally) are important functional movements, because it is through these movements that the foot adapts itself to uneven surfaces during walking. The most important function of the subtalar joint is to keep the balance during walking.
The mobility of the left and right feet was compared and expressed as "the same" or "worse".

The calf circumferences of the left and right legs were compared as well. After removal of the brace there was impairment of knee function in two patients, compared to the contralateral side: in one case of less than fifteen degrees and in the other of more than fifteen degrees. In eleven cases, dorsiflexion in the talocrural joint was less than in the contralateral ankle. Of these, two were less than fifteen degrees.
In five cases, plantarflexion was impaired compared to the contralateral joint. Of these, four were less than fifteen degrees. In fifteen cases, subtalar mobility was less than the contralateral side.

Although the ankle was mobilised at an early stage and early weight-bearing was pursued, calf atrophy was present in ninety-two per cent after removal of the brace. The average was 2.4 cm.

The functional criteria mentioned above were also measured at follow-up one year after the fractures. At follow-up all the patients had normal function of the knee without flexion or extension impairment. In ten cases, dorsi-flexion was still impaired, but by less than fifteen degrees. In six cases, plantar flexion was impaired (Table 13.1.).

	after removal of the brace	at follow-up
Knee function impairment	2	0
Dorsoflexion impairment of the ankle	11	10
Plantar flexion impairment of the ankle	5	6
Subtalar mobility impairment	15	11
Calf atrophy none	14	169
1-4 cm	159	7
5 cm	3	-

table 13.1

Quadriceps atrophy was found in five patients. Seven patients still had calf atrophy, compared to the contralateral leg. In eleven cases, subtalar mobility was limited, compared to the contralateral side.
By using functional brace treatment, impairment of the mobility of the joints was almost completely prevented.

CHAPTER 14

CLINICAL FEATURES AND RESULTS IN THE SIX FRACTURE TYPES

As mentioned above, the fracture types were classified into six groups. The data regarding the injury, treatment, full weight- bearing, return to ADL, consolidation and complications are shown in table 14.2. The follow-up date are presented in table 14.3. The criteria on which the final results were evaluated are presented in table 14.1, in accordance with Johner [54].

criteria for evaluation of final results

	Excellent	Good	Fair	Poor
Non-union, osteitis, amputation	none	none	none	yes
Neurovascular disturbance	none	minimal	moderate	severe
Deformity				
varus/valgus	none	2°-5°	6°-10°	>10°
apex anterior/apex posterior	0°-5°	6°-10°	11°-20°	>20°
shortening	0-5 mm	6-10 mm	11-20 mm	>20 mm
Mobility				
knee	normal	>80%	>75%	<75%
ankle	normal	>75%	>50%	<50%
subtalar joint	>75%	>50%	<50%	
Pain	none	occasional	moderate	severe
Gait	normal	normal	insigficant limp	significant limp
Strenuous activity	possible	limited	severely	impossible

Tablel 14.1

Transverse fractures

Transverse fractures are often the result of direct force. These fractures are not prone to displacement with plaster immobilisation once adequate reduction has been obtained. Occasionally, satisfactory closed reduction cannot be achieved or maintained because of soft tissue interposition. In operative fracture treatment, these fractures are very suitable for closed or open nailing. In this group, most of the fractures were closed and caused by traffic accidents and sport, mainly soccer. Primary treatment mainly comprised a toe-to-groin plaster cast. The brace was applied after an average of twenty three days. Full weight-bearing was possible after an average of 6.6 weeks. Hospitalisation time was 5 days. Mean consolidation time was 14.6 weeks (table 14.2). One delayed union developed, which healed after fibulotomy. At follow-up, three patients had varus angulation of 5 degrees and one had an apex anterior deformity of 5 degrees. The final results were excellent in 89 per cent, good in 7 per cent and fair in 4 per cent (table 14.3).

Oblique fractures

In this series, eight of the 46 oblique fractures were open fractures. Most of the fractures were caused by a traffic accident or a fall from a height.

In five cases the primary treatment was calcaneal traction; 76 per cent had a toe-to-groin plaster for an average of 33 days; 76 per cent of the tibial fractures were associated with a fibular fracture. Full weight-bearing was possible after an average of 70 days. Hospitalisation time was 10 days (average) (table 14.2). Two delayed unions developed and one non-union. Both the delayed unions healed after fibulotomy. The non-union is still a radiological non-union without inconvenience to the patient (as described above). The final shortening was greatest in this group; eleven patients had a shortening of more than five millimeters. Only one patient had a varus deformity of 5°. The final results in this group of fractures was excellent in 52 per cent, good in 39 per cent and fair in 9 per cent table (14.3).

data concerning injury, treatment, hospitalisation and complication rate

	Fracture Group Transverse	Oblique	Spiral	Commi-nuted	Segmental	Green-stick
No.Fractures	57	46	22	42	5	4
Average	22	30	29	27	39	13
Accident						
- Traffic	25	19	4	28	2	3
- Sport	29	9	11	9	1	1
- Fall from height 2	10	5	1	-	-	
- Others	1	8	2	4	2	
- Closed	53	38	20	19	3	4
Open	4	8	2	23	2	-
- First degree	3	2	2	12	21	-
- Second degree	-	5	-	9	21	-
- Third degree	1	1	-	2	-	1
Primary treatment						
- Reposition	18	19	7	21	-	-
- Calcaneal tract.	5	1	9	2	-	
- Toe-to-groin plaster	55	35	20	17	2	4
- Wedging of the plaster	5	4	3	6	-	-
- External fixation	2	8	1	16	1	-
Localisation						
- Proximimal	1	3	-	2	1	3
- Middle	39	23	10	31	4	1
- Distal	17	20	11	9	-	-
Fibular fracture	25	35	13	33	4	1
Application of brace post-accident (days average)	23	33	28	44	26	15
Weight-bearing after applica tion of brace (kg)	39	35	38	34	45	20
Full weight bearing (weeks)	6.6	9.9	6.9	11.3	9.2	5.5
Return to ADL (weeks)	12	18	8	25	16	6
Days in hospital	5	10	3	22	23	8
Consolidation (weeks)	14.6	19.5	13.2	22.4	19.8	9.7
Complications						
- Refractures	2	1	-	-	-	-
- Delayed union	1	2	-	2	-	
- Non-union	1	-	1	-	-	
- Skin maceration	1	1				
Secondary operations						
- Fibulotomy	1	2	2			
- Internal fix.	1	2				
- Bone grafting	2					
- Sequestrectomy	1					

table 14.2

FOLLOW-UP DATA (min. one year after trauma)

	Transverse	Oblique	Spiral	Commi-nuted	Segmental	Green-stick	No.	%
No. of patients examined at follow-up	57	46	22	42	5	4	176	100
General complications								
- None	57	46	22	42	5	4	176	100
Local complications								
- None	57	45	22	42	5	4	175	99.4
- Osteïtis	-	-	-	-	-	-	-	-
- Non-union	-	1	-	-	-	-	1	0.6
- Infected Non-union	-	-	-	-	-	-		
- Amputation	-	-	-	-	-	-		
Malalignment								
- Shortening of 5 mm	-	3	1	3	-	-	7	3.9
- Shortening of 10 mm	-	8	-	2	-	-	10	5.7
- Shortening of 10 mm	-	3	-	3	1	-	7	3.9
- Varus of 5°	3	1	-	7	-	-	11	6.25
- Valgus of 5°	-	-	-	-	-	-		
- Apex anterior of 5°	1	1	-	2	-	-	4	2.3
- Apex posterior of 5°	-	-	-	1	-	-	1	0.6
- Rotation	-	-	-	-	-	-		
Final results								
- Excellent left/right	51	24	16	25	4	4	124	70.5
- Good	4	18	6	11	-	-	39	22.1
- Fair	2	4	-	6	1	-	13	7.4
- Poor	-	-	-	-	-	-		

table 14.3

Spiral fractures

In this series six of the twenty-two spiral fractures were caused by sport, ski injuries or falls in the street or at home. Two fractures were open; in one the primary treatment was external fixation. The localisation was distributed equally in the middle and lower third of the tibia. The brace was applied 28 days (average) after trauma (table 14.2). Full weight-bearing was possible after an average of 8 weeks. The average time of consolidation was 13.2 weeks for this group. There were no complications at all, but at follow-up, one patient had a shortening of 5 mm. The final results in this group of fractures was excellent in 74.5 per cent and good in the remaining 25.5 per cent (table 14.3).

Comminuted fractures

Comminuted fractures were mostly caused by traffic accidents (16 per cent). They appear to be produced by a bending moment with axial loading. Nine patients sustained a comminuted fracture due to sport. Of the 42 fractures, 23 were open and 19 closed. For nine patients, the primary treatment before application of the brace, was calcaneal traction, for 17 patients it comprised plaster. In 6 cases, the plaster was wedged to achieve proper alignment.
In 16 patients external fixation was the primary treatment (table 14.2).
In 73.8 per cent, the fracture was localised in the middle one third of the tibia.
The average application time of the brace was after 44 days. Full weight-bearing was achieved after 11.3 weeks. Average stay in hospital was 24 days. Consolidation time was 22.4 weeks; 2 delayed unions developed. Both healed after a fibulectomy. Two fractures resulted in a non-union. Both healed after internal fixation and cancellous grafting. At follow-up, there were no local complications. However, there were more malalignments than in any other group. In 3 patients, there was a shortening of 5 mm, in 2 patients a shortening of between 5 and 10 mm and in 3 patients the shortening was more than 10 mm. Seven patients had varus malalignment of 5° and 1 an apex posterior deformity of 5°. The final results for the comminuted fractures were excllent in 59.5 per cent, good in 26.1 per cent and fair in 14.4 per cent (table 14.3).

Segmental fractures

In cases with a two-level fracture of the tibia, reduction of the fracture is difficult and maintenance of good alignment is even more so. This series only included five segmental fractures. Mean age was highest in this group. Two fractures were caused by a traffic accident, one by sport and the two others by miscellaneous accidents. Primary treatment was calcaneal traction in two patients, external fixation in one and plaster cast immobilisation in two. The brace was applied after an average of 26 days. Full weight-bearing was possible after an average of 9.2 weeks. Mean consolidation time was 19.8 weeks (table 14.2).
At follow-up, all the fractures had healed without general or local complications. One patient had radiological and clinical shortening of more than 10 mm. The final result in 4 patients was excellent and in one patient fair (table 14.3).

Greenstick fractures

Greenstick fractures are easy to manage with conservative treatment. They are treated with a functional brace applied below the knee after one week. Average consolidation time was 9.7 weeks. At follow-up, the results of the four fractures was excellent, as had been expected (table 14.3).

CHAPTER 15

COMPARISON OF CONSOLIDATION TIME WITH THE LITERATURE

It is almost impossible to compare series concerning the treatment of tibial fractures, because the patient populations, the nature of the trauma and the soft tissue lesions differ too much to draw definite conclusions.

There are few publications in which the consolidation time of the fracture is shown in a cumulative percentage curve. [7]
In order to compare the data from our series to those published by Juttman in 1978, the frequency distribution curve was converted into a cumulative percentage curve.

In Juttman's series the mean consolidation time was 17.8 weeks and in this series, 16.4 weeks. [56]

In principles the primary treatment for both series was the same. Juttman treated the patients with a near-skin cast, in accordance with Dehne's method.

In figure 15.1, the cumulative percentage curves are shown in one figure. There is hardly any difference between the curves. The mean consolidation time was the

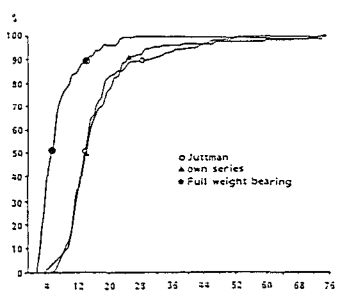


Figure 15.1 cumulative percentage curves of the consolidation time in Juttman's and the present series and the curve of the interval until full weight-bearing.

same in both series. After fifteen weeks, Jutmann's curve bows a little to the right, possibly due to the fact that the open fractures were treated primarily with a near-skin cast.

In his series, Juttman did not state the time when the patients walked with full weight-bearing and without crutches. In figure 15.1, the cumulative full weight-bearing curve of this series, inclines strongly to the left compared to the consolidation curves. Patients in this series were back to normal daily activities earlier than those in Juttman's series.

Compared to the series published by Ellis, Nicoll, Hamza et al, (Figure .2) Brown and Urban, Weissman et al and Burwell, our cumulative percentage curve corresponds with the curves presented by Ellis, Nicoll, Hamza et al and with the moderate group in Burwell's series. [19,22,35,84,142]

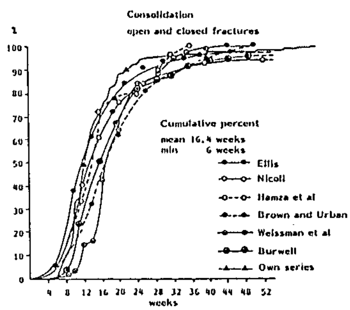


Figure 15.2 comparison of our cumulative percentage curves with series in the literature

CHAPTER 16

FUNCTIONAL BRACING VERSUS INTERNAL FIXATION

The controversy that surrounds the treatment of fractures of the tibial shaft, will still exist in the future because reports are not comparable. Data concerning injury, treatment, full weight-bearing, ability to work, complications and the final results for different groups of fractures are not often presented in publications on the treatment of tibial fractures. In our series the fractures were divided into six types:

1. Transverse
2. Oblique
3. Spiral
4. Comminuted
5. Segmental
6. Greenstick

All data mentioned above are presented.

Johner and Wruhs presented a series of tibial fractures treated by rigid internal fixation (1983). They classified the fractures into nine main groups.

1. A1 Spiral fractures
2. A2 Oblique fractures
3. A3 Transverse fractures
4. B1 Spiral fractures with butterfly fragment
5. B2 Transverse fractures with one butterfly fragment
6. B3 Fractures with several butterfly fragments
7. C1 Comminuted
8. C2 Segmental fractures
9. C3 Crush fractures

There is only one study in the literature the one by Johner and Wruhs published in 1983, which incorporated all the data described in table 14.1, 14.2 and 14.3 in the previous chapter. A comparison between the main types in this series and those in Johner and Wruhs' study is now possible (table 16.1). For practical reasons, our series is called the brace group; the series described by Johner and Wruhs is the IF (internal fixation) group. For the evaluation of these series, the same criteria were used.

	BRACE				INTERNAL FIXATION				
	Transverse	spiral	oblique	com.	A3	A1	A2	B3+C2	B3
No. of fractures	57	22	46	47	31	39	26	66	43
Average age years	22	29	30	33	27	41	39	40	39
Accident									
- traffic	25	4	19	30	14	5	20	48	26
- sport	29	11	9	10	7	13	3	13	12
- others	3	7	18	7	10	21	3	5	5
Localisation									
- proximal	1	3	3	2	2	5	21	13	
- middle	39	10	23	35	16	5	10	19	10
- distal	17	11	20	9	13	32	11	25	20
Skin lesion									
- first degree	3	2	2	11	8	2	5	12	6
- second degree	-	5	10	2		5	12	8	
- third degree	1		1	4			1	1	
Days in hospital									
average	15	3	10	22	23	8	15	30	17
Local complications									
none	55	22	44	45	24	39	23	44	30
non-union			2	1				2	2
osteitis					1			3	1
soft tissue									
infection				1	2		1	5	4
infected non-union					1			2	
implant failure				1			6		3
refracture	2		1	2		1	2		1
Full weight-									
bearing after									
0 - 5 wks	25	9	8	5	5		2	2	1
6 -11 wks	26	11	26	24	10	14	7	3	2
12-18 wks	6	2	7	13	8	17	5	24	17
18 wks			5	5	7	1	7	28	16
Malalignment									
Shortening of 5 mm		1	11	8			1	2	
Valgus/Varus 5°	3		1	7	2	2		9	5
Apex ant/post 5°	1		1	3		2		3	
Return to work									
full-time after									
(days)	84	56	126	170	104	100	173	224	221
Final results									
- excellent	51	16	24	29	15	24	7	12	8
- good	4	6	18	11	9	10	15	33	22
- fair	2		4	7	4	2	1	8	6
- poor					2		1	9	4

table 16.1: Follow-up data brace group and internal fixation group

TRANSVERSE FRACTURES IN THE BRACE GROUP VERSUS TRANSVERSE FRACTURES: (A3) IN THE INTERNAL FIXATION GROUP

The brace group was larger than the IF group. The localisation distribution for both groups was the same. In the brace group, there were 5 per cent grade one open fractures compared to 25 per cent in the IF group. Two per cent of the former group were grade three open fractures and six per cent of the IF group were grade two open fractures.

Hospitalisation time was far shorter in the brace group, even compared to the patients in the IF group who had no additional injury, see Table 16.2.

Local complications in the brace group were refractures (3.5 per cent), compared to 2.5 per cent in the IF group. The 12 per cent infection rate in the IF group was probably due to there being 30 per cent open fractures.

Early weight-bearing was achieved in the brace group: 45 per cent walked without crutches within 6 weeks; 90 per cent achieved full weight-bearing within 12 weeks, compared to 48 per cent in the IF group. There was no shortening of more than 5 mm in both groups.

Both groups had the same amount of varus/valgus and apex anterior/posterior deformities.

Excellent results were documented in 48 per cent of the IF group compared to 89 per cent in the brace group; 13 per cent in the IF group were fair against 4 per cent in the brace group. There were no poor results in the brace group.

	Hosp. time average in days	Full weight bear.within 12 weeks, (%of patients)	Ability to walk after days	Infect rate per cent.	Final results excel.+ good %	Consolidation time
Transverse fract.						
brace group	5	90	84	0	96	14.6
A3 IF group	23	48	104	12	77	-

table 16.2 comparison between the A3 fractures in the IF group and the transverse fractures in the brace group

SPIRAL FRACTURES IN THE BRACE GROUP VERSUS SPIRAL FRACTURES (A1) IN THE INTERNAL FIXATION GROUP

All the spiral fractures in the brace group were compared to the simple spiral fractures in the IF group. Spiral fractures are not as common in Holland as they are in Switzerland. (B1 fractures are seldom seen). The uniform method of internal fixation was lag screws for interfragmentary compression and an additional plate for protection.

The primary treatment of most of the spiral fractures in the brace group comprised a toe-to-groin plaster cast.

Average stay in hospital for the IF group was 8 days compared to 3 days for the brace group.

Full weight-bearing was possible within twelve weeks for 99 per cent of the brace group compared to 36 per cent of the IF, Table 16.3.

Shortening of 5 mm was noticed in 4.5 per cent of the brace group; there were no varus/valgus or apex anterior/posterior deformities in this group. In the IF group, there were 5 per cent varus/valgus deformities and the same percentage of apex anterior/posterior deformities.

The average interval until full-time work resumption was 56 days for the brace group compared to 100 days in the IF group.

The final results in the brace group were 100 per cent excellent or good compared to 87 per cent in the IF group.

	Hosp. time average in days	Full weight bear.within 12 weeks, (%of patients)	Ability to walk after days	Infect rate per cent.	Final results excel.+ good %	Consolidation time
Spiral fractures brace group	3	99	56	0	100	13.2
A1 IF group	8	36	100	0	87	-

table 16.3 comparison of the A1 fractures with our spiral fractures

OBLIQUE FRACTURES IN THE BRACE GROUP VERSUS OBLIQUE FRACTURES (A2) IN THE INTERNAL FIXATION GROUP

For comparison of the oblique fractures, the fractures in the brace group were compared with the simple A2 oblique fractures in the IF group. There were 11 open fractures in the IF group compared to eight in the brace group.
Average hospitalisation time was ten days for the brace group and 15 days for the IF group.
Local complications in the brace group were one non-union (radiological) and one refracture (4 per cent). In the IF group, there was one case of soft tissue infection and one refracture (8 per cent). Full weight-bearing was possible within twelve weeks for 74 per cent of the braced fractures and 35 per cent of the IF fractures (table 16.4).
Shortening of 5 mm was present in 24 per cent of the brace group and in 4 per cent of the IF group.
The average interval until full-time work resumption was 120 days for the brace group and 173 days for the IF group. Excellent or good results were achieved in 91 per cent of the brace group and in 84 per cent of the IF group; 4 per cent of the fractures treated with internal fixation had a poor result. In the IF group, the final results of 2 patients were not mentioned.

	Hosp. time average in days	Full weight bear.within 12 weeks, (%of patients)	Ability to work after days	Infect rate per cent.	Final results excel.+ good %	Consolidation time
Oblique fractures						
brace group	10	74	120	0	91	19.5
A2 IF group	15	35	173	4	84	-

table 16.4 comparison of the A2 fractures with our oblique fractures

COMMINUTED AND SEGMENTAL FRACTURES IN THE BRACE GROUP VERSUS COMMINUTED AND SEGMENTAL FRACTURES (B3 AND C2) IN THE INTERNAL FIXATION GROUP

The average age and the cause of the trauma were exactly the same for both groups. In the brace group, 59 per cent of the fractures were open as opposed to 37 per cent in the IF group.
Average hospitalisation time was 22 days for the brace group compared to 30 days for the IF group.
Two patients had local complications in the brace group: one a non-union which healed after central bone grafting + bracing and one had a soft tissue infection, which healed after sequestrectomy (4 per cent). Local complications in the IF group occured in one third of the fractures: 25 per cent comprised infections, 3 patients suffered from osteitis, 5 had a soft tissue infection and 4 an infected non-union.
Full weight-bearing was possible within 12 weeks for 8 per cent in the IF group, whereas 62 per cent of the brace group walked within 12 weeks without crutches. In the brace group, shortening of 5 mm occurred in 17 per cent, compared to 3 per cent in the IF group. Varus/valgus and apex anterior/posterior deformities were the same in both groups.
The interval until full-time work resumption was 224 days for the IF group compared with 170 days for the brace group (table 16.5).
Good and excellent results were seen in 85 per cent of the patients in the brace group and in 68 per cent in the IF group. Nine patients in the IF group had a poor result.

	Hosp. time average in days	Full weight bear.within 12 weeks, (%of patients)	Ability to work after days	Infect rate per cent.	Final results excel.+ good %	Consolidation time
Comminuted + seg fractures						
brace group	22	62	170	0.6	85	22.4
B3+C2 IF group	30	8	224	25	69	-

table 16.5 comparison of the B3 and C2 fractures to our comminued and segmental fractures

COMMINUTED AND SEGMENTAL FRACTURES IN THE BRACE GROUP VERSUS FRACTURES WITH SEVERAL BUTTERFLY FRAGMENTS (B3) OF THE INTERNAL FIXATION GROUP

When the comminuted and segmental fractures in the brace group were compared to only the B3 fractures in the IF group, the mechanism of trauma and the percentage of open and closed fractures were found to be identical. Average hospitalisation time was 17 days for the IF group and 22 days for the brace group (table 16.6).
Local complications in the IF group occurred in 28 per cent: infection rate was 16 per cent, 2 fractures developed a non-union and 3 had a refracture. Full weight-bearing was possible within 12 weeks for 7 per cent of the IF group.
In the IF group, the interval until full-time work resumption was at 221 days and excellent and good results were achieved in 30 patients (73 per cent).

	Hosp. time average in days	Full weight bear.within 12 weeks, % (%of patients)	Ability to walk after days	Infect rate per cent.	Final results excel.+ good %	Consolidation time
Comminuted + seg fractures						
brace group	22	61	170	2	85	22.4
B3 IF group	17	17	221	16	73	

table 16.6 comparison of the B3 fractures to our comminuted and segmental fractures

CHAPTER 17

THE INFLUENCE OF EARLY WEIGHT-BEARING ON CONSOLIDATION

The policy of early weight bearing for the treatment of fractures of the tibial shaft was introduced by Dehne et al in 1950 and the findings suggested that union occured earlier and with better functional results than delayed weight-bearing. Later reports confirmed these observations. [19, 124].
Functional below the knee bracing allows early weight bearing and early exercise of the joints. The role of functional weight bearing on the healing of the fractures has been described above.

The amount of weight bearing was measured during treatment and a note was made of the date on which the patient could walk, bearing full weight without crutches. To establish whether there is a correlation between early full weight bearing and the consolidation time, a comparison was made between full weight bearing and consolidation time for open and closed fractures.

To examine the correlation between the interval until full weight-bearing and the consolidation time, the patients with delayed union or non-union were excluded.

In the open fracture group the correlation was analysed in thirty five patients (Figure 17.1). Mean consolidation time = 10.8 + 0.85 x the full weight-bearing time ($r=0.71$, $p< 0.001$). This correlation remained valid after the age of the patients and the grade of the fracture had been taken into consideration and was proved by a multi variable technique (multiple regression).

For the closed fractures, the correlation was analysed in 133 fractures (Figure 17.2). Consolidation time in this group = 10.6 + 0.55 x the full weight-bearing time ($r=0.47$, $P< 0.001$). This correlation was also valid after of the age the patients had been taken into consideration.

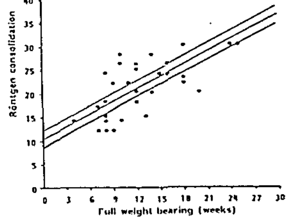


Figure 17.1 correlation between the date of full weight-bearing and consolidation time for the open fractures

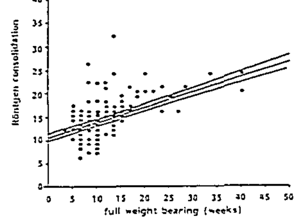


Figure 17.2 correlation between the date of full weight-bearing and consolidation time for the closed fractures

CASE REPORTS

Patient v.d. B., 19 years, male

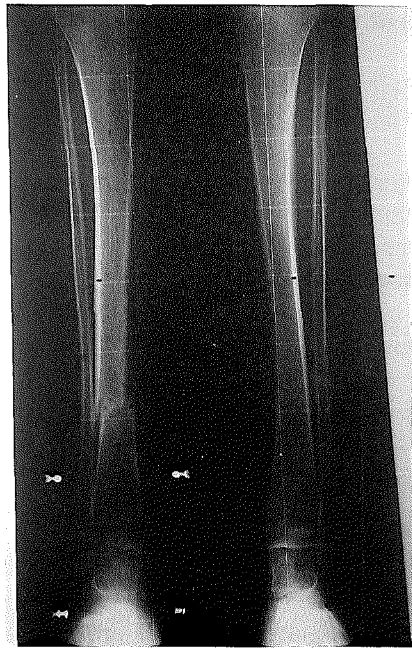
Closed fracture of the left tibia caused by a traffic accident, moderate pain and swelling at the fracture side.

Fracture type:	transverse with fibular fracture
Fracture level:	distal one third
Primary treatment:	reduction and toe-to-groin plaster
Application of brace:	after 35 days weight-bearing 35 kg.
Full weight-bearing:	9 weeks
Return to work:	9 weeks
Hospitalisation time:	7 days
Clinical and radiological consolidation:	19 weeks

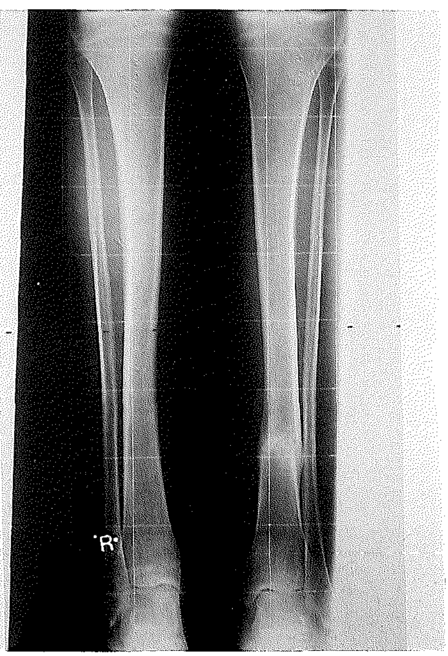
Progress:

After 4 weeks of plaster treatment, reduction because of a nine degree apex posterior deformity was necessary. After brace removal, complete function of the knee, ankle and subtalar joints were observed. There was 3 mm. calf atrophy.
At follow-up one and a half years after the trauma: no pain in the tibia, no oedema; walking and standing were unlimited.
Participating in the same sport at the same level as before the fracture. Radiological and clinical union was achieved with shortening of less than 5 mm.

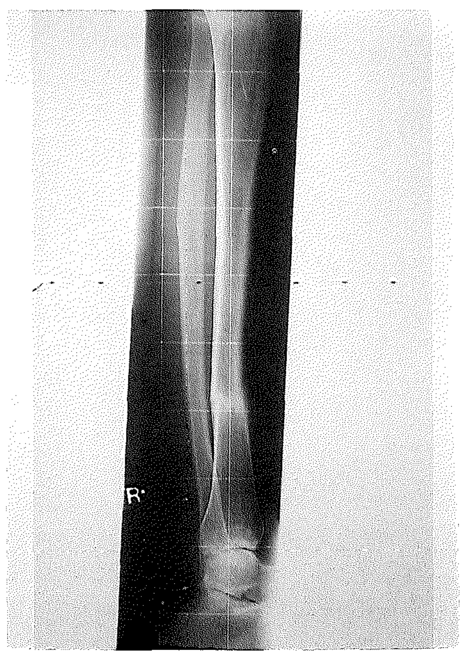
Figure 18.1 a. transverse fracture of the tibia with fibular fracture, AP view



b. X-ray AP view after bracing



c. healed fracture after 19 weeks, AP view



d. lateral view

Patient v.d. P., 17 years, female

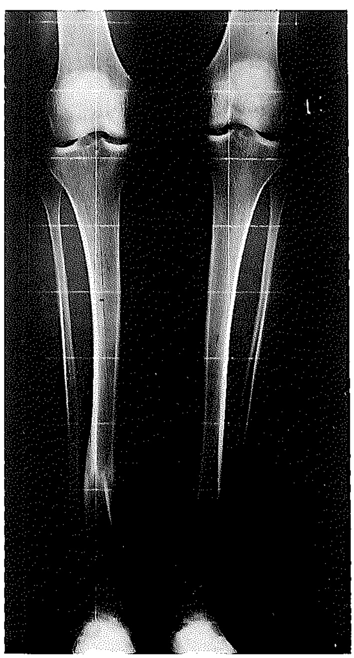
Open fracture of the right tibia caused by a traffic accident, wound of 5 cm. Severe pain and moderate swelling at the fracture site.

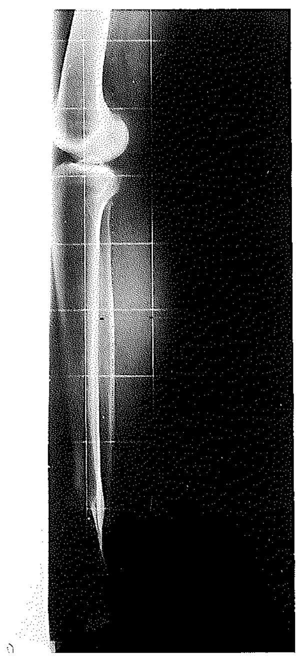
Fracture type:	transverse with fibular fracture
Fracture level:	distal one third
Primary displacement:	75 per cent
Primary treatment:	calcaneus traction and toe-to-groin plaster
Application of the brace:	after 21 days, weight-bearing 25 kg.
Full weight-bearing:	9 weeks
Hospitalisation time:	15 days
Clinical and radiological consolidation:	12 weeks

Progress
After brace removal, there was no calf atrophy. Normal function of the knee, ankle and subtalar joints. At follow-up 3 years after the trauma: no pain or oedema of the leg; standing and walking unlimited; participating in the same sport and work as before the accident.
Clinical and radiological union was achieved with shortening of 6 mm.

Figure18.2 a Transverse fracture of the tibia with fibular fracture.

b. X-rays after application of the brace





c. X-rays of the healed fracture at 12 weeks post-trauma; AP view

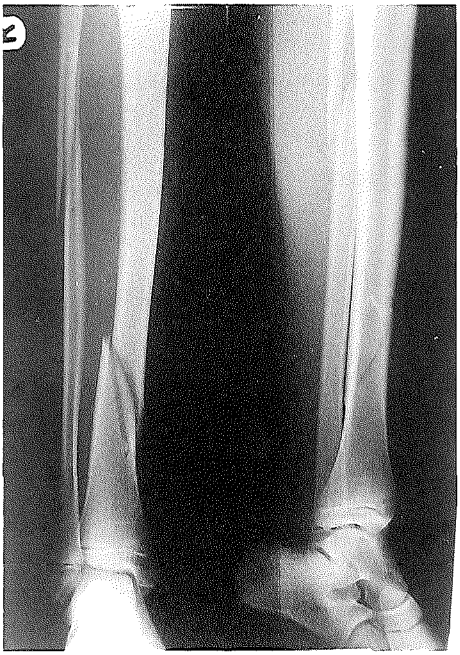
d. lateral view

Patient v.d. O, 14 years, male

Closed fracture of the right tibia with minimal pain and swelling

Fracture type:	spiral with fibular fracture
Fracture level:	distal one third
Primary dislocation:	10 per cent
Primary treatment:	reduction and toe-to-groin plaster
Application of the brace:	25 days; weight-bearing 35 kg.
Full weight-bearing:	5 weeks
Hospitalisation time:	None
Clinical and radiological Consolidation:	15 weeks

Progress:
After removal of the brace normal function of the knee, ankle and subtalar joints were observed with 2 mm calf atrophy. At follow-up one and a half years after the trauma: no pain or oedema of the leg; standing and walking unlimited.
Clinical and radiological union was achieved with shortening of less than 5 mm.



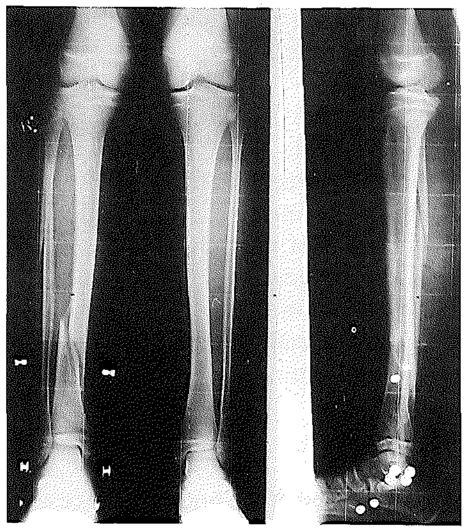
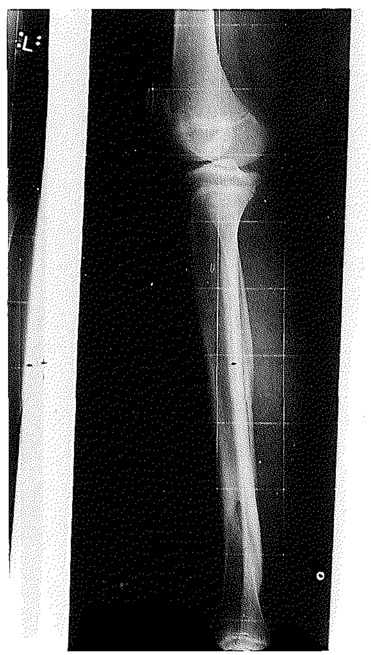


Figure 18.3 a: Spiral fracture of the right tibia and fracture of the fibula.

b: X-rays AP and lateral views after application of the brace

c: X-rays AP view at 15 weeks



d. lateral view

Patient v. T. 61 years, male

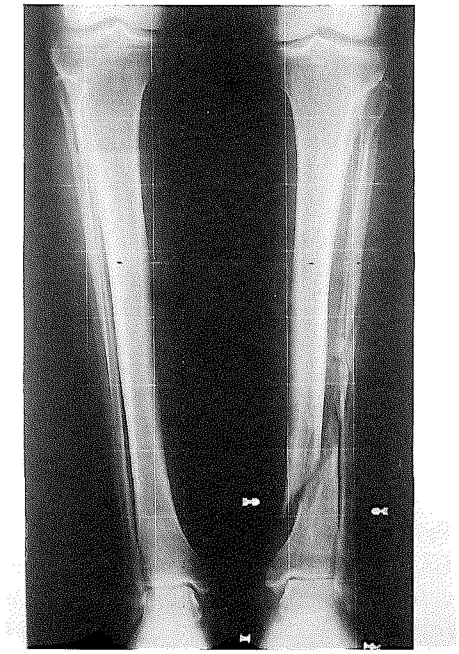
Closed fracture of the right tibia caused by a kick from a cow. Severe pain and swelling at the fracture site.

Fracture type:	oblique with fibular fracture
Fracture level:	distal one third
Primary displacement:	100 per cent
Primary treatment:	calcaneal traction and toe-to groin plaster
Application of the brace:	33 days; weight-bearing 75 kg.
Full weight-bearing:	7 weeks
Hospitalisation time:	16 days
Clinical and radiological consolidation:	22 weeks

Progress:

After removal of the brace there was 3 cm calf atrophy, normal function of the knee, ankle and subtalar joints. At follow-up one a half years after the trauma: no pain or oedema of the leg; standing and walking unlimited. Participating in the same work as before the accident. Clinical and radiological union was achieved with a shortening of 15 mm.

Figure 18.4 a: Oblique fracture of the right tibia and fibular fracture.



b: X-rays AP view after application of the brace.

c: X-rays AP view of the healed fracture at 22 weeks.

d. lateral view

Patient v.d. M., 14 years

Open fracture of the left tibia caused by a traffic accident. Severe pain and swelling at the fracture site.

Fracture type:	comminuted with fibular fracture
Fracture level:	distal one third
Primary displacement:	100 per cent
Primary treatment:	irrigation, debridement reduction calcaneal traction and toe-to-groin plaster
Application of brace:	after 48 days, weight-bearing 40 kg.
Full weight-bearing:	9 weeks
Hospitalisation time:	28 days
Clinical and radiological consolidation:	22 weeks

Progress:
Delayed wound healing and sequestrectomy. After removal of the brace there was calf atrophy of 4 cm, normal function of the knee, ankle and subtalar joints. At follow-up one and a half years after the trauma: no pain or oedema of the leg; standing and walking unlimited; participating in the same sport as before the accident.
Clinical and radiological union was achieved with a shortening of 5 mm.

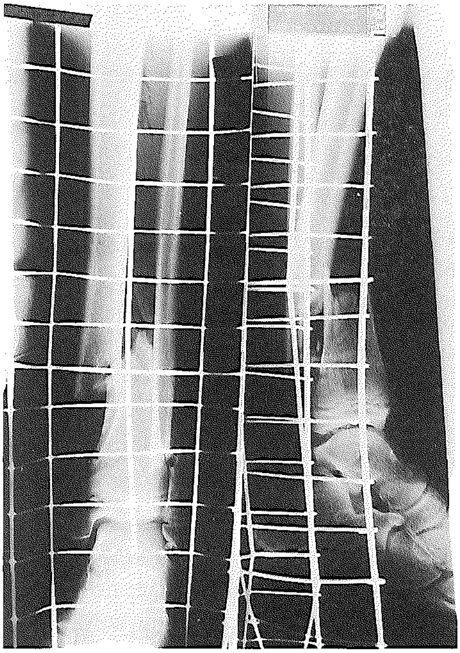
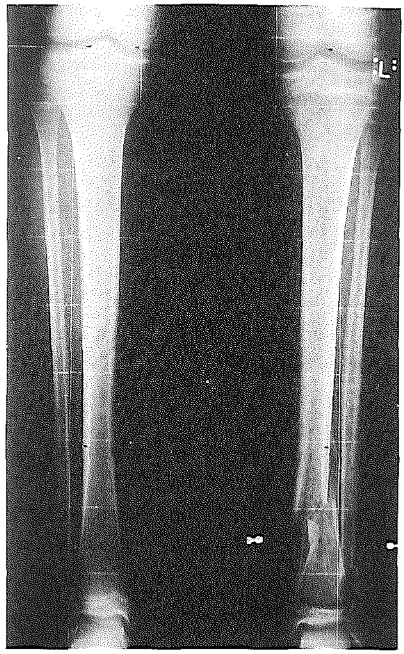
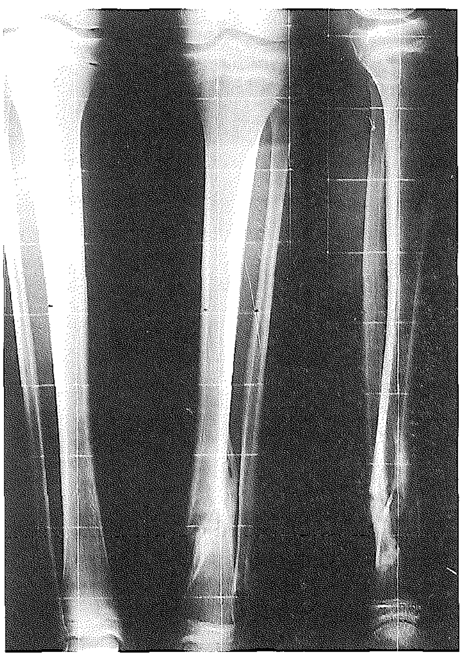


Figure 18.5 a Comminuted fracture of the left tibia with fibular fracture.



b: X-ray AP view after application of the brace.



c: X-rays AP and lateral views at 22 weeks.

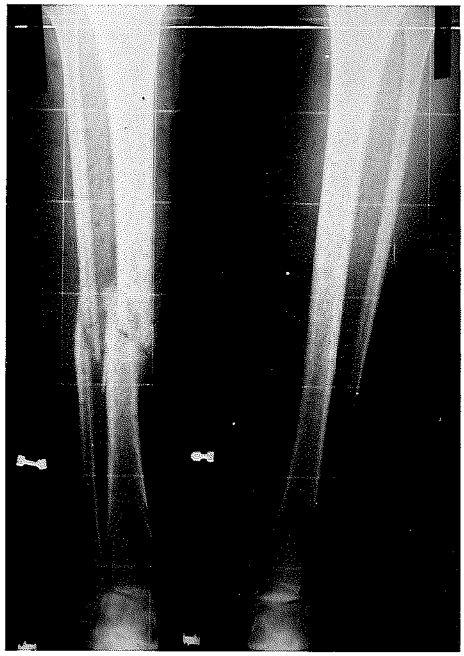
Patient v.d. W, 25 years, female

Closed fracture of the right tibia caused by sport trauma. Moderate swelling and severe pain at the fracture site.

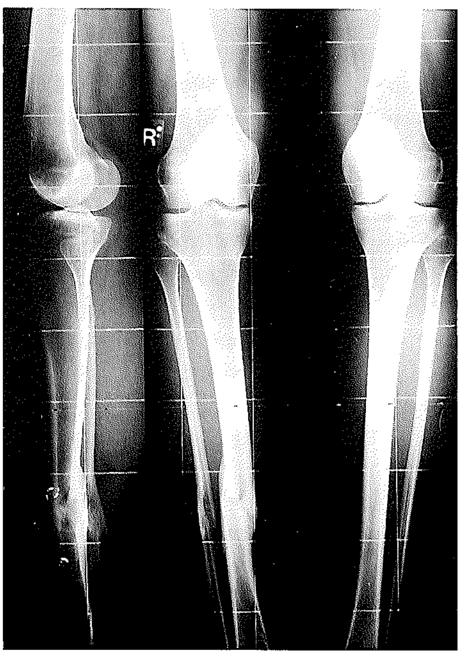
Fracture type:	Segmental
Fracture level:	middle third
Primary treatment:	reduction, traction and toe-to-groin plaster
Application of brace:	after 48 days; weight-bearing 45 kg
Full weight-bearing:	8 weeks
Work resumption:	after 10 weeks
Hospitalisation time:	14 days
Clinical and radiologi -cal consolidation:	13 weeks

Progress:
After removal of the brace there was calf atrophy of 3 cm, normal function of the knee, ankle and subtalar joints. At follow-up 2 years after the trauma: no pain or oedema of the leg; standing and walking unlimited; participating in the same sport and work as before the accident. Clinical and radiological union was achieved with a shortening of less than 5 mm.

Figure 18.6 a: Segmental fracture of the right tibia and fibular fracture.



b: X-ray AP view after application of the brace.



c: X-rays AP and lateral views 13 week post-trauma

CHAPTER 19

DISCUSSION

The treatment of choice for tibial fractures remains controversial. A conservative or operative approach is possible. Many forms of operative treatment for tibial fractures are known, such as internal fixation with a plate and screws, external fixation and intramedullary nailing.
For conservative treatment, the toe to groin plaster cast was and still is the treatment of choice for many surgeons.
In the Netherlands, between eleven and thirteen per cent of all tibial fractures are open fractures. Between 1969 and 1977, the incidence of operative treatment has increased from thirty-three per cent to fifty-five per cent (GAK, 1977).
In the fracture statistics 1978-1981 (GAK 1985) 2837 tibial fractures have been recorded. Of these fractures, 363 were open, 772 comminuted and 1772 were classified as "other". A total of 87.2 per cent were closed fractures.
Internal fixation was applied in 45 per cent of the 2074 closed fractures, external fixation in 3 per cent and conservative treatment in 52 per cent. Nearly half of the closed fractures were treated surgically.

The SMR (Stichting Medische Registratie) showed that 52 per cent of the closed fractures and 73 per cent of the open fractures had been treated surgically.

As is always the case with fractures, the goal of the treatment for a fractured tibia is to achieve a useful, dependable and comfortable extremity. However, some compromise with the ideal is usually necessary and no method described can consistently and safely attain healing of a fractured tibia without some complications.

The aim of open reduction and internal fixation with plates is anatomical reduction and rigid immobilization of the fracture fragments. Although limb function and joint motion may be initiated directly following surgery on the tibia, protected weight-bearing is recommended. The fracture unites by primary bone healing. Although rehabilitation is concurrent with this treatment, complications such as severe stress-shielding beneath the plate and disuse osteoporosis are often observed.
Another surgical method is medullary fixation. This technique aims at preserving the periosteal blood supply while stabilizing the fracture fragments. The fracture unites by the formation of peripheral callus. Disuse osteoporotis can be minimized by progressional weight-bearing, as determined by pain tolerance.
An alternative form of operative treatment is external fixation. This method is used to stabilize the fracture fragments without invading the fracture site. An external fixation device immobilizes the fracture fragments, but allows motion in the adjacent joints. Minimal peripheral callus is seen with external fixation. Weight-bearing is restricted.

Although joint motion and normal function are restricted using the plaster cast method for the management of tibial fractures, fracture motion is not completely eliminated. Healing progresses with the formation of peripheral callus. Once the fracture has united, a prolonged period of rehabilitation is required to obtain a normal range of motion and to reverse the changes caused by disuse osteoporosis.
A functional brace is never used in the initial stages of treatment of tibial fractures, but can be applied once the acute symptoms have subsided. Braces do not immobilize joints or fracture fragments but control fracture fragment motion. The patient is encouraged to progressively increase weight-bearing on the extremity. Therefore, healing progresses with the formation of periphearal callus and rehabilitation is concurrent with treatment.

When selecting a treatment method, the aim is to achieve a 100% functional leg. It is not only important to take the incidence of complications which may be anticipated into consideration, but also their severity.
The main complication after conservative treatment using a toe-to-groin plaster, which has immobilised the extremity for some five months, is: a stiff knee, ankle and subtalar joint. The rehabilitation period is very long.
Prolonged immobilization of a joint can give rise to alterations in cartilage nutrition which may not be reversible and can lead to impairment of the joint function.
Severe complications can arise after internal fixation, for which there is no alternative treatment besides reoperation.

The results of this study are similar to those reported by Johner and Wruhs, who treated open and closed tibial fractures using rigid plate osteosynthesis. The same data were examined in both studies. Other reports in the literature only mention the major complications and the consolidation process. In the study by Johner and Wruhs, the functional end results are reported with well-defined criteria. It is important to realize that this was not a consecutive series. Therefore, the results will generally be more favourable.

For many years, we have emphasized the importance of conducting randomized research into the treatment of tibial fractures. However, the differences in insight into the treatment of these fractures between general and orthopaedic surgeons, has made this impossible. The results of such a study could be used to establish the correct treatment for every type of fracture.

In our series of 176 tibial fractures treated with a functional brace applied below the knee and early weight-bearing, the serious complication rate was 6.2 per cent, comprising 1.7 per cent refractures, 2.8 per cent delayed unions and 1.7 per cent non-unions. All but one of these complications healed after fibulectomy, internal fixation, cancellous bone grafting and bracing.

Refracture occurred in 3.5% of the transverse fractures in our study compared to 6% in Johner and Wruhs' A3 group. For oblique fractures these percentages were 5% and 3%, respectively. Delayed union was diagnosed after 26 weeks in 2% of the transverse fractures, 4% of the oblique fractures and 4% of the comminuted fractures. All delayed unions healed following fibulectomy, internal fixation and/ or bracing. The percentage of delayed unions observed after the treatment of closed tibial fractures using internal fixation was 3%, which agrees with the 2.8% mentioned above. Delayed union was not mentioned in the study by Johner and Wruhs.
Non-unions were diagnosed in three patients: 4 per cent with oblique fractures and 2 per cent with communited fractures.
In Johner and Wruhs' series, these percentages were 3% and 5%, respectively.
There was very little difference between the complication rates of both treatment methods.

In our series we observed one case of soft tissue infection (0.6%) in a ptient with an open comminuted fracture, which healed following sequestrectomy. In a similar study, the infection rate was 7.3%.
Minor malalignment complications (3.6%) and shortening (16.9%) of the healed fracture were seen in 20.6 per cent. In the internal fixation group, these complications were diagnosed in 11 per cent. However, if shortening of less than 10 mm, is not considered to cause functional or cosmetic problems for the patient, the total minor complication rate falls to 13 per cent. All the other complications were varus, valgus, apex anterior and apex posterior malalignment deformities of 5 degrees. Most minor complications were seen in patients with communited fractures (13); this is comparable with Johner and Wruhs' series. In the oblique fracture group, there were five minor complications and the final percentage of shortening was highest in this group. Johner and Wruhs only mentioned one patient with shortening of 5 mm in their group.

At follow-up, all the patients had normal knee function. In 10 patients a dorsiflection impairment in the ankle of less than 15 degrees still remained and in 6 the plantar flexion was impaired. The subtalar mobility was limited compared to the controlateral side in 11 cases.

Within 12 weeks, 80 per cent of the patients in our series could walk without crutches compared to 20 per cent of those in Johner and Wruhs' series. The average hospitalisation time was 10 days, this is far less than that mentioned in comparable series.

Loss of fracture reduction only occurred in 4 patients, which was corrected during functional brace treatment. Biomechanical analysis has shown that it is possible to eliminate external and harmful forces acting on the fracture fragments during brace treatment.

CHAPTER 20

CONCLUSIONS:

The recent interest in functional bracing is undoubtedly a reflection of the economics of medical care. Nowadays, the most expensive item in patient care is the cost of hospitalisation, therefore the focus of attention is to reduce the amount of time spent in hospital without reducing the standard of care. It is inevitable that time must be spent in hospital after fracturing a tibia, at least initially, if the fracture is treated with internal fixation. But there is also the additional time spent later for removal of the device and the treatment of any complications.
Therefore it would be better to reserve internal fixation for specific indications and treat most fractures conservatively. But it will be necessary for the results of conservative treatment to be as good as or better than those of surgical treatment. In the light of the results of this study, in which brace therapy was compared to internal (rigid) fixation and to other conservative methods, it can be concluded that functional brace treatment is the method of choice for closed transverse, oblique and spiral fractures. External fixation can be considered for open and comminuted fractures.

Indications for functional bracing are:
- all closed tibial fractures, if limb shortening and fracture alignment are within acceptable limits
- open tibial fractures with healed soft tissue wounds

Contra-indications for functional bracing are:
- unacceptable shortening or alignment
- non-cooperative patients
- sensibility disorders of the broken leg

Functional bracing applied below the knee is a good choice of treatment for tibial fractures because

1. the complication rate is low
2. there is a rapid return to normal daily activities
3. the consolidation time is fast
4. it is not inconvenient for the patient
5. during treatment hygiene is optimal as the brace can easily be removed for a daily shower
6. the brace is easy to apply
7. hospitalization time is short because of early full weight-bearing
8. it is a conservative regime
9. it is probably the cheapest of all methods of treatment for tibial fractures.
10. no infections

SUMMARY

The subject of this thesis is the treatment of tibial fractures with a functional brace applied below the knee. The treatment results of the first 176 patients are described.

The aim of the study is formulated in Chapter 1, Introduction.
A brief overview of the history of fracture treatment is given in Chapter 2. Functional treatment is becoming increasingly popular.

In Chapter 3 bone healing is described, from the trauma to the time that the bone has resumed its normal form. Bone healing takes place in phases which overlap each other. An overview is also given of primary bone healing, which occurs during rigid fixation of a fracture.

The vascularization of the tibia and the importance of the blood supply for callus formation are described in Chapter 4. The pumping action of the calf muscles during functional treatment of tibial fractures increases the blood supply which gives rise to good quality callus formation. Weight-bearing increases the blood perfusion by 50% to 70%.

The influence of functional weight-bearing of the fractured bone on bone healing is described in Chapter 5. A review of the literature on cyclic weight-bearing or functional weight-bearing of the broken limb is given.
Functional weight-bearing of a broken limb gives rise to early, firm periosteal callus. The precise mechanism of bone healing during cyclic weight-bearing of fractured bone is still not fully understood.

The function of soft tissue with regard to fracture stabilization is described in Chapter 6.
Owing to the fact that the functional brace firmly encircles the soft tissue of the lower leg and compromises the muscles, the soft tissue simulates the behaviour of a selaed watercolumn. According to Pascal's law, pressure exerted on a water column will be equally distributed in all directions. Soft tissue also has an elastic function, which causes the fracture fragments to return to the resting phase after weight-bearing.

In chapter 7 a biomechanical analysis is made of the tibial brace. A schematic representation is given of the way in which forces act on the lower leg and how they are transmitted via the brace, soft tissue and bone.

Chapter 8 comprises a detailed step by step account of the application procedure of the brace with Orfit, illustrated with photographs.

The patient material is reviewed in Chapter 9, including the cause of the trauma, classification, location, distribution of the 176 tibial fractures over open and closed

fracture groups, the complication rate: 2,8% delayed unions, 1.7% non-unions, 1.7% refractures, 0% thromboembolism and the number and classification of the soft tissue injuries.

In Chapter 10 the primary treatment is described; 129 patients underwent conservative treatment with a toe-to-groin plaster cast.
The dates of application of the braces are expressed in form of cummulative percentage curves. A very accurate calculation is made of the amount of weight, in kilogrammes, that a patient may exert on the fractured limb after the brace has been fitted. Cummulative percentage cruves also show the date of full-weight bearing and the consolidation time for the closed and open fractures separately. The case histories of two patients are described in detail.

In Chapter 11 complications are described. There are 2.8% delayed unions, 1.7% non unions, and 1.7% refractures. There were no trombo embolic processes. Case histories of the two patients are described.

In Chapter 12, displacement and shortening are described. The X-rays were taken such that an image of both lower legs (from ankle to knee) was obtained on one film. The degree of accuracy of our measurements was 2 mm. In 96 patients, the shortening was less than 10 mm. The same X-rays were used to measure the varus, valgus, apex anterior and apex posterior displacement. The position changes during brace treatment are also shown.

The functional results are reported in Chapter 13, including atrophy, knee and ankle function.

In Chapter 14 the results are described for each fracture type separately; an evaluation is made in accordance with Johner's criteria. The best results were achieved with spiral fractures: 100% excellent.

In Chapter 15 the consolidation time and the interval until full weight-bearing is possible are compared to these data in Juttman's series, with the aid of cumulative percentage curves. Our data have also been compared to a number of series in the literature.

The separate fracture types are compared to similar fracture types in Johner and Wruhs' series in Chapter 16.

The correlation between the interval until full weight-bearing is possible and the consolidation time is described in Chapter 17. The correlation is significant for open as well as closed fractures.

Case histories of a transverse, spiral, oblique, comminuted and deux etage fracture are given in Chapter 18.

In the discussion, the present form of treatment for lower leg fractures and particularly closed lower leg fractures are described. The results of this study were compared to the literature.

Chapter 20 comprises the conclusions.

SAMENVATTING

In dit proefschrift wordt de behandeling van onderbeensfracturen met een functionele onderbeens brace beschreven. De behandelings resultaten van de eerste 176 patienten worden weergegeven.

In hoodstuk 1, Introductie, wordt het doel van het onderzoek beschreven.

In hoofdstuk 2 wordt een kort overzicht gegeven van de fractuurbehandeling door de jaren heen. Meer en meer wordt de fractuur functioneel behandeld.

In hoofdstuk 3 wordt de botgenezing beschreven vanaf het trauma totdat het bot de normale vorm weer heeft aangenomen. Botgenezing wordt beschreven in fasen welke elkaar overlappen. Ook wordt een overzicht gegeven van de primaire botgenezing zoals deze gebeurt na rigide fixatie van de fractuur
stukken.

In hoofdstuk 4 wordt de vascularisatie van de tibia beschreven en het belang van de bloedvoorziening bij callusformatie.
De pompactie van de kuitspieren tijdens de functionele behandeling van onderbeensfracturen verhoogd de bloedtoevoer en zorgt aldus voor een goede kwaliteit van de te vormen callus.
Tijdens belasting wordt de bloedperfusie met 50 to 70% verhoogd.

In hoofdstuk 5 wordt de invloed van functionele belasting van het gebroken been op de botgenezing beschreven. Een overzicht uit de literatuur met betrekking tot cyclische belasting of functionele belasting van de gebroken ledemaat wordt gegeven.
Door functionele belasting van een gebroken ledemaat ontstaat er vroeg stevige periostale callus. Het preciese mechanisme van cyclische belasting van het gebroken bot met betrekking tot botgenezing is nog niet geheel duidelijk.

In hoofdstuk 6 wordt de functie van weke delen met betrekking tot het stabiliseren van de fractuur beschreven.
Doordat de onderbeensbrace de weke delen van het onderbeen stevig omvat en de spieren comprimeert, gaan de weke delen zich gedragen als een afgesloten vloeistofkolom.
Volgens de wet van Pascal wordt een druk uitgeoefend op een vloeistofkolom gelijk verdeeld in alle richtingen. De weke delen hebben ook nog een elastische functie. Zij zorgen ervoor dat de fractuuruiteinden na belasting terugkeren in de rustfase.

In hoofdstuk 7 wordt een biomechanische analyse gegeven van de onderbeensbrace. Aan de hand van vrij-lichaamsdiagrammen worden krachten welke op het onderbeen werken beschreven en hoe deze via de brace of weke delen en bot worden voortgeplant.

In hoofdstuk 8 wordt uitvoering ingegaan op het aanleggen van de brace met Orfit. Stap voor stap wordt de techniek beschreven en geillustreerd met foto's.

In hoofdstuk 9 wordt het patiënten materiaal beschreven. De oorzaak van het trauma wordt gemeld, de classificatie en locatie van de 176 tibiafracturen wordt vermeld en de indeling in open en gesloten fracturen. Ook wordt het aantal fibulafracturen vermeld en de classificatie hiervan. De primaire verkorting en de geaccepteerde verkorting worden gemeld. Er is een indeling van de weke delen laesies. De primaire verplaatsing en de geaccepteerde verplaatsing worden vermeld.

In hoofdstuk 10 wordt de primaire behandeling beschreven, bij 129 patiënten was dit een lang gips. De datum van aanleg van de brace wordt beschreven in cummulatieve percentage curves. De hoeveelheid kilogrammen die de patiënt kan belasten na het aanleggen van een brace wordt nauwkeurig beschreven. In de cummulatieve percentage curves wordt het tijdstip van volledig belasten weergegeven voor de gesloten en open fracturen afzonderlijk. De consolidatie wordt eveneens weergegeven in de cummulatieve percentage curves.

In hoofdstuk 11 worden de complicaties beschreven. Er zijn 2.8% delayed unions, 1.7% non-unions, en 1.7% refracturen.
Trombo embolische processen deden zich niet voor. De casuîstiek van twee patiënten wordt uitvoerig beschreven.

In hoofdstuk 12 wordt de asafwijking en de verkorting beschreven. De röntgenfoto's werden zo gemaakt dat beide onderbenen van de enkel tot en met de knie op een röntgenfoto kwamen. Nauwkeurige meting tot 2 mm lengteverschil was zo mogelijk. 96% van de patiënten had een verkorting van minder dan 10 mm. Op dezelfde foto's werden de varus, valgus, apex anterior en apex posterior afwijking berekend. Ook is weergegeven de verandering van stand gedurende de brace behandeling.

In hoofdstuk 13 worden de functionele resultaten beschreven. En met name met betrekking tot atrofie, functie van de knie, onderste en bovenste spronggewrichten.

In hoofdstuk 14 worden de resultaten van de fractuur types afzonderlijk beschreven en geëvalueerd aan de hand van criteria volgens Johner. De beste resultaten werden verkregen met spiraal fracturen, 100% excellent.

In hoofdstuk 15 wordt de consolidatietijd en de tijd welke nodig is tot volledig belasten met behulp van cummulatieve percentage curves vergeleken met de consolidatietijd van de serie van Juttman. Eveneens wordt een vergelijking gemaakt met een aantal series uit de literatuur.

In hoofdstuk 16 worden de fractuurtypes afzonderlijk vergeleken met vergelijkbare fractuurtypes uit de serie van Jöhner en Wruhs.

In hoofdstuk 17 wordt de correlatie beschreven tussen tijd die nodig is dat patiënt volledig kan belasten en de tijd tot consolidatie. Zowel voor open als gesloten fracturen is er een significante correlatie.

Hoofdstuk 18 geeft de casuistiek weer van een dwarse-, spiraal-, schuine-, communitieve en deux etage fractuur.

In de discussie wordt de huidige vorm van behandeling van onderbeensbreuken en met name gesloten onderbeensbreuken beschreven. De resultaten van dit onderzoek werden vergeleken met de literatuur.

In Hoofdstuk 20 worden de conclusies weergegeven.

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