# Functional Bracing of Tibial Fractures

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Traditionally the management of fractures of the tibia and other long bones of the appendicular skeleton has been predicated upon the principle that immobilization of the injured bone and the adjacent joints is a prerequisite for fracture healing.

The rigid adherence to this principle has been challenged by the results obtained with certain fractures which consistently achieve healing in the absence of immobilization. Abundant callus frequently seen around fractures of active patients as well as in those with spastic neurological conditions testify to the fact that osteogenesis continues in the presence of motion of the damaged bony structures.

In 1963 I first conceived the idea that tibial fractures could be successfully managed by means of a special cast which would permit early freedom of motion of the knee joint and weight-bearing ambulation without increased shortening of the extremity or interference with normal osteogenesis.[6]

Experiences with this below-knee functional cast led later to the development of a brace that permitted the patient with a fractured tibia to free his ankle and knee joints and to bear weight within a relatively short period after the initial injury.[7] Simultaneously, studies led to the use of similar functional methods of treatment for fractures of the femoral shaft. An above-the-knee brace that allowed the patient with a fractured femur to ambulate within a few weeks after the initial injury with freedom of motion of all joints was standardized.[8] Satisfactory results with tibial and femoral bracing brought about the development of techniques of management and functional bracing of certain forearm fractures.[4, 5, 9]

Early clincal experiments with fracture bracing were carried out with plaster-of-Paris appliances which were soon replaced by plastic materials of lighter weight, and cooler and easier to apply.[7]

Ten years of experience with 722 tibial, femoral and forearm fractures with a very low morbidity, a high rate of union, a rapid restoration of function and virtually the elimination of the common sequella of immobilization have convinced me that rigid immobilization of fractured long bones and adjacent joints is not a prerequisite for fracture healing. I've further theorized that limited motion at the fracture site, if the result of function, favorably enhances the reparative process.[6] Clinical and laboratory experiences strongly suggest that provision of stability and prevention of shortening of acute fractures immobilized in circular casts or braces is primarily the result of the role played by the incompressible soft tissue mass that surrounds the fractured site and the visco-elastic nature of the musculature and fascial structures.[7]

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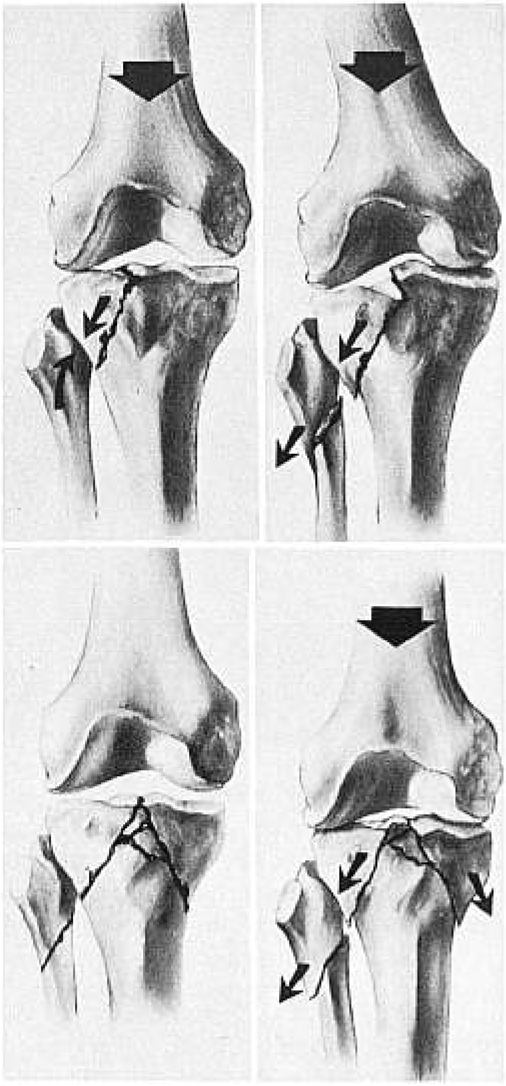
FIGS. 1A. (left) and B. (right). Below-the-knee functional cast.

## EXPERIENCES

Successful experiences with PTB prostheses (Patellar Tendon Bearing) for the below-knee amputee prompted my studies on the possibility of utilizing prosthetic principles in the treatment of fractures of the tibia. The PTB prosthesis had eliminated the need for the traditional thigh corset in the below-knee prosthesis by the utilization of total contact between the stump and the socket and the distribution of weight-bearing pressures through bony areas of the proximal tibia and the patellar tendon. This new prosthesis also eliminated bulky metallic knee joints and thigh corsets and gave the amputee the opportunity to develop a more functional and cosmetic gait through the unencumbered use of his remaining musculature.

I was intrigued with the possibility that a below-the-knee plaster-of-Paris cast molded like a PTB prosthesis could provide sufficient and comfortable stabilization for a fractured tibia while allowing normal and uninterrupted healing. Such a cast could, theoretically by its firm molding over the proximal tibia, transfer weight-bearing pressures from the floor to the bony prominences to the tibial plateaus and patellar tendon virtually by-passing the fracture site. Initial attempts to treat fractures of the tibia with such a cast were successful and further experiences demonstrated satisfactory and consistent maintenance of reduction of fractures with adequate stability to permit uninterrupted osteogenesis (Figs. 1A and B).

Using this new cast in numerous instances I found that it was best to initially immobilize fractured tibiae in toe-to-groin casts and to encourage patients to bear increased weight on the injured extremities.[2] In acute fractures with severe displacement and considerable soft tissue damage, it is preferable to recommend recumbency and elevation of the leg to encourage reduction of swelling. Otherwise weight-bearing ambulation may be introduced early.



FIGS. 2 A. (top) and B. (bottom). The condition of the fibula significantly determines the development of varus and valgus deformities in intra-articular and proximal tibial fractures.

After two weeks, the toe-to-groin cast may be removed and a below-the-knee functional cast applied. This two-week period can be reduced only in those instances when the initial injury was not accompanied by severe soft tissue damage manifested by only moderate swelling. Open fractures resulting from high velocity missiles or vehicular accidents with considerable displacement of the fragments frequently may require immobilization in the toe-to-groin cast for periods longer than two weeks. It is the degree of soft tissue pathology that determines whether or not a below-the-knee functional cast may be applied.

At the time of application of the below-knee functional cast, minor corrections in alignment and rotation of the fragments can be obtained. Most patients experience only minimal discomfort from gentle manipulation of the limb after the two-week period of ambulation in the long-leg cast. It is desirable however, that the best possible reduction be obtained originally prior to the first application of the initial toe-to-groin cast.

Radiological examination of the limb following the application of the toe-to-groin, as well as the below-knee cast, is imperative. The recognition of angulatory or rotary deformities must be corrected preferably by the removal of the cast and reapplication of a new one. In the hands of a skillful individual, wedging is possible in many instances.

Following the application of the below-knee functional cast, ambulation is encouraged anticipating that within a few days full weight-bearing will be tolerated easily. Most patients are capable of abandoning all types of external support within two weeks after the application of the first below-knee functional cast.

In the overwhelming majority of instances of closed fractures of the tibia the initial amount of shortening constitutes the ultimate shortening of the fractured bone. The interosseous membrane and the support provided by the visco-elastic soft tissues of the extremity prevent any further shortening.

Fractures with marked displacement originally and especially those with open wounds, develop the greatest amount of shortening. It is in these types of fractures that the initial insertion of pins above and below the fracture is desirable for approximately a three-week period.

Failure to correct angulatory deformities following the application of the weight-bearing cast may result in increased deformity. This is particularly true for fractures of the distal tibia, especially when the deformity is that of recurvatum.

Fractures of the tibia with intact fibula, particularly open ones, have a ready tendency to angulate toward the fibula with resulting varus deformity. This deformity may be encountered regardless of the type of cast used and in the absence of weight-bearing ambulation.

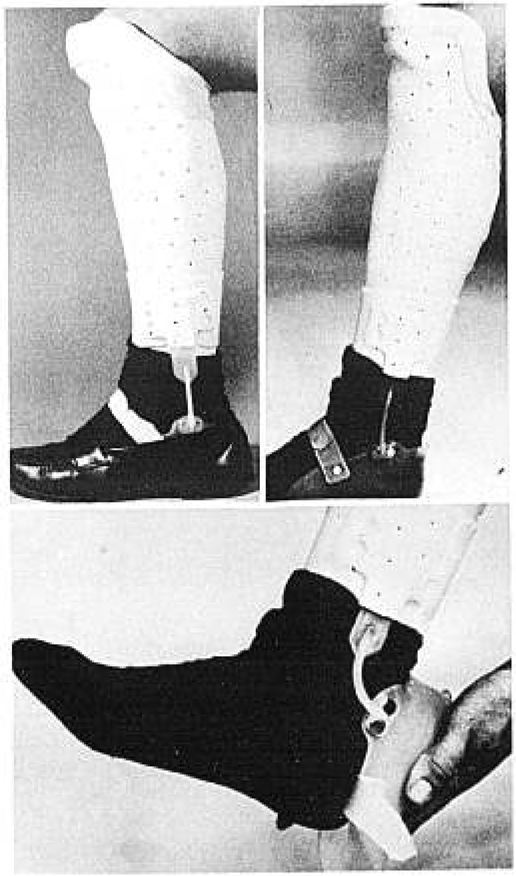
Rotary deformities are for the most part easily preventable and experiences have shown that further increase is not likely to occur.

Intra-articular fractures of the proximal tibia may be treated with below-the-knee functional casts but special attention must be given to the type of fracture and the condition of the fibula. Fractures with intact fibula have a ready tendency to develop angulatory deformities upon subjection to weight-bearing stresses. Varus deformities may occur with high fractures when the fibula is intact (Figs. 2A and B).

Fractures of the distal tibia with intra-articular involvement should be protected from weight-bearing if restoration of congruity has been obtained. Loss of reduction has been found several times after unprotected weight-bearing ambulation.

Even though in several instances we have used below-the-knee functional casts following open reduction and internal fixation of fractures, the results have not been consistently satisfactory. In the case of plated tibiae, the below-the-knee casts do not seem to provide adequate protection against sheering stresses particularly in oblique fractures. Following intramedullary fixation, our experiences have been better, but not necessarily excellent in all cases.

The success achieved with this new below-knee functional cast for fractures of the tibia which permitted freedom of motion of the knee joint and early weight-bearing ambulation was followed by attempts to free the ankle joint as well.[7, 9, 10] Initially these attempts were met with the problem of swelling around the suddenly freed foot and ankle of the injured extremity, frequently reaching degrees of severity sufficient enough to produce considerable discomfort. However, I recalled that patients treated with the below-knee functional cast, who actively ambulated on their injured extremities, rarely experienced ankle swelling upon removal of the cast even after long periods of immobilization. Continued experiences finally resulted in the standardization of a method which calls for immobilization of the injured limb



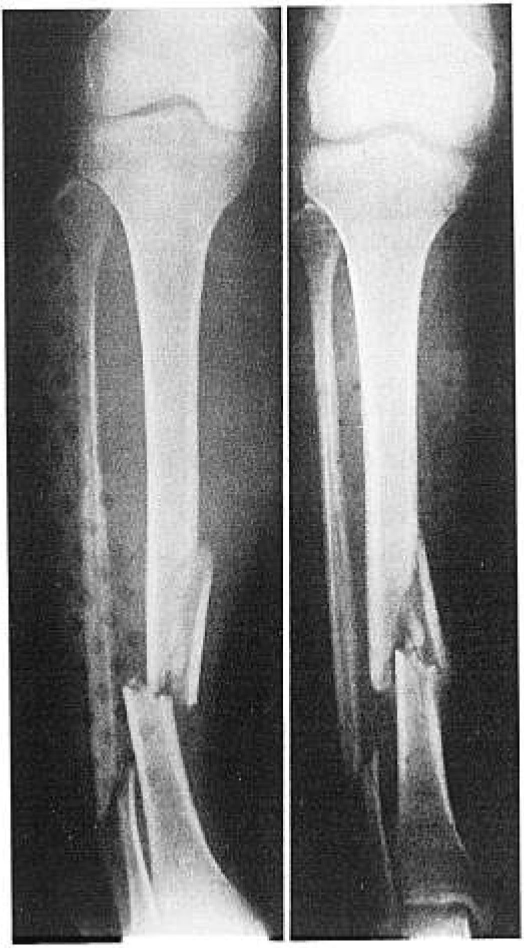
FIGS. 3 A, B and C. Functional ORTHOPLAST brace with flexible plastic insert.

FIG. 4 A. Transverse fracture of tibia and fibula which healed without shortening or angulatory deformity.

in a toe-to-groin cast for approximately two weeks, followed by an additional two-week period in the short-leg functional cast prior to the application of the brace which permits complete freedom of motion of the knee and ankle joints.

During the past several years, efforts have been made to reduce the period of immobilization in the toe-to-groin casts as well as in the below-knee functional casts prior to the application of the functional below-knee brace in fractures of the tibia. It has become apparent that the severity of soft tissue injury determines, for the most part, the period of time for which the limb must be immobilized in long or short-leg cast devices. An open fracture of the tibia resulting from a severe injury with great initial displacement of the fragments and massive soft tissue damage requires a longer period of immobilization. Frequently such fractures require immobilization in a long-leg cast and bed rest for periods of time that exceed the average two weeks previously cited. However, it has also been my experience that closed fractures with minimal soft tissue damage and minimal displacement can receive the functional brace within a time period as short as one or two weeks following the injury. In these instances, however, some patients experience discomfort and find weight-bearing ambulation difficult and painful. Therefore, it is best to delay the application of the brace in order to insure the greatest degree of comfort and success.

FIG. 4 B. See legend for Figure 4 A.



FIGS. 5 A and B. Comminuted open fracture which healed with moderate shortening but without angulatory deformity.

Initial experience with tibial bracing was carried out with plaster-of-Paris and single axis metallic joints. After treating 96 cases in this manner, I began to use plastic materials that replaced first the plaster-of-Paris and recently the metallic joints as well. Mr. William F. Sinclair, C.P.O., Director of the Prosthetic–Orthotic Research Laboratory at the University of Miami School of Medicine, was responsible for the development of the various metallic and plastic joints as well as the fracture bracing techniques.[10]

Patients are encouraged to ambulate with external support until discomfort has subsided. Most patients abandon canes or crutches within two weeks after the application of the brace. Patients are permitted to remove the shoe from the brace during recumbency and for cleansing purposes. The Velcro strap placed over the dorsum of the foot prevents the brace from sliding down.

The new plastic insert which replaced the metallic joints by virtue of its fit over the heel and mid-tarsal area provides sufficient stability to prevent rotational deformities (Figs. 3A to C).

FIG. 5 C. See legend for figures 5 A and B.


FIG. 6 A. Bilateral tibial fractures treated with functional below-the-knee ORTHOPLAST braces. The functional braces were applied four weeks after the initial injury.

## MATERIAL

This is a report of the results of 482 tibial shaft fractures which have been treated with below-the-knee functional methods. None of these patients had internal fixation of their fractures. There were an additional 53 patients who were lost to follow-up. The first 100 patients had below-knee functional casts and the remaining 382 had below-knee braces. Twenty-two patients had bilateral fractures. There were two non-unions. One occurred in an alcoholic patient with advanced cirrhosis of the liver who sustained an open comminuted segmental fracture of the proximal and middle thirds of the tibia. The second occurred in a 35-year-old woman with a closed transverse fracture of the middle third of the tibia without association fracture of the fibula.

There appears to be no significant difference in the results obtained with fractures treated with the below-the-knee cast as compared with those treated with the below-the-knee brace.[7] The first 85 patients had their fractures immobilized in below-the-knee functional braces made of plaster-of-Paris and the remaining in plastic (ORTHOPLAST) braces. This is not a report of a consecutive group of tibial fractures treated at Jackson Memorial Hospital, University of Miami, since a small though as yet undetermined number of patients were not included in this series. Those cases were patients who did not receive the functional brace within the first

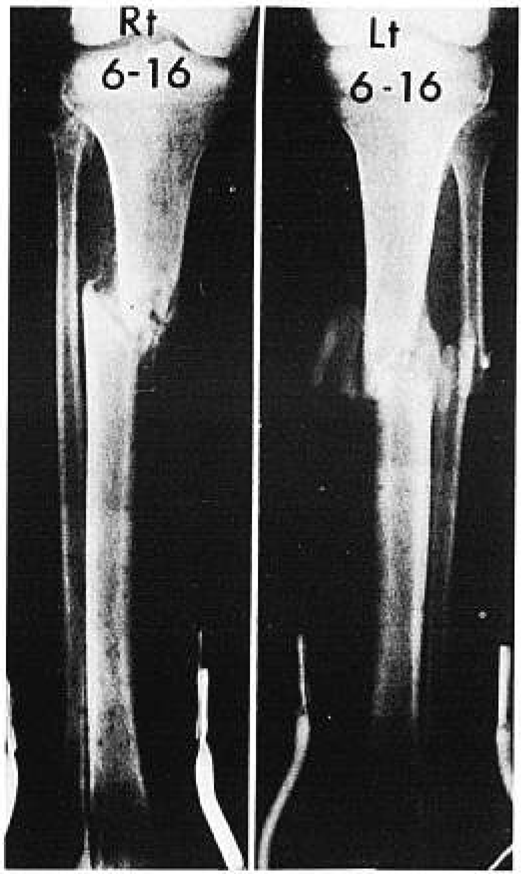



FIG. 6 B. See legend for Figure 6 A.

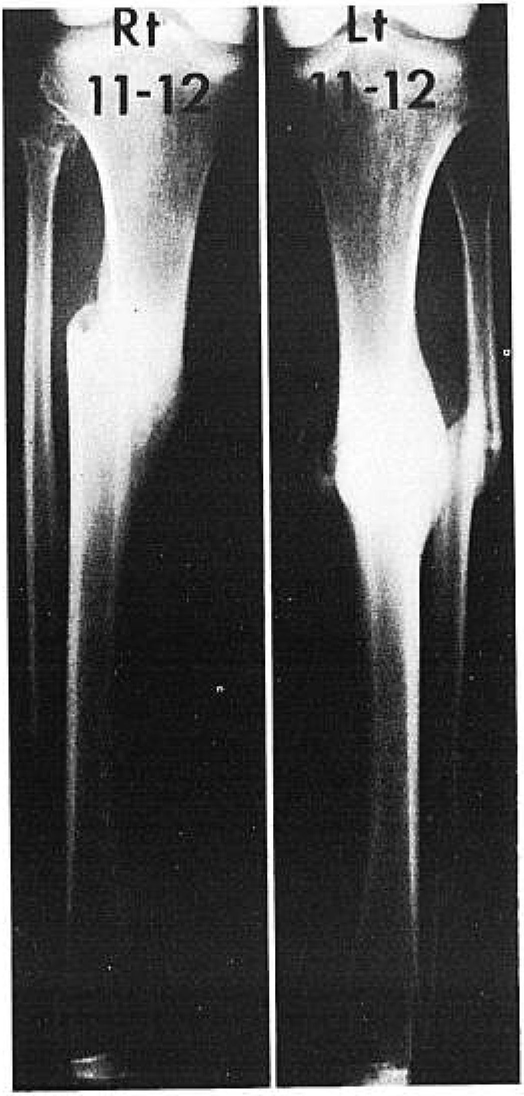


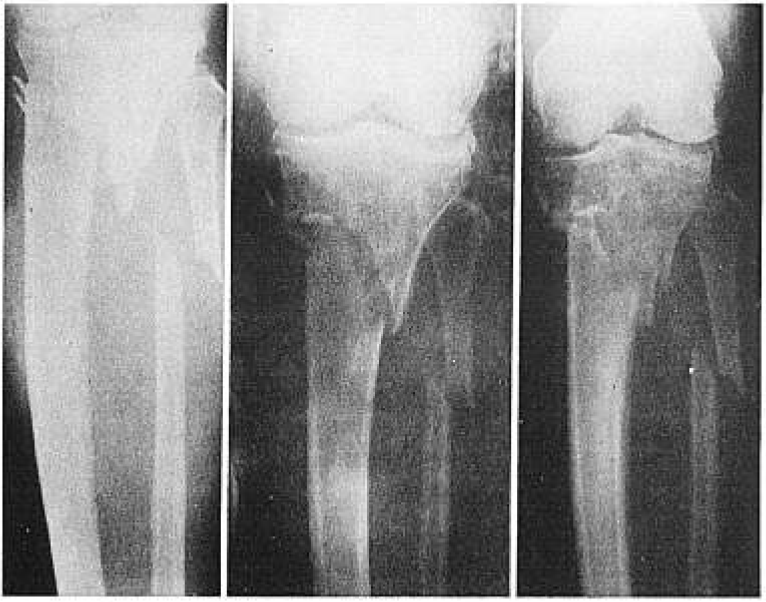

FIG. 6 C. See legend for Figure 6 A.

6 weeks of injury either because of associated injuries or massive soft tissue damage that precluded their ambulation or who were referred to the Fracture Brace Clinic later than 6 weeks after the inital injury. I have arbitrarily established the 6 weeks period since it is my impression that the most rapid and consistent healing takes place when function is introduced during the early post-injury days. Eighty-nine per cent of all the closed fractures in this series were braced within the first 4 weeks.

There appears to be no major difference in the healing time of tibial fractures according to the type of fracture. Transverse fractures healed at a median of 15 weeks as compared to comminuted and oblique fractures which healed at a median of 14 weeks. Segmental fractures healed at a median of 17 weeks.

Minimal difference was detected in the healing time of fractures at various levels of the tibia. Fractures of the proximal and distal thirds of the tibia healed at a median of 14 weeks, those in the middle third at 15 weeks.


FIG. 6 D. See legend for Figure 6 A.



FIGS. 7 A, B, and C. Oblique fracture of the proximal tibia and fibula in an osteoarthritic patient. The associated displaced fibular fracture permitted settling without angulatory deformity.

Ninety-nine fractures were open and healed at a median time of 16 weeks. Two hundred eighty-one were closed and healed at a median time of 14 weeks.

Two hundred seventy-six fractures had associated fractures of the fibula and healed at a median time of 14 weeks. One hundred-four fractures without fractures of the fibula healed at a median time of 15 weeks.

The average and median healing time for the entire group was 14.5 weeks.

In the group of patients braced with below-the-knee functional braces, 73 patients (19%) by-passed the below-the-knee cast stage and went directly from the original toe-to-groin cast into the below-the-knee functional brace. Three hundred seven patients (81%) received the intermediate stage of a below-the-knee functional cast.

The maximum angulation experienced in the entire series was 12° of varus, 8° of valgus and 8° of recurvatum. Ninety-one per cent of the patients had less than 5° of angulatory deformity.

The median shortening was 6.4 mm. Closed fractures experienced a median of 6.4 mm shortening as compared to open fractures which experienced 6.8 mm. The maximum amount of shortening in the entire series, 2.54 cm, was accepted in a patient with an open fracture of the middle third of the tibia with associated multiple injuries. Eighty-eight per cent of the patients had less than 4.1 mm shortening. Pins above and below the fracture were used in 28 cases and kept in place for periods of time ranging from 2 to 5 weeks with a median of 3 weeks.

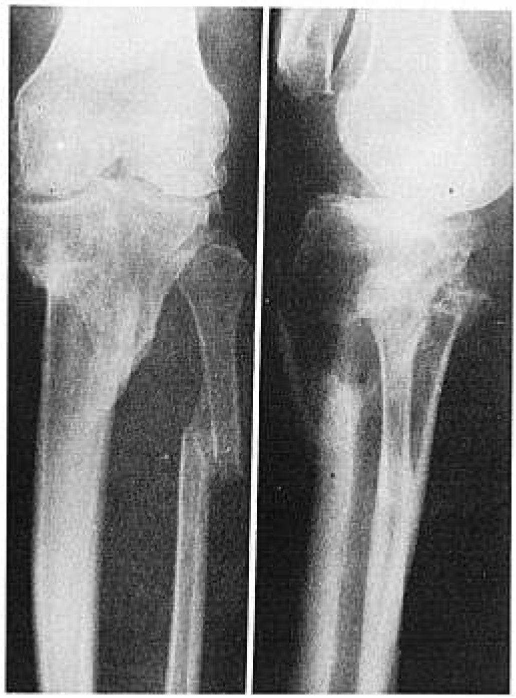


FIG. 7 D. See legend for Figures 7 A–C.

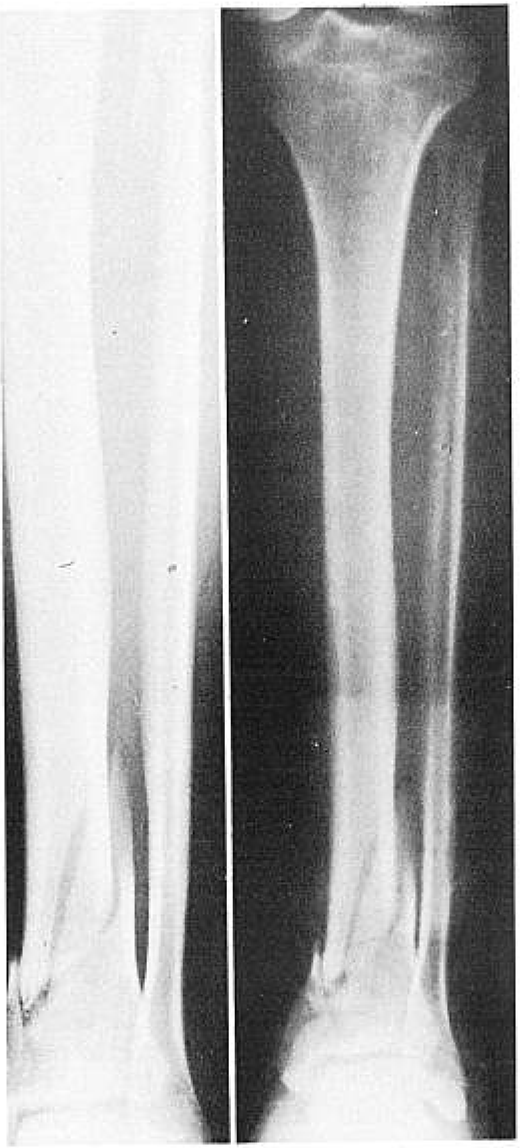


FIG. 8 A and B. Comminuted fracture of the distal tibia and proximal fibula which healed uneventfully in a below-the-knee functional ORTHOPLAST brace.

The oldest patient was 89 years and the youngest 16 years. Data on patients younger than 16 years are not being presented in this report.

There was no incidence of thrombo-embolic disease, pulmonary emboli or anterior tibial syndrome in the entire series.

Limitation of motion of the knee or ankle joints was not carefully recorded. However, it is my impression that permanent limitation of motion has not been encountered and that most patients regained full use of their joints and extremities prior to removal of the brace.

Forty-five per cent of the patients sustained their fractures as passengers on 2 or in 4-wheel vehicles; 15 per cent as pedestrians injured by moving vehicles; and 28 per cent from falls or twisting injuries. Firearm wounds accounted for 9 per cent of the injuries sustained and 3 per cent were incurred by other means (Figs. 4A through 10).

Two patients experienced refractures within the first 8 weeks following the removal of the brace. In both instances the fractures united uneventfully following re-application of the functional brace.

I have also had the opportunity to use functional below-the-knee braces for delayed unions and non-unions of the tibia in some instances associated with infection. Spontaneous union and/or disappearance of infection did not take place in all instances. However, I am of the impression that a functional environment affects

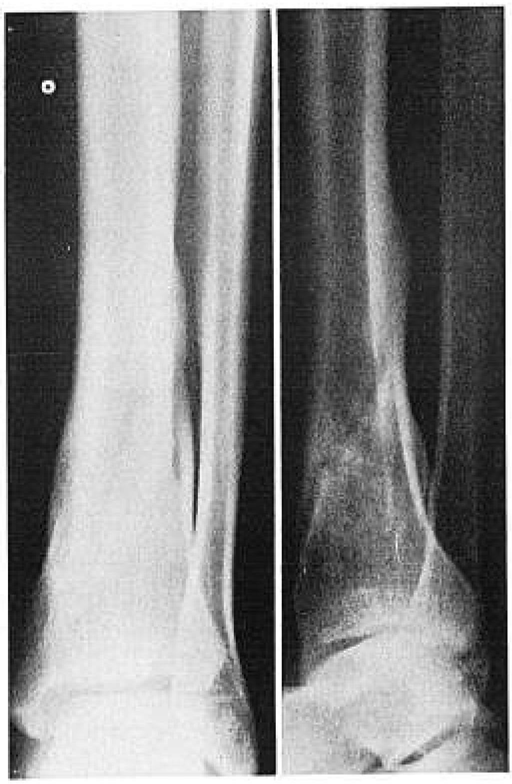


FIG. 8 C. See legend for Figures 8 A and B.

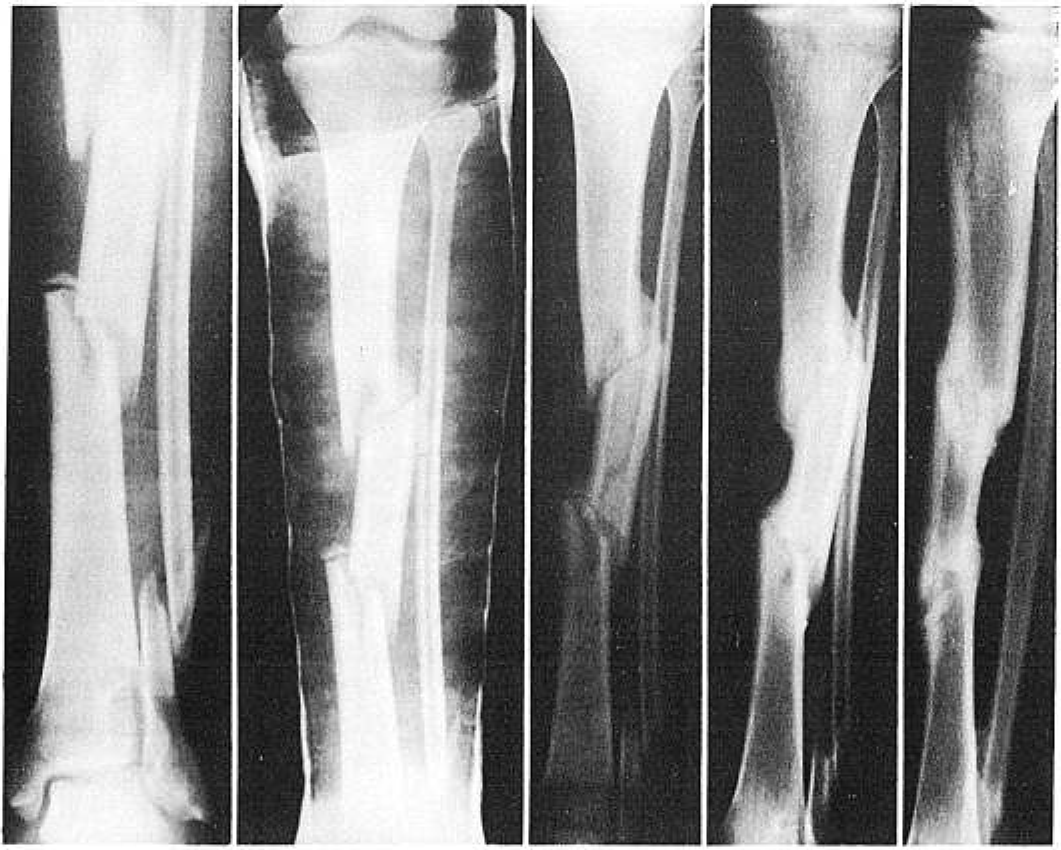


FIG. 9. Segmental fracture which healed without additional shortening or angulatory deformity. The below-the-knee ORTHOPLAST functional brace was applied five weeks after the initial injury.

favorably the condition of the soft and bony structures of those limbs. In the event that a period of activity does not result in healing of the fracture and surgery or debridement are necessary the metabolic and physiologic condition of the extremity will improve, therefore enhancing the success from the necessary surgical procedure (Fig. 11).

Experiences with a functional method which I have developed over the past 10 years for the treatment of certain tibial fractures have demonstrated a high success rate by virtue of elimination of surgical infection and a significant reduction of non-unions. The early freedom of motion of joints has permitted functional activity and independence not possible with other conventional methods of treatment. Osteoporosis of disuse and joint stiffness secondary to prolonged immobilization have been virtually eliminated.

This functional method of treatment does not at the present time constitute the primary and total treatment for tibial fracture. Bracing is introduced after a period of immobilization in plaster-of-Paris. The brace does not rigidly immobilize the fracture fragments as demonstrated by cineradiographic studies. It appears, however, that this minimal motion at the fracture site — being the result of function — has not been detrimental to

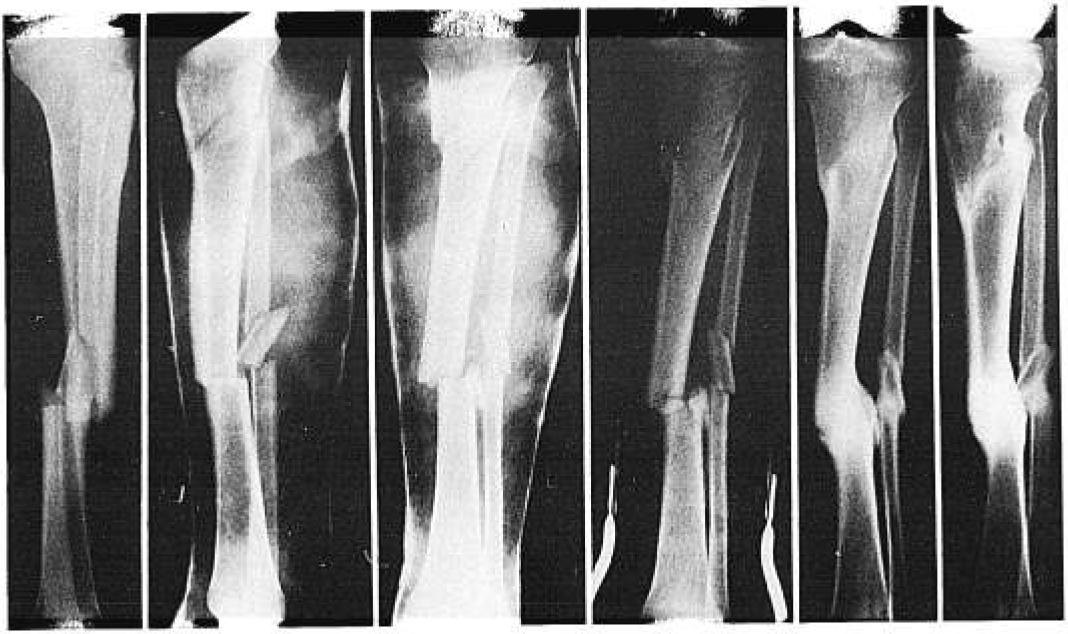


FIG. 10. Segmental fracture demonstrating healing of the fracture with only minimal additional shortening and mild valgus deformity.

fracture healing. On the contrary, it seems to promote rapid intrinsic stability of the fractures.

Experiences with 482 tibial fractures treated in this manner have strongly suggested that shortening of the extremity does not take place from the introduction of weight-bearing in the fractured extremity stabilized with below-the-knee functional casts or braces. The initial degree of shortening of closed fractures is usually the total amount of shortening detected at the completion of healing.

Open fractures with severe soft tissue damage are more likely to develop greater initial shortening.[1, 3] For this reason I believe that in open and severely displaced open fractures of the tibia that restoration of length by mechanical means should be performed. I prefer the use of transfixion pins above and below the fracture and the stabilization in toe-to-groin casts, preferably no longer than three weeks. The degree of soft tissue damage and initial displacement of the fragments are of importance since the ultimate degree of shortening seems to be directly related to it. Tibial fractures treated with early functional below-the-knee braces rarely have more than 6.8 mm of shortening. Closed fractures have averaged 6.4 mm shortening and open fractures 6.8 mm. Rarely is that amount of shortening detectable during gait after continued use of the extremity following healing of the fracture. Indeed, shortening between 1.27 cm and 1.91 cm is rarely troublesome or noticeable. Angulatory varus deformities, if limited to only a few degrees, are cosmetically acceptable. Similar degrees of valgus deformity are more readily recognizable. Their prevention is therefore more important, particularly in the female patient. Fractures of the distal one-half of the tibia with intact fibula, particularly open ones, have a ready tendency to angulate toward the fibula resulting in varus deformity of the leg. This varus de-

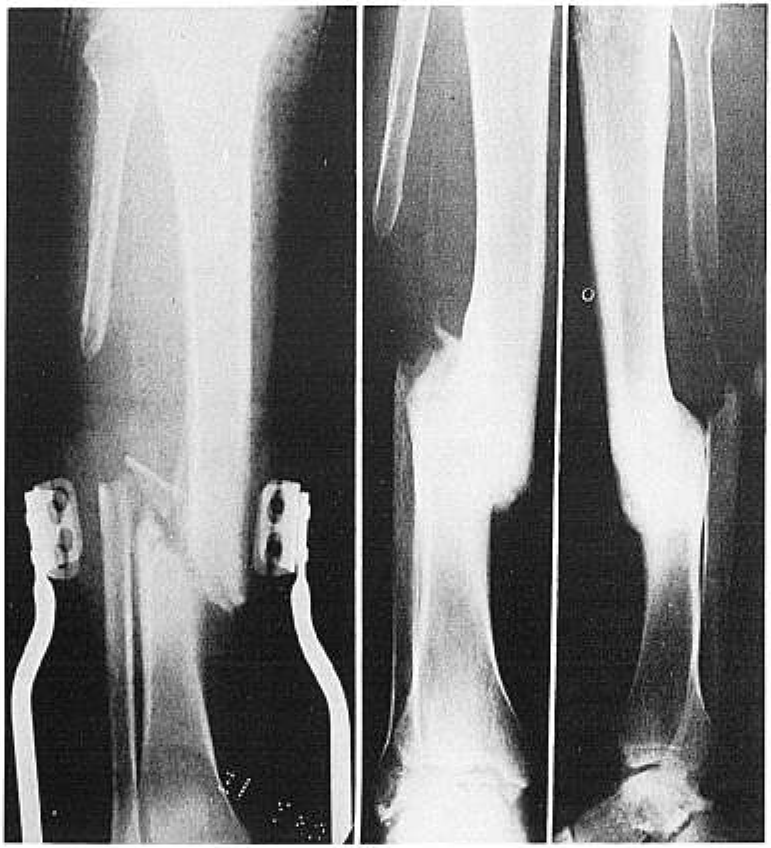


FIG. 11. Two and one-half month old open infected fracture which healed without additional shortening or deformity.

formity, in my experience, has not been severe enough to justify its correction by open reduction or osteotomy of the fibula.

Recurvatum deformities, if accepted at the time of the application of the cast or brace, may increase on weight-bearing. Intra-articular fractures of the distal tibia are best not subjected to the weight-bearing stresses because of the likelihood of increased deformity. The behavior of fractures of the proximal tibia with or without intra-articular involvement is influenced significantly by the condition of the proximal fibula. An intact fibula could easily lead to a varus deformity in the presence of a vertical fracture particularly if it enters the joint in its medial aspect. The proximal tibiofibular joint allows the head of the fibula to function as a supporting strut in controlling or preventing distal displacement of the lateral tibial condyle. Fractures of the proximal tibia including both tibial plateaus with associated fibular fractures can, as a rule, be braced and the knee mobilized anticipating an even collapse without varus or valgus deformity. The use of a thigh corset attached to the leg brace with metallic joints is desirable, particularly in patients with large and flabby legs.

Contrary to popular belief there appears to be no difference in the healing time of fractures of the tibia at various levels. The type of fractures — oblique, transverse, comminuted — with this method of treatment heal at approximately the same rate. It is my belief, however, that comminuted

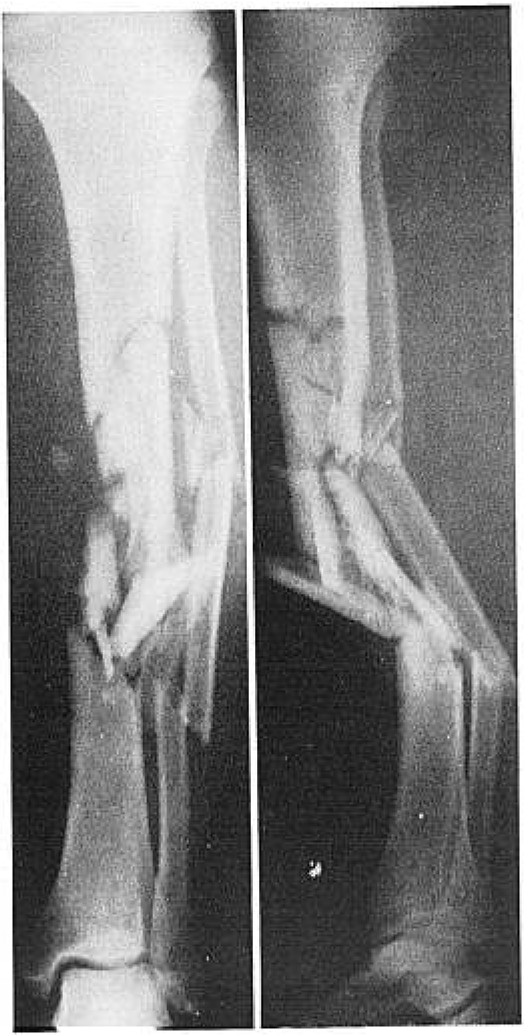


FIG. 12 A. Open severely comminuted fractures of the tibia and fibula with associated low grade infection.

fractures become intrinsically stable before transverse ones. The functional bracing of tibial fractures has been used in closed as well as open fractures with an equal degree of success. However, in general, the bracing has been delayed longer in open fractures and the healing has taken longer. Open fractures as a rule are treated by debridement and immobilization in toe-to-groin casts without attempting to perform primary closure of the skin[2, 11] (Figs. 12A through H).

There is strongly suggestive evidence that functional management of tibial fractures is most successful when introduced early after the initial insult. A period of a few days of relative rest to the extremity following the onset of the fracture is however highly desirable. Prolonged postponement of weight-bearing and functional activity do not consistently bring about uneventful osteogenesis. I believe that the ideal time for functional

FIG. 12 B. Fracture was stabilized with pins above and below the fracture.

FIG. 12 C. The wound was debrided and one large fragment of bone excised.

bracing of fractured tibiae is between the end of the second and fourth week.

Failure to detect bony areas about the proximal tibia as weight-bearing areas prompted me to suspect that the soft tissues of the extremity are highly responsible for the distribution of pressures during weight-bearing ambulation. Clinical and laboratory studies have demonstrated considerable pressure concentration over the gastrocnemius mass suggesting that the prevention of shortening is partially the result of the creation of an environment subject to the principles of incompressibility of fluids. The vertical loads of ambulation tending to shorten the fractured fragments are balanced by the lateral and oblique forces created by the soft tissues against the rigid walls of the cast or brace. The large musculature of the leg with its high water content is, for practical purposes, separated from the thigh and foot at the knee and ankle joints by relatively inelastic ligamentous structures. The muscle bellies of the flexors and extensors of the knee as well as the flexors, extensors,

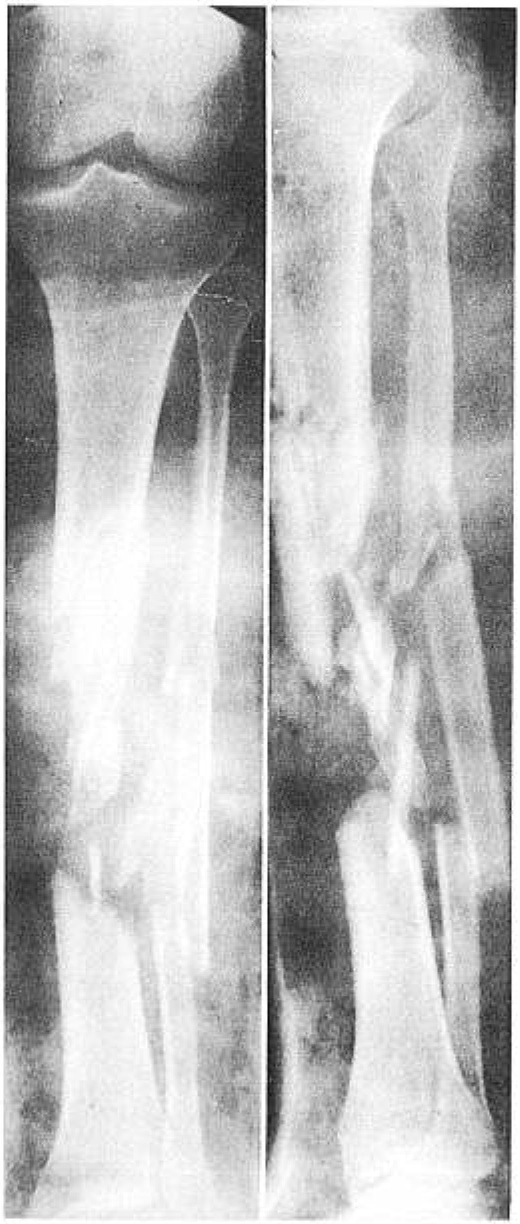


FIG. 12 D. Two weeks after the initial injury, a below-knee functional cast was applied.

FIG. 12 E. Four weeks later a below-knee ORTHOPLAST brace replaced the plaster-of-Paris.

invertors and evertors of the foot and ankle have become tendinous in nature prior to their reaching the knee or ankle joints. These tendinous structures are held close to the underlying bony structures by crural ligaments just above the ankle joint, virtually separating the lower leg from the adjacent anatomical segments of the limb (Fig. 13). Perhaps of special importance is the visco-

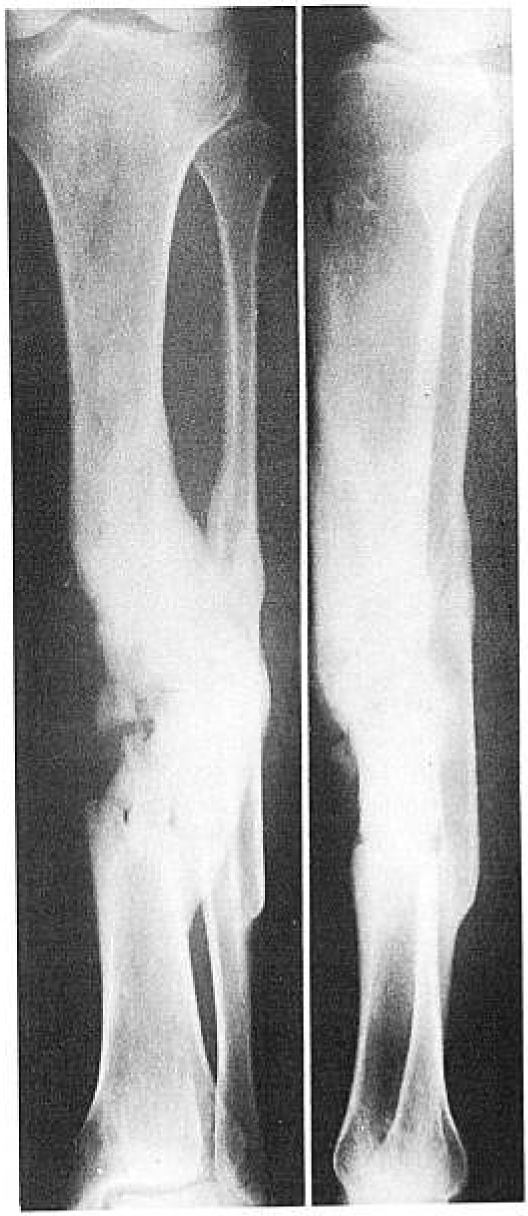


FIG. 12 F. The fracture united uneventfully.

FIG. 12 G. The overall appearance of the fractured extremity was satisfactory. No attempts were made at the time of surgery to close the wound.

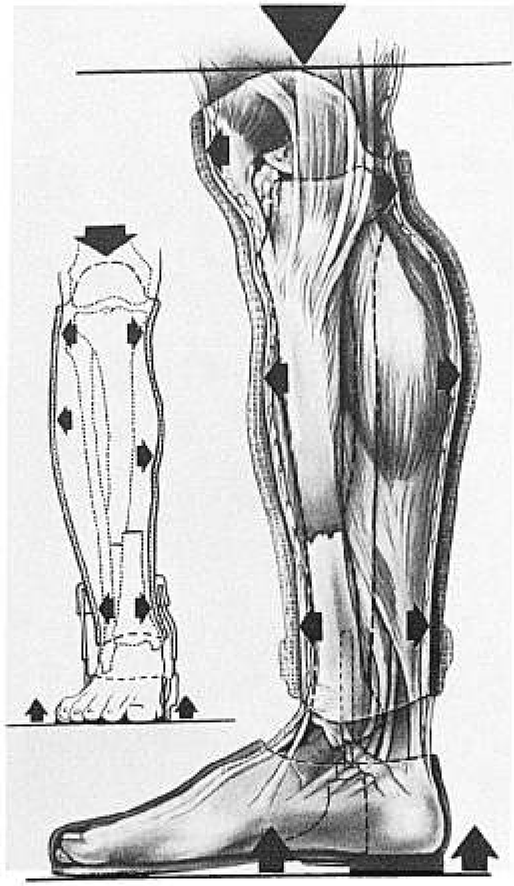


FIG. 13. Artist's conception of the application of the principle of incompressibility of fluids to the stability of tibial fractures. The relatively incompressible soft tissues surrounding the fractured bone do not permit shortening under vertical loading because of the resistance provided by the rigid walls of the brace.

elastic nature of the musculo-fascial structures surrounding the fractured bones. There is laboratory evidence which strongly suggests that the initial damage to the elastic musculofascial tissue inserting into and enveloping the fracture site determine the initial and ultimate degree of shortening of the extremity. These observations have suggested that the brace plays a most important role in the prevention of angulation as well. (See Chapter on "The Role of Soft Tissues in Fracture Stability.")

The interosseous membrane also appears to play a major role in the stabilization of tibial fractures and in determining the initial and ultimate degree of shortening of the extremity. Laboratory studies in progress at this time indicate that this membrane with its strong relationship with the periosteum and muscle origins serves physically as a limiting force in the prevention of shortening of the extremity under weight-bearing conditions. It appears that the damage to the interosseous membrane is a determining factor in longitudinal as well as in transverse displacement of the fragments at the

time of the initial injury and later during the weight-bearing ambulation. I have extrapolated, based on clinical and laboratory observations, that the maintenance of length and alignment of tibial fractures is governed primarily by the hydraulic environment provided by the supporting brace and the influence of the checkrein mechanism of the interosseous membrane. (See Chapter on "The Role of Soft Tissues in Fracture Stability.")

I have attempted to explain the high success rate of these methods on the basis of the fact that the fractured limbs by virtue of the freedom of motion of the joints and activity are placed in a physiological environment which is conducive to osteogenesis. The intermittent compression of the fractured parts brought about by weight-bearing and functional activity as well as physiological muscle contractions probably create a thermic, vascular and metabolic milieu which enhances the normal reparative process.

## SUMMARY

Ten years of experience with non-surgical functional methods of treatment in 482 fractures suggests that healing of fractures of the tibia can be obtained in the overwhelming majority of instances and can be enhanced by functional activity of the musculature, motion of joints in the affected extremities, and weight-bearing. The functional method of treatment does not provide rigid immobilization to the fractured structures, and in fact allows minimal amounts of motion at the fracture site which associated with limb function, encourages early osteogenesis. Tibial fractures usually rest at the time of injury in a position of the total and eventual shortening found at the completion of healing. The soft tissues of the injured extremity — particularly the incompressible water-rich and visco-elastic musculature — are probably the major stabilizing forces and the main determinants of subsequent shortening. The initial damage suffered by the interosseous membrane is also most likely influential in determining the initial and eventual shortening and alignment of the fragments.

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