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SURGICAL TECHNIQUE

Surgical Technique

Static Intramedullary Nailing of the Femur and Tibia Without Intraoperative Fluoroscopy

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Abstract
Background On a recent mission directed at definitive care for victims of the Haitian earthquake, the orthopaedic team developed a technique for freehand distal locking of femoral and tibial nails without intraoperative fluoroscopy or proximally mounted targeting jigs.
Description of Technique After performing open antegrade or retrograde nailing by standard techniques, the freehand lock must be obtained before doing standard outrigger locking. This allows the surgeon to control the nail and deliver the locking hole in the nail to a unicortical drill hole in the femur. Before nail insertion, the distance of the desired locking hole is measured from the outrigger in a standard way such that it can be reproduced after the nail is inserted. Through a unicortical drill hole, the nail is palpated with the tip of a Kirschner wire and systematic maneuvers allow the Kirschner wire to palpate and fall into the locking hole. The Kirschner wire is tapped across the second cortex before drilling. The screw is inserted, and the ball-tipped insertion guidewire is placed back into the nail to palpate the crossing screw confirming position.
Patients and Methods We treated 16 patients with 18 long bone fractures using the described technique. We assessed patients clinically and radiographically immediately postoperatively.
Results A total of 19 blind freehand interlocks were attempted, and 17 were successful as assessed by direct intraoperative observations and by postoperative radiographs.
Conclusions We describe a simple technique for performing static locked intramedullary nailing of the femur and tibia without fluoroscopy. This technique was successful in most cases and is intended for use with any nailing system only when fluoroscopy or specialized systems for nailing without fluoroscopy are not available.

Each author certifies that he or she has no commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.
Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research.
This work was performed in Santo Domingo, Dominican Republic at Hospital Dr Darios Contreras.

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Introduction

We recently traveled to the Dominican Republic to provide definitive fracture care for survivors of the Haitian earthquake. A single C-arm unit was available but we had the resources to run five to six simultaneous operating rooms. The majority of long bone fractures were high energy with a substantial incidence of comminuted subtrochanteric fractures. We believed the best treatment would include static locked nailing. We had the patients, the nails, the operating rooms, and the personnel but no intraoperative fluoroscopy. The team made a decision to reserve the C-arm unit for cephalomedullary fixation and to treat the majority of diaphyseal fractures with open nailing.

The use of interlocking intramedullary nails has become the preferred method of treatment for almost all fractures of the femoral shaft from the lesser trochanter proximally to the condyles distally [4]. The interlock allows for maintenance of length and rotation in even the most severely comminuted fractures. Since the development of interlocking in the 1970s [6, 8, 9], intraoperative fluoroscopic targeting has been an integral part of this technique [2, 3].

Various techniques have been developed to interlock intramedullary implants while minimizing or negating the need for radiation [1, 7, 14]. These techniques include laser [5] or computer guidance [12] and the use of long proximally mounted targeting devices [10, 11, 13, 15]. The Surgical Implant Generation Network (SIGN) (Richland, WA, USA) nail has a proven record of success in treating femoral shaft fractures without intraoperative fluoroscopy [15]. However, we did not take any SIGN nails with us and discovered that we had limited fluoroscopy after we arrived in the Dominican Republic. We had sufficient implants and supplies, but we were without intraoperative fluoroscopy, the primary technology that we routinely rely on to perform locked intramedullary nailing. This led to development of an improvised technique. This technique is not recommended if imaging is available or if specifically designed implants such as the SIGN nail are available.

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Patients are placed in the lateral position for antegrade femoral nailing and in the supine position for retrograde femoral nailing and tibial nailing. Preoperatively, contralateral rotation is noted. Nail length is obtained by palpating and measuring the contralateral limb from the greater trochanter to the top of the patella. Nail length is undersized by at least 20 mm. Fractures closer to the knee should be fixed with retrograde techniques and those closer to the hip with antegrade nails. Standard open nailing techniques are used (Appendix 1). Coronal plane reduction nearly always was secured by the implant in these diaphyseal injuries, and also was evident by direct inspection of the fracture. Rotational alignment was judged by gross inspection of the limb, by comparing the hip internal/external rotational arc with the uninjured limb, and by direct inspection of the fracture cortices.

It is important to complete the blind/freehand distal locking before the proximal outrigger guided locking. The technique is the same for antegrade and retrograde nailing and applies to lateral to medial (LM) and anterior to posterior (AP) locking. In other words, for antegrade nailing, distal locks should be performed first, and for retrograde nailing, proximal locking should be performed first.

Initially, the nail is loaded on the insertion device with the locking outrigger attached. On the back table, a careful measurement is taken from the distal end of the outrigger to the desired distal interlocking hole (Fig. 1). We recommend choosing dynamic holes whenever possible to increase the chance of expedient and successful locking. For this measurement, we typically used the inner core of the depth gauge because it is ruled. Any linear device with recognizable markings will suffice (in cases with no inner depth gauge core, we typically made marks on an osteotome). The depth gauge measurement device tip is placed flush to the distal end of the outrigger. Subsequently, a free Kirschner wire (or any straight object) is placed perpendicular to the depth gauge measurement device and centered on the desired lock hole creating a rectangle. All members of the surgical team should confirm that perfect right angles are used among the outrigger, depth gauge, and the perpendicular wire centered over the distal locking hole. A right angle retractor can help confirm proper angles. The ruled number on the depth gauge is recorded (or external marking on an improvised device), and the nail is inserted.

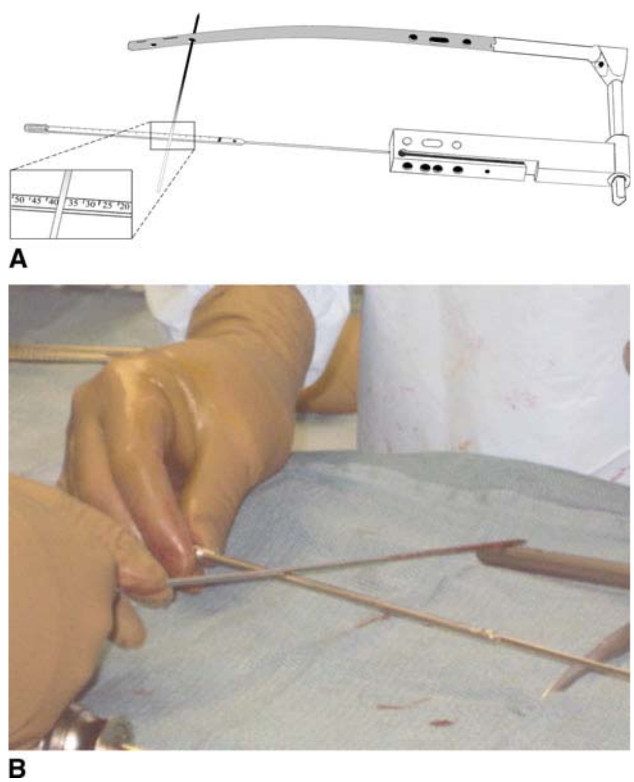

Fig. 1A–B (**A**) A schematic representation of the rectangle technique using a depth gauge and a Kirschner wire to template the distal locking distance from a proximally mounted outrigger and (**B**) a clinical photograph of this measurement on the back table are shown.

Once the nail is inserted to its final depth, the steps described are reproduced. An external guidewire placed in line with the nail as determined by the nail insertion device helps center the distal interlocking skin incision. All scrubbed members observe the position of the depth gauge and the wire placed perpendicular to the depth gauge recreating the rectangle. A 2- to 3-cm incision is made at the estimated position for the distal interlocking screw (Fig. 2). Error is inherent to this measurement technique, and we found it helpful to have multiple members agree on recreation of the rectangle each time it is used.

It is important to clear the local periosteum and palpate the boundaries of the femur to precisely place the drill bit in the center of the femur. In the case of AP locking, the medial and lateral borders are palpated with the tip of the drill and it is docked on the true anterior center part of the femur. The drill bit position is checked again with the assistant recreating the rectangle of the depth gauge and perpendicular wire. Drill bit direction is determined by the orientation of the outrigger (Fig. 3). The drill should be exactly parallel to the outrigger for medial to lateral locking and minimally divergent for AP locking (as a result of the anterior bow of the nail). The specific nail used should be inspected carefully before insertion so that the external outrigger can be used as a reliable reference for drill direction. Once the drill bit position is optimized, it is drilled through the near cortex. Using this technique, approximately one-third to one-half of the time the drill bit entered the locking hole in the nail. Alternatively, the drill bit either hit a solid part of the nail or missed the nail completely.

If the drill bit did not enter the locking hole, a Kirschner wire (2–3 mm) or the inner core of the depth gauge is used to circumferentially palpate the nail through the drill hole (Fig. 4). The position of the hole is reassessed against the rectangle of the depth gauge and wire. Typically, the hole will be slightly proximal or distal to the previous

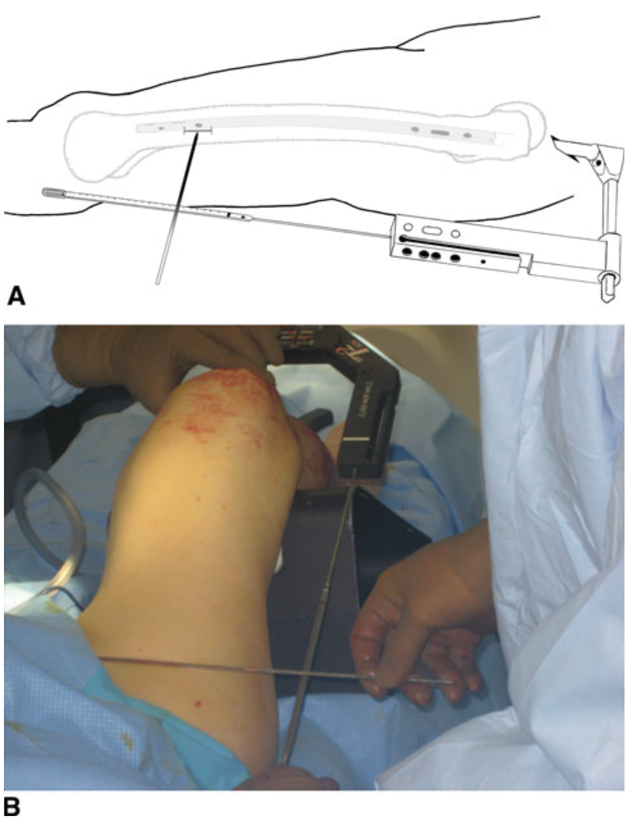

Fig. 2A–B (**A**) A schematic representation of locking measurement reproduced with nail in situ and (**B**) an intraoperative photograph of this measurement being performed for proximal AP locking of a retrograde nail are shown.

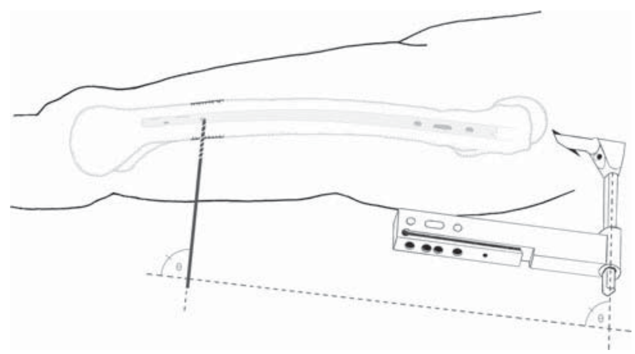

Fig. 3 The center of the bone is palpated with the tip of the drill, which then is docked in a central position. Drill direction can be referenced off of the nail outrigger. Depending on nail shape, most medial to lateral locks will be parallel as drawn. AP locks tend to be slightly divergent to a perpendicular reference on the outrigger as a result of the anterior bow of the nail (reference points can be observed before nail insertion).

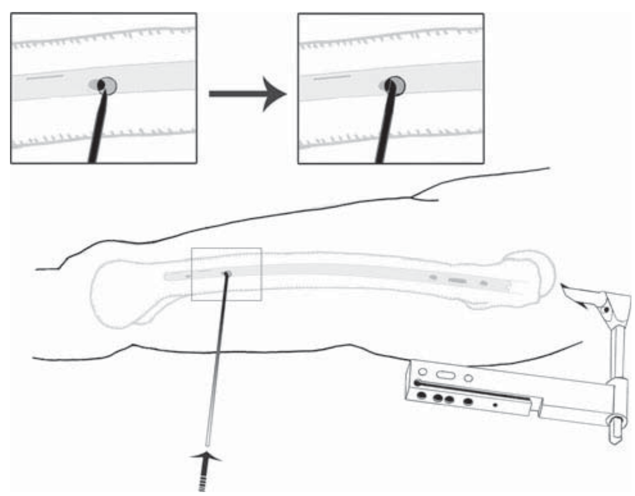

Fig. 4 Palpation of the nail with the tip of a Kirschner wire through a unicortical drill hole is shown. If the locking hole on the nail and the drill hole overlap by 1 to 2 mm, this contour can be palpated. Tapping on the Kirschner wire causes the overlap to dilate to the diameter of the Kirschner wire allowing for successful drilling.

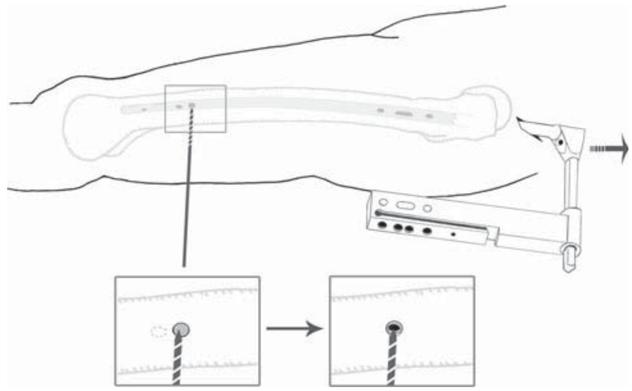

Fig. 5 If the unicortical drill hole is too proximal or distal, the solid nail will be palpated. The measurement is reassessed using the inner core of the depth gauge and guidewire. The nail is advanced slowly or withdrawn to deliver the locking hole in the nail to the unicortical drill hole in the bone. When the holes align, this can be felt definitively with the tip of a Kirschner wire.

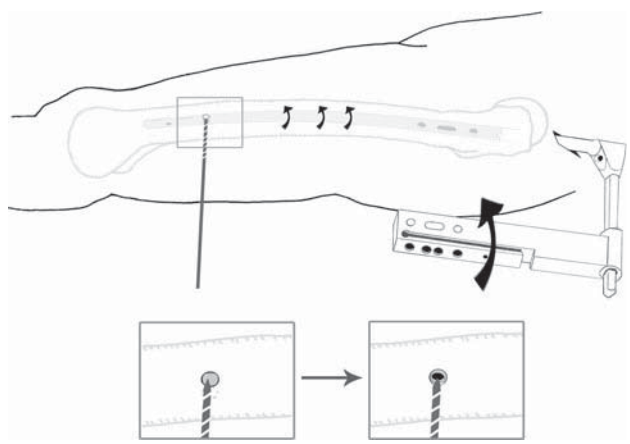

Fig. 6 If the unicortical drill hole is not centered on the bone or the outrigger is not aligned in the midcoronal plane, the outrigger can be rotated to deliver the locking hole in the nail to the unicortical drill hole in the bone.

measurement. The nail is appropriately advanced or retracted allowing the wire to fall through the locking hole (Fig. 5). If the wire does not fall into the locking hole with proximal/distal repositioning of the nail (implying that the true center of the bone was missed), then the nail length is adjusted to place the wire at the optimal predetermined distance based on the depth gauge. Subsequently, the nail is rotated either clockwise or counterclockwise until the wire falls into the locking hole (Fig. 6). In most cases, there were subtle amounts of linear and rotational adjustments to get the wire to fall into the locking hole.

Once the surgeon has located the locking hole, the outrigger is rotated with the wire in the hole. The wire should rotate appropriately with nail movement confirming the interlocking hole has been located (Fig. 7). Subsequently, the drill bit is placed through the cortical hole and

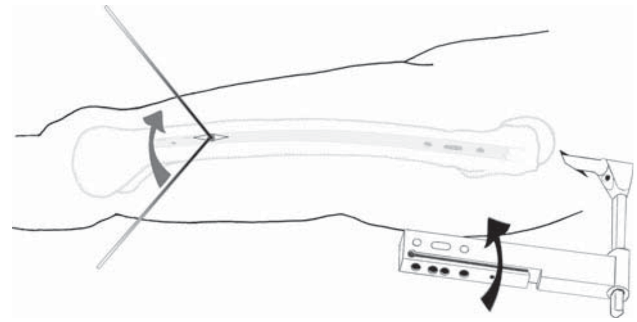

Fig. 7 Rotation of the nail outrigger will cause the Kirschner wire to move in the same direction as the nail rotation, confirming that the Kirschner wire is positioned in the locking hole.

through the hole in the nail. The ball-tipped insertion guidewire then is reinserted through the nail to the level of the interlocking hole. The surgeon can clearly feel the metal-on-metal contact of the guidewire colliding with the drill bit. The drill bit is drilled through the far cortex and the screw is inserted. The screw position is confirmed again by passing the insertion guidewire up the nail to impact the locking screw. Once the lock has been obtained, rotation and length must be confirmed and the proximal screws are placed with the outrigger locking guide. Before leaving the operating room, careful evaluation of length and rotation should be performed, with the patient in the supine position.

Patients and Methods

We treated 16 patients with a total of 18 femur or tibia fractures using this technique. One patient had bilateral femur fractures and another had a floating knee. Sixteen femur fractures and two middiaphyseal tibial fractures were stabilized with these techniques. The femoral fracture patterns included eight middiaphyseal simple patterns (transverse, oblique, spiral, transverse with butterfly fragment), three segmental fractures, four subtrochanteric fractures, and one distal intraarticular fracture. Femoral fractures were stabilized with seven antegrade femoral nails and nine retrograde femoral nails. The two tibial nails were placed through tendon-splitting approaches. A total of 19 blind freehand locks were attempted.

Results

All except two attempts were successful as confirmed by direct feel of metal-on-metal with the ball-tipped insertion guidewire (Fig. 8). The key to confirmation of a successful interlock was locking from the farthest possible lock and working toward the entry point. This allowed direct palpation of the screw from within the nail and definite confirmation. We obtained postoperative xrays for all patients, but owing to resources and local protocol, one view was obtained in most cases. Using this AP view, we were able to confirm anterior to posterior locks but unable to confirm medial to lateral locking. In every case the xray findings correlated with intraoperative confirmation.

One of the unsuccessful distal interlocks occurred with an antegrade nail. In hindsight, the chosen nail was too long, resulting in a metaphyseal location of the distal locking hole. When the nail is no longer a simple tube, locating the nail through a central unicortical drill hole becomes more challenging. We also attempted to insert the screw into a 5.0-mm locking hole instead of the dynamic hole. Therefore, we were attempting to fill a smaller hole in a less-captured nail position in the bone (conceptually, this technique works based on the nail filling the intramedullary canal, however this relationship no longer holds true in the distal metaphysis). After 20 minutes, the C-arm unit was mobilized from another room, and it revealed that locking attempts were 1 cm posterior to the nail. Subsequently, the nail was locked successfully under fluoroscopic guidance. In the other case of a retrograde nail, we made the mistake of locking the most distal proximal hole (LM) before performing the more proximal freehand lock near the hip (AP). Therefore, we could not palpate the second freehand screw using the guidewire through the nail to confirm proper screw position. The missed lock was identified on postoperative radiographs (Fig. 9).

Fig. 8A–B (**A**) A postoperative radiograph after open antegrade nailing of a segmental femur fracture using the described technique is shown. The lateral to medial distal lock was obtained using the blind freehand technique. (**B**) A postoperative radiograph after a retrograde open nailing using the blind freehand technique for proximal AP cross-locking is shown.

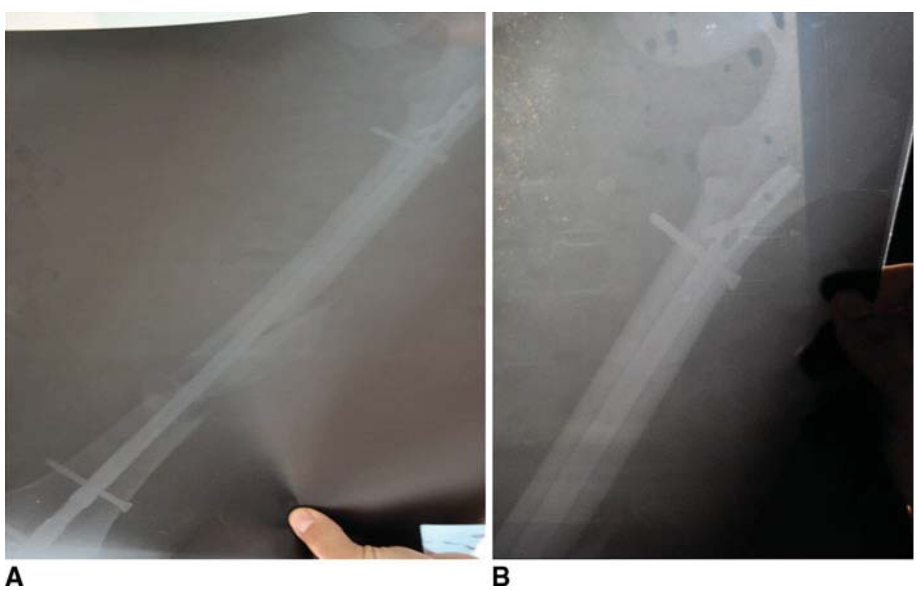

Fig. 9A–B (**A**) A postoperative radiograph shows a missed AP interlock. Early during the mission we did not recognize the importance of working from the tip of the nail toward the outrigger allowing each locking screw to be definitively palpated by reinsertion of the initial insertion (ball-tipped) guidewire. (**B**) Blow-up of proximal locks highlighting missed anterior to posterior lock.

Fig. 10 The original measurement technique for freehand locking used an osteotome and Hohmann retractor to mark the distance for distal locking. This later evolved to the use of a ruled instrument such as the inner core of the depth gauge.

The blind locking technique was first attempted on a patient with a middiaphyseal transverse femur fracture. The distal locking distance was determined using an osteotome and retractor handle (Fig. 10). We had to make marks on the osteotome to reproduce the distance, so this quickly evolved into using a ruled instrument such as the inner core of a depth gauge to determine distal hole position. We were fortunate to find the locking hole immediately in the first case, which reassured us that the technique could work, but it also gave us a false sense of confidence. During the first case, we believed the screw was inserted properly but had no way to confirm this. Subsequently, one of our colleagues from the Dominican orthopaedics residency reinserted the guidewire through the nail, which collided with the screw, confirming its proper position. This confirmation technique was adopted immediately for the rest of the mission.

During the second operation, once the distal locking hole was drilled, we could feel the nail but no interlocking hole. After an intraoperative debate, we decided to adjust the position of the nail to try to deliver the interlocking hole to the position of the drill bit inserted through the hole in the cortex. Before adjusting the nail position, the

Table 1. Tips to optimize success of the freehand cross-locking procedure

Key	Rationale
Undersize the nail length	Finding the locking hole is based on a round nail filling a round bone; at the metaphyseal flare, it is much more difficult to locate the nail through one drill hole
Target dynamic holes when possible	A larger hole increases the odds of expedient success; this technique also works for static locking holes
Fractures close to the knee should have retrograde nailing and those close to the hip should have antegrade nailing	This typically allows for one freehand cross-lock
A retrograde nail must be inserted 1 cm farther than usual	There is no room for a nail to be proud in the knee; to locate the locking hole, the nail may require some back-tapping; inserting farther than usual allows for some error; once the outrigger is removed, the intraarticular starting point should be palpated directly
Each step must be as precise as possible	This technique relies on the ability to compensate for imprecision; as long as measurements get the surgeon within 3 to 4 mm, there will be 1–2 mm of overlap between the drill hole and the locking hole
Inspect and understand the nail contour around locking holes	Using a Kirschner wire to feel the nail through a drill hole is surprisingly helpful; if the surgeon understands the nuances of the nail (notches or slots), they will quickly know where they are in relation to the locking hole; mastering this step seems to be the key to the entire procedure
When performing the distal lock of an antegrade femoral nail, if the nail is not easily palpated through a centrally drilled unicortical hole, the surgeon should suspect that the nail is anterior drill hole.	Antegrade femoral nails tend to drift anteriorly as they pass the distal metadiaphyseal region of the femur. The task of locking is more difficult in the metaphysis. If the nail is not readily palpated through the unicortical drill hole (with K-wire), the surgeon should expect the nail to be anterior to the K-wire. By dropping their hand and directing the K-wire anterior, the nail can usually still be palpated, and locked through this drill hole.
If going for two freehand locks, target the farthest first	Once the nail is locked, the surgeon no longer can rely on moving the nail; by locking the far hole first, the surgeon is still afforded the ability to palpate the Kirschner wire, drill, and screw with the initial insertion wire put back in the nail; the second hole is harder but can be obtained with careful planning

measuring rectangle was recreated and we determined that the cortical hole was drilled several millimeters too proximal. Therefore, the nail was slowly retracted until the drill bit fell into the locking hole. It was with technical adjustments such as this that the technique evolved, and improved over several days (Table 1).

Discussion

Although a single C-arm unit was available, the quantity of femur and tibia fractures needing surgery made developing an alternative technique desirable. There is nothing novel about our approach, because it just applies common sense orthopaedics. The techniques we described are likely similar to countless femoral nailings performed by local or missionary surgeons under similar conditions. Like any other procedure, we became more adept and efficient with experience.

Our study is limited by several factors. First, we performed this procedure only in 18 fractures. Although 16 of the 18 attempts succeeded in achieving locking, we do not have a large series in which to determine the rate of success. Second, these cases represented our first attempts to apply the technique. With more experience and learning to avoid mistakes, the success rate might increase. Third, we did not confirm locking radiographically in two planes because we typically had a single view. However, based on the intraoperative check and the single postoperative radiograph, we believe we correctly determined whether locking was achieved.

The Dr Dario Contrares Hospital is the primary trauma center for the Dominican Republic, and we observed a large volume of patients with acute trauma in Santo Domingo during our 3 days. Between our operations, we observed our Dominican colleagues performing open femoral nailings skillfully and efficiently. They used a system with an extended distal targeting device but quickly pointed out that it was far from accurate if incorrectly applied. It was obvious that the techniques we developed were not novel among this group.

We have described a simple and reproducible technique that we used to perform distal freehand interlocking in intramedullary nails. This technique is not recommended if fluoroscopy is readily available or if systems designed for use without fluoroscopy are available. The thought process and technical skills associated with this technique will help any surgeon who performs intramedullary nailing.

Acknowledgments We thank the other surgeons and fellows on our mission who were involved in the development and use of this technique: Dr. Ed Perez, Dr. Larry Bloomstein, Dr. Marc Tompkins, and Dr. Melvin P. Rosenwasser. We also thank the orthopaedic surgeons and residents at Dr Dario Contreras Hospital in Santo Domingo, Dominican Republic, for the assistance and guidance on this mission. We also acknowledge Dr. Lewis Zirkle and the SIGN nail on which many of these orthopaedic concepts are based, and the countless efforts of missionary surgeons across the world. Their commitment and innovations have made a manuscript such as this possible.

Appendix: Description of Standard Antegrade and Retrograde Femoral Nail Technique Used in Conjunction With The Freehand Locking Technique Described Technique

Antegrade Femoral Nailing

For antegrade nailing, the patient is placed in the free lateral position, and a small incision is made at the level of the fracture. Direct dissection into the fracture affords control of the proximal fragment, and a ball-tipped guidewire is inserted retrograde into the proximal fragment (with the ball tip oriented distally). The guidewire is advanced proximally until resistance is felt in the proximal femoral cancellous bone. A mallet then is used to drive the guidewire through the proximal femur. This routinely will drive the guidewire out of the proximal femur through the piriformis fossa, optimizing the starting point for an antegrade femoral nail. Once the wire is through the fossa, it is advanced until it can be palpated subcutaneously. A scalpel is used to cut down on the wire creating a tract for instrumentation.

The fracture subsequently is reduced under observation for simple patterns and the guidewire is passed into the distal fragment. Alternatively, in comminuted fractures, the guidewire can be passed from the proximal to the distal fragment under direct observation. The guidewire is advanced by hand until resistance in felt in the distal femoral cancellous bone. The guidewire is seated firmly by tapping it with a mallet in the distal femur. A second guidewire of identical length then is used to determine the distal position of the intramedullary guidewire and to confirm estimated nail length. Subsequently, the canal is opened proximally and the femur prepared with standard techniques depending on available instrumentation. The nail length is confirmed by holding the nail next to the limb while palpating the tip of the greater trochanter and the superior pole of the patella.

Retrograde Femoral Nailing

A skin incision is made from the middle of the patella to 1 cm above the tibial tubercle. A medial parapatellar tendon arthrotomy is made from the inferior pole of the patella to the tibial tubercle. A starting guidewire is placed under direct palpation of the notch. It is slightly medial and posterior to the center. The opening wire is advanced and the distal femur opened with either an awl or end-cutting reamer depending on instrument availability. The ball-tipped guidewire then is advanced to the level of the fracture. The fracture is opened through a lateral approach and the guidewire is identified in the distal fragment. The fracture is reduced and the guidewire is passed into the proximal fragment under direct observation. The wire is advanced until resistance is felt and tapped into the proximal femoral cancellous bone. A second wire of identical length is used to determine the approximate proximal position of the guidewire and grossly confirm selected nail length.

Reduction of Fracture

Direct observation and inspection of the fracture ends are the best indicators of length, alignment, and rotation. This does not necessitate an anatomic reduction, but simply means that the clues of the fracture configuration assist the surgeon in positioning the distal fragment. This holds true for simple and for comminuted fracture patterns.

Rotation can be controlled until the nail has been locked proximally and distally. All clues must be used including preoperative evaluation of the contralateral arc of hip rotation, and preoperative palpation of the contralateral greater trochanter compared with the patella. It is with all of these steps that the surgeon will approximate rotation. Rotation can be confirmed by taking the operative leg through an arc of rotation after the nail is locked proximally and distally. If the free limb is draped, then this can be done while sterile allowing for alterations if required.

A clamp can be used through the surgical wound at the fracture site to maintain reduction while preparing the canal and passing the nail in fracture patterns that are amenable.

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