Use of a Motorized Intramedullary Bone Transport Nail for Trauma: Tips, Tricks, Corticotomy Techniques, and Rate and Rhythm

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Summary: The introduction of internal magnetic nails (IMNs) for bone lengthening and bone transport has given us exciting new tools with which to treat segmental bone loss. Distraction osteogenesis has a long record of success in recreating even large segments of bone, but the availability of IMNs now offers the possibility of performing distraction osteogenesis without the drawbacks of external fixation. However, there are aspects of treatment with IMNs that are critical to understand to achieve success and minimize complications. These include assessment of feasibility in relation to available bone stock and segment configuration, the condition of the soft tissue envelope, and the presence of contamination or infection. They also include execution aspects such as bone end preparation, nail placement, need for and positioning of adjuvant fixation, corticotomy techniques, rate and rhythm of distraction, staged screw exchange, docking site preparation, and nail extraction. We discuss these issues in detail and introduce some novel techniques not previously described including the comminuted wedge osteotomy, testing of the nail with initial compression, and retention plug application for nail extraction to assist in optimizing success in certain clinical situations.

Key Words: internal magnetic, lengthening nail, precice, bone transport nail, distraction osteogenesis, distraction histeogenesis, bone defect, segmental bone loss, transport, open tibia, open femur open fracture

(*J Orthop Trauma* 2021;35:S31–S38)

INTRODUCTION

Since being introduced by Ilizarov in the 1980s, bone transport with distraction osteogenesis (DO) has proven to be a powerful method of treating open fractures and creating a new bone for even massive segments of bone loss.[1,2] Before the introduction of internal magnetic nails (IMNs), performing DO relied on external fixation. Circular external fixation is a powerful tool but has drawbacks, especially when used to reconstruct large segments of bone loss. These include a long duration with an uncomfortable and inconvenient fixator in place; pin problems such as cellulitis, loosening, or breakage; risk of joint contractures; potential for unsightly scars; refracture after fixator removal; and difficult usage in areas with a large soft tissue envelope such as the thigh. These issues usually do not prevent an ultimately successful outcome but are a burden for patient and provider.[3]

IMNs offer the possibility of harnessing the power of DO while avoiding complications associated with external fixation. The internal nature of these devices eliminates not only the inconvenience and discomfort of the fixator but also pin cellulitis, joint contractures, and linear scarring caused by periarticular wires. IMNs are also highly advantageous in large soft tissue envelopes, such as the thigh, where pin problems are magnified and maintaining stability and alignment can be difficult.[4,5]

These major advantages are coupled with the possibility of improved outcomes including an earlier return to work, greater ease of travel, increased early social interaction, decreased need for pain medications with the attendant risk of dependency and addiction, decreased complications related to antibiotics used to treat pin cellulitis, and the need for fewer clinic visits. Many of these points have already been validated for limb lengthening with internal magnetic lengthening nails.[6] Published data to support these outcome results for bone transport are still limited, given the newness of the internal magnetic bone transport nail (BTN), but personal experience and conveyances from other surgeons have so far validated the seemingly obvious differences.

Although the potential advantages of IMNs are substantial, it must be recognized that IMNs behave very differently than standard intramedullary nails. The forces exerted on the bone end and implants during the process of DO can lead to deformity during the reconstructive process and may place the tibiofibular syndesmosis at risk. In addition, there are quite a few other unique and significant technical details to consider when planning a reconstruction using a BTN. The following discussion will address many of these unique considerations and help optimize success while minimizing risks.

PREPARATION OF BONE ENDS

Segmental bone defects secondary to acute trauma, septic nonunion, and osteomyelitis have the added challenges of contamination and, frequently, a compromised soft tissue

Accepted for publication March 9, 2021.
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Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (www.jorthotrauma.com).
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DOI: 10.1097/BOT.0000000000002121

envelope with a consequent increase in risk of infection.[7,8] The priority in treatment is to optimize the zone of injury before bone reconstruction. The first step in all circumstances is to debride all contaminated and/or infected tissues and obtain adequate soft tissue coverage. Once achieved, there are key differences in the treatment of the fracture site bone ends depending on the planned reconstruction pathway.

For bone grafting methods, it is often recommended to leave as much bone as possible at the site of the fractured bone ends to minimize any gap that must be addressed. This approach accepts a greater chance of leaving questionably viable and/or contaminated bone in exchange for decreasing the total volume of bone loss.[9] When planning for DO, it is optimal to resect the bone spikes at the fracture ends back to at least a 75% intact bone circumference of healthy bleeding bone (Fig. 1).[3] This not only helps to assure that there is a complete resection of devitalized bone but also optimizes the biology and mechanics at the docking site when the transport is complete by having large flat bleeding bone surfaces capable of being well apposed. This approach inherently makes the total volume of bone loss greater, but this trade-off is justified, given the advantages noted earlier together with the fact that DO is very reliable at creating the needed new bone.

The author recommends the following protocol for bone end preparation for bone transport: The bone is cut using a low-energy Micro-100 saw at a location where the bone is either circumferentially intact or at least 75% intact. This decision is made at the surgeon's discretion based on how much additional bone length would be lost to get to a completely intact cortical rim. Constant irrigation of the saw blade with iced saline solution is used, and there are frequent pauses while performing the bone cut to minimize the chances of thermal necrosis. Iced saline solution is created by adding

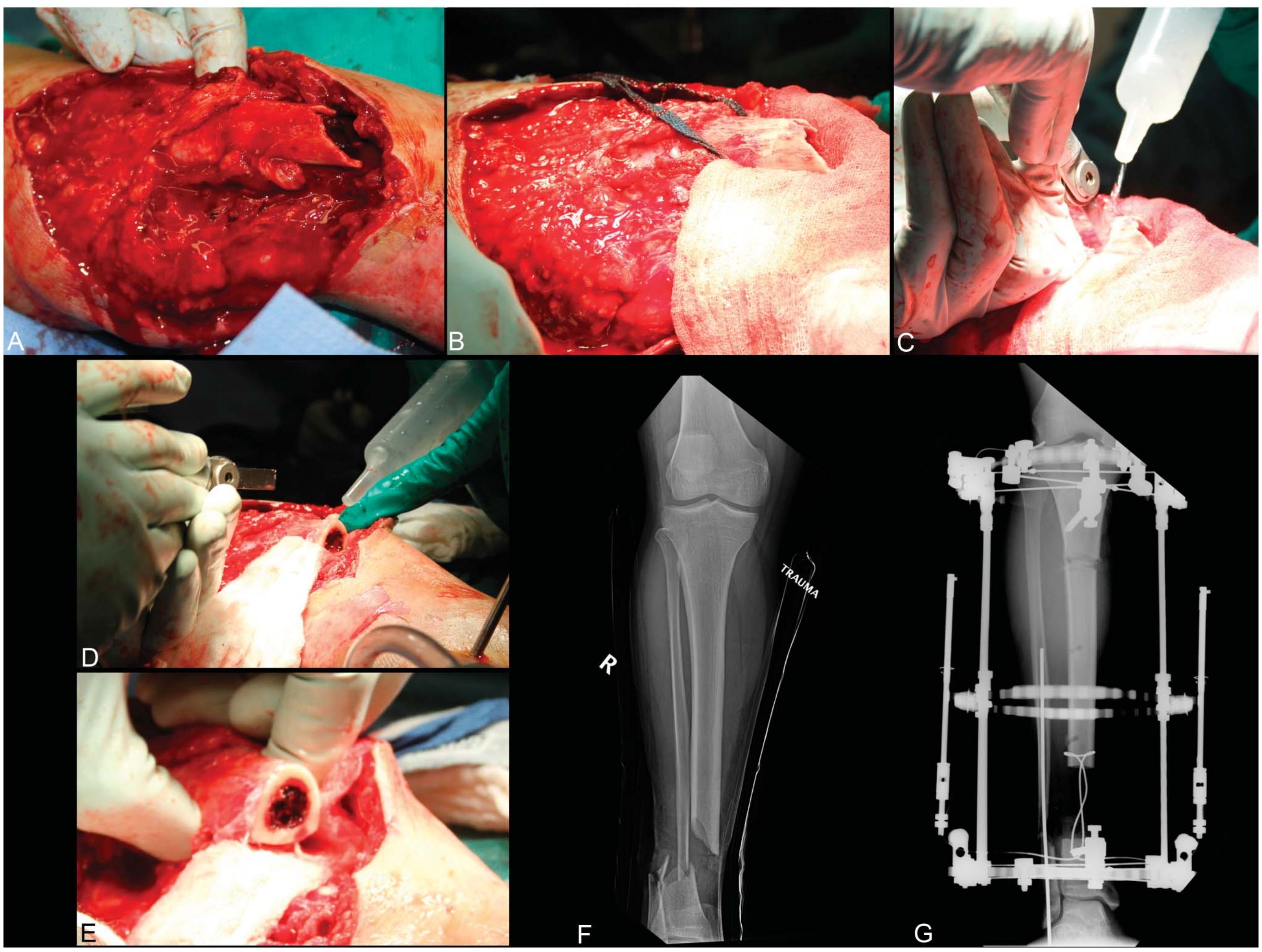

FIGURE 1. A, Picture of a bone end from an open tibia fracture after opening wound at the time of second debridement. B, Appearance of bone end after wound debridement and irrigation showing stripping of the bone end and no bleeding distally. C, D, Bone cut is performed using a low-energy saw. Constant iced saline irrigation of the saw blade is performed, and the saw is paused intermittently during the cut to assure that there is no thermal necrosis of the bone end. E, Examination of the bone end after osteotomy reveals healthy bleeding bone circumferentially with a 100% intact cortical rim. This is the ideal situation for bone preparation. F, G, Radiographs of an open tibia fracture defect before and after osteotomies were performed to prepare for bone transport. Note that the cuts are flat and orthogonal to the long axis of the bone in both coronal and sagittal planes.

previously frozen, double-packed sterile saline to regular sterile saline in a basin on the back table. Although not commonly used in orthopaedics, double-packed sterile saline is widely available for purposes of organ transplant.

The bone cut is made orthogonal to the long axis of the bone segment in both coronal and sagittal planes. An initial cut is sometimes made nearer the fracture site than the intended final cut location to allow for adjustments to assure that the configuration of the final cut is optimal. This same process is performed at the opposite bone end in a similar fashion. It should be noted that if one of the bone ends is a metaphyseal segment with a much larger diameter, then it may not be necessary to cut the surface completely flush because the smaller diameter shaft segment can be inset within the opposite metaphysis.

CORTICOTOMY/OSTEOTOMY

The most common methods of performing an osteotomy for bone transport are the multiple drill-hole technique and the Gigli saw method.[10,11] Both these can form excellent regenerate bone, but using a BTN often demands the osteotomy be in a very specific location, and fracture propagation of the osteotomy can be a major problem. The surgeon should be careful to choose a method that in his hands will be adequately precise and of low energy. We have found that using sharp Ilizarov osteotomes with a large wrench to complete a multiple drill-hole osteotomy is an effective method to achieve the required precision (Fig. 2). We also recommend using both percutaneous posteromedial and anterior incisions to facilitate the passage of the drill through each cortex to minimize the chances of fracture propagation. However, the

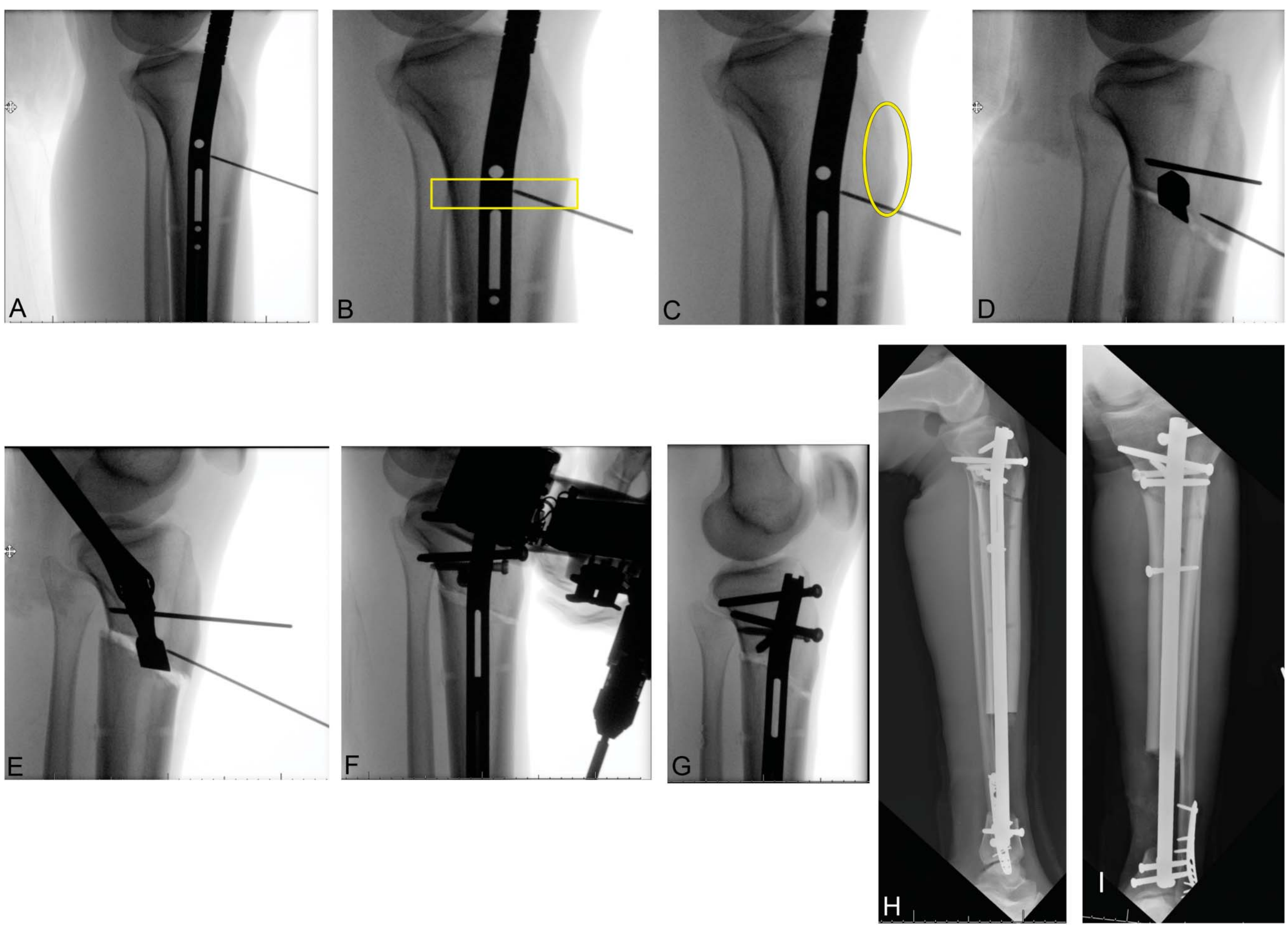

FIGURE 2. A, The nail is inserted and set to an optimal depth distally. The site of the osteotomy is marked in this case using a Steinmann pin. B, It is essential that the osteotomy be made in the tight 1cm interval between the top of the screw slot and the bottom of the locking screw hole if we are to assure 10 cm of stroke length and use of the most distal locking screw in the proximal cluster. C, The osteotomy must also avoid the tibial tuberosity. Osteotomies performed through the tibial tuberosity have the potential to result in fibers from the patellar tendon remaining attached to the transport segment, which must be avoided. D, E, The osteotomy is made obliquely from anterior to posterior, in this case, to avoid the patellar tendon but optimize the amount of bone available proximal to the nail. The osteotomy is completed by using a 13 mm wrench to rotate the handle of an Ilizarov osteotome. F, G, Lateral view of osteotomy site while compression is being applied to test the nail and following testing with compression of 4 mm. H, I, Initial postoperative radiographs showing the final construct and excellent apposition of the osteotomy site.

Gigli saw osteotomy offers an excellent alternative that for some will be an easier method of gaining the needed precision.

A special circumstance is when the osteotomy is being used to correct malalignment in addition to DO. We have found that a novel method that we call a comminuted wedge osteotomy works very well. The osteotomy is performed using percutaneous incisions over the posteromedial and anterolateral corners to create a line of drill holes that will allow for comminution of the segment of bone that will be compressed to achieve angular correction (Fig. 3). After the drill holes are placed, a small osteotome is used to comminute the zone between the drill marks, and then, finally, the cortex at the apex of the deformity is fractured to allow the angular correction. This allows for excellent apposition of the bones at the osteotomy site with the additional comminuted fragments as a form of vascularized bone graft. Using this method, excellent regenerate has been observed as opposed to opening wedge osteotomies, which tend to form relatively poor regenerate. The IMN can easily make up for the small overall loss in bone length caused by the closing wedge.

ADJUNCTIVE FIXATION

IMNs produce large forces on the bone segments during DO. Locking screws placed through holes in the nail control length and rotation well but are inadequate to prevent secondary deformity. Having a tight cortical fit with the nail is necessary to prevent secondary deformity, and if this is not present, then, stabilization screws are essential[12] (Fig. 4). Stabilization screws are similar in concept to blocking or Poller screws in that they are placed adjacent to the nail and provide increased stability by substituting for a bony cortex. However, the goal of a stabilization screw is to assure stability during DO instead of assisting with obtaining fracture alignment. Screws serving a stabilization function can be placed before nail insertion, such as with a blocking screw, but this makes it harder to

FIGURE 3. A–C, Anteroposterior, lateral, and full-length XRs of a patient with a history of rickets and previous surgery as a child requesting correction of alignment of his right tibia. D–G, Fluoroscopic images showing how a comminuted wedge osteotomy is performed by creating 2 drill lines that converge on the CORA of deformity on the far cortex. The bone on the closing wedge side is comminuted with a small osteotome before completing the osteotomy through the far side. H, I, Postoperative radiographs showing accurate correction of alignment with the comminution on the medial side acting as vascularized bone graft. Note that if the patient wanted lengthening, then an IMLN would have been used. CORA, center of rotation and angulation; IMLN, internal magnetic lengthening nail.

assure that the screw is placed in the ideal position directly adjacent to the IMN. We routinely use a previously described fixator-assisted nailing technique to facilitate optimal alignment during nailing, and if there is a need for further adjustment, we typically use 2.4-mm Steinmann pins as blocking wires.[13] These are temporary and only in place until the nail is seated, and afterward, the stabilization screws are placed directly adjacent to the nail and the wires removed. There may also be times when adding a plate in addition to the IMN is necessary to maintain stability. This is most often the case for the treatment of intraarticular fractures and very short bone segments.

SYNDESMOTIC FIXATION

Concerns for the tibiofibular syndesmosis are unique to transport in the tibia. In theory, bone transport with a BTN should not require stabilization of the syndesmosis, given that the relative length of the fibula does not change during transport. However, there is a potential risk to the syndesmosis because bridges of callous or heterotopic bone can form between the transport segment and the fibula. It is a reasonable consideration to monitor for signs of bony synostosis and stability of the proximal and distal tibiofibular joints. Syndesmotic stabilization can also be helpful when docking into a small distal segment. In this situation, the transport segment may overpower the locking screws when compression is applied, causing the ankle to drift into valgus. Stabilization of the syndesmosis is usually performed with a 4.5-mm solid screw placed opposite to the direction of pull.

TESTING THE BTN

Initially, testing the nail with a 1 or 2 mm of distraction after the nail and fixation are in place was recommended to assure proper nail function. We believe that unless the maximum nail length is needed for transport,

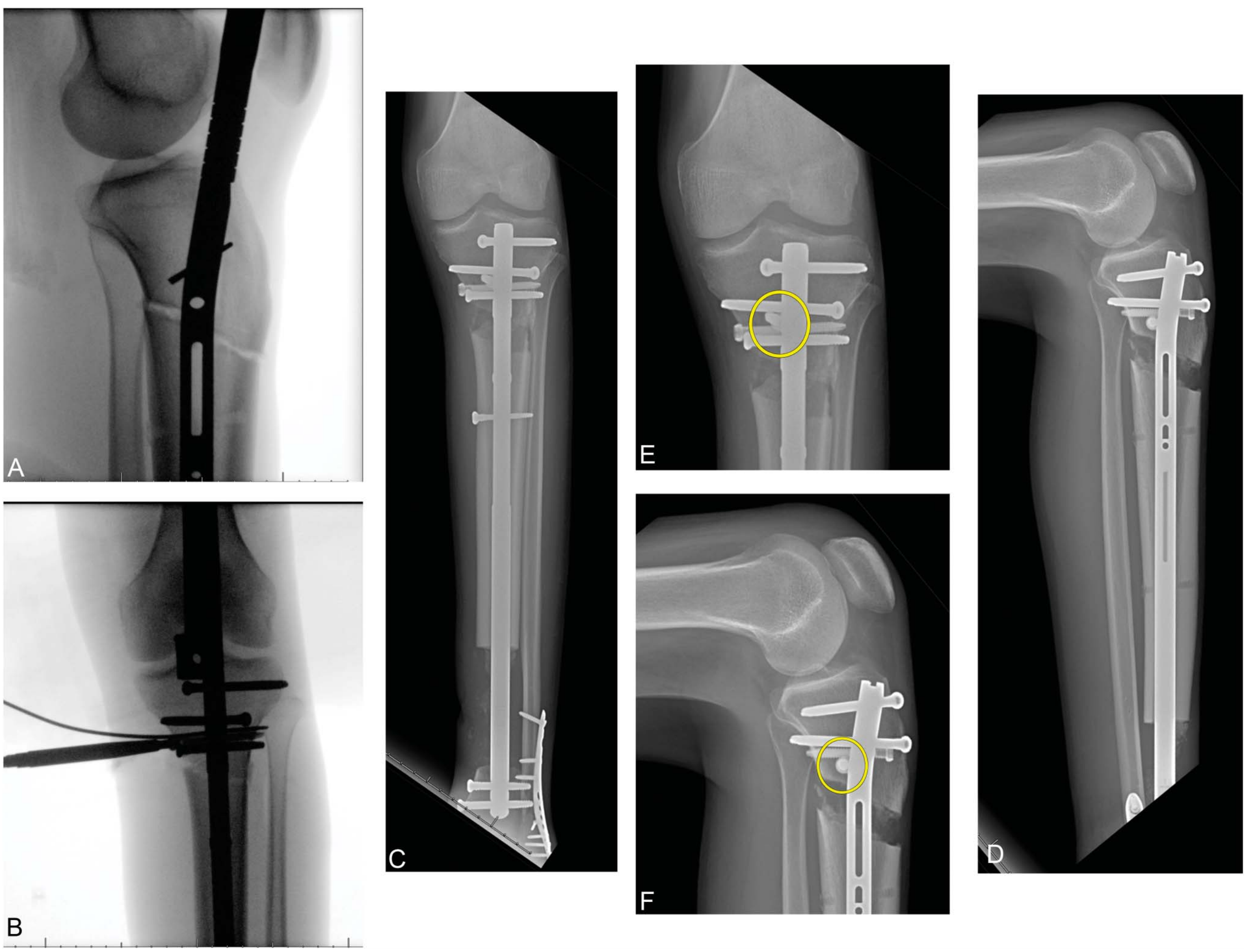

FIGURE 4. A, Lateral fluoroscopic image showing BTN inserted with a posterior blocking wire in place in the proximal segment. B, AP fluoroscopic images showing posterior stabilization screw being placed in the proximal segment before removal of the blocking wire. C–F, AP and lateral full-length and close-up XRs after 2 cm of distraction showing final construct with both posterior and medial blocking screws preventing change in alignment.

a different approach of testing in compression is preferred. To do this, the IMN is predistracted 5–10 mm with a fast distractor before insertion. After nail insertion and after fixation is applied, the IMN is tested by adding compression to the osteotomy site. We compress until the nail has shortened by at least 1 mm or more until strong bony apposition of the osteotomy site has been achieved (Fig. 3F–I). Good bone apposition is favorable for the formation of healthy regenerate at the start of transport, and this method eliminates any gapping that may have occurred at the osteotomy site during IMN placement. Predistraction of the nail by at least 5 mm also provides a salvage pathway if something goes wrong during the transport. In this scenario, the transport segment can be brought to the original location, and then, the osteotomy site can be strongly compressed to form a new regenerate. For both these reasons, we advocate this approach whenever possible.

LATENCY PERIOD

The optimal latency period for a BTN is not yet determined, but experience to date indicates that a longer latency period than the classic 7–10 days may be preferred.[12] Forming initial regenerate bone seems to take longer after placement of an intramedullary nail, and far fewer instances of premature consolidation have been noted. One hypothesis for this is that the intramedullary blood supply is disrupted by passage of the nail. Intramedullary nailing data tell us to expect a rebound recovery of blood flow about 2 weeks after nailing, so logically initial callous formation may be better at that time. In addition, the amount of regenerate that forms is smaller overall because the nail is taking up some of the space where regenerate would have formed. This results in a longer lag time before premature consolidation would be expected. Regardless of the cause, the observation is made that it is best to wait 2–3 weeks before starting distraction in an adult.

RATE AND RHYTHM

The optimal rate and rhythm are still not well defined, but rates slower than 1 mm in the tibia seem to be optimal. The author currently recommends for the tibia 0.8 mm/d split into sessions of 0.2 mm 4 times daily and for the femur 1 mm/d femur split into 3 or 4 equal sessions.

DOCKING SITE PREPARATION

At the end of bone transport, it is optimal to clean out any scar or other interposed tissue at the docking site. It is unknown if bone grafting is necessary; however, data from bone transport over a nail indicates that bone grafting decreases time to union and increases union rates. Optimally, the docking site is compressed so that the 2 flat-cut bleeding bone ends are well apposed before preparation of the outside edges of the bone for placement of graft around the docking site if grafting is performed. This is preferred over placing bone graft directly between the compressed bone ends whenever possible.

SCREW EXCHANGE

The NuVasive Precice Bone Transport System is currently indicated to perform up to 10 cm of bone transport, but lengths greater than 7 cm require a screw exchange. The 280 and 300 mm nails are designed to achieve 6 or 7 cm of bone transport, respectively, using a single screw slot. Nails of length 320 mm and greater have 2 slots to allow for additional transport beyond 7 cm. The configuration of longer

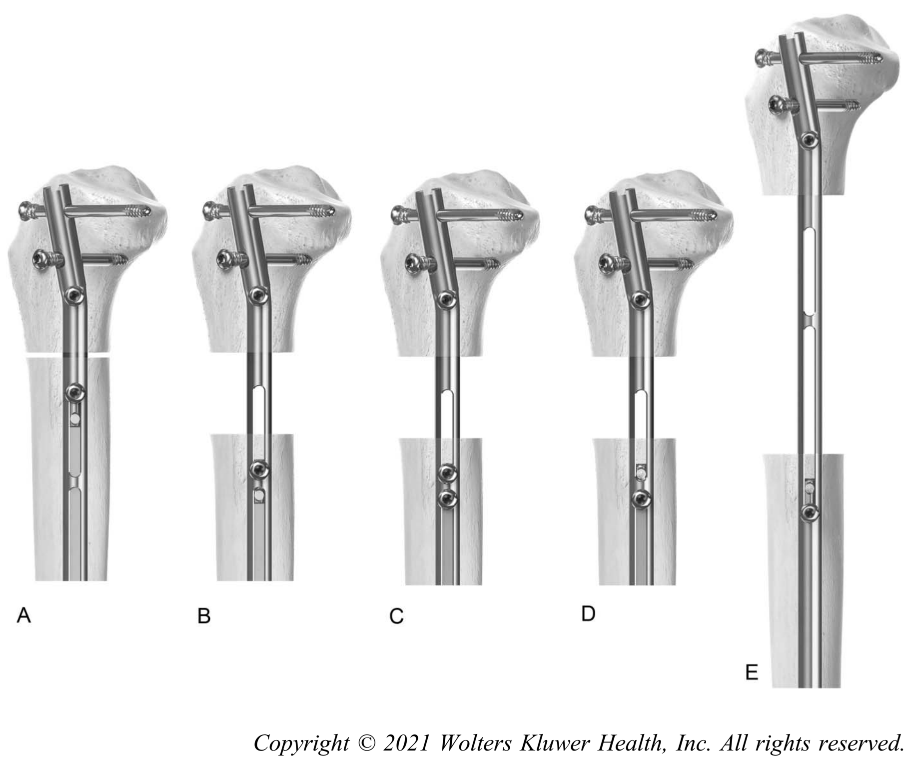

FIGURE 5. A, For transport greater than 7 cm, the intercalary locking holes should be located as close as possible the driving end of the nail. During the index operation, an intercalary locking screw is placed in the hole nearest the driving end of the nail "near hole." B, Transport proceeds until the hole farther from the driving end of the nail "far hole" has passed the locking screw slot bridge. C, The patient returns to the operating room, and a new locking screw is placed in far hole before removal of the screw from the near hole. D, Fixation is now on the far side of the bridge, and transport can proceed. E, The transport proceeds for up to another 7 cm until the far screw reaches the bottom of the slot.

nails and their associated slots can be seen in **Supplemental Digital Content 1** (Figure 1, http://links.lww.com/JOT/B468). The longest major slot length was restricted to 7 cm, and the presence of a locking hole slot bridge is the reason that screw exchange is necessary. Planning for a screw exchange must be undertaken at the index operation. Only 1 intercalary locking screw should be placed at the index surgery, and it must be in the intercalary locking hole near the driving end of the nail (near hole) (Fig. 5A). Transport will proceed until the currently empty far intercalary locking hole is seen on the far side of the bridge (Fig. 5B). The timing of the screw exchange and when the locking holes will reach the optimal location depend on the length of the short slot (1, 2, or 3 cm), the latency period chosen, and the speed of distraction. These factors can be used to calculate the timing of the exchange, but in all circumstances, the exchange must coincide with when the far intercalary locking screw hole crosses the locking screw slot bridge.

Screw exchange requires a staged return to the operating room. The screw exchange consists of adding an intercalary locking screw to the hole far across the bridge and then removing the near intercalary locking screw (Figs. 5C and D). The preexisting near screw should be left in place until the new far locking screw is in place to both stabilize the transport segment for screw placement and to prevent regenerate rebound. Regenerate rebound results from the inherent tension within the regenerate column that will cause it to shorten when left uncontrolled. It is essential to always have direct control of the transport segment to prevent rebound from occurring. Once the new screw is in place, the initial screw can be safely removed. The transport then proceeds in the standard fashion until it is complete (Fig. 5E).

NAIL REMOVAL

Routine removal of the BTN is recommended after complete healing is verified, typically at 12 months from the start of reconstruction. Nail removal is performed in the standard fashion, but one issue related to the nails from the first-generation launch is notable. These nails have the potential to

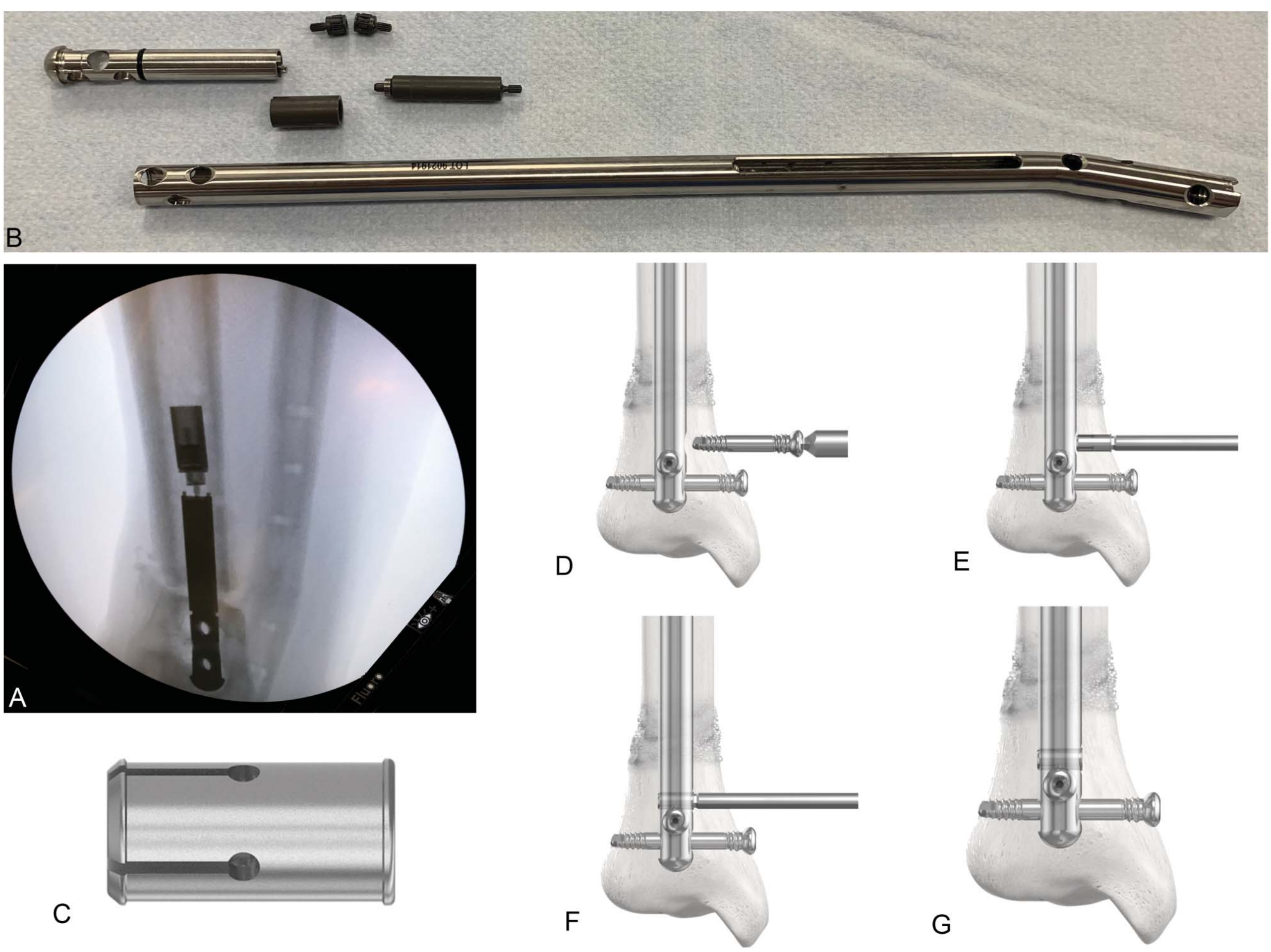

FIGURE 6. A, Decoupled nail within intramedullary nail at the time of nail extraction. *Courtesy of Dr. Spence Reid B, decoupled nail and associated parts. *Courtesy of Dr. Spence Reid. C, Retention plug used to prevent decoupling of the nail. D, A distal locking screw is removed. E, The retention plug is placed through the hole from which the locking screw was removed. F, The retention plug is engaged within the nail and left in place. G, The additional locking screws can be removed and the nail extracted without risk of decoupling with the retention plug in place.

decouple at the time of extraction with the distal part of the nail left within the canal (Figs. 6A and B). Decoupling occurs secondary to moment of inertia within the nail and can often be avoided with a more cautious approach using less forceful extraction. In fact, decoupling occurred in only 2 of the first 7 nails extracted, and none of the 3 that were removed after this issue was recognized. Decoupling has now been successfully addressed without recurrence using a retention plug inserted into one of the locking holes on the far side of the nail before extraction (Figs. 6C and D). It is anticipated that the second-generation nail will permanently solve this issue.

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