**Tibial Lengthening Over an Intramedullary Nail**

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**Summary:** Lengthening over a nail (LON) or transport over a nail (TON) are relatively new techniques and were first described in the femur by Paley and Herzenberg in 1997. The technique combines traditional Ilizarov distraction osteosynthesis with the convenience of a tibial intramedullary (IM) nail and requires only 1/3 of the external fixator time compared with standard Ilizarov technique. The most serious potential complication of osteomyelitis can arise as superficial infection tracks along a wire or pin which is in contact with the IM nail. Osteomyelitis was not encountered in the Vietnam LON/TON series and can be avoided by careful placement of wires and pins. Expensive implants are not required and hence it is suitable for the management of post-traumatic shortening (LON) and segmental bone loss (TON) in developing countries. The Surgical Implant Generation Network IM nail system can be used reliably with these techniques.

**Key Words:** lengthening over a tibial nail—post-traumatic tibial shortening—Ilizarov—tibial lengthening—distraction osteosynthesis—Surgical Implant Generation Network (SIGN).

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**General Considerations and Principles**

Patients presenting with limb length inequality or segmental bone loss require a careful history and thorough physical examination. Radiographs should be carefully reviewed to look for deformity and the center of rotational axis identified and measured on both the anteroposterior and lateral radiographs. The ideal patient for LON should not have pre-existing tibial deformity. Patients with open tibial fractures and segmental bone loss require early soft-tissue coverage as well accurate assessment of the length of the opposite limb and tibia to identify the correct length. When considering TON in a patient with an external fixator already in place, a recent pin or wire-site infection is a contraindication to intramedullary (IM) rod fixation. The treating surgeon should consider using traditional Ilizarov bone transport technique in this clinical situation.

LON and TON are relatively new methods which combine Ilizarov external fixation with a tibial IM locking nail (Fig. 1). Proximal tibial osteotomy is performed using drill osteoclasis or a Gigli saw. Tibial osteotomy may be performed using drill osteoclasis and osteotome or with a Gigli saw. A latent interval of 2 weeks is required to allow early callus formation. The ring fixator is then used to distract the osteotomy gap and transport the distal tibia down the nail until the desired tibial length has been reached. The ring fixator acts as the motor for transport of the tibia over the distal end of the nail whereas the proximally locked IM nail helps to maintain appropriate alignment during the lengthening process.

Use of the IM nail is rational since valgus and procurvatum are common problems with traditional Ilizarov tibial lengthening through a proximal tibial metaphyseal corticotomy. The reason for this is that regenerate bone tends to form earlier and more exuberantly in the posterior and lateral distraction gap where there is an excellent blood supply from the surrounding soft-tissue envelope. This stiffer, more mature posterolateral bone acts like a physeal bar in a growth plate and tethers the distraction gap, leading to valgus and procurvatum. The majority of these traditional lengthenings require the use of hinges to perform the final angular deformity correction before allowing the osteotomy gap to consolidate. This type of valgus procurvatum deformity is not observed with LON since the IM nail maintains alignment (Fig. 2). Tibial lengthening using the Taylor Spatial Frame avoids this problem but the patient must keep the frame on until the consolidation process is completed.

With LON, the distal tibial interlocking screws are inserted after the desired length has been achieved and the external fixator is removed. Distraction bone will fill the gap while the patient ambulates free of a cumbersome ring fixator.

The main advantage of lengthening over the IM nail is that the patient experiences much less pain and, although the consolidation phase of the lengthening remains the same, the time to full weight-bearing is much shorter.

**Principle, Technique, and Surgical Tips**

**Intramedullary Nail Selection**

The most important principle of LON and TON technique is to avoid contact between the IM nail and tensioned lengthening wires. Ideally, this will require the use of an image intensifier in the operating room to obtain careful lateral or oblique views to make sure that there is no contact.

One problem which is encountered in the Vietnamese population is smaller tibial dimension including narrower tibial medullary canals which frequently requires the use of an 8 mm diameter nail. As a result, we prefer to use a solid 316 L stainless steel, Food and Drug Administration-approved IM nail to avoid or minimize the potential for implant failure during the distraction callus maturation phase. Smaller tibial anatomy can lead to potential intraoperative technical diffi-
culties because of limited implant selection most of which may be avoided by careful preoperative planning.

The IM nail must be able to slide smoothly in the distal to proximal direction within the distal portion of the tibia during the distraction phase of LON technique. Early experience with TON rendered a complication of almost 40% and therefore there is a clear need for careful preoperative preparation by an experienced lengthening surgeon. For TON technique (Fig. 3), the transport segment must slide efficiently over a portion of the IM nail during the distraction process. We prefer to use an IM nail which has a low coefficient of friction, however, the process of LON is an extremely complex process which is dependant on nail contact surface area with bone and hence total frictional area, coefficient of friction of the nail itself, initial distraction inertia because of residual bony attachments and surrounding soft-tissue tension because of the periosteal sleeve, muscle and tendon attachments. We prefer the Surgical Implant Generation Network (SIGN, Richland, WA) nail because of its economical cost in developing countries, its solid cross-section and excellent fatigue strength and availability of an 8 mm nail in a variety of tibial nail lengths.

The principle of TON is similar to LON except that the overall tibial length is maintained and a segment of tibia is transported to treat segmental bone loss. There are 2 options: proximal to distal transport or distal to proximal transport. The latter should generally be performed more slowly because the soft-tissue envelope is not as good in the distal tibial region. In the young adult, a distraction rate of 0.75 to 1 mm may be used for a proximal to distal transport whereas a 0.5 mm per day or slower transport rate should be used for a distal to proximal transport. TON technique can only be used after thorough resection of an infected bone segment in the case of infected nonunion or osteomyelitis. The use of an IM nail in this clinical situation remains controversial. In practice, there may be fluid draining from the site of segmental resection, but as the transport proceeds, the drainage diminishes and the drainage tract will become dry as the transport segment contacts the main tibial fragment. There is some evidence from animal studies that a solid nail may have clinical benefit in this clinical situation by way of a decreased surface area available for infective glycocalyx formation.9

**FIGURE 1.** Lengthening over a nail combines a ring fixator for lengthening and a regular Intramedullary nail.

**FIGURE 2.** Lengthening over a tibial nail. The normal mechanical axis (dotted lines) is more predictably maintained during the lengthening process.
External Fixator Selection

A half-ring fixator or 5/8 ring may be used in the proximal tibial region to allow the use of tensioned wires and to allow greater than 120° of knee flexion during the distraction phase of treatment. For LON femoral treatments an Orthofix (McKinney, Texas, USA) unilateral fixator may be used to achieve distraction. All of these external fixators may be manufactured economically in developing countries.

Surgical Technique

Step 1: Intramedullary Nail Insertion

Select a transpatellar incision to approach the tibial nail insertion entry point. Ream 1 mm over the planned tibial nail diameter, insert the IM nail and lock the proximal end (Fig. 4) of the nail using 2 medial-to-lateral SIGN locking screws.

Step 2: Tibial Corticotomy

The posterior tibial corticotomy is performed using a Gigli saw at the junction of the proximal and middle 1/3 of the tibia. This metaphyseal junction offers the potential for superior regenerate bone formation. Diaphyseal osteotomy should be avoided as much as possible but if it cannot be avoided, the transport rate should be a maximum of 0.25 mm per day. The anterior and lateral corticotomy is performed using a 1/2 inch (1.2 cm) osteotome. Drill osteoclasis can be performed before completion of the osteotomy using the osteotome.

Step 3: Application of the Ring Fixator

The 2-ring frame is applied perpendicular to the axis of the tibial shaft. The 1.8 mm Ilizarov wires are inserted using a drill. These wires are placed in a crossing fashion posterior to the tibial nail (Fig. 5). In the distal tibia, the wires should be placed at least 2 cm superior to the ankle joint to avoid intracapsular placement and at least 1 cm distal to the tip of the tibial nail. Fibular transfixion is important to prevent ankle and proximal tibio-fibular joint subluxation.

Step 4: Fibular Osteotomy

The fibular osteotomy may be performed in the middle or junction of middle and distal third of the fibular shaft. Some surgeons prefer an oblique osteotomy to increase the surface area for distraction bone formation but fibular non-union is usually asymptomatic. The osteotomy may be performed by drill osteoclasis and an osteotome or a Gigli saw. Be careful not to injure the peroneal artery which lies posterior to the fibula.

Step 5: Compress the Osteotomy

Compress the osteotomy site (Fig. 5) using the ring fixator and close the 3 incisions.
Step 6: Postoperative Care

- Rest and elevate the leg for 1 to 3 days.
- Some surgeons use a short course (10–14 days) of low-molecular weight heparin subcutaneous injection for deep vein thrombosis prophylaxis.
- Encourage quadriceps straight-leg raise exercises and knee range of motion.
- Ambulate the patient partial weight-bearing (50%) with crutches or a walker (Fig. 6).
- Discharge the patient from hospital on the fifth postoperative day.

FIGURE 5. A, Orientation of the Ilizarov transfixion wires in the posterior aspect of the tibia. Note the nail insertion site anteriorly and the superimposed tibial tuberosity. B, Appearance of the limb after insertion of the nail and application of the external fixator. C, Postoperative radiograph showing a compressed osteotomy gap.

FIGURE 6. Partial (50%) weight-bearing is permitted during the lengthening process.

- Begin distraction on the 10th day to 14th day. Young adults may begin distraction on the 10th day. The distraction rate is usually between 0.5 and 1 mm per day with metaphyseal

FIGURE 7. Lengthening Over a Nail (LON). The nail slides proximally within the distal tibial segment as lengthening proceeds.
osteotomies in young adults being distracted at 1 mm per day.
● Stop the distraction when the desired tibial length had been achieved (Fig. 7).

Step 7: Second Stage Distal Interlocking and Frame Removal

The desired tibial length is usually reached after 3 to 4 months and the average lengthening can be achieved in the 6 to 8 cm range for patients who have sustained post-traumatic shortening and do not have excessive scarring of the soft-tissue envelope (Fig. 8). However, 15% lengthening of the tibia is a reasonable lengthening goal for non-traumatic LON procedures.

Insert 2 distal interlocking screws from medial to lateral under fluoroscopic control to maintain the tibial length that has been achieved during the distraction process. Remove the tibial frame (Fig. 9).

Step 8: Postoperative Care

Active and passive-assisted range of motion (ROM) exercises for the knee and ankle are required to restore knee motion, improve quadriceps strength, and prevent or treat Achilles tendon contracture (Fig. 10). Most patients develop difficulties with knee flexion but regain full knee flexion by 3 months after the initial surgery (Table 1). The patient may be permitted to begin full weight-bearing without walking aids approximately 3 to 4 weeks after the external fixator has been removed (Fig. 11). Squatting with full ankle dorsiflexion can usually be achieved by 1 month after frame removal and distal interlocking. Long-term problems with equinus contracture have not been an issue to date with LON patients. Running and jumping may be permitted when sufficient distraction bone is present in the osteotomy gap.

![Figure 8.](image1.png) LON. Note the distraction gap in the proximal fibula.

![Figure 9.](image2.png) Distal interlocking has been performed and the external fixator removed.

![Figure 10.](image3.png) Ankle and knee stretching exercises are important to prevent contracture.

![Table 1.](image4.png) Knee range of motion

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<th>Removing frame</th>
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usually by 6 months after frame removal. Patients may drive a motorized vehicle once they are able to ambulate without pain.

Regular follow up x-rays are obtained every 4 to 6 weeks until the distraction callus has fully matured. Do not consider removal of the IM nail until all 4 cortices (anterior, posterior, medial, and lateral) have been completely reconstituted (Fig. 12), usually greater than 18 months after surgery. Regenerate bone will first become evident on the postoperative x-rays by approximately 4 weeks as microcolumn new bone formation proceeds (Fig. 13). The fibrous interzone is an area of intramembranous bone formation which should be carefully examined to make sure that it is not excessively wide. Once the distraction has been completed, the fibrous interzone will close (Fig. 14) and increasing bone maturation will be evident at each repeat x-ray until the gap is completely healed, usually by 10 to 12 months following surgery (Fig. 15). The cortex will reform across the gap by 15 to 18 months (Fig. 16).

FIGURE 11. Femoral LON. A, Metaphyseal supracondylar osteotomy and retrograde SIGN nail fixation and distal interlocking. B, After the lengthening process is completed, proximal femoral interlocking screws are placed and the external fixator removed.

Wire-site pain usually occurs in the first 2 weeks of the lengthening process, and can be diminished if the distraction rate is slowed to about 0.5 mm per day and disappears once the distraction process ends. No pain was experienced during the distraction process in 9 of 12 LON patients. Knee pain in the first 1 to 4 weeks after surgery was experienced by 4 of the 12 patients and is the main cause of incomplete knee ROM prior to ring fixator removal. Similarly, ankle pain was observed in 2 of 12 patients in the early postoperative period and disappears when the ROM returns to normal. Foot and ankle swelling is common in the initial 1 to 2 weeks postoperatively.

**COMPLICATIONS OF LON TECHNIQUE**

- Nonunion is the most serious complication noted in this series and occurred in the oldest male patient, a 43-year-old who underwent a 6 cm lengthening. The proximal portion of the IM nail fractured in the 12th month after surgery and the regenerate bone had not bridged the gap after 1 year. This problem was managed by reamed exchange nailing, iliac crest bone grafting and relocking of the IM nail.
- Fracture of the proximal locking screw. This was noted in an 18-year-old woman and was managed by the application of a long-leg plaster cast for 4 weeks.
- Pin-site infection was observed in 1 of 12 cases (Fig. 17) and was treated with oral antibiotics. When recurrent wire or pin-site infections occur during conventional Ilizarov lengthening, the offending pin or wire usually requires removal.
- Over-drilling the wire or pin path followed by intravenous antibiotic therapy is important to achieve thorough bony debridement and prevent the formation of a draining osteomyelitic focus.
- Achilles tendon contracture, knee stiffness, foot drop and osteomyelitis were not observed.
- A fractured tibial nail was observed in 1 case. The patient was completely asymptomatic and the broken tibial nail was noted on the radiographs 1 month after surgery. The nail had broken at the site of the distal interlocking screw hole. A long-leg cast was applied for 2 months to maintain position and length of the tibia while the 7 cm lengthening consolidated.
- Fracture of the external fixator ring was noted in 2 cases but these rings were manufactured early in our lengthening experience. Patients typically experience pain at the wire site of the broken ring. This complication is managed by removing the broken ring, applying a new ring, and retensioning the transfixion wire which alleviates the local pain.
- Inability to distract the osteotomy site occurred in 1 patient. In this clinical situation, the patient had delayed the latent interval of the osteotomy gap to 6 weeks instead of the normal 10 to 14 days. Distraction was attempted for 2 weeks, without success and the decision was made to repeat the osteotomy. At the time of repeat osteotomy, bridging callus was observed between the 2 fragments. Two weeks after

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**FIGURE 13.** Time of regenerate bone appearance.

**FIGURE 14.** Time to distraction gap bridging.

**FIGURE 15.** Time to bone consolidation.

**FIGURE 16.** Cortex reconstitution.
repeat osteotomy, distraction proceeded uneventfully at a normal rate.

- Posterior subluxation of the knee has been described with femoral LON but tends to occur with lengthenings of over 20% of the femur. Three of 22 patients also required removal of the femoral nail because of the development of osteomyelitis.

**TRANSPORT OVER NAIL**

After completion of the osteotomy, the bone transport segment was transported over the nail until it contacts the remaining bone. In most cases, the segmental defect involves the distal tibial shaft and the transport direction is from proximal to distal. As with LON technique, the distraction speed is approximately 0.8 to 1 mm per day. When the docking site closes, the external fixator is removed once the regenerate bone in the distraction gap is sufficiently stiff to prevent loss of fracture gap compression (Fig. 18). Because the orientation of the proximal and distal ends of the fracture gap are never similar, iliac crest cancellous bone grafting of the docking site is usually required. Any soft tissue which is interposed in the docking site must be carefully removed and the bone ends freshened before placing the bone graft. Obtain a culture of the docking site to rule out an occult infection.

In clinical experience with 8 TON cases, there has been no need for free tissue transplant coverage of the surrounding soft tissues. In contrast, Oh noted that 5 of 12 patients with chronic osteomyelitis and treated with TON technique required myocutaneous or free flap coverage of soft tissue defects. All patients underwent serial debridement before TON and only 1 patient was noted to have ongoing infection at follow-up assessment.

In 1 of the 8 TON cases in the current series, a small plate and unicortical screws were used to maintain compression at the docking site. This is the simplest technique if the soft tissue envelope is healthy and early removal of the fixator is desirable. In 1 case, interlocking holes were made in the IM nail and anteroposterior interlocking screws placed across the transport segment in the appropriate docking site position (Fig. 19). Such modification of IM nails is not recommended until further clinical experience from high-volume TON centers is available.

Ilizarov recommended using the fibula as a guide to the assessment of appropriate tibial length for bone transport cases. If the segmental defect is long and the required lengthening and maturation phases unreasonable by way of the patient’s age or nutritional status, it may be preferable to allow the tibia to heal with residual shortening (Fig. 19). Another indication for TON in a shortened tibia is the closure of a soft tissue defect. Cavitory soft tissue defects which are oriented in the transverse direction close much more nicely compared with superficial defects which may require split-thickness skin grafts for complete healing.

**DISCUSSION**

LON is a technically demanding method of lengthening which reduces the incidence of temporary deformity during the lengthening process compared with standard Ilizarov treatment.
and results in a more rapid recovery for the patient.\textsuperscript{13} Lengthening and then nailing (LATN) has been advocated\textsuperscript{14} and represents a reasonable option to LON. Rozbruch performed a retrospective case-matched comparison of patients lengthened with LATN (39 limbs in 27 patients) technique versus traditional Ilizarov technique (34 limbs in 27 patients). It was noted that “the LATN group wore the external fixator for less time than the classic group (12 vs. 29 weeks)” and that “the LATN group had a lower external fixation index (0.5 vs. 1.9) and a lower bone healing index (0.8 vs. 1.9) than the classic group. LATN confers advantages over the classic method including shorter times needed in external fixation, quicker bone healing, and protection against refraction.”

Some centers are now performing femoral LON with angular deformity correction\textsuperscript{15} but this requires very careful planning by identifying the center of the deformity and planning the final position of the nail to permit interlocking. Although valgus deformity of the proximal tibia can still occur with LON, there is significantly less angulation of the proximal tibia and less knee ligament laxity because of proximal tibiofibular joint distraction with the technique compared with conventional Ilizarov lengthening. Shyam noted that 86% of patients with lateral knee joint laxity after tibial lengthening were skeletally immature.\textsuperscript{16} Femoral lengthening using the IM Skeletal Kinetic Distractor is a new technique but difficulty in achieving the desired length can occur in a quarter of patients and uncontrolled lengthening can occur in 21%.\textsuperscript{17} The desired length was achieved in all but 1 patient in Simpson’s series of 33 patients and failure to lengthen was avoided by over-reaming by 2.5 to 3 mm which is consistent with SIGN femoral nail technique. For femoral shortening with mild deformity, fixator-assisted nailing followed by LON is a reasonable option and allows for a much shorter external fixation time and avoids plastic deformation of the regenerate bone.\textsuperscript{18} The deformity correction is performed acutely and stabilized using the IM nail. Distal interlocking screws are placed, lengthening performed followed by proximal locking screw insertion.

CONCLUSION

LON or TON are relatively new techniques and were first described in the femur by Paley and Herzenberg in 1997. The technique combines traditional Ilizarov distraction osteosynthesis with the convenience of a tibial IM nail and requires only 1/3 of the external fixator time compared with standard Ilizarov technique.\textsuperscript{19} The most serious potential complication of osteomyelitis can arise as superficial infection tracks along a wire or pin which is in contact with the IM nail. Osteomyelitis was not encountered in the Vietnam LON/TON series and can be avoided by careful placement of wires and pins. Expensive implants are not required and hence it is suitable for the management of post-traumatic shortening (LON) and segmental bone loss (TON) in developing countries such as Vietnam. The Surgical Implant Generation Network (SIGN, Richland, VA) IM nail system can be used reliably with LON and TON.

REFERENCES


FIGURE 19. Transport over a tibial nail. A: Note the segmental fibular fracture which makes length assessment more difficult; B: Transport of proximal and distal segments has begun. This type of treatment reduces the time to docking or closure of the segmental defect and also reduces the maturation phase during which regenerate bone increases in strength; C: Transport complete and regenerate bone evident in the distraction gaps. Note there is fibular overlap evident which suggests residual shortening.


