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ESSENTIAL SURGICAL TECHNIQUES

SUBSPECIALTY PROCEDURES

Tibial Bone Transport Over an Intramedullary Nail Using Cable and Pulleys

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Abstract

Background: Massive bone defects (>8 cm) will not unite without an additional intervention. They require a predictable, durable, and efficient method to regrow bone. The Ilizarov method of tension stress, or distraction osteogenesis, first involves a low-energy osteotomy[1-5]. The bone segments are then pulled apart, most often using an external device at a specific rate and rhythm (distraction phase), after which the newly formed bone (the regenerate) requires time for consolidation. The consolidation phase is variable and usually requires a substantially greater amount of time before the external device can be removed. Our technique of tibial bone transport over an intramedullary nail using cable and pulleys combines internal and external fixation, allowing the external fixator to be removed at the end of the distraction phase. This increases the efficiency of limb reconstruction and decreases the external-fixator-associated complications.

Description: The procedure begins with thorough debridement, orthogonal tibial cuts, osteotomy, and insertion of a custom intramedullary nail. A 1.8-mm steel cable is wrapped around the anterior cortex of the distal end of the transport segment and exits the skin distal to the docking site. Two standard rings are applied at the proximal and distal aspects of the leg, and 2 pulleys are attached to the ring at the ankle. The steel cable is then attached to slotted threaded rods that connect to the compression distraction rods that will pull the cable up and the bone segment down. Two Ilizarov “clickers” that rotate 0.25 mm with each “click” are the motor of the system. Once the bone transport system is removed, a custom interlocking bolt is placed to capture the transport segment. This prevents recoil of the fragment as there is a substantial amount of tension in the system.

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Alternatives: There are no nonsurgical options for reconstruction of massive bone loss. The several alternatives for surgical reconstruction include the inducible membrane Masquelet technique; circular fixation alone with standard Ilizarov bifocal transport, hexapod bifocal transport, or trifocal transport; bone transport and then insertion of an intramedullary nail (Lengthening and Then Nailing, or LATN); and amputation[2-8].

Rationale: The standard Ilizarov method for posttraumatic bone loss with external fixation is a well-established surgical procedure with high union rates. However, an external fixator has a high association with pin site infection, and it is cumbersome for the patient. In addition, scarring associated with the wires and half-pins as they progress down the limb is unsightly and painful. The advantage of the cable-pulley system is that the frame is used only in static mode; the cable that pulls the bone transport segment remains at the same exit point of the skin, thus limiting scarring. In addition, as soon as the distraction phase is completed, the external device can be removed. This substantially decreases the time that the external fixator needs to be in place.

Introductory Statement

Use of a cable-pulley system over an intramedullary nail for posttraumatic bone loss mitigates many of the disadvantages of classic Ilizarov bone transport with external fixation alone; the following description of the procedure is for a distal tibial diaphyseal defect with the transport from proximal to distal (anterograde).

Indications & Contraindications

Indications

- Larger diaphyseal defects or meta-diaphyseal defects (Figs. 1 and 2). Typically, defects of >8 cm require use of the external fixator for a substantial amount of time. This procedure decreases that time substantially.
- Acute or chronic acquired bone loss.
- Acute or chronic infection. The principle for reconstruction is to manage the infection prior to the bone loss. The algorithm for infection management consists of thorough irrigation and debridement, achievement of bone stability, and targeted intravenous antibiotics. We rely on clinical examination (to determine the status of soft tissues), radiographs, and measurements of the C-reactive protein (CRP) level, erythrocyte sedimentation rate (ESR), and white blood-cell count (WBC) to determine if an infection is present. However, we often perform an initial debridement to ensure that the bone is viable (bleeding) and send deep tissue for culture.

Contraindications

- Small periarticular segments that preclude sufficient fixation of the intramedullary nail. This applies to proximal and distal defects.
- A medullary canal that is too small to accommodate the intramedullary nail.
- A non-patent medullary canal.
- Skeletal immaturity precluding intramedullary nail placement through the physis.
- Presence of a knee or ankle replacement, blocking the medullary canal.

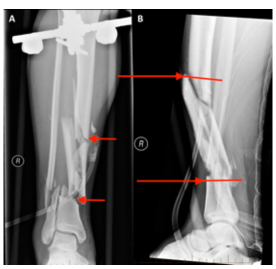

Fig. 1

Fig. 2

Figs. 1 through 11 A 29-year-old man who was involved in a high-speed motorcycle accident. He was initially treated at an outside hospital, where another surgeon performed an irrigation and debridement procedure and placed a uniplanar external fixator. Forty-eight hours later, the surgeon performed a repeat irrigation and debridement procedure, removed the nonviable bone, and placed an antibiotic cement spacer. The patient was referred to the definitive center 7 days later, where he was brought back to the operating room for irrigation and debridement, resection of the tibia (with orthogonal cuts for bone transport), insertion of a new antibiotic cement spacer, and placement of a standard intramedullary nail. Six weeks later, the patient returned to the operating room for removal of the cement spacer, exchange of the intramedullary nail for 1 with a custom hole, passing of the cable, and application of an Ilizarov circular fixator. **Figs. 1-A and 1-B** Anteroposterior and lateral radiographs made after the initial irrigation and debridement and application of an ankle-spanning uniplanar external fixator. The large segmental tibial fracture was devitalized during the initial surgery. The red arrows and lines in **Figure 1-B** outline the proximal resection that is required for bone transport. This additional geometric flat-cut resection is unique to bone transport.

Fig. 2 Intraoperative photograph showing the tibial bone defect. The traumatic incision was medial. A femoral distractor was used to obtain and maintain appropriate alignment prior to insertion of the tibial nail.

Step-by-Step Description of Procedure

Step 1: Debridement

The local environment requires thorough debridement.

- Gain access to the bone defect site through traumatic incisions, previous surgical incisions, or elevation of a soft-tissue flap, if applicable (Fig. 2).
- Excise all nonviable (non-bleeding) tissue, including bone. If gross purulence is present, consider staging with an interim antibiotic spacer, external fixation, and use of culture-specific antibiotics. Soft-tissue coverage should be addressed in concert with a plastic surgeon at the initial stage.
- Deflate the tourniquet, if one was used.
- Cut the bone ends orthogonal to the anatomic axis of the tibia in the anteroposterior and lateral planes (Fig. 3). Orthogonal cuts of the tibia are required to allow appropriate healing once the transported segment reaches the docking site. Use temporary 1.6 or 2.0-mm Kirschner wires as guides for the saw.
- Ensure that the bone ends that remain are alive; drill (using irrigation) the bone ends and look for punctate bleeding.

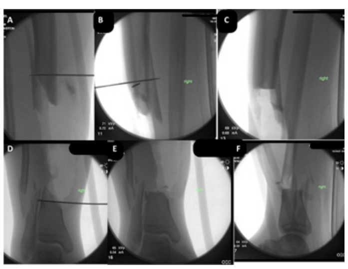

Fig. 3

Figs. 3-A through 3-F Intraoperative fluoroscopic images demonstrating resection of the tibia in preparation for bone transport. **Figs. 3-A and 3-B** Anteroposterior and lateral views of the tibia with a guidewire perpendicular to the anatomic axis of the proximal part of the tibia. **Fig. 3-C** Lateral view of the proximal part of the tibia after resection. **Fig. 3-D** Anteroposterior image with part of the guidewire perpendicular to the axis of the distal part of the tibia, which will serve as the docking site. **Figs. 3-E and 3-F** Anteroposterior and lateral images after resection with a saw.

Step 2: Proximal Tibial Osteotomy for Lengthening

In the planned location, perform the tibial osteotomy prior to insertion of the intramedullary nail (Fig. 4).

- Make a 1 to 2-cm longitudinal incision just medial to the tibial crest.
- Use a periosteal elevator to ensure that the osteotomy is performed subperiosteally, thus maintaining a sleeve of periosteum bridging the proximal and distal segments.
- Use a 4.8-mm drill-bit (or one of similar size) to make 3 or 4 passes into the bone.
    - Use fluoroscopy to ensure that the drill-bit is perpendicular to the axis of the tibia.
    - Clean the flutes after each pass.

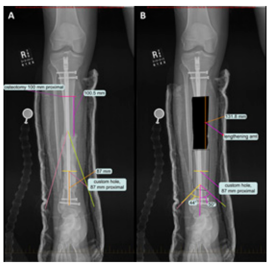

Fig. 4

Fig. 4 Pre-lengthening (**Fig. 4-A**) and post-transport (**Fig. 4-B**) postoperative radiographs, made using in-house CAD (computer-aided design) planning software, after resection of nonviable tibial bone, removal of the external fixator, and insertion of a temporary intramedullary nail. Note the osteotomy location for lengthening, the estimated amount of lengthening required, and the location of the custom interlocking bolt. Based on the final location of the transport segment, we instructed the vendor who manufactured the nail to place an additional hole for an interlocking bolt 87 mm proximal to the end of the nail.

Step 3: Insertion of the Intramedullary Nail

Prepare the nail path by reaming the medullary canal of the tibia.

- Insert a preplanned custom intramedullary tibial nail into the tibia after preparing (reaming) the canal. The nail is custom in that it contains an extra hole for insertion of an interlocking bolt to capture the transported bone segment to prevent it from displacing proximally (Fig. 5). This intramedullary nail can be ordered from 1 of the major vendors. In our experience, since the customization involves only adding a medial-to-lateral hole, it has not increased the cost of the implant. However, another option is to use a Midas Rex high-speed pneumatic surgical drill (Medtronic) to make the hole for the interlocking bolt.
- If the segment is small, secure it with 3 interlocking bolts.
- The material obtained from the reaming will be deposited at the osteotomy site, which has already been vented.
- Insert the intramedullary nail up to, but not across, the osteotomy site. Complete the osteotomy with a sharp osteotome and pass the nail into the distal segment.

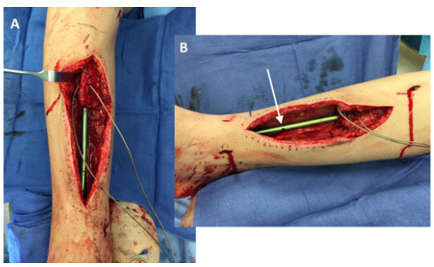

Fig. 5

Fig. 5 Intraoperative photographs after insertion of the custom tibial intramedullary nail. Cable has been wrapped around the proximal tibial segment. The arrow demonstrates the custom hole that was drilled by the vendor.

Step 4: Wrapping the Steel Cable Around the End of the Tibia (Fig. 6)

Wrap a 1.8-mm Ilizarov threaded cable around the end of the anterior aspect of the tibia.

- Measure 1.5 cm proximal from the end of the bone to pass the cable.
- Use a 2-mm drill-bit with frequent irrigation.
- Because this is a transport over an intramedullary nail, the cable must remain intracortical (that is, outside the path of the nail).
- Drill 2 overlapping, but not intersecting, 2-mm holes in the anterior cortex of the tibia.
- Keep the first drill-bit in the hole as you drill the second hole. The 2 holes cannot intersect, as it will make passing the cable impossible.
- Pass the cable through from distal to proximal and around the anterior aspect of the tibia and back around the other end. Use a Hewson suture passer to help pass the cable.
- Ensure that both limbs of the cable are of equal length.

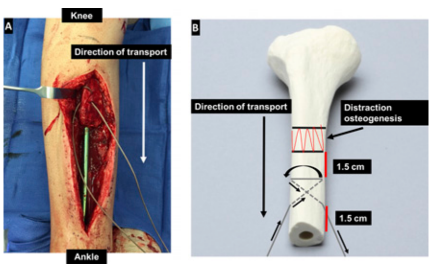

Fig. 6

Fig. 6 Intraoperative photograph (**Fig. 6-A**) and diagram (**Fig. 6-B**), detailing the cable insertion around the transported segment. Our experience has indicated that the cable should be secured leaving at least 1.5 cm of intact tibia distal and proximal to the entry point and crossing cable, respectively.

Step 5: Passing the Cable from the Tibia to the Pulley (Fig. 7)

Bring the threaded cable out of the leg at the planned level of the pulleys.

- Insert the steel cable into the plastic tubing of a Hemovac drain (Zimmer Biomet), keeping the trocar on the end of the plastic tubing.
- Pass the trocar through the skin, in the mid-sagittal plane.
- The cable should exit the skin just distal to the docking site.

Fig. 7

Fig. 7 Intraoperative photograph after the cables have been passed percutaneously through the distal aspect of the leg. The cable is inserted into the plastic tubing of a Hemovac drain. The metal trocar acts as the shuttle to bring the cable outside of the leg at the appropriate location. The wounds are closed at this point, as the next step is application of the circular fixator.

Step 6: Wound Closure

Close the surgical wounds prior to mounting the circular frame.

- Use standard techniques of wound closure in most cases.
- For wounds under tension, consider using the Allgöwer-Donati technique[9].

Step 7: Mounting a 2-Ring Circular Frame

Mount a 2-ring circular fixator to the top and bottom parts of the tibia.

- Take care to avoid the path of the intramedullary nail.
- Use a combination of 1.8-mm Ilizarov wires and 6-mm hydroxyapatite-coated half-pins for external fixation; 2 or 3 fixation points in each segment are sufficient.
- Ensure that the rings are perpendicular to the coronal plane of the tibia and parallel to the tibia in the sagittal plane.
- Connect the 2 rings with 4 threaded rods.
- Apply 2 Ilizarov clickers, which attach to the cable and the slotted compression distraction rod.

Step 8: Mounting the Pulleys

Mount pulleys to the distal ring (in cases in which the transporting bone segment is moving from the top of the leg down to the ankle).

- Use a female post and a nylon nut to connect the pulley.
- Ensure that the plane of the pulleys is in the mid-sagittal plane.

Step 9: Connecting the Steel Cable to the Frame

Wrap the steel cable around the pulley and connect it to a slotted threaded rod.

- Place 2 nuts to crimp the cable.
- The threaded distraction compression rod is connected to the clicker. This pulls the threaded rod into the chamber, thus pulling the cable up, and around the pulley, which pulls the bone segment down.
- Each quarter-turn “click” of the clicker represents 0.25 mm.

Step 10: Bone Transport (Fig. 8)

Initiate the Ilizarov method of distraction osteogenesis.

- Distraction osteogenesis starts 7 days after the corticotomy (latency phase).
- Distraction occurs at a rate of 0.25 mm 4 times a day (distraction phase). Perform weekly follow-up initially to ensure that the actual distraction rate (measured on radiographs) equals what the patient is performing. The rate may need to be increased temporarily until the slack in the cable is eliminated (Fig. 9).

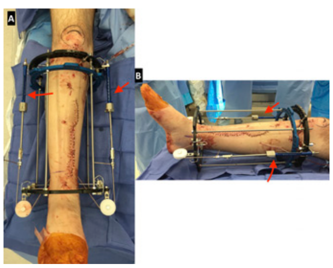

Fig. 8

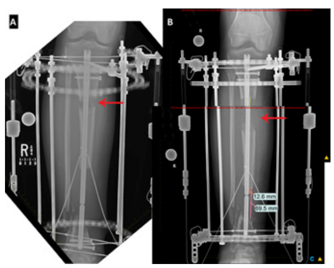

Fig. 9

Fig. 8 Intraoperative front (**Fig. 8-A**) and side (**Fig. 8-B**) views of the right tibia after application of the circular fixator and pulleys. The cables have been wrapped around the distal pulleys and connected to 2 threaded rods that are subsequently attached to the “clickers” (red arrows).
Fig. 9-A Anteroposterior radiograph made during bone transport. **Fig. 9-B** Interval radiograph showing progression of the transport segment. The red arrows point to the site of lengthening (distraction zone where immature bone called *the regenerate* is located).

Step 11: Fixation of the Transported Segment with an Interlocking Bolt in the Custom Hole (Fig. 10)

Place an interlocking bolt into the bone transport segment.

- Perform a sterile prep, including the entire external fixator within the surgical field.
- Place Betadine (povidone-iodine)-soaked sponges around the wire and half-pin sites for added sterility.
- Under fluoroscopic guidance, insert a distal interlocking bolt into the custom hole using a freehand technique in the standard fashion.
- Remove the external fixator and use a curet to debride the pin sites after the new incision is closed. Take care not to curet too deeply as it is important to avoid contact with the intramedullary nail.

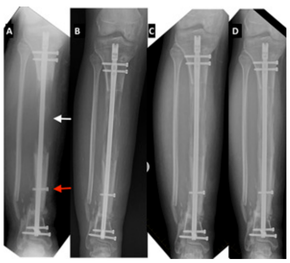

Fig. 10

Fig. 10-A Intraoperative anteroposterior radiograph made after insertion of the custom interlocking bolt (red arrow) and removal of the external fixator. Note the immature regenerate (white arrow) that is support by the statically locked intramedullary nail. **Figs. 10-B, 10-C, and 10-D** Interval anteroposterior radiographs demonstrating progression of healing of the docking site and regenerate.

Step 12: Postoperative Management

Postoperative management consists of range-of-motion and strengthening exercises with limited weight-bearing initially.

- After removal of the external fixator, the patient is encouraged to work on range-of-motion and strengthening exercises.
- The patient should be limited to partial weight-bearing (30 lb [13.6 kg]) and progress to full weight-bearing as the consolidation progresses.

Results

In comparison with classic bone transport (using external fixation alone), our technique involves a similar number of surgical procedures to complete the tibial reconstruction as well as a similar prevalence of unplanned surgical procedures. However, combining the external fixation with internal fixation—specifically, lengthening over an intramedullary nail—dramatically reduces the external fixation index, or EFI (the number of months per centimeter of lengthening while the external fixator is in place). With classic external fixation alone, typical EFIs range from 1.5 to 2.5 months/cm. In the illustrative case shown in Figures 1 through 11 and Video 1 (a patient with a 14.5-cm tibial bone defect who had the external fixator in place for 6 months), the EFI was drastically reduced to 0.41 month/cm (Fig. 11).

In our previous study[6], no patient had recurrence of infection and all had osseous union at the time of final follow-up.

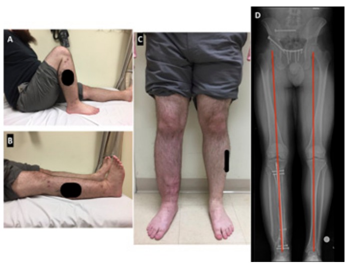

Fig. 11

Figs. 11-A through 11-D Clinical and radiographic images made after removal of the external fixator and insertion of the custom interlocking bolt into the transport segment. **Figs. 11-A and 11-B** Clinical photographs of the patient demonstrating the knee and ankle ranges of motion. **Fig. 11-C** Standing image of the patient. **Fig. 11-D** Final standing hip-to-ankle radiograph demonstrating neutral limb alignment and equal leg lengths.
Video 1 Surgical steps.

Pitfalls & Challenges

- Overream the medullary canal by 2 mm to allow the transported segment to move freely over the nail.
- Consider building the frame preoperatively on a Sawbones model (Pacific Research) and using it as a template in the operating room.
- Preoperatively, plan the location of the custom interlocking bolt to capture the transported segment once the distraction phase is completed.
- Use 3 interlocking bolts in smaller periarticular segments; there is a substantial amount of shear, which may cause translational or angular deformity.
- The alignment of the limb (length, rotation, coronal angulation, and sagittal angulation) is established immediately after the interlocking bolts are placed in the intramedullary nail. Therefore, it is critical to verify the correct alignment of the tibia prior to bone resection and maintain this alignment during the insertion of the intramedullary nail and until the final interlocking bolts are placed. This can be done with a temporary external fixator, femoral distractor, or unicortical plate.
- Consider the vector of pull of the cable as it pulls down the leg. This may require increasing the rate of lengthening, since lengthening along an oblique vector will result in less axial distraction.
- As stated above, as the transported bone segment moves, the vector (and angle) of pull changes; thus, the soft tissues need to be monitored as the cable may elevate the skin as the tension increases. This is avoided by placing the pulleys as close to the skin as possible and having the cables exit the skin distal to the docking site.
- If there is poor regenerate formation, we typically slow down the rate of distraction. Alternatively, we have had success in injecting bone marrow aspirate concentrate into the regenerate.

- In the case of fracture of the tibia at the cable site, we modify the construct to a bone transport over a nail.
- Pin track infections are treated with a 10-day oral course of cephalexin (500 mg every 6 hours). Bactrim DS (sulfamethoxazole-trimethoprim), twice daily, is used when infection does not resolve within 48 hours, or if you are in an area with a high prevalence of methicillin-resistant *Staphylococcus aureus* (MRSA).
- The decision to stage the procedure depends on patient, surgeon, and institutional factors.
- The patient must appreciate the algorithm for reconstruction and demonstrate his/her ability to comply with postoperative instructions. The surgeon needs to be prepared to design a detailed algorithm for reconstruction and manage problems as they arise.
- The institution where the surgeon practices should be able to support frequent returns to the operating room (dedicated trauma block time) and timely approval for implants.

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