Simultaneous Treatment of Tibial Bone and Soft-tissue Defects With the Ilizarov Method

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Objectives: To evaluate the potential for limb salvage using the Ilizarov method to simultaneously treat bone and soft-tissue defects of the leg without flap coverage.

Design: Retrospective study.

Setting: Level I trauma centers at 4 academic university medical centers.

Patients/Participants: Twenty-five patients with bone and soft-tissue defects associated with tibial fractures and nonunions. The average soft-tissue and bone defect after debridement was 10.1 (range, 2–25) cm and 6 (range, 2–14) cm respectively. Patients were not candidates for flap coverage and the treatment was a preamputation limb salvage undertaking in all cases.

Intervention: Ilizarov and Taylor Spatial Frames used to gradually close the bone and soft-tissue defects simultaneously by using monofocal shortening or bifocal or trifocal bone transport.

Main Outcome Measurements: Bone union, soft-tissue closure, resolution or prevention of infection, restoration of leg length equality, alignment, limb salvage.

Results: The average time of compression and distraction was 19.7 (range, 5–70) weeks, and time to soft-tissue closure was 14.7 (range, 3–41) weeks. Bony union occurred in 24 patients (96%). The average time in the frame was 43.2 (range, 10–82) weeks. Lengthening at another site was performed in 15 patients. The average amount of bone lengthening was 5.6 (range, 2–11) cm. Final leg length discrepancy (LLD) averaged 1.2 (range, 0–5) cm. Use of the trifocal approach resulted in less time in the frame for treatment of large bone and soft-tissue defects. There were no recurrences of osteomyelitis at the nonunion site. All wounds were closed. There were no amputations. All limbs were salvaged.

Conclusions: The Ilizarov method can be successfully used to reconstruct the leg with tibial bone loss and an accompanying soft-tissue defect. This limb salvage method can be used in patients who are not believed to be candidates for flap coverage. One also may consider using this technique to avoid the need for a flap. Gradual closure of the defect is accomplished resulting in bony union and soft-tissue closure. Lengthening can be performed at another site. A trifocal approach should be considered for large defects (> 6 cm). Advances in technique and frame design should help prevent residual deformity.

Key Words: Ilizarov, tibia, wound, nonunion, bone defect, Taylor spatial frame

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Tibial diaphyseal fractures are among the most common types of open fracture and > 50% are classified as high-energy Gustilo-Anderson type III fractures.[1–3] Management of these fractures is further complicated by accompanied vascular and soft-tissue injury, putting these limbs at risk for infection, bone loss, and even amputation.[4–7] Even if bony union is achieved, these difficulties may still lead to impaired function of the treated limb and result in poor functional outcome from limb length discrepancy, deformity, and joint contractures.[8]

The Ilizarov method has been used successfully in the treatment of tibial fractures, nonunions, and malunions, deformity, and shortening.[8–12] The dynamic frame enables gradual lengthening, deformity correction, and nonunion or delayed union compression while remaining minimally invasive.[5,11,13–16] The Ilizarov method of intercalary bone transport has been used to deal with tibial bone loss and achieve limb salvage.[8,17,18]

The soft-tissue damage found in these fractures and wound management often are the main factors affecting outcome.[6,19,20] The preferred treatment of these wounds during tibial fixation is early application of a local flap if the defect is in the proximal two-thirds of the tibia or a free muscle flap if it is in the distal one-third.[21–23] Local flaps can, however, be suboptimal because the tissue that

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would be rotated often falls in the zone of injury. Application of a free flap requires microsurgery and a local blood supply, which may have been compromised by vascular trauma.

Occasionally, the treating plastic surgeon will declare a patient is not a candidate for a flap. Reasons may include unavailability of local soft tissue, poor potential vascular supply to a free tissue transfer (single vessel limb, after a revascularization procedure, or plaque disease of vessels) and medical comorbidities that are a contraindication to a long free flap procedure. Additionally, revision flap coverage may not be an option after previous flap necrosis, in which case the patient's remaining standard option is amputation.

A novel approach to this complex problem of a bone and soft-tissue defect was first used by G. A. Ilizarov in Russia.[10,16] It has been mentioned sporadically in reports on bone transport.[8] This design utilizes the Ilizarov external fixation device for both skin and bone transport.[24–27] This novel method can use a monofocal, bifocal, or trifocal approach. With the monofocal approach the 2 bony segments surrounding the defect are transported toward each other resulting in shortening. The bifocal approach utilizes an osteotomy away from the defect site. The intercalary segment is then transported away from the corticotomy site and compressed at the defect site maintaining optimal bone length. A trifocal approach uses 2 lengthening osteotomies in addition to compression of the defect.[8]

The purpose of this study was to assess the efficacy of using the Ilizarov method to simultaneously close both soft tissue and bone defects of the leg in patients who were not considered candidates for flap coverage by the treating plastic surgeon. This was a preamputation limb salvage undertaking in all cases.

MATERIALS AND METHODS

Between 1996 and 2004, 25 patients from 4 university centers treated by 4 surgeons with high-energy open tibial fractures with bone loss or subsequent nonunions that required bone excision and associated soft-tissue loss were retrospectively reviewed. This group was a combination of acutely treated patients and patients referred at a later time. Flap coverage of the soft tissue defects was not considered a viable option by the plastic surgeon for these patients, and all elected for this treatment as an alternative to amputation. Twenty-three cases were initially Gustilo-Anderson grade III open fractures (3A: 5, 3B: 14, and 3C: 4) and 2 patients had grade II open fractures.[2] All patients had open wounds with bone loss and soft-tissue loss. Two patients presented with failed flaps over bony defects (Table 1). The necrotic bone and soft tissue was debrided creating the defect. Skin grafts were used on 5 patients during treatment; however, none of the grafts was sufficient to permanently cover the defect site. The Vacuum-Assisted Closure (VAC) device was used in 3 cases to aid in wound management of the defect site[28] and wet to dry gauze dressing were used in the rest.

TABLE 1. Soft-Tissue Injury and Infection Profile

Soft-Tissue Injury Profile	Infections at Presentation
Gustilo Anderson-type open fracture	Bone infections (n = 11)
Grade 3C (n = 4)	Soft-tissue infection (n = 17) (3 patients had both bone and soft-tissue infection)
Grade 3B (n = 14)	
Grade 3A (n = 5)	
Grade 2 (n = 2)	Organisms
Failed Flaps (n = 2)	Methicillin-resistant *Staphylococcus aureus* (n = 8)
	Pseudomonas aeruginosa (n = 6)
	Methicillin-sensitive *Staphylococcus aureus* (n = 3)
	Enterococcus coli (n = 3)
	Enterococcus fecalis (n = 2)
	Klebsiella pneumoniae (n = 1)
	Proteus mirabilis (n = 1)
	Staphylococcus epidermidis (n = 1)

The average patient age was 34 (range, 16–61) years. There were 17 men and 8 women. The mechanism of injury was motor vehicle accident in 12, motorcycle accident in 5, gunshot wound in 5, and fall in 3. Eight patients had associated contralateral tibial fractures that were successfully treated with another method. Seven patients had associated femur fractures and 3 had fractures of the foot. Two patients in motor vehicle accidents also experienced closed head injuries and another 3 had abdominal injuries. Two patients with gunshot wounds experienced arterial disruption in the same leg studied.

The average time from injury to application of the Ilizarov frame was 15.5 (range, 0.5–94) weeks. The time frame from injury to treatment was as follows: < 2 weeks in 11 patients, between 2 to 11 weeks in 5 patients, and > 11 weeks in 9 patients.

On hospital admission, all wounds were debrided by the Ilizarov surgeon. The average wound size after debridement was 10.1 (range, 2–25) cm, and the bone defects averaged 6 cm (range, 2–14) cm.

At surgery, 11 patients were noted to have bone infections and 17 had infections of the soft tissue. The predominant bacteria were methicillin resistant *Staphylococcus aureus* (MRSA) and *Pseudomonas aeruginosa* (Table 1). Average duration of antibiotics treatment was 4.9 (range, 2–6 weeks). Intravenous antibiotic treatment was used in 22 patients.

Compression and distraction adjustments were made daily by the patients according to individualized programs. Ten patients had monofocal transport and gradual shortening (Fig. 1). Fifteen patients had simultaneous lengthening (Table 2). Twelve patients had a bifocal approach (Fig. 2), and 3 patients had a trifocal approach (Fig. 3). Ilizarov frames were used in 23 patients and Taylor Spatial Frames (TSF; Smith & Nephew, Memphis, TN) were used in 2 patients.

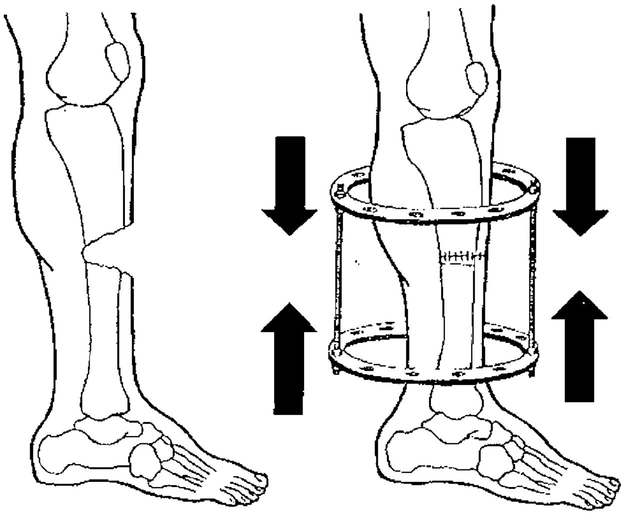

FIGURE 1. Schematic representation of a bone and soft-tissue defect and the use of monofocal treatment depicting gradual closure of the defect. This results in limb shortening.

The main outcome measurements of this study were bony union, soft-tissue closure, resolution or prevention of infection, restoration of leg length equality, alignment, and successful limb salvage.

SURGICAL TECHNIQUE

General Considerations

All nonviable bone and soft tissue is debrided. Bone is debrided back to healthy-appearing bone with open intramedullary canals and with bleeding surfaces. This is best performed without the use of a tourniquet. Bone cuts are typically made perpendicular to the anatomic axis of the tibia using a power saw cooled with saline irrigation. A K-wire placed with the help of fluoroscopy is used as a guide for the bone cut. Ideally, the soft-tissue defect is fashioned into an oval shape. This helps the wound edges gradually approximate like that seen with an elliptical excision of a lesion. The edges of the bone defect should ideally be covered with soft tissue to prevent bone desiccation and secondary necrosis and osteomyelitis. In the adult patient, rings are applied with a combination of 1.8-mm Ilizarov wires and 6-mm hydroxyapatite coated half-pins. Smaller sized wires and half-pins may be used in children. The first 1.8-mm reference wire is placed perpendicular to the axis of the bone in the coronal plane. The ring is attached with approximately 2-fingerbreadth spacing between the skin and the ring and the wire is tensioned to 130 kg. The half-pin is then placed setting the ring perpendicular to the sagittal plane bone axis. A ring block is 1 or 2 rings. Each ring block should have a combination of 3 to 4 wires and/or half-pins. In situations where there is a very short proximal or distal tibia segment, consideration should be given to extending the fixation across the knee or ankle. This strategy is most commonly used for a short distal tibia segment with extension of the frame to the foot, at least temporarily.

TABLE 2. Lengthening Sites in 15 Patients

Monofocal (n = 10)	Bifocal (n = 12)	Trifocal (n = 3)
n/a	Proximal tibia (n = 9)	Proximal tibia (n = 3)
	Femur (n = 1)	Middle tibia (n = 2)
	Distal tibia (n = 1)	Distal tibia (n = 1)
	Fibula transport (n = 1)	

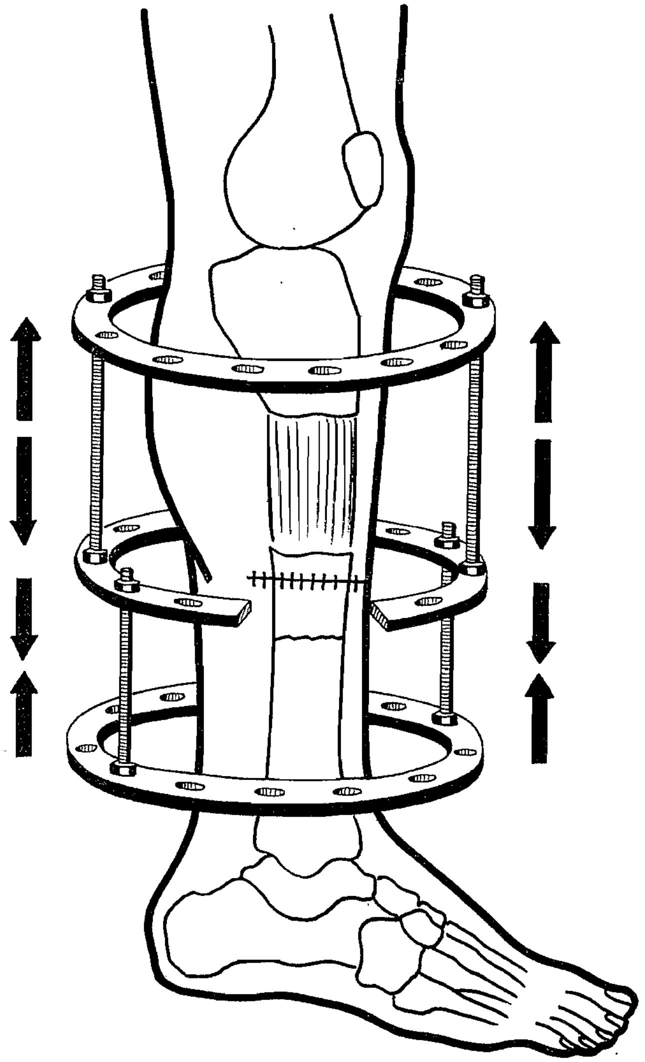

FIGURE 2. Schematic representation of bifocal treatment depicting gradual closure of bone and soft-tissue defect with bone transport. Although there is shortening across the defect, there is simultaneous lengthening through a proximal tibial osteotomy. This maintains the length of the limb.

Monofocal Approach

A ring block is applied both proximal and distal to the defect (Fig. 1). The space between the innermost rings

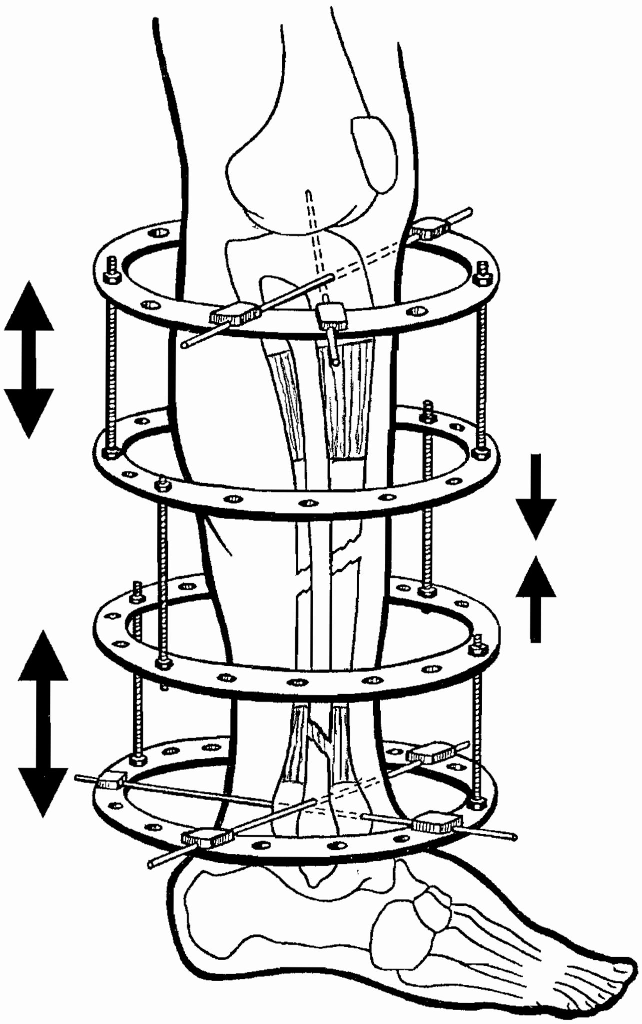

FIGURE 3. Schematic representation of trifocal treatment. There are 3 foci of dynamic activity. There is gradual closure (shortening) across the defect and simultaneous lengthening (transport) through 2 osteotomies of the tibia. This maintains the length of the limb.

and the respective bone ends is chosen so that after docking there will be adequate room to approach the docking site for possible bone grafting or wound revision surgery. Ideally this space should be > 5 cm between rings at bone contact. Connecting rods or struts are placed between the innermost rings to be used for compression or gradual shortening. The fibula must have a defect that is comparable to the tibial defect. A modest amount of acute shortening may be done. Pulses should be checked to make sure that this does not cause any vascular compromise. Limb shortening will occur with this method. We do not usually do more than 3 cm of acute shortening. The soft-tissue envelope will affect the amount that can be done. In general more acute shortening can be performed closer to the time of the injury.

Bifocal Approach

This is called bifocal because there are 2 segments with activity (Fig. 2). One segment (the defect) is undergoing compression/shortening, and 1 segment (the bony regenerate) is undergoing distraction lengthening to maintain the length of the limb. A ring block is applied on either side of the bone defect. Another ring block is placed on the other side of the anticipated lengthening osteotomy site. Rods or struts are applied across this segment and are set up for lengthening or distraction. The rods are then disconnected in preparation for the osteotomy. The osteotomy is done in a percutaneous fashion using either the multiple drill hole and osteotome technique or the Gigli saw technique.[29] Care is taken to perform this osteotomy outside the zone of injury in healthy bone. Ideally this osteotomy is done in the metaphyseal bone. The proximal metaphyseal location is preferable to the distal metaphysis because of increased bone regeneration potential.[16]

Trifocal Approach

This is called trifocal because there are 3 segments with activity (Fig. 3). One segment (the defect) is undergoing compression/shortening, and 2 segments of bony regenerate are undergoing distraction/lengthening. This can maintain the length of the limb. Rings are placed on either side of the defect. Additional rings are placed around what will be 2 lengthening sites. If the defect is in the middle of the tibia, 2 osteotomies are performed: 1 in the proximal, and 1 in distal tibia. Two intercalary bone segments are transported toward each other (Fig. 3). If the defect is in the proximal or distal tibia, another trifocal option exists where 2 intercalary segments are transported in the same direction (not shown in Fig. 3).

Ilizarov Frame Considerations

The frame should be applied to the leg so that rings are perpendicular to the tibial axis, the rods are parallel to the bone axis, and there is adequate clearance between the soft tissues and the rings especially at the posterior leg. The bone defect edges should be perfectly pointed toward each other to avoid deformity and to optimize contact at the anticipated docking site. If deformity should occur, this can be managed with frame modification and/or a surgical procedure to optimize contact at the docking site.

Taylor Spatial Frame Considerations

Rings are placed on either side of the defect site and the anticipated lengthening site(s) (Fig. 4). The rings can be placed independently to optimally fit the leg. This is called the *rings first method.* One ring is chosen as the *reference ring* for each level of movement, and it is important that this ring be placed orthogonal to the axis of the tibia. Mounting parameters are defined by the center of the reference ring and this will define the point in space where the deformity correction will occur. It is important to maintain enough distance between rings so that the struts can fit properly. In this frame, one is limited by the shortest length of strut. The advantages of

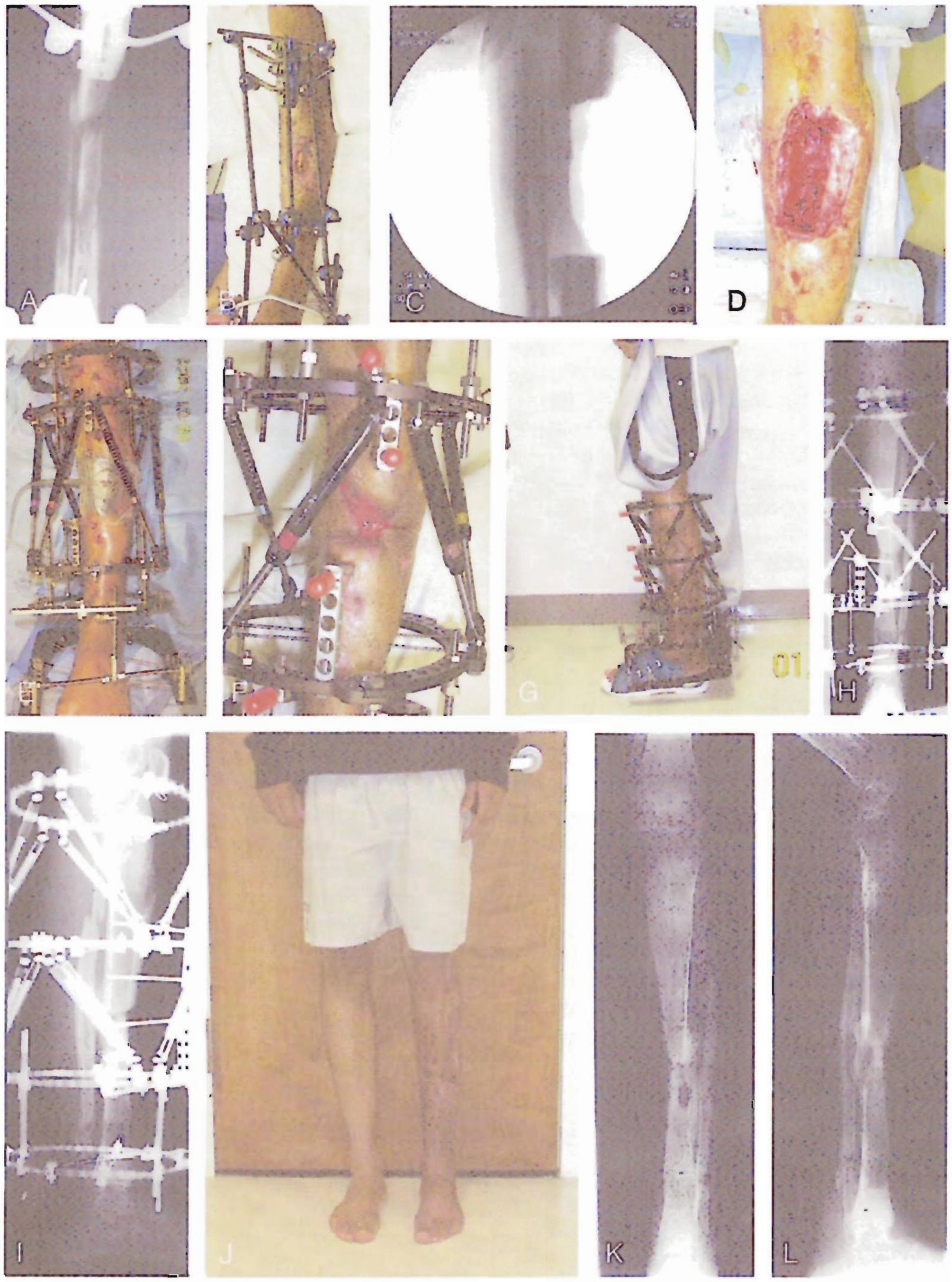

FIGURE 4. Clinical case example of trifocal bone transport. A, Anteroposterior radiograph of an infected tibia nonunion 1 year after a pedestrian versus motor vehicle bumper crush injury that was a Gustilo Anderson grade IIIC open fracture. B, Clinical appearance of this infected tibial nonunion. Previous free flaps were performed and exposed desiccated bone is present. Subsequent operative cultures grew MRSA, *Pseudomonas aeruginosa*, and *Klebsiella pneumoniae*. C, Lateral intraoperative radiograph after resection of dead infected bone showing an 11-cm defect. D, Intraoperative appearance of leg after wound debridement and bone resection showing a 13-cm × 8-cm soft-tissue defect. E, Leg with Ilizarov/Taylor Spatial Frame (TSF) in place. This frame has struts across the middle defect and rods across the proximal and distal tibial lengthening sites. There is a VAC device covering the wound. There is extension of the frame across the ankle for treatment of an ankle equines contracture. F, Interim appearance during gradual closure of the wound. Complete closure occurred after 23 weeks. G, Standing side view at 7 months postoperative. H, I, Anteroposterior and lateral radiographs of the leg at 7 months showing excellent alignment, closure of the defect, and partial bony healing of the docking site and the proximal and distal tibia lengthening regenerate sites. J, Standing front view 3 months after frame removal. Total time in frame was 53 weeks. K, L, Anteroposterior and lateral radiographs of the leg at 3 months after frame removal.

this frame is that the application is easier and the fit on the leg is better when using the *rings first method*. Also, residual deformity at the lengthening and docking sites can be addressed by using the same frame to correct angulation and translation simultaneously in the coronal, sagittal, and axial planes without major frame modification. This allows precise docking with optimal bone contact and minimizes angular deformity at the docking and lengthening sites.[11]

Wound Management

All necrotic tissue is debrided. Bone is not left exposed. The wounds are left accessible while the leg is in the frame. In some cases, skin graft can be placed as a biologic dressing in a temporary fashion during the transport. In most of the cases, the wound was managed with daily wet to dry gauze dressings during the transport until closure. More recently, we have used the VAC device (Fig. 3) over the open wound during transport. As the transport progresses, the wound size will decrease. At the end of transport, the skin can become infolded into the docking site. In some cases the skin will gradually pop out of the crevice, whereas at other times, a surgical procedure to excise the infolded skin may be needed.

RESULTS

The results at an average follow-up of 3 years (range, 13 months to 6 years) of the entire group and subgroups of monofocal, bifocal, and trifocal approaches are summarized (Table 3). The 1 patient who did not have a bony union achieved a stiff nonunion with no infection recurrence (after having an MRSA bone and soft-tissue infection) and was satisfied at 5-year follow-up, refusing any further treatment. Bone grafting using autograft or demineralized bone matrix was performed at the docking site in 12 patients. Three patients underwent secondary intramedullary nailing of the tibia to achieve union. This was chosen because they were infection free and the nonunions were located in the diaphysis.

Fifteen patients had bone lengthening at other sites to compensate for longitudinal deficiency of the tibia with a mean lengthening of 5.6 (range, 2–11) cm. The sites of lengthening and transport included the proximal tibia, distal tibia, fibula transport, and femur (Table 2). The femur lengthening was done over a nail. This patient had a retrograde femoral nail in place for an associated femur fracture that had healed. The proximal interlocking screws were removed, a monolateral frame was applied, and the osteotomy was performed around the nail. After lengthening was complete, the proximal interlocking screws were reinserted and the frame was removed.

In the trifocal approach group, the average size bone and soft tissue defect was 8.2 cm and 16 cm respectively, and this group underwent 8 cm of lengthening with compression/distraction time of 15.3 weeks, experienced wound closure in 14.3 weeks, and was in the frame for a total of 34.3 weeks. In the bifocal approach group, the average size bone and soft-tissue defect was 6.4 cm and 11.3 cm respectively, and this group underwent 5 cm of lengthening with compression/distraction time of 22.4 weeks, experienced wound closure in 16.5 weeks, and was in the frame for a total of 46.9 weeks. Overall treatment time was longer in the bifocal group than the trifocal group despite smaller bone and soft tissue defects. There were 6 patients in a subgroup of the bifocal group with bone defects that were > 6 cm and these patients were comparable to the 3 patients in the trifocal group. The patients in the trifocal group had shorter frame times (34.3 vs. 50.3 weeks), shorter time until wound closure (14.3 vs. 21.3 weeks), and shorter time of compression/distraction (15.3 vs. 21.3 weeks) (Table 3).

Seven patients experienced residual deformity of 5.6° valgus (range, 3°–9°) and 5.6° recurvatum (range, 5°–8°). Pin tract infections occurred in 11 patients, 3 of whom required pin or wire exchanges. The remainder responded well to oral antibiotics alone. There was no recurrence of osteomyelitis at the nonunion site.

TABLE 3. Results of 25 Patients With Subgroups

	Monofocal (n = 10)	Bifocal (n = 12)	Bifocal With Bone Defect > 6 cm (n = 6)	Trifocal (n = 3)	Total (n = 25)
Bone defect (cm)	4.8 (2–9) SD 2.2	6.4 (3–14) SD 3.3	8.9 (6–14) SD 3	8.2 (6–11) SD 2.1	6 (2–14) SD 3.0
Soft-tissue defect (cm)	7.1 (2–17) SD 5.3	11.3 (6–25) SD 5.2	13.1 (6–25) SD 6.1	16 (10–25) SD 6.5	10.1 (2–25) SD 6.2
Compression/distraction time (weeks)	17.7 (7–40) SD 10.4	22.4 (5–70) SD 16.7	21.3 (11–35) SD 7.9	15.3 (7–30) SD 10.4	19.7 (5–70) SD 14
Time until wound closure (weeks)	7.8 (3–23) SD 6.8	16.5 (4–41) SD 12.2	21.3 (4–41) SD 14.4	14.3 (9–23) SD 6.2	14.7 (3–41) SD 10
Time in frame (weeks)	41.5 (22–82) SD 18	46.9 (16–79) SD 19.2	50.3 (16–75) SD 17.9	34.3 (10–53) SD 18	43.2 (10–82) SD 19.1
Lengthening (cm)	N/A	5 (2–11) SD 3	6.8 (2–11) SD 3.2	8 (6–11) SD 2.2	5.6 (2–11) SD 3.1
Final leg length discrepancy (cm)	1.7 (0–3) SD 1.1	0.9 (0–4) SD 1.2	1.2 (0–4) SD 1.4	0.9 (0–1.6) SD 0.7	1.2 (0–4) SD 1.2

Data are number (range) with standard deviations (SD).
SD, standard deviation.

DISCUSSION

High-energy open tibial fractures with associated soft-tissue injury are difficult to treat. Deep infection, nonunion, malunion, delayed union, chronic edema, and compartment syndrome are known complications that coincide with these types of fractures.[11,30,31] Comminuted fractures of this type are difficult to treat with standard intramedullary nailing or internal fixation particularly in the setting of large bone and soft-tissue defects. Although bone grafting also may be used to fill a bone defect, autogenous bone grafting has its own associated morbidity, its use is limited to smaller defects, and can only be used after mature soft tissue cover. This is done as a secondary procedure and requires lifting the flap.[1,30]

External fixation has come into prominence during the past few decades as a method to achieve union in comminuted fractures, correct angular deformity, and reconstruct bony defects using distraction osteogenesis, even when a free flap is used. Additionally, the surgery is performed percutaneously, minimizing soft-tissue trauma.[32,33] Advanced techniques using the Ilizarov method may provide healing of the associated large soft-tissue defects without the need for flap use and also could provide an alternative to amputation in a number of cases.[32,34]

Muscle flap coverage has been the method of choice most recently to provide the barrier to infection and promote healing.[20,33] Many have reported the necessity of appropriate soft-tissue coverage to prevent infection and bone desiccation. However, with the extensive soft-tissue injury and even vascular disruption that can accompany a severe tibial fracture, the options for flap coverage may be limited. In fact, controversy still exists over the use of a free flap in a single-vessel limb, especially after revascularization procedure.[21,35] The use of local fasciocutaneous and muscle flaps often is limited in these cases because they are within the zone of injury.[1,21] Without adequate wound coverage or closure, many patients would face inevitable osteomyelitis and even amputation.

Distraction histogenesis has been used for skin expansion.[36] Several authors also have reported instances of soft-tissue expansion along with bone transport for tibial injuries.[5,8] In the English language orthopaedic literature, there is a single case report[34] and 1 recent series[24] of acute fractures that focus on the use of the Ilizarov method for gradual closure of both bone and soft-tissue defects. In the current series, we have shown that soft-tissue defects associated bone loss from an acute fracture or an infected nonunion will gradually close during bone transport.

It is a matter of philosophy, whether soft-tissue transport should be used as a last resort only when flap coverage is not an option or whether it should be used as a first resort to avoid the need for a flap. Flap coverage works well[20,23,25] with bone transport under a healthy soft-tissue envelope. This report and others[24,26,30] also show that bone and soft-tissue transport can be successful and avoid the need for a flap. The final choice will depend on the surgeon's preference and availability of plastic surgery expertise. We are more likely to choose a flap for a patient with a large soft-tissue defect and to choose bone and soft-tissue transport for patient with a smaller soft-tissue defect. Other factors, such as vascular anatomy and medical comorbidities, also will be considerations.

We observed that the use of the monofocal approach resulted in the greatest amount of LLD (average, 1.7 (range 0–3) cm). The trifocal approach resulted in the smallest amount of frame time, compression/distraction time, and time until wound closure compared with the bifocal approach even with larger bone and soft-tissue defects. This may be explained by the fact that in the bifocal group, the entire lengthening is done at 1 location, and in the trifocal group, the lengthening is divided into 2 locations, each with a smaller regenerate gap. The numbers in the trifocal group were, however, small and statistical analysis was not believed to be relevant.

Paley and Maar[8] suggested the use of the trifocal approach rather than a bifocal approach when dealing with defects > 10 cm. We agree with this but would even consider use of the trifocal approach for defects > 6 cm. We base this consideration on our observation that the subgroup of patients in the bifocal group with bone defects > 6 cm had longer frame times, longer times to wound closure, and longer compression distraction time than the comparable trifocal group in which all the patients had bone defects that were > 6 cm. Again, the numbers of patients in these groups are small and statistical analysis would not be relevant.

The monofocal approach leads to some limb shortening. This approach requires that the fibula not be intact. In this group, the average shortening was 1.7 (range 0–3) cm. LLD was treated with a shoe lift in all of these patients.

Although every case must be approached individually, we suggest the following guidelines: if the defect is < 2 cm, use the monofocal approach and accept modest shortening; use the bifocal approach for defects that range between 2 to 6 cm; consider a trifocal approach if the defect is > 6 cm. Other considerations include patient's age, patient preference, defect location, and soft-tissue condition.

Bone grafting can be used to improve healing at the docking site or the regenerate site, but can only be used after wound closure and eradication of infection.[30] Patient involvement and cooperation is of utmost importance using this method as incremental adjustments are made by the patient 3 to 4 times each day. Wound care also is essential during the adjustment phase until closure occurs.[32] We have used a wet-to-dry dressing change regimen daily. Recently, we have used the VAC device in conjunction with soft-tissue compression. Some of the patients in this series had a skin graft placed over the defect temporary biologic coverage. Further advances in external fixator design, such as the computer-assisted

TSF, are expected to reduce or even eliminate residual deformity that occurred in some of our cases. We generally use TSF rings because these can be used with straight rods or TSF struts. The transport can be started with rods that are less costly and can be used when the distance between rings is small. If there is deformity during the transport, the rods can be replaced with struts for a computer-assisted 6 axis deformity correction.[11]

We want to emphasize the complexity of these patients' injuries, the time and energy required to perform such salvage procedures, and the potential complications confronted by the patients. Treatment times are long. Patients experience pain, especially during the distraction phase. Potential complications include pin tract problems, knee and ankle stiffness, nonunion, recurrent infection, and loss of limb.

This study has limitations. It is retrospective and represents the experience of 4 surgeons from 4 different centers. The numbers are small, particularly when attempting to subgroup patients. Functional data were not available and no comparisons were made to patients who have undergone amputation. Despite these limitations, this is a report of a reasonably sized homogenous group of patients with a limb threatening situation of bone and soft-tissue defect of the leg where flap coverage was not a treatment option.

In conclusion, the Ilizarov method can be used successfully to reconstruct the leg with tibial bone loss and an accompanying soft-tissue defect. This limb salvage method can be used in patients who are not believed to be candidates for flap coverage. One also may consider using this technique to avoid the need for a flap.

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