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SURGICAL PROCEDURE

Limb Salvage Reconstruction of the Ankle with Fusion and Simultaneous Tibial Lengthening Using the Ilizarov/Taylor Spatial Frame

Nazzar Tellisi, MD · Austin T. Fragomen, MD · Svetlana Ilizarov, MD · S. Robert Rozbruch, MD

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Introduction

Despite early appropriate treatment with modern orthopedic trauma surgery protocols, distal tibia and ankle injuries do not uncommonly result in posttraumatic ankle arthritis. Ankle fusion offers reliable pain relief and improved function for many of these patients [1]. Ilizarov reconstruction with ankle arthrodesis has been used successfully to treat the more complex ankle pathology in many cases as an alternative to amputation [2–7]. These complex fusions can be limb salvage undertakings, as the treatments are often complicated by the presence of bone loss, osteomyelitis, associated deformity, and a poor soft tissue envelope with compromised healing potential. Most of these patients had failed multiple previous surgeries including open reduction with plates and screws, attempted ankle fusion, total ankle replacement, and external fixation with limited internal fixation. Various techniques for achieving complex ankle fusion have been reported including fixation with crossed lag screws, a fixed angle plate and screws, retrograde intramedullary nailing, and external fixation [8–16]. Although all of these methods can be used to obtain bony union, bone loss remains a challenging problem in these patients. Leg length inequality commonly results in altered gait and symptomatic malalignment of the pelvis and spine. Large shoe lifts are difficult to manage and poorly tolerated, and compliance is low. The use of structural allografts with internal or external fixation has been advocated to reestablish length [17–19]. Problems with graft collapse, infection, and nonunion accompany this technique. Proximal tibial lengthening provides an alternative means of equalizing leg lengths and improving function and self-perception. The need to implant large devitalized bone graft at a compromised healing site is obviated by the use of the patients own bony regenerate at a separate lengthening site. This technique allows for bony contact at the fusion site without intervening graft that is thought to facilitate union. In cases of severe bone loss, acute shortening to obtain bony contact at the fusion site may not be possible, and bone transport may become necessary.

The use of circular fixation for ankle fusion was first described by Ilizarov [20]. The rationale for using the Ilizarov frame is to provide fixed angle stable fixation of the bone fragments, a percutaneous approach that is particularly useful in the presence of poor skin, and avoid the use of internal implants in the presence of infection. Using these frames, chronic deformity can be corrected with reduced risk of soft tissue complications, compression can be maintained throughout the postoperative period, and limb function is preserved through early weight bearing and physical therapy.

The Taylor spatial frame (TSF) is a newer version of the Ilizarov fixator and has greatly simplified our ability to combine fusion with gradual simultaneous deformity correction and/or lengthening. Lengthening at a proximal osteotomy site can be done at the time of ankle fusion or staged a few weeks later as the clinical situation dictates. Staged lengthening requires returning to the operating room (OR) for frame modification and osteotomy. In complex ankle arthrodesis, it is not uncommon to be faced with having to close a large defect that is not amenable to bone grafting. The Ilizarov/TSF can be used to simplify this otherwise daunting problem by performing a gradual shortening with or without simultaneous lengthening or bone transport.

N. Tellisi, MD · A. T. Fragomen, MD · S. Ilizarov, MD · S. R. Rozbruch, MD (✉)
Institute for Limb Lengthening and Reconstruction, Limb Lengthening and Deformity Service, Hospital for Special Surgery, Weill Medical College of Cornell University, 535 East 70th Street, New York, NY 10021, USA
e-mail: RozbruchSR@hss.edu

Indications

The technique of ankle fusion with simultaneous lengthening is indicated for the patient with end-stage ankle arthrosis and concomitant limb shortening or a bone defect. Various pathologies that benefit from the Ilizarov method include sequelae of septic arthritis of the ankle, infected nonunion of pilon fracture, nonunion or malunion of a previous arthrodesis, loss of talus from necrosis, infection or trauma, failed total ankle arthroplasty, Charcot joint disease, and rheumatoid arthritis. The decision of whether or not to perform tibial lengthening depends on several issues: final leg length discrepancy; patient factors, including ability to make quality regenerate; and ultimately, patient preference. In our experience, limb shortening of more than 2–2.5 cm is often poorly tolerated in young adults. Lengthening of the tibia can be performed simultaneously with the ankle arthrodesis as a single-stage procedure or in a staged fashion. A two-staged procedure is preferred in the presence of infection where the potential exists for contamination of the osteotomy site.

Preoperative planning

Physical exam

Although the amount of deformity and leg length discrepancy present is mostly recorded based on x-ray findings, there is no substitute for a good physical exam. In particular, rotational deformities and joint motion are best appreciated through examination of the patient. Physical exam provides the opportunity to see how adjacent joints have compensated for chronic abnormalities and to assess the ability of these joints to accommodate the correction of the deformity. For example, a patient may have developed a dysfunctional knee recurvatum deformity as the result of a long-standing ankle equinus contracture. By recognizing this deformity preoperatively, plans can be made to correct it through flexion at the proximal tibial osteotomy site during the lengthening. Similarly, soft tissue hyperextension will often be remedied with lengthening, as the gastrocnemius tightens reducing recurvatum. Similarly, a forefoot that is positioned in pronation to compensate for hindfoot varus with an arthritic ankle joint will be picked up on examination and can be addressed in the preoperative planning.

Leg length discrepancy can be measured with some accuracy by having the patient stand up and sequentially placing blocks under the foot of the shorter limb until the pelvis becomes level with the floor. This test also allows the patient to assess their overall comfort standing on varying block heights. It is important to establish how much additional length will make the patient's low back, hips, and limbs feel well aligned before surgery. The clinical and radiological analysis is repeated after first stage (Fusion) with the frame in place to accurately assess the exact amount of limb length discrepancy (LLD). The patient's involvement in the decision-making process helps ensure satisfaction.

The soft-tissue envelope should be carefully examined to plan surgical incisions and to predict risk of wound healing problems (Fig. 1)

Radiographic exam

Long radiographs

Once an estimate of LLD has been made with blocks, a 51 in., erect, bipedal radiograph is needed. This film will not only provide very accurate leg length information, but will also allow an accurate assessment of any mechanical axis deviation along with the source of deformity. Patellae need to face straight ahead during the x-ray, and the knees should be held in full extension (the true bone loss is the sum of the preoperative LLD, the bone defect, and additional bone resected at surgery).

Ankle radiographs

Weight-bearing ankle x-rays help assess the condition of the ankle joint. Deformity originating from the ankle joint is best measured on radiographs centered on the ankle. One should accurately measure deformity involving the joint, recognize hardware that needs to be removed, and look for the presence or absence of nonviable, potentially infected bone (Fig. 1). A Saltzman view [21], which is a weight-bearing view of both hind feet, provides excellent information about the subtalar joint position. Valgus or varus deformity from the ankle and/or from the subtalar joint will be seen on this view.

Magnetic resonance imaging

Magnetic resonance imaging (MRI) scan is a sensitive means to assess presence and extent of osteomyelitis and necrosis of talus and distal tibia [22, 23]. We have found MRI to be too sensitive in that the scan will often overestimate the extent of the bony involvement of the osteomyelitis.

Laboratory testing

Serum erythrocyte sedimentation rate, C-reactive protein, and complete blood count are advised when infection is suspected. In the presence of infection, one should plan to acquire five sets of deep intra-operative cultures and a gram stain and delay preoperative antibiotics until the cultures are obtained. Once the operating room (OR) cultures have been taken and the tourniquet is released, intravenous antibiotics should be administered. We think that the cultures will be most reliable if the patient has been off of antibiotics for several weeks before surgery.

Correction of deformity: acute versus gradual

Long-standing deformities may be corrected acutely or gradually. The benefit of acute correction is that final alignment is established and bony healing can begin before the patient leaves the OR. However, acute correction typically requires more bone resection to avoid placing excessive tension on the soft tissues. Alternatively, if extra bone is not removed, and the soft tissues are acutely stretched, then there is a risk of neurovascular compromise. Varus and equinus deformities carry the highest risk of

Fig. 1. **a** Preoperative AP of the ankle showing tibial plafond bone loss secondary to chronic osteomyelitis after a pilon fracture. **b** Medial clinical view showing compromised soft-tissue envelope

posterior tibial artery and tibial nerve compromise if corrected quickly. If faced with a large equinovarus deformity, we are more likely to use gradual correction.

Gradual correction of long-standing deformities is a well-tolerated and safe method to resolve severe malalignment without compromising length or endangering nerves and vessels. Both classic Ilizarov hinged frames and the TSF can accomplish these realignments.

Lengthening

The decision to perform a lengthening procedure is made preoperatively in most cases. The ideal candidate for a tibial lengthening is a nonsmoker, young adult, with a strong family support system, who has greater than 3 cm of shortening. Smoking is strongly associated with failure of limb salvage [24, 25]. The true amount of lengthening that will be required can only be determined after the ankle fusion site has been prepared and ultimate leg length discrepancy measured.

Technique

Preparations

The patient is taken to the OR and placed under regional or general anesthesia. In our experience, spinal–epidural anesthesia works very well for this procedure. The epidural catheter will be discontinued immediately postoperatively for accurate limb monitoring if the surgery includes an osteotomy (with risk of compartment syndrome). Similarly, if an acute shortening of dead space or acute deformity correction is performed, with risk of kinking or stretching the neurovascular bundle, the epidural is removed so that a reliable neurologic exam may be performed. We favor a well-padded pneumatic thigh tourniquet for preparation of the ankle arthrodesis site. A padded bump is placed under the ipsilateral buttock to position the patella forward, preventing external rotation of limb. The leg and knee are prepped and draped into the surgical field in a standard fashion.

Lateral exposure

A lateral incision is used to resect the distal fibula and access the tibiotalar joint. The fibula is exposed in standard fashion, and using subperiosteal dissection, the lower end of the fibula is cut at the level of the syndesmosis and resected. Intraoperative cultures, gram stain, and frozen section are obtained. In cases where gram stain and frozen section suggest the presence infection, bone graft is withheld. In cases of gross infection with purulence, antibiotic polymethylmethacrylate cement beads are introduced temporarily. In cases where infection has been excluded, the fibula can be used as source of bone graft, although this is not our routine practice.

Medial exposure

Typically, we approach the fusion site from the medial side as well. This exposure is well tolerated and provides optimal access for excision of the medial malleolus and visualization of the medial aspect of the distal tibia and talus to complete preparation of both surfaces. We prefer to medialize the talus and calcaneus which requires resection of the medial malleolus. When valgus deformity is present, this approach allows acute correction through a wedge resection of the medial malleolus and plafond. In this instance, we favor a transverse incision. The redundant skin produced by wedge resection and acute closure becomes well opposed, simplifying wound closure. If soft tissue is severely compromised on one side, then the approach is modified accordingly. If a draining sinus is present, we will excise that through the incision.

Tibial cut

Under C-arm fluoroscopy, a K-wire is placed at the planned resection level perpendicular to the long axis of the tibia. As the distal tibial cut needs to be perpendicular to the axis of the tibia in both the coronal and sagittal planes, a second wire is often placed anterior–posterior (AP) to the first to mark the correct sagittal plane. Using these wires as a cutting guide, an oscillating saw, cooled with saline, is used to perform a minimal resection osteotomy. The aim is to minimize the amount of the bone loss from the tibia, depending on the situation. We typically remove approximately 5 mm of bone to expose a viable fusion surface but will extend this resection as needed in the presence of osteomyelitis until bleeding cancellous bone is rendered. Once the tibia is prepared, the cut surface is “fish-scaled” with a thin osteotome to enhance bone healing.

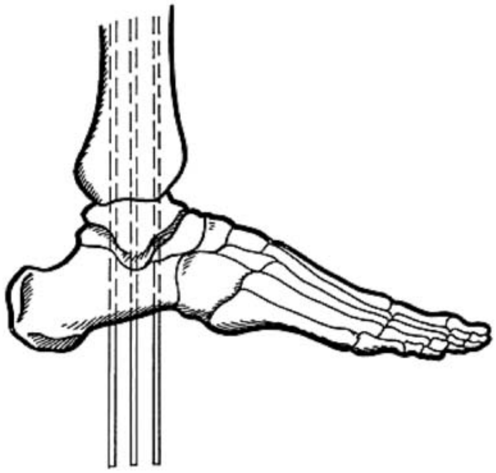

Fig. 2. Provisional fixation of ankle arthrodesis with axial wires before application of the Ilizarov/Taylor spatial frame

Talus cut

A 5-mm cut of bone is removed from the proximal part of the talus parallel to the sole of the foot. The surface of the talus cut is fish scaled or drilled with a 1.8-mm wire to enhance bone healing. This serves to soften and bring blood supply to the hard subchondral bone surface. In cases of advanced talar collapse with bone loss, one must decide between attempting salvage of the talus remnant and performing a talectomy and tibiocalcaneal arthrodesis.

Alignment and temporary stabilization

In the majority of cases the talus is opposed to the tibia and provisionally stabilized with two or three axial K-wires introduced through the heel in a retrograde fashion (Fig. 2). Biplanar fluoroscopy is used to assess the apposition of the two bony cuts, and appropriate adjustments are made to ensure both ideal alignment and maximal contact area at the fusion site. The ankle should be held in neutral to 5° valgus coronal alignment, plantigrade and 15° of external rotation of foot with respect to the patella. Ankle fusion in varus is poorly tolerated by the subtalar joint and may cause lateral metatarsalgia [1]. Attention should be paid to rotational alignment using the patella for referencing. The talus is medialized and positioned directly below the tibia to maximize the surface area and stability. The wound is irrigated and closed over a drain in layers. The tourniquet is deflated and appropriate antibiotics administered.

Bone graft

If infection is a concern, no bone graft is used. In absence of infection adjuvant bone graft can be used if bone healing capacity is felt to be compromised. We use demineralized bone matrix (DBM) putty as an adjuvant therapy in most cases. Use of bone morphogenic protein has been reserved for very difficult cases where DBM is thought to be inadequate or not recommended (i.e. infection). In revision fusion cases, if the soft tissue envelope is satisfactory, adjuvant therapy with internal bone stimulation may help speed bone healing. [26]

Application of the Ilizarov frame

For this procedure, we use an Ilizarov/TSF (Fig. 3). The versatility of this frame allows fine adjustments to be made to ensure success in achieving solid fusion in an accurate position. Two appropriately sized Taylor spatial rings (usually 155 or 180 mm) are connected with four 120-mm connecting rods to form a ring block that is mounted in orthogonal alignment to the mid-distal tibia. Each ring is fixed with a minimum of one tensioned wire and one half pin for a total of four to five points fixation (Fig. 3a). A long foot ring is closed and attached to the distal tibial ring with five connecting rods (120–150 mm) making sure to mimic the position of the foot (Fig. 3b,c). The foot is then fixed to the foot ring using four 1.8-mm smooth K-wires including two oblique calcaneus wires, one midfoot wire, and one talus wire. The talus wire should hold the subtalar joint in distraction to prevent compression injury to the articular cartilage at this joint. The temporary transfixing wires are removed from the heel, and acute compression between the tibial and the foot ring blocks is performed. The final position is assessed by using biplanar fluoroscopy ensuring

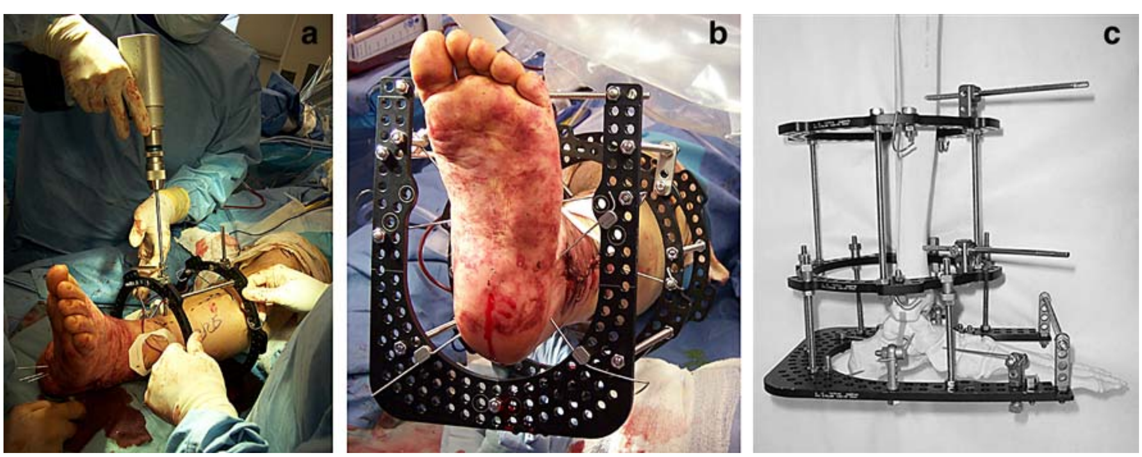

Fig. 3. a Intraoperative photo showing application of tibial ring block. **b** Axial view showing configuration of foot wires. **c** Ankle arthrodesis frame on a sawbone. Note the talus wire that serves to prevent compression of the subtalar joint

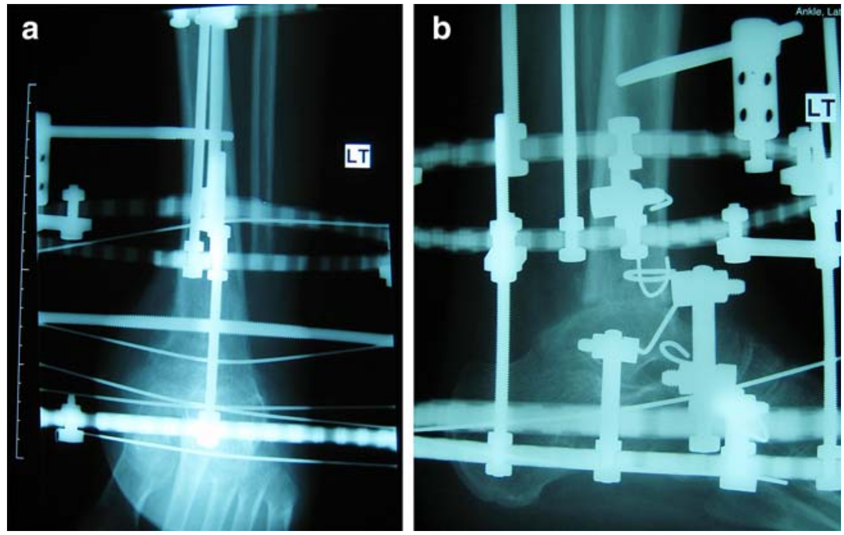

Fig. 4. AP (**a**) and lateral (**b**) views showing well aligned ankle fusion in the frame

non-displacement at the fusion site and final foot and the ankle alignment (Fig. 4).

Staged proximal tibial osteotomy

Often, we perform the proximal tibial osteotomy in a staged fashion several weeks later. This involves adding a ring at the proximal tibia and struts between this ring and the middle tibial ring block (Figs. 5 and 6). Often, the fusion site has been previously infected, and the possibility of contamination of the osteotomy site exists if the lengthening is done at the same setting as the arthrodesis. In addition, accurate assessment of leg length discrepancy can only be determined after the fusion has been performed. A long radiograph can be obtained in the office after fusion and before the lengthening to precisely measure the magnitude of the lengthening that will be needed. Having this information available before embarking on the lengthening will improve preoperative planning and expectation management of both the patient and the physician. If the lengthening is to be performed simultaneously with the fusion, then the steps for proximal ring application and osteotomy are followed as described below.

Set up

The patient is placed supine on a radiolucent table with a bump under the ipsilateral buttock. The procedure is performed under regional anesthesia in our institution but could be done under general anesthesia as well. A tourniquet is used only if fibular osteotomy will be performed. The leg is prepped and draped in the usual sterile fashion to include the patella to the level of the mid-thigh. The frame is not altered and is prepped into the operating field. The pin sites are wrapped with povidone iodine-soaked sponges at the skin interface.

Fibula osteotomy

Fibula osteotomy is usually necessary to prevent tethering and angular deformity at the tibial lengthening site. The extremity is exsanguinated, and the tourniquet is inflated to 250 mmHg. The fibula is approached at the mid-diaphysis through a direct lateral approach, utilizing the interval between the lateral and posterior compartment. Care is taken when performing the subperiosteal dissection of the anterior fibular periosteum, as the motor branch to the extensor hallicus longus lies close to the anteromedial border of the fibula. The soft tissue is protected with Hohman retractors. A microsagittal saw or multiple drill holes cooled with saline can be used. The osteotomy is completed with a narrow osetotome. The fascia is left open, and the skin is closed in layers. The tourniquet is then deflated for the remainder of

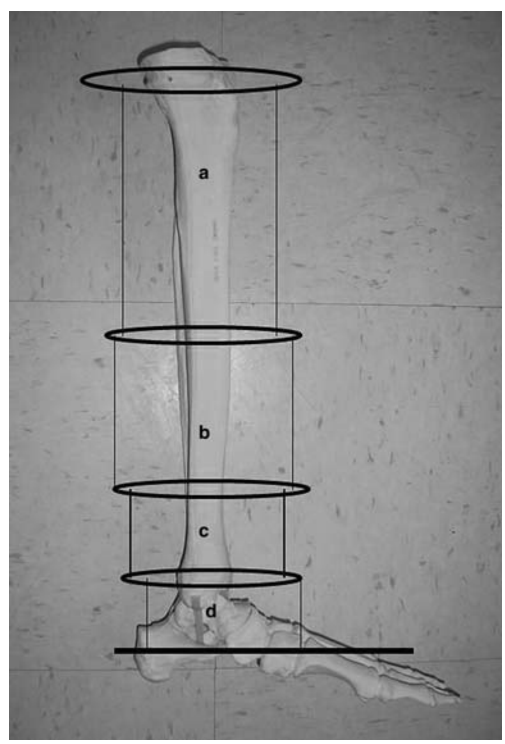

Fig. 5. Schematic drawing depicting the various zones of treatment with the Ilizarov method. **a** Proximal tibia lengthening zone. **b** Tibial ring block. **c** Supramalleolar correction zone (not used in this case). **d** Ankle fusion zone

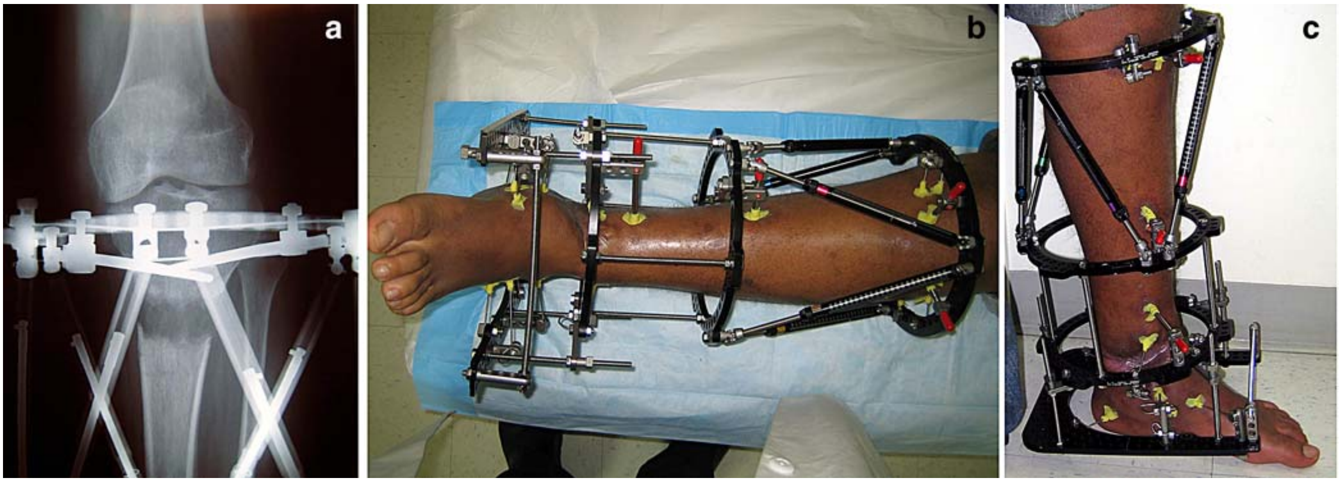

Fig. 6. **a** AP view of proximal tibial corticotomy during the distraction phase. Front (**b**) and side (**c**) views of frame showing the ankle arthrodesis section and the proximal tibial lengthening section

the operation. During lengthening, we usually find that that both the fibula osteotomy separates and the distal fibula migrates proximally.

Proximal ring application

An appropriately sized Taylor spatial ring is selected for the proximal tibial metaphysis (usually a 155 or 180 mm ring is used). We prefer to use a 2/3 ring in this location to accommodate posterior leg swelling and allow proximal knee flexion. Alternatively, two half rings could be applied and connected around the leg. The technique used to apply the ring is the "rings first" method [27, 28]. Once again, the tourniquet is not recommended for this portion of the surgery. Adequate blood flow is thought to help to cool wires and drills, as they pass through bone and soft tissue preventing thermal necrosis. Using the fluoroscopic AP projection, a smooth 1.8-mm Ilizarov wire is advanced across the proximal tibial metaphysis from lateral to medial perpendicular to the mechanical axis of the lower extremity. The wire should start 14 mm distal to the lateral tibial plateau to remain out of the joint capsule [29]. It is usually directed slightly more proximal on the medial side. Once this wire has been placed, the proximal ring is centered on the leg, and the wire is tensioned. The anterior aspect of the ring should lie between 1–2 finger breaths from the tibial crest. The ring is held in a position orthogonal to the mechanical axis of the tibia in the sagittal plane, as a half pin is placed from anteromedial to posterolateral. We use hydroxyapatite-coated half pins for this procedure. The pin is secured to the ring, and an additional half pin is placed anterolateral at Gerdy's tubercle in a posteromedial direction. A second wire is placed through the fibular head exiting the anteromedial tibia. When placing wires through the fibular head, great care is taken to avoid damaging the peroneal nerve. The surgeon places the wire by hand onto the fibular head while the foot is observed for signs of movement indicating nerve impalement. Paralyzing agents during anesthesia are avoided for this reason. The ring must be positioned in proper rotation with respect to the patella and should be orthogonal to the mechanical axis of the tibia, as it will be used as the *reference* ring for lengthening using the TSF computer web-based program (Smith and Nephew, Inc., Memphis, TN, USA). It is vital to include the fibula in the laterally introduced wire to secure the proximal tibial–fibular relationship and prevent distal migration of the fibula during lengthening. Failure to successfully fix the fibula may cause tightening of the lateral collateral ligament leading to flexion contracture of the knee joint. The TSF program requires input of frame, mounting, and deformity parameters. This is beyond the scope of this article. The six struts are attached to both proximal and middle rings. The struts are secured to the proximal ring without introducing any tension or compression forces to the system. Free rotation of the struts should be possible, as the shoulder bolts spin through the ring. The strut lengths are recorded, and the struts are detached from the proximal ring to carry out the tibial osteotomy.

Proximal tibial osteotomy

The tibial osteotomy should be made distal to the tibial tubercle to prevent involvement of the extensor mechanism, but it should be proximal enough that it courses through cancellous metaphyseal bone to ensure reliable regenerate formation. We use a 1-cm incision made over the tibial crest just distal to the tibial tubercle for this percutaneous osteotomy. The incision is carried down through the periosteum and onto the crest. A 5-mm elevator is used to gently raise a portion of the periosteum on either side of the tibia. The cortex is predrilled in multiple directions along the same plane with a 4.8-mm drill with the fluoroscopic c-arm in the lateral position. A 5-mm osteotome is advanced through the cortical bone of the tibia's medial and lateral faces. When the osteotome is fully seated through the width of the bone and is engaging the posterior cortex, it is twisted with a wrench producing an audible crack, as the posterior cortex fails. The distal ring is gently externally rotated with respect to the proximal ring to ensure that the corticotomy is complete. The bone ends are reduced to their pre-osteotomy position relieving stress on the periosteum and decreasing bleeding. The struts are reattached to the rings at their previously measured lengths stabilizing the osteotomy site. The wound is closed with simple sutures, and the pin sites are dressed with xeroform and sterile dressings. An Ace bandage is used to support the forefoot in a neutral position. The epidural is discontinued in the immediate postoperative period to avoid masking early signs of compartment syndrome.

Lengthening

A latency phase of 7–10 days is used before the start of lengthening. Lengthening is performed at a rate of 1 mm/day split into three daily intervals (struts 1 and 2 are adjusted in the morning, struts 3 and 4 in the afternoon, and struts 5 and 6 in the evening). The patient learns how to perform the adjustments before discharge from the hospital and, in most cases, completes the schedule on their own at home. Frequent follow-up visits and radiographs are needed to ensure that the osteotomy is separating and that the regenerate is forming correctly. At times, the rate of lengthening has to be increased or decreased depending on the quality of the regenerate (Fig. 6).

Consolidation

The consolidation period begins when the desired length has been obtained. In the setting of ankle fusion, we usually aim for 5 mm shortening to optimize gait. The struts are checked daily to ensure that none have moved from their final positions. The total healing time needed for bony consolidation is typically 1.5–2 months/cm of lengthening (Fig. 7).

Frame removal

The frame may be removed when there are definitive signs of healing at both the fusion and lengthening sites. The fusion typically requires 4–6 months for complete bony healing. The regenerate is considered healed when radiographs demonstrate three of four healed cortices and the patient is able to bear full weight without pain. Fixators are removed in the OR under sedation. The half pin sites are curettaged and a patellar tendon bearing or long leg casts applied. The patient is made 50% weight bearing for 2 weeks

Fig. 8. A 51-in. standing bipedal radiograph showing optimal leg lengths and normal alignment

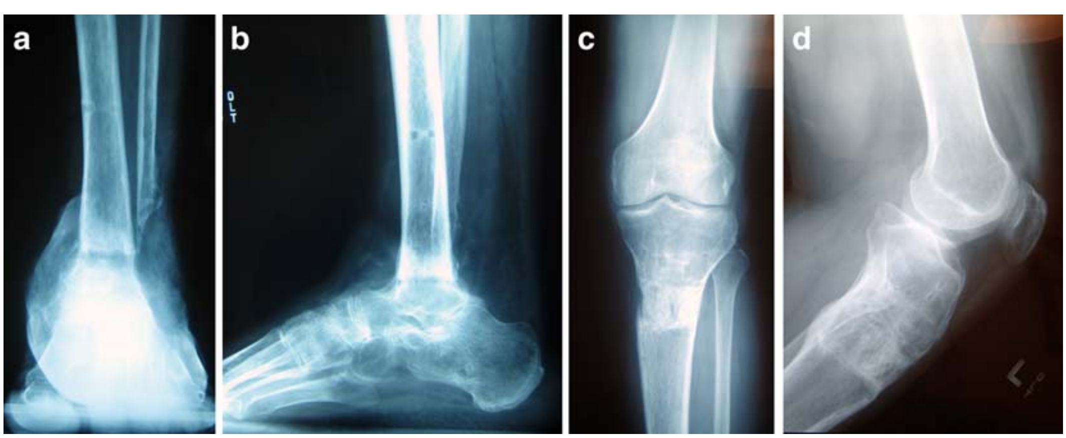

Fig. 7. AP (**a**) and lateral (**b**) views of the ankle arthrodesis. AP (**c**) and lateral (**d**) views of the proximal tibia lengthening site (3 cm; 12-month follow-up visit)

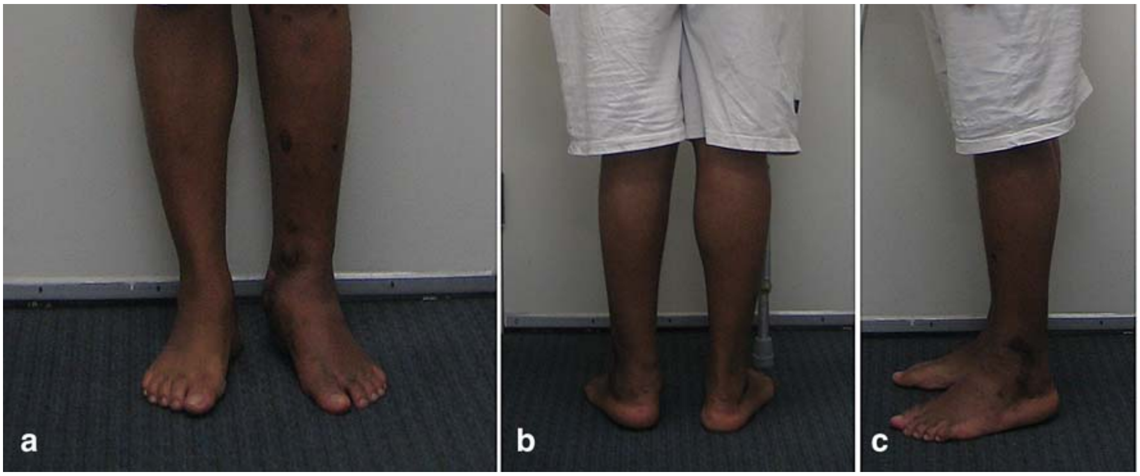

Fig. 9. Clinical picture taken at 12-month follow-up visit, showing a well aligned stable ankle fusion and plantigrade foot, with optimal leg length. **a** Front, **b** back, **c** side

and then is advanced to weight bearing as tolerated ambulation. The cast is used for 6 weeks total (Figs. 8 and 9).

Results

In our series of 53 complex ankle fusion surgeries treated with the Ilizarov method, 12 patients underwent simultaneous ankle fusion and proximal tibial lengthening. Ten of 12 were tibiocalcaneal fusions. Patient age ranged from 10–59 years old with an average of 41 years old. Eight of 12 (66%) of patients had active ankle osteomyelitis. Two of 12 were actively smoking during the treatment. The tibial osteotomy was performed as a staged procedure in nine cases and concomitantly with the fusion in three cases, including a bone transport ankle fusion (Fig. 10). The average preoperative bone loss was 4.2 cm (range 1.4–8.0), which increased after further bone resection during the index procedure. The average amount of lengthening was 5.5 cm (range 2.0–15.0 cm). Latest follow-up averaged 29 months (range 9–70 months). Average final LLD was 1.1 cm (range 1–2.4 cm). Average external fixation time was 8.4 months (range 5–23 months). External fixation index averaged 54 days/cm of lengthening (range 25–100 days/cm). All osteotomy sites healed. Bony union was achieved at the ankle fusion site in 84% of cases on the initial attempt. There were 2/12 nonunions (16%) at the fusion site that required further surgery. Both nonunions occurred in smokers, which was significant (p=0.03). One

Fig. 10. A 43-year-old woman with infected pilon fracture and bone defect treated with a bone transport ankle fusion. **a** Preoperative AP x-ray showing a 5-cm distal tibia bone defect with a destroyed ankle joint. **b** Bipedal x-ray showing LLD of 5 cm. The true bone loss is 10 cm. **c** AP x-ray 2 weeks after surgery showing bead pouch at infected ankle defect site and early proximal tibia distraction. A *Pseudomonas aeruginosa* infection was treated with 6 weeks of intravenous antibiotics. **d**, **e** At the end of distraction, there is bone contact at the ankle fusion site and a 9-cm proximal tibia lengthening. **f**, **g**, **h** At 16-month follow-up, there was a well-healed ankle fusion and proximal tibia lengthening in excellent position, and this patient had 1-cm LLD. At 5-year follow-up, the patient has been stable with no recurrence of infection

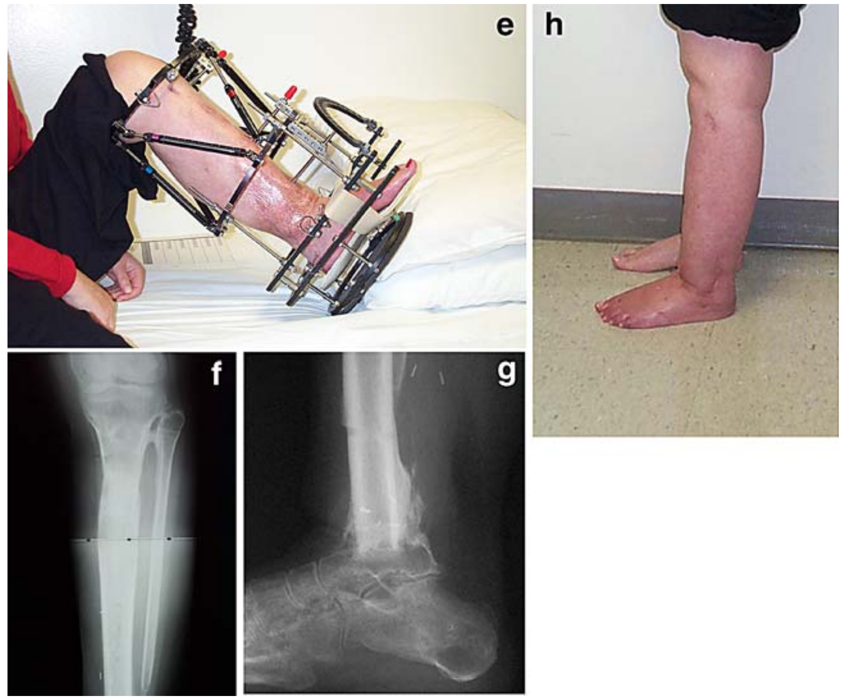

Fig. 10. (continued)

patient went on to heal with a revision Ilizarov fusion technique, and the other elected transtibial amputation and has resumed his occupation as a golf instructor. Latest outcomes include 10/12 patients (the two patients that were excluded include the amputee and one that was lost to follow up). The average American Orthopaedic Foot and Ankle Society score was 74 (55–100). Association for the Study and Application of the Methods of Illizarov score included all excellent bone scores and 80% good functional scores. One patient who had a poor functional score had multiple medical comorbidities that precluded a good score, and the other was addicted to pain medication.

Complications

Pin infection

Pin site infection is a commonly encountered complication with circular frames. The infection usually begins as cellulites around the pin site and commonly caused by *Staphylococcus aureus* and respond very well to antibiotics and meticulous pin care management. The reported incidence of pin site infection is in the region of 18% [30, 31], and the superficial infection is by far the commonest. Pin site infection can occasionally involve deep tissues and only rarely involve the bone. This type of infection can be readily treated with intravenous antibiotics and removal of the offending wire. In case of vital wire infection, replacement of the effected wire is performed in the OR. The key to avoiding pin care infection is attention to detail to wire insertion techniques and meticulous pin care. We use hydrogen peroxide/normal saline wash and application of xeroform gauze on the pin sites. Oral antibiotics are prescribed to treat pin site infection as soon as pin site redness or pain develops.

Pin loosening

Pin loosening can result from continual stress on the pins. The strength of fixation of the pin interface tends to deteriorate with time and can be caused by mechanical loosening or infection. In the case of mechanical loosing, thermal necrosis of the pin site caused at the time of insertion is usually the reason for this complication. The use of sharp drills at full speed will help minimize heat generation and bone necrosis. Paying attention to pin insertion techniques and the use of hydroxyapatite-coated pins can delay the onset of mechanical loosening [32].

Neurologic complications

Acute correction of the equinovarus deformity is a significant risk for stretching injury to the posterior tibial nerve. Ankle arthrodesis should be performed under a type of anesthetic that does not compromise postoperative nerve function. In our practice, intraoperative epidural with postoperative intravenous patient-controlled analgesia has been very effective. It confers good intraoperative and postoperative pain control and allows immediate postoperative check of the nerve function. Assessing the neurovascular status after surgery is of paramount importance, as swift intervention is required if nerve compromise is detected. Reversing the operative correction and essentially recreating the deformity is all that is required on most occasions. Replacing the Ilizarov rods with TSF struts allows this restoration of the presurgery position without compromising the stability of the entire Ilizarov construct. This switch is only an option when one uses the TSF rings for ankle arthrodesis. The patient is followed up very closely to assess the recovery of the nerve function for 24–

48 h while keeping the option of surgical decompression of posterior tibial nerve open if recovery of the nerve is not detected.

Postoperative management

Pin care

Pin site care begins on the second postoperative day. The patient is taken through the various steps of pins site care before being discharged home. The patient or a responsible relative should be conversant with the pin care protocol to ensure optimal pin site care management. Patients are also encouraged to shower and use chlorinated pools. It is also vital to ensure that patients have a supply of oral antibiotics that can be started as soon as pin site is suspected.

Weight bearing

The choice of weight bearing status is case dependent. Weight bearing as tolerated is encouraged as a general principle in all patients. In the case of a neuropathic, weight bearing is allowed for only transfers to a wheelchair throughout the frame treatment period. The rationale of restricting weight bearing in this patient group is the high incidence of wire breakage and pin site trauma in case of patient with peripheral neuropathy.

Follow-up

Close follow-up is required in the immediate postoperative period. Patients are seen 2 weeks after surgery and every 10–14 days during the distraction phase, then followed up on monthly basis.

Future of the technique

Computer navigation would help in refining the current technique. It will increase the accuracy of bone cuts, therefore, helping in reducing the margin of error and improve final outcome. Currently, we are relying excessively on the use of x-ray imaging, resulting in excessive exposure to radiation. We feel that the addition of computer navigation to the existing technique will help minimize the need for imaging.

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