## How I do it

# Soft tissue defects and bone loss in tibial fractures—treatment with free flaps and bone transport

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Open tibial fractures, with loss of soft tissue and bone, and established infected nonunions require soft tissue cover, bone reconstruction and eradication of infection to regain a functional extremity. The outcome has traditionally been considered uncertain. The fractures and soft tissue damages are usually caused by high energy trauma, and the surgeons often have to address other injuries which may influence the choice of treatment of the leg injury.

## Classification and scoring systems

The relationship between soft tissue damage, fracture healing and complications was established by Gustilo and Anderson in 1976. They classified open fractures according to the extent of soft tissue damage where type I has a wound shorter than 1 cm. Type II fractures include larger lacerations, but without extensive soft tissue damage, flaps or avulsions. Type III covers open segmental fractures, fractures with extensive soft-tissue loss, and traumatic leg amputations. In 1984, the same group found that type III was too inclusive, and they proposed a subclassification for severe open tibial fractures into type III A and III B, according to the amount of soft tissue stripping and devascularization of bone at the fracture site. Type III C included fractures with additional injuries to the major leg arteries (Gustilo et al. 1984). The prognostic value of the extended classification has been demonstrated by Caudle and Stern (1987). None of the type III A fractures in their series was associated with deep infection or required secondary amputation, whereas three quarters of the type III C patients eventually had an amputation.

Scoring systems to distinguish between salvageable and doomed limbs on objective criteria are established (Johansen et al. 1990), but they have been criticized as not sensitive enough (McNutt et al. 1989) and are not widely used.

To assess a patient's functional ability with their salvaged limb after type III B and III C fractures, Puno et al. (1996) designed a 7-scale score including pain, function, motion, deformity, strength, sensation and radiographic changes. The authors used this functional scoring system in 71 type III B and III C fractures, and they disagreed with those who claimed that most salvaged limbs will have poor function.

## Primary amputation vs. reconstruction

Protected attempts at limb salvage may destroy a person physically, psychologically, socially and financially. Hansen (1987) favored an early decision to amputate severely injured lower limbs, since postinjury below-knee amputees rehabilitate well. Walker et al. (1994) found little evidence in the literature supporting this view. In their survey of long-term outcome of 87 lower limb amputations following injury, little functional difference was seen between early and delayed amputations. Two thirds of the below-knee amputees had skin breakdown problems, more than half had frequent or constant stump pain and one third required further stump surgery. Almost two thirds considered themselves more or less disabled and one quarter had to visit the prosthesis clinic between 5 and 10 times in the preceding year. The authors concluded that, although amputation may be preferable to attempted limb reconstruction, it is important for the surgeon and the patient to realize that amputation by no means returns every young adult to a normal, pain-free existence.

New techniques in the surgical management of tibial fractures with gross tissue loss, such as assessment of areas of tissue for debridement, methods for

Treatment of 32 tibial fractures types III B and III C (1984–96)

| | No. | Mean bone defect (cm) | Mean healing time (months) | Nonunion | Secondary amputation |
|---|---|---|---|---|---|
| Pedicled gastrocnemius or soleus flap | 3 | 0 | 4 | 2 [a] | 0 |
| Free skin flap with or without cancellous bone graft | 11 | 2 (0–3) | 10 (3–33) | 0 | 2 [b] |
| Compound free flap (skin and bone) | 8 | 6 (2–12) | 14 (4–54) | 0 | 0 |
| Free skin flap followed by bone transport | 6 | 6 (4–9) | 8 (5–11) | 1 [a] | 0 |
| Free skin flap followed by free fibula/iliac crest transfer | 2 | 10 (5–15) | 12 | 1 | 1 [c] |
| Free fibula only | 1 | 13 | 17 | 0 | 0 |
| Bone transport only | 1 | 8 | 12 | 0 | 0 |

External fixation was used in all cases.
Healing time is the time from flap transfer/start of bone transport to bony union.
[a] Still under treatment.
[b] Amputation due to sepsis early postoperatively.
[c] Amputation due to nonunion.

stabilization of the fracture, transfer of vascularized bone, segmental bone transport, and free flaps for soft tissue cover do not seem to be fully implemented in the scoring systems (Johansen et al. 1990, Robertson 1991). Recent reports indicate that limb salvage can be achieved with good function in most patients with tibial fractures type III B and III C when one or more of these methods are used (Godina 1986, Jupiter et al. 1990, Francel et al. 1991, Cotteano et al. 1992, Hammer et al. 1992, Reigstad et al. 1992, Tukiainen and Asko-Seljavaara 1993, Spiro et al. 1993, Dendrinos et al. 1995).

## My experience

We treated 32 tibial fractures types III B and III C in the period 1984–1996 (Table). Our selection of treatment was influenced by the development of new free flaps, e.g., lateral arm flap and the osteocutaneous scapular flap (Katsaros et al. 1984, Swarts et al. 1985) and the introduction of the Ilizarov method (1989) in the period. Most patients were admitted to our hospital after failure of the acute treatment at the referral hospital. Reduction and fixation of the fractures were frequently insufficient, the debridement of devitalized tissue had not been radical enough and the delay between injury and referral for further treatment was too long, mean 59 (0–275) days. All this may have caused the slow healing of some fractures, as also may have insufficient removal of avascular bone prior to flap transfer or bone transport.

## My current approach

### *General*

The clinical evaluation of a patient admitted to the hospital for a severe leg trauma should include a general assessment of the patient's condition (Prokuski and Marsh 1994). Multitrauma, head injury, chest and abdominal injuries, high age, poor health and abuse favor the simplest treatment of the mangled leg, which often will be below-knee amputation. Serious injury to the contralateral leg favor a salvage procedure.

### *Primary local treatment*

The injured leg should be assessed for ipsilateral fracture of the femur, knee injury and injury to the ankle or foot which may favor amputation, as also does severe muscle crush injury. However, an uninjured vascularized foot with sensibility in the foot sole strongly favors a salvage procedure.

High energy fractures of the two distal thirds of the tibia will often leave enough viable muscle proximally, with sufficient motor function for foot extension and flexion, although the anterior tibial artery and the deep peroneal nerve may have been crushed. Posteriorly, the tibial nerve and the posterior tibial artery may be damaged. If all three leg arteries are divided, revascularization/replantation must be considered in clinically stable cases with an uninjured foot. The skeleton has to be stabilized before revascularization. The foot should be revascularized within 8–10 hours after the injury by suture/grafting of either the tibial arteries. The tibial nerve should be sutured or grafted, as well as the deep peroneal and sural nerves, whenever possible.

The tibia should always be stabilized by an external fixator. I prefer a unilateral device because it provides easy access to the limb for later flap transfer (Figure 1). It is less bulky and better tolerated by the patients, it does not block raising local flaps and it has a more straightforward application than tension wire ring systems. (Meléndez and Cólon 1989). In cases where



Figure 1.Severe laceration of the right leg with soft tissue defects from the knee to the distal tibia. A closed ipsilateral femoral fracture had been plated before transfer for further treatment of the Grade III B tibial fracture. A closed ipsilateral ACL lesion was left untreated. The unstable Hofmann frame was replaced by an Orthofix® monolateral fixator after reduction of the fracture and revision of the soft tissue. The artery of an 8 × 23 cm simple scapular flap was anastomosed end-to-side to the posterior tibial artery which was the only open lower leg artery. Other defects were split-skin grafted. The fracture healed after a secondary procedure which included removal of an avascular bone fragment, osteotomy of the fibula and cancellous bone grafting 11 months after the flap transfer. An acceptable valgus/procurvation deformity, a slight ACL instability and some cosmetic problems remain. The mobility of the foot, ankle and knee is normal as well as sensation in the foot.

later bone transport is found necessary, a unilateral transport fixator should be used (Figure 2). It should be mounted in such a way that later bone transport is possible without relocation of the fixator (Marsh et al. 1994). Correct leg length, tibial axis and rotation must be achieved and the mechanically strong fixator should give the patient a fully stable leg to allow pain-free mobilization. Obvious dead bone fragments and necrotic soft tissue should be removed and the complex wound should be converted into surgically clean areas. Fasciotomies should be carried out, if needed, and exposed viable clean muscles may be split-skin grafted (Figure 1).

The situation is now stabilized. Wet dressings should be changed once or twice daily, and serial revisions of nonviable bone and soft tissue may be necessary on the following days. It may be difficult to assess how radical the debridement should be in cases with potentially viable tissue. My experience is that necrotic bone too often is retained, resulting in sequestration, sinus formation and delayed union (Figure 1). Arteriography of the leg arteries is mandatory before any secondary procedure in order to get an overview of possible recipient arteries for a free flap.

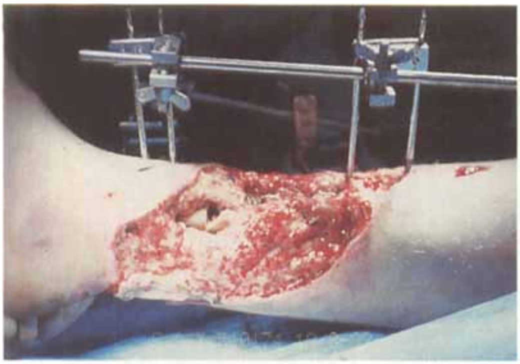
### *Secondary procedures*

The soft tissue cover should be carried out as soon as the wound is clean, preferably within a week. Proximal anterior defects can sometimes be covered with a local gastrocnemius flap, but often the damage in the area and the extension of the defect exclude the use of local flaps (Figure 1). Cross leg flaps or free flaps are then the only options, even in proximal fractures. Local flaps can hardly be used in extended soft tissue defects over midshaft fractures and distal tibial fractures. I prefer a free flap to cross leg flaps, since the former provides a large injured area having well vascularized tissue, without deriving blood supply from the adjacent tissue which may be inferiorly vascularized. It is more convenient for the patient and the donor morbidity is lower. Often the posterior tibial artery is the only open leg artery. In such cases, the flap artery may be anastomosed end-to-end to the anterior tibial artery proximally to the injured zone. It is important to know that the intima can be injured at a more proximal level than estimated from gross inspection during surgery (Chen et al. 1994).

I have worked with the scapular and the lateral arm flaps (Nassif et al. 1982, Katsaros et al. 1984) for larger and smaller soft tissue covers, respectively. Both flaps may, like the iliac crest and the fibula, be raised as compound flaps (Taylor et al. 1979, Yoshimura et al. 1983, Swartz et al. 1986) with underlying muscle and bone (Figure 3). The latissimus dorsi flap covered by split-skin grafts is used for soft tissue cover in several centers (Francel et al. 1991). It cannot be harvested with bone, but it is claimed that a muscle flap, in addition to cover, can promote fracture healing (Godina 1986, Small and Mollan 1992).

## Fracture treatment

The choice of fracture treatment depends upon the



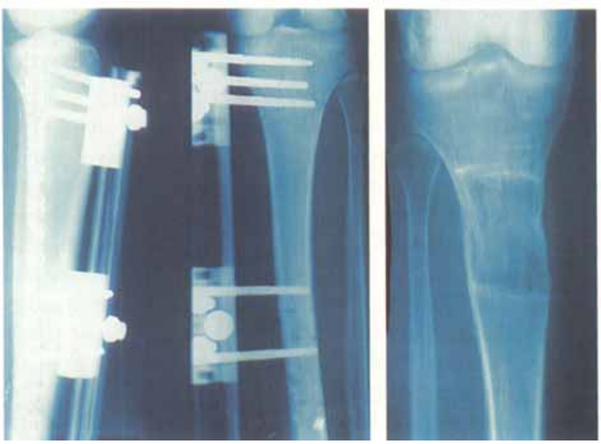
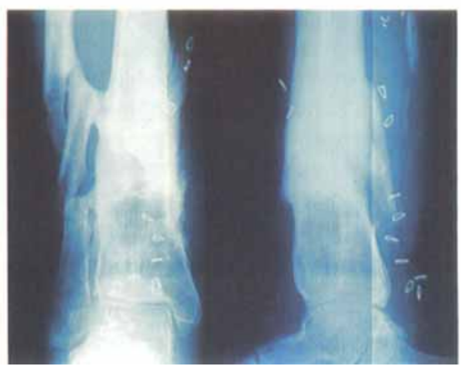




Figure 2. Grade III B fracture referred after failed acute treatment. The unstable external fixator was replaced by an Orthofix® transport fixator, the dead fracture ends were resected down to a defect of 8 cm and the soft tissue defect was covered with a scapular flap which necrotized. The flap was replaced by a lateral arm flap which healed uneventfully. After healing of the soft tissue defect, 3 weeks later a proximal tibial osteotomy was performed and the bone transport started 10 days thereafter. The fracture and donor defect were healed 5 months after the flap transfer. The function of the foot, ankle and knee is normal.

degree of bone comminution and length of the bone defect. Defects less than 3 cm can be filled with cancellous or corticocancellous bone from the iliac crest simultaneously with the flap transfer, if the wound is clean. Small defects can also be filled with vascularized bone from a compound flap, perhaps in combination with cancellous bone chips (Figure 3). In cases with bone defects between 3 and 8 cm, segmental bone transport should be carried out. This procedure should be delayed until the soft tissue is stabilized and possible infection is cured. The bone ends must be resected down to viable bone (Figure 2). The tibial osteotomy, which should be placed as proximally as possible, can be carried out with an oscillating saw under cooling, close to the distal screw in the proximal fixator clamp. We prefer vertical standard clamps to T-clamps, because of better stability of the former. If the fracture is located near the ankle joint, sufficient screw fixation of the distal clamp can be difficult to achieve. Fixation can be improved by passing the screws through the fibula. If a proximal tibial defect is to be treated by bone transport, a distal osteotomy is needed. I have no experience with distal donor site or with proximal and distal double osteotomy, but I fear delayed healing of a distal tibial osteotomy. For this reason, I prefer a vascular bone graft instead of bone transport in proximal defects. The bone transport starts 10–14 days after the osteotomy. A distraction of

0.5 mm is performed twice daily until the bone ends meet. The external fixator should be locked and kept in place until the donor and recipient sites are healed. After completed transfer, the patient is allowed full weightbearing.

If the tibial defects are longer than 8 cm, I would prefer transfer of vascularized bone by microvascular technique. Both fibulae (Yoshimora et al. 1983) and the iliac crest (Taylor et al. 1979) can be raised with overlying skin. However, the skin vessels of the former flap are often inconstant and the skin of the latter flap is bulky (Figure 4), especially in obese patients. I therefore prefer to cover the soft tissue defects by a flap, before treating a long bone defect with a vascularized fibula (Figure 5).

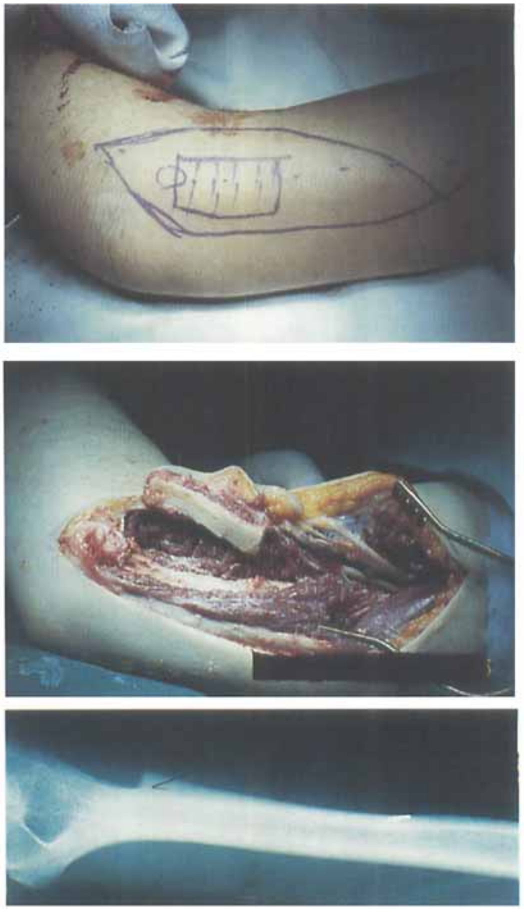


Figure 3. The lateral arm flap with bone. The wound can be closed directly without significant donor site problems.

## Problems

Infection is common and the patient is often threatened with sepsis (Georgiadis et al. 1993). In most cases, prophylactic intravenous antibiotics are given. How broad the antibiotic cover should be is a matter of discussion. It is wise to start with a drug that covers Staphylococcus aureus, and this occurs frequently in the initial stage (Georgiadis et al. 1993). In the later course, pseudomonas, which is difficult to treat with antibiotics, may be a problem, especially in cases with retained avascular tissue. Treatment with antibiotics alone in such cases is regularly disappointing, because of limited vascularization in the infection site and development of resistant bacteria. We always keep close contact with bacteriological expertise when choosing antibiotic treatment. Most important are radical debridement and primary stable fixation of the fracture by an external fixator, which reduce the infection problem, as also early cover of the defect with viable tissue.

Occlusion of the flap vessels occurs in about 10% of the transfers (Udesen et al. 1996). Revision of the anastomoses may salvage some flaps. In cases of flap failure, amputation or secondary flap transfer must be considered (Figure 2). Another possibility for treatment, after removal of the necrotic flap, is by judicious limb-shortening to obtain cover of the fracture with viable tissue (Prokuski and Marsh 1994). After healing of

Figure 4. Tibial defect treated by compound iliac crest flap.

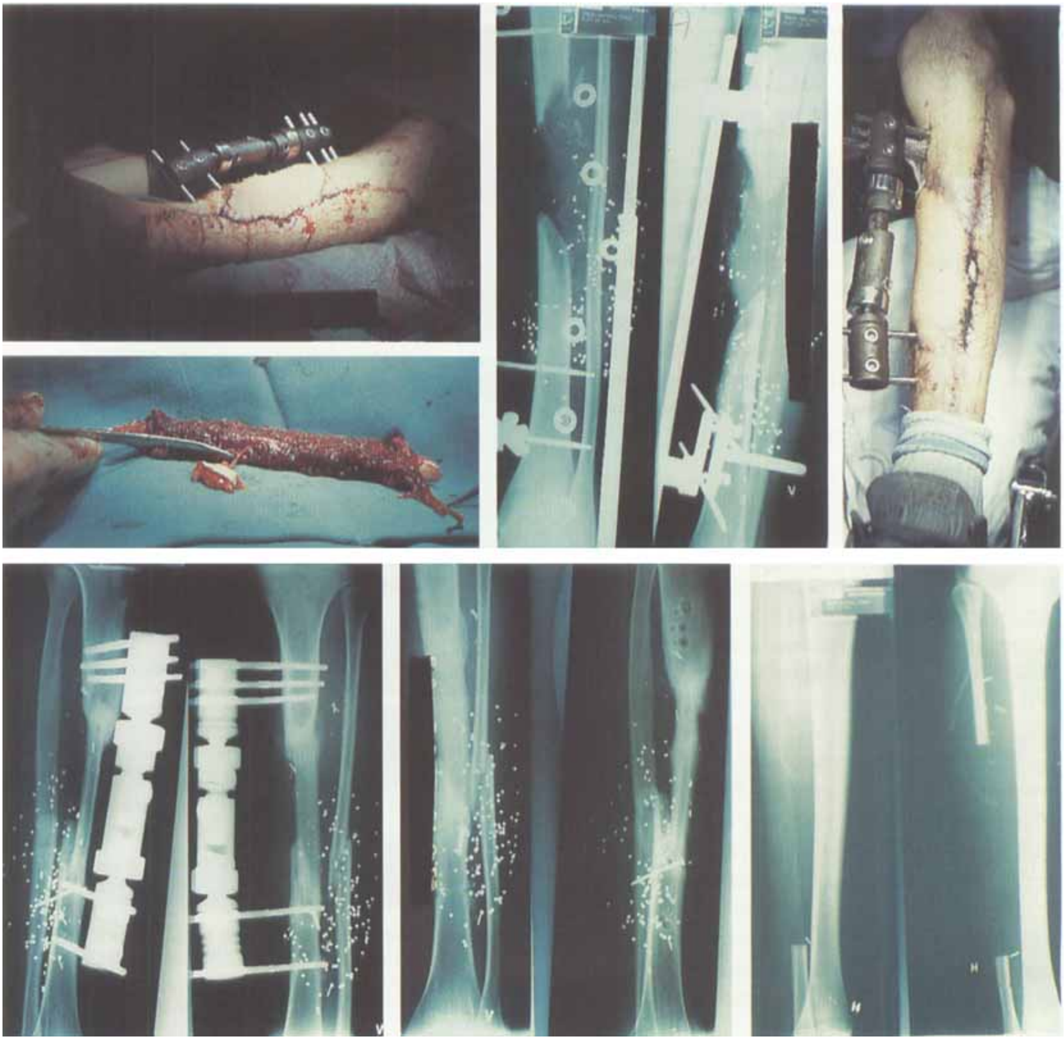


Figure 5. Gun shot injury primarily treated by resection of avascular soft tissue and bone, reduction and fixation of tibia with Orthofix®, and soft tissue cover with a simple scapular flap. The tibial defect was later treated with a 15 cm long fibula graft. Both free flaps were anastomosed end-to-side to the posterior tibial artery which was the only open lower leg artery. The fracture healed 12 months after the injury. The dynamized external fixator was removed after the fibula had hypertrophied.

the shortened tibia, a secondary Ilizarov elongation procedure may be carried out to equalize the leg length. This two-stage method may also be chosen as primary treatment for bone defects (Figure 6).

During the healing period, the external fixator, which is scheduled to be borne until fracture union, must be supervised by specially trained nurses, the patient and the surgeon. Any reaction around the bone screws should be recognized and treated. In case of screw loosening or screw fracture, the fixator must be replaced. Possible mechanical failure of the fixator must be repaired.

The healing time of types III B and III C fractures is longer than that of less severe tibial fractures, regardless type of treatment (Caudle and Stern 1987), but the rate of delayed union can be reduced by correct primary and secondary treatment. Transplantation of cancellous bone to the dock site and osteotomy of the fibula are often necessary after bone transport (Green 1994), whereas the proximal donor site usually heals without any further procedures (Dendrinos et al. 1995). Before cancellous bone transplantation, compression, alternating with distraction at the dock site produced by the external fixator, can be tried to induce fracture healing. Joint contractures of the knee and ankle may develop during the bone transfer. The patients should therefore be examined and treated by a physiotherapist.

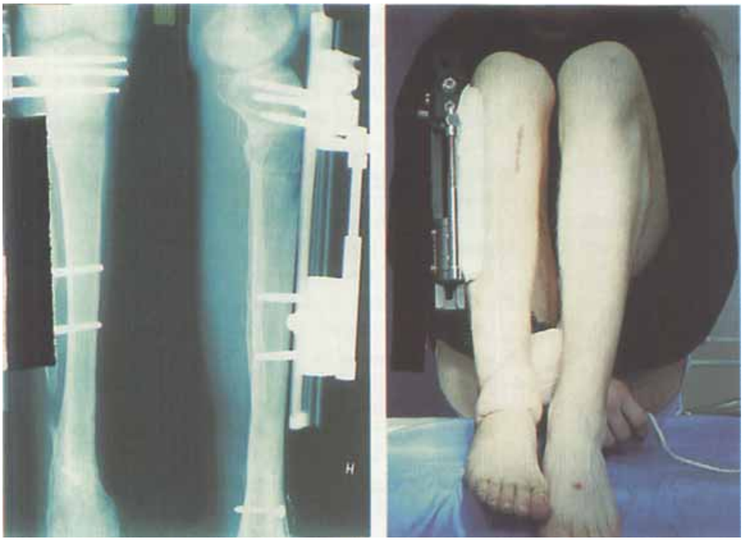



Figure 6. Distal tibial/ankle laceration treated by revascularization of the foot, 4.5 cm shortening of the tibia and soft tissue cover by a scapular flap. After healing of the distal tibia and the ankle arthrodesis, a lengthening procedure of 3 cm was carried out.

A transferred fibula needs time to hypertrophy enough to withstand the stress of full weightbearing (Figure 5). For this reason the external fixator should remain for 6–8 weeks after healing to avoid stress fracture. The fixator may be dynamized for some time before removal, and the patient should be equipped with a functional brace until the transferred fibula is considered strong enough radiographically. Delayed union of one or both ends of a transferred fibula may be treated with cancellous bone grafting and/or osteotomy of the ipsilateral fibula 6–8 months after the transfer.

Clawing of the toes due to ischemic contracture of the long flexors may be treated with tenotomies at the distal tendon insertion. A drop foot can be treated with triple arthrodesis and/or transfer of the tendon of the posterior tibial muscle. Significant donor site problems after flap transfer or bone transport are rarely seen (Reigstad et al. 1992, Tukiainen and Asko-Seljavaara 1993).

## Discussion

By combining and refining the new methods for soft tissue cover and bone reconstruction, one can save mangled lower legs which earlier would have been amputated. However, after the acute treatment, it is wise to inform the patient that repeated admissions to the hospital for soft tissue problems, infections and delayed union may be needed and may end with secondary amputation. The patient should also be informed about an average fracture healing time of approximately one year, after which he can expect a functioning limb. With a correctly placed external fixator he will be ambulatory with one or two crutches, and possibly be weightbearing for most of the treatment period. If an early below-knee amputation is chosen after a severe lower leg trauma, the patient should know that rehabilitation takes one year. Thereafter, the majority can expect good walking ability, but about two thirds of the patients are troubled by phantom limb or stump pain (Purry and Hannon 1989).

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