Complex Ankle and Hindfoot Arthrodesis Using Circular External Fixation

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Authors:
Andrew R. Hsu, MD
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Dr. Hsu is Chief, Division of Foot & Ankle Surgery and Assistant Clinical Professor of Orthopaedic Surgery, Department of Orthopaedic Surgery, University of California-Irvine, Orange, California.

Address correspondence to: Andrew R. Hsu, MD, Department of Orthopaedic Surgery, University of California-Irvine, 101 The City Drive South, Pavilion 3, Building 29A, Orange, CA 92868 (tel, 650-906-8923; fax, 714-456-7547; email, hsuar@uci.edu).

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Take-Home Points

- Ankle and hindfoot fusion using circular external fixation is a useful surgical technique in patients with diabetes, Charcot, osteomyelitis, deformity, and/or bone and soft tissue compromise in order to obtain solid bony fusion, stable limb alignment, and eradication of infection in cases of complex pathology.
- Deformity correction with osteotomies and meticulous joint preparation is required in order to obtain broad, cancellous bony surfaces for fusion with neutral alignment. Autograft from the distal fibula and/or medial malleolus can be combined with bone allograft to assist with joint fusion.
- The ankle and hindfoot are provisionally pinned into neutral coronal and sagittal alignment through the plantar surface of the foot using large K-wires prior to placement of the lower leg in the center of a circular 3-ring compression frame. Typically, 2 to 3 points of fixation are used per ring with a combination of half-pins and smooth wires.
- Ring attachments are built up or down to the level of the half-pins and wires in order to prevent pins and wires from bending, breaking, or causing iatrogenic deformity during tensioning. Crossing olive wires are used in the midfoot and calcaneus with dual tensioning devices to ensure an even pull on both sides of the foot.
- Dynamic or static compression struts are used to obtain 8 to 10 mm of compression across the ankle and hindfoot, followed by addition of an anterior foot ring to increase construct rigidity. Daily pin care is started 3 to 4 days after surgery and patients are kept non-weight-bearing for approximately 2 months in the frame with a total frame period of 3 to 8 months depending on bony healing on X-ray.

Patients with complex ankle and hindfoot deformity present a unique challenge to both nonoperative management and surgical reconstruction. Nonoperative management focuses on wound care, bracing, and immobilization using
ankle-foot orthoses, total contact casts, and Charcot restraint orthotic walker boots for external stabilization. Fusion using the Ilizarov technique with circular fixation is a salvage limb-preservation procedure that has shown good results in select patient populations.\textsuperscript{1-5} Indications include post-traumatic, degenerative, and rheumatoid arthritis, osteomyelitis, tumors, neuromuscular conditions, and salvage of failed ankle and hindfoot procedures.\textsuperscript{6-9} Relative contraindications include wet gangrene, severe limb ischemia, and soft tissue compromise requiring urgent amputation. In addition, circular frames are not recommended in patients who are unable to comply with postoperative restrictions, and pin and wire care for the duration of frame placement because of personal, psychological, or socioeconomic reasons.

The Ilizarov technique of ring fixation provides dynamic, modular, and rigid fixation in multiple planes to control shear, bending, and rotational forces, and allows for early weight-bearing and postoperative adjustments as needed.\textsuperscript{10,11} Percutaneously placed half-pins and wires allow for solid fixation in the setting of both poor bone and soft tissue quality, and fusion can be achieved in the presence of active infection in a 1-stage procedure. The goal of ankle and hindfoot fusion using the Ilizarov technique is to achieve an infection-free, stable, plantigrade foot with neutral ankle alignment to allow for patient ambulation and return to activities of daily living.

Nonunion rates with circular fixation are reported to be as high as 16\% to 54\%, due to medical comorbidities, such as smoking, peripheral vascular disease, and Charcot neuroarthropathy.\textsuperscript{1} Charcot, in particular, is a risk factor for nonunion as patients lack protective sensation, and have a higher rate of wound dehiscence, noncompliance with weight-bearing precautions, pin site infections, and frame breakage. In these patients, tibiotalocalcaneal (TTC) arthrodesis is preferred over the isolated ankle, or subtalar fusion to both provide a stable platform for ambulation and reduce the incidence of adjacent joint breakdown. Common complications of the Ilizarov technique include pin site infections, wire breakage, talar necrosis, and tibial stress fractures after frame removal.\textsuperscript{1,2,6,11-13} Circular frames are typically maintained for 3 to 8 months, until solid fusion is achieved radiographically. Frames are removed in the operating room with the concurrent examination of the fusion sites under anesthesia followed by a period of protected weight-bearing in a cast or tall controlled ankle motion (CAM) boot.

This article reviews several technical details, tips, and tricks that can help improve the intraoperative and postoperative outcomes of combined ankle and hindfoot arthrodesis using the Ilizarov technique with circular external fixation.

**Surgical Technique**

**Setup and Approach**

Patients are positioned supine with padding under the operative extremity to achieve neutral leg rotation (Figures 1A-1D). A thigh tourniquet is placed with the foot positioned at the end of the bed and on top of the radiolucent padding to avoid interference of the contralateral leg during lateral X-rays. After sterile prepping and draping, the extremity is exsanguinated above the level of an active infection, and the tourniquet inflated.

For isolated ankle arthrodesis, an anterior or lateral approach can be used, while for TTC arthrodesis, a lateral approach is required to access both the ankle and subtalar joints. A 10-cm longitudinal incision is made along the distal fibula, curving slightly and anteriorly along the distal extent of the incision. Dissection is continued down to bone using full thickness flaps, and the distal fibula is removed 2 to 3 cm above the ankle joint using a saw and osteotome (Figures 2A-2G). The distal fibula can be used subsequently as bone grafts depending on the quality of bone. The peroneal tendons are retracted posteriorly, and dissection is then continued to the posterior facet of the
subtalar joint.

**Joint Preparation and Alignment**

Both the anterior and posterior neurovascular bundles are protected along the distal tibia with Hohmann retractors while a saw is used to create flat cuts across the tibial plafond and talus to allow apposition of flat, broad cancellous bony surfaces. Flat cuts followed by later joint compression will often shorten the limb by 2 to 3 cm. This leg length discrepancy can later be accommodated using a shoe lift, as needed. All retained hardware and/or infected and necrotic tissues in the ankle and hindfoot are removed using a rongeur and a pituitary rongeur.

The medial malleolus is osteotomized vertically using a direct medial incision and approach with full thickness flaps, and in line with the previous tibial plafond, is both cut and removed. The medial malleolus can also be used for bone grafts in fusion sites. A smooth-tip lamina spreader is placed in the subtalar joint for distraction and a curved osteotome, curettes, and a small rongeur are used to remove all remaining cartilage from the subtalar joint. Flat cuts in the subtalar joint can remove excessive bone, particularly from the inferior aspect of the talus. The subchondral bone is perforated using a 2.5- to 3.0-mm drill bit and a curved osteotome.

A bone graft from the distal fibula and medial malleolus, with or without the addition of allograft adjuvants, is placed evenly across the ankle and subtalar joints (Figures 3A-3E). At this point, the ankle and subtalar joints can be manipulated in multiple planes to achieve neutral coronal, sagittal, and axial alignment. With both the ankle and hindfoot held in a neutral position, multiple Steinman pins and K-wires in different orientations are inserted through the plantar aspect of the heel to hold the ankle and subtalar joints in place temporarily. Wires are cut short to prevent interference with subsequent foot olive wire placement through the frame.

X-rays should be carefully checked to ensure proper alignment. Wounds are gently irrigated, and vancomycin powder (2 g) can be placed within wounds for local antibiotic delivery. Lateral tissues are sharply debulked to allow for decreased tension on the incision, and small ulcers can be excised in their entirety. Wounds are closed in a layered fashion using 0-polydioxanone (PDS, Ethicon) suture for deep tissue, 2-0 PDS for subcutaneous tissue, and 2-0 nylon for skin closure. The tourniquet is deflated for the remainder of the case to reduce limb ischemia during frame placement.

**Circular Frame Concepts and Placement**

The majority of circular frames for both ankle and hindfoot fusion have multiple ring sizes available in aluminum and radiolucent carbon fiber reinforced polymer (Hoffmann LRF, Stryker). Rings are available in full, open, segment, and both short- and long-foot options. Frames can be sterilized in a prebuilt 3 to 4 ring construct with 4 static or dynamic (telescopic) struts (100-277 mm). The most commonly used tibia and foot ring sizes are 155 cm, 180 cm, and 210 cm. Ring size should be able to accommodate posterior soft tissue swelling and avoid circumferential soft tissue abrasion against the rings. Anterior foot arches are used for increased construct stability and can be locked to the distal tibia ring for weight-bearing support. Wire and half-pin bolts, adaptors, and nuts are used to join each ring of the frame to the patient’s bone.

For TTC arthrodesis, 2 rings are typically used in the tibia, and 1 ring is used in the foot. For isolated ankle arthrodesis, an additional ring can be added with olive wires in the talus to permit compression only across the ankle joint. Multiple points of fixation are used in each ring in different planes to achieve both maximal stability and rotational control. If a single wire or half-pin becomes infected and requires removal, there are still multiple other points of fixation in the ring to maintain stability. Fixation within each ring should be off axis compared with
the adjacent ring to both avoid stress risers and increase construct rigidity.

The prebuilt frame is checked on the back table to ensure proper orientation and component alignment. The frame is then placed over both the foot and ankle, and multiple stacks of towels are placed behind the heel, ankle, and calf to center the foot and ankle in the frame (Figures 4A-4F). At least 4 to 6 cm of space is needed in between the posterior soft tissues and each ring to accommodate postoperative swelling. On the lateral view, the foot ring should be in the mid-portion of the calcaneus. If there is a concern, particularly in Charcot patients, regarding early weight-bearing noncompliance, the foot ring can be placed flush with the plantar aspect of the foot, and olive wires can be inserted using longer adaptors. The frame should be checked from multiple viewpoints to ensure that both the foot and ankle are centered and in neutral rotation.

**Tibia Ring Fixation**

Tibia rings can be fixed using 2 to 3 half-pins (4-6 mm) alone or 2 half-pins in combination with a smooth wire. A small incision is made over the area of planned half-pin insertion, and the periosteum is cleared away using a hemostat. An adaptor sleeve is used, and the bone is drilled bicortically, followed by insertion of the half-pin. Hydroxyapatite-coated pins are used to improve the strength of the bone-pin interface and reduce the incidence of pin tract infections. Pins are inserted along both the anterior and medial aspects of the tibia, avoiding the thick lateral musculature. Care is taken to protect the medial neurovascular structures during pin placement following established Ilizarov safe zones.

After each pin is placed in the bone, the pin is secured to the adaptor that is then tightened to the ring. This process is repeated for both the proximal and distal tibia rings. Pins should be placed above and below each ring to avoid creating stress risers. During smooth wire placement, each wire is pushed by hand through the soft tissues and then drilled into the bone while the exposed segment is held with a damp sponge to reduce the incidence of thermal bone necrosis. Once the wire is drilled bicortically, a mallet is used to tap the wire through the remaining soft tissues to avoid wrapping them up in the wire. Each wire should be parallel to the ring to get an even line of compression.

Each wire is secured on 1 end and then tensioned to 130 kg using a hand tensioner. An additional tool can be placed in the wire adaptor to prevent the wire from bending during tensioning. If the wire is passing above or below the ring, longer wire adaptors should be used to build to the wire. The wire should never be bent toward the ring as this can increase the likelihood of improper pin tensioning and breakage. Wire placement should be avoided posteriorly as this can make it difficult to secure and/or tension wires, and also increases the risk of damage to posterior structures.

Ring fixation in the distal tibia near the plafond may require 1 half-pin and 2 wires to avoid damage to the tibialis anterior and posterior tibial tendons. In this case, smooth wires should be placed in a crossing pattern and tensioned simultaneously to avoid pulling the ankle away from the center of the frame. Wires should be bent and curved over each ring and then cut to facilitate subsequent removal.

**Foot Ring Fixation**

In the foot, olive wires are used to increase fixation against bone. For each olive wire, a small incision is made to accommodate the diameter of the olive through the soft tissue. Similar to the distal tibia, 2 olive wires should be placed above and below the foot ring in a crossing pattern through the calcaneus (Figures 5A-5F). The axial view of the frame should be checked to ensure proper wire orientation. When using olive wires, it is essential to tension both at the same time to 90 kg, as the foot can be pulled medially or laterally in the frame if 1 wire is tensioned.
Forefoot olive wires should also be placed in a crossing pattern, with 1 wire fixed through the first, second, and third metatarsals, and 1 wire through the fourth and fifth metatarsals. Additional forefoot olive wires can be placed if compression is needed across the midfoot or Chopart joints for fusion. Multiple X-rays should be checked to ensure that the calcaneus and forefoot olive wires are firmly fixed both in and against bone.

**Joint Compression and Final Frame Adjustments**

Once all rings are secured to the bone with half-pins and wires, the previously placed Steinman pins, and K-wires through the heel are removed. Both ankle and subtalar joint alignments are rechecked, and then axial compression is placed through the foot ring with the knee extended and the struts unlocked. Static or telescopic struts are used to achieve 8 to 10 mm of bony compression. X-rays are taken before and after to analyze final joint compression and alignment. Struts should be sequentially tightened (1/2 turn of a static strut) 1 at a time as final tightening of 1 strut alone can bind and interfere with both the compression and tightening of the remaining struts.

Once final compression is achieved, the struts are locked, and the front foot arch is closed anteriorly and connected to the distal tibia ring for increased stability (Figures 6A-6D). Each pin and wire is covered in a sterile dressing followed by gauze to allow for soft tissue padding. The entire frame is then overwrapped in bias stockinette rolls or ace wraps.

Walking attachments can be added immediately to the frame that allows for early weight-bearing. Rocker shoe attachments with a 15° anterior and posterior slope and rubber soles can help offload the ankle and subtalar joints, decrease pressure on heel strike, and reduce ankle motion during ambulation (Hoffmann LRF, Stryker).

**Postoperative Protocol**

Depending on individual characteristics, patients can be immediately weight-bearing in the circular frame. Patients with Charcot neuroarthropathy are recommended to remain non-weight-bearing for the first 2 months to reduce the likelihood of pin, wire, and frame breakage along with nonunion. Pin and wire site care and maintenance are initiated the day after surgery and continue on a daily basis for the duration of frame placement. Sutures are removed 4 to 5 weeks after surgery to ensure adequate wound healing. Serial X-rays are taken monthly to analyze fusion sites.

If pins or wires become infected, patients are placed on oral antibiotics, and both pins and wires can be removed or exchanged in the operating room. Once fusion is achieved in 3 to 8 months (Figures 7A-7C), the frame is removed in the operating room, and fusion sites are examined under dynamic fluoroscopy. If fusion is confirmed, patients are made weight-bearing as tolerated in a short-leg cast or tall CAM boot for 6 to 8 weeks, and then transitioned to an ankle brace in an accommodative shoe.

**Discussion**

A key aspect of recovery after ankle and hindfoot fusion using the Ilizarov technique is balancing pin care, soft tissue swelling, and weight-bearing status. The average time patients will spend in the frame is approximately 25 to 28 weeks, but can range from 12 to 84 weeks. Given the considerable variability in both soft tissue healing and bony union, patients should be extensively counseled before surgery to set expectations correctly and ensure
that they have the necessary help and support to care for the frame during the treatment period. Patients should be followed closely during the first 6 weeks to ensure that pins and wires do not become infected or break, as both of these issues require immediate intervention.

In a review of 11 patients who underwent tibiocalcaneal arthrodesis using an Ilizarov external fixator for infected talar nonunions or extrusions, Rochman and colleagues reported an 81% rate of successful fusion with a final mean American Orthopaedic Foot and Ankle Society score of 65 (out of a maximum 86). Similar results were reported by Saltzman in a series of 8 patients with diffuse ankle osteomyelitis treated with resection of all infected tissue and hybrid-frame compression arthrodesis. All patients received 6 weeks of intravenous antibiotics, and frames were removed at 3 months, and walking casts were applied for 1 to 2 additional months. Ankle sepsis was eradicated in all patients, and 7/8 (87.5%) ankles successfully fused at an average of 13.5 weeks (range, 10-16 weeks). One limb required below-knee amputation at 5 weeks due to non-reconstructible vascular insufficiency. At an average of 3.4-year follow-up, none of the 7 fused ankles required further surgery.

Fragomen and colleagues retrospectively reviewed 101 patients who underwent complex ankle fusion using the Ilizarov technique and found that 76/91 (83.5%) patients achieved fusion at an average of 25 weeks (range, 10-65 weeks). Smoking was associated with a 54% rate of nonunion and 15/19 (79%) patients with Charcot neuroarthropathy achieved ankle fusion, but had a subsequent subtalar joint failure, thus highlighting the need for TTC arthrodesis in Charcot patients. Salem and colleagues reviewed 21 Ilizarov ankle fusions and reported that all patients achieved fusion at an average of 28 weeks (range, 12-84 weeks). Complications occurred in 11 patients, including 2 nonunions that healed after revision frame application and 4 pin tract infections.

**Conclusion**

Overall, the Ilizarov technique using circular external fixation is a powerful tool that can be used to treat a variety of disorders including complex foot and ankle deformity and infection. While case series generally show favorable outcomes, patients must be informed that this technique is a salvage procedure for limb preservation that requires meticulous operative technique, diligent postoperative care, and tight control of medical comorbidities, such as blood sugar levels in individuals with diabetes to achieve a successful outcome.

**Key Info**

**Figures/Tables**

Figures / Tables:

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Figure 1. (A) Anteroposterior (AP) and (B) lateral clinical views of a 60-year-old man with Charcot neuroarthropathy and pre-existing ankle and hindfoot symptomatic arthritis who sustained a closed ankle fracture. The patient was provisionally splinted at an outside hospital, continued to bear full weight on the ankle, and developed both an infected sinus tract and osteomyelitis over the distal fibula. (C) Preoperative AP and (D) lateral X-rays show the gross destruction of the anteromedial tibial plafond and distal fibula with vascular calcifications and poor bone quality.
Figure 2. (A) A saw is used to remove the distal fibula 2 to 3 cm above the ankle joint. (B) A flat cut is made in the tibial plafond on X-ray, (C) making sure to avoid both the anterior and posterior neurovascular structures. (D) A flat cut is made across the talus dome, and (E) the medial malleolus is osteotomized in line with the previous tibial plafond cut through a separate incision. (F) X-ray is checked to ensure opposing broad, cancellous bony surfaces. (G) A smooth-tip lamina spreader is placed in the subtalar joint, and all remaining cartilage is removed with a curved osteotome followed by subchondral perforation with a drill.
Figure 3. (A) A bone graft from the distal fibula and/or medial malleolus is inserted into both fusion sites, and (B) the ankle and hindfoot are provisionally pinned into place using multiple Steinman pins and K-wires through the plantar heel. (C) Anteroposterior, (D) lateral, and (E) axial X-rays are checked to confirm the appropriate ankle and hindfoot alignment before frame placement. All wounds are irrigated and closed in a layered fashioned, and the tourniquet is then deflated.
Figure 4. (A) The foot and ankle are placed in the center of the prebuilt circular frame (Hoffmann LRF, Stryker) with stacks of towels behind the leg to create adequate space in between the posterior soft tissue and the rings. (B) An axial view is taken to ensure that the foot is in the center of the foot ring. (C) Each tibia 5-mm half-pin is predrilled bicortically followed by insertion of a hydroxyapatite-coated pin through an adaptor. (D) Pin length is checked on an X-ray, followed by (E) insertion of a smooth wire that is tensioned to 130 kg. (F) The wire is confirmed on X-ray to be in the center of the tibia. The above process is repeated for the distal tibia ring.
Figure 5. (A) Two olive wires are placed in the calcaneus in a crossing pattern, and (B) tensioned to 90 kg simultaneously to allow for even pull on both sides of the foot. (C) Two forefoot wires are placed in a crossing pattern to capture the first to third metatarsals and fourth to fifth metatarsal, respectively. (D) The provisional Steinman pins and K-wires are removed from the heel, and axial compression is placed through the foot ring with the struts unlocked. (E) Anteroposterior and (F) lateral X-rays are checked for a goal of 8 to 10 mm of compression across both the ankle and subtalar joints.
Figure 6. (A) After final joint compression, the struts are locked into place, and the anterior foot ring is connected to the distal tibia ring for added stability. (B) Lateral and (C) axial views are checked to ensure proper frame alignment, and room for soft tissue swelling. (D) All pins are individually wrapped in sterile dressings and gauze, and the entire frame is overwrapped followed by placement of rocker shoe attachments to allow for immediate weight-bearing, with offloading of the ankle.
References


5. Eylon S, Porat S, Bor N, Leibner ED. Outcome of Ilizarov ankle arthrodesis. Foot Ankle Int.


**Multimedia**

**Product Guide**

- STRATAFIX™ Symmetric PDS™ Plus Knotless Tissue Control Device
- STRATAFIX™ Spiral Knotless Tissue Control Device
- BioComposite SwiveLock Anchor
- BioComposite SwiveLock C, with White/Black TigerTape™ Loop
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