Computerized Fluoroscopic-Based Navigation-Assisted Intramedullary Nailing

Amal Khoury, MD, Meir Liebergall, MD, Yoram Weil, MD, and Rami Mosheiff, MD

Abstract

Intramedullary nailing, a fixation method commonly used for most diaphyseal fractures, relies heavily on fluoroscopy and delivers a significant amount of radiation to both patient and surgical team. Fluoroscopy-based computerized navigation enables accuracy in implant placement and minimizes soft-tissue dissection while reducing radiation. Navigation facilitates intramedullary nailing in determining entry-point location, insertion of locking and blocking screws, and nail and screw length measurement. We refer to our preliminary experience with 150+ cases to describe the technique of navigation-based intramedullary nailing and its various applications.

Intramedullary nailing is a preferred surgical option in many cases of long bone fractures.[1,2] Although it is a routine procedure performed by most trauma surgeons, it is not devoid of technical pitfalls and complications.[3-6] Achieving accurate and successful results entails exposure to a considerable amount of radiation for both patients and surgeons.[7-10]

Fluoroscopy-based navigation systems have recently increased in popularity and are of potential benefit for orthopedic trauma surgery.[11-14] New compact navigation systems are user-friendly, efficient, and easy to set up. The number of orthopedic traumatology applications for these systems is increasing.[3,10,15,16] Computerized navigation can function as "augmented fluoroscopy" in closed intramedullary nailing by increasing precision and minimizing soft-tissue damage and radiation.[1,17,18] Locating nail entry points, inserting locking screws, and correcting alignment by means of blocking screws represent some of these useful applications.

Dr. Khoury is Attending Orthopedic Surgeon and Instructor, Dr. Liebergall is Chairman and Associate Professor, Dr. Weil is Attending Orthopedic Surgeon and Instructor, and Dr. Mosheiff is Attending Orthopedic Surgeon and Associate Professor, Department of Orthopedic Surgery, Hadassah University Hospital, Jerusalem, Israel.

Requests for reprints: Rami Mosheiff, MD, Department of Orthopedic Surgery, Hadassah Medical Center, PO Box 12000, Jerusalem il-91120 (tel, +972-2-6778611; fax, +972-2-6423074; e-mail, ramim@cc.huji.ac.il).

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In this article, we describe the technique of computerized assisted navigation in intramedullary nailing based on our preliminary experience with more than 150 procedures in which fluoroscopic navigation was used to insert intramedullary nails.

Surgical Technique

Computerized navigation is based on tracking the location of moving objects in space. Tracking requires a position sensor and one or more trackers. Fluoroscopy-based computerized navigation uses a calibration-targeting device placed on a C-arm fluoroscope, a computer, and 2 trackers, one firmly attached to the patient's skeleton and the other to a surgical instrument (Figure 1). A position sensor (in this case, an optical infrared camera) determines the spatial location of the calibration-targeting device and the trackers. The trackers and the calibration-targeting device on the C-arm contain several infrared-transmitting diodes (IREDS). By attaching trackers to target rigid objects, such as surgical tools and bone structures, surgeons can follow and update their relative spatial positions in real time on the computer display.

> "Computerized navigation can function as 'augmented fluoroscopy' in closed intramedullary nailing..."

To create a virtual anatomic image, the surgeon has to triangulate the optical tracking device with both the C-arm fluoroscope and a tracker attached to the patient's skeleton, serving as a fixed point of reference. Several essential fluoroscopic images are then acquired. Optimal images are stored in the computer and undergo "activation"; these images are used later on for navigation.

The next stage involves activating the vocational surgical tool (eg, wire, awl, drill bit) attached to an IRED frame, commonly called the *instrument tracker* (Figure 1). A tracked surgical tool can be spatially recognized while being tracked by the position sensor.

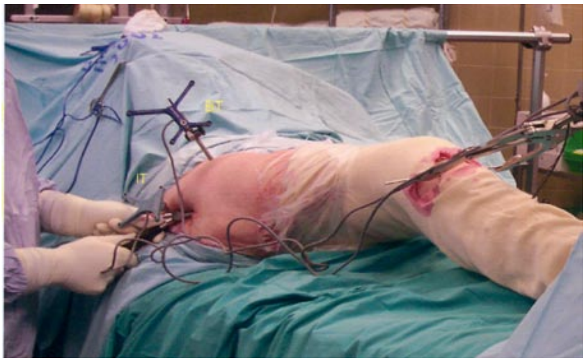

Figure 1. Setup for antegrade femoral nailing. The patient lies supine on a radiolucent table. Skeletal traction can be applied. The bone tracker (BT) is attached to the iliac crest, and the drill guide connected to the instrument tracker (IT) is inserted to the entry point in the piriformis fossa.

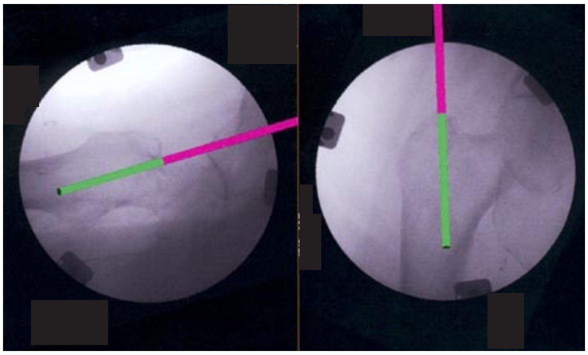

Figure 2. Navigating the entry point for antegrade femoral nailing. The instrument tracker is depicted as a purple line on anteroposterior and lateral images; the expected trajectory in the bone is depicted as a green line.

Its virtual image is now displayed on activated fluoroscopic images. Actually, the navigation process is a virtual fluoroscopy of the surgical instrument using the acquired images of the anatomy.

In this article, we describe use of a fluoroscopy-based surgical navigation system implemented at different stages of intramedullary nailing: nail entry, nail- and screw-length measurement, and freehand locking and placement of auxiliary screws. We used Fluoronav™ spine software on the iON™ system (Medtronic Surgical Navigation Technologies, Inc, Louisville, Colorado) for our procedures without modifying any of the system hardware or software components. Setup takes 5 to 10 minutes, all before surgery, and can be done by operating room technicians. Reference frame insertion and real-time fluoroscopic registration take another 5 minutes. The learning curve requires a few cases (4-5).

Entry points for all nail types are easily determined with simultaneous virtual fluoroscopic views, mostly anteroposterior (AP) and lateral. Before incision, a drill guide attached to an instrument tracker is approximated to the skin while its trajectory is viewed to minimize surgical exposure. The entry point is established while the tracked drill guide is moved to its optimal position (Figure 2). No further fluoroscopy is needed, and a verification fluoroscopic image is taken only after insertion of a guide wire. Then, an awl, drill bit, or guide wire (according to manufacturer instructions) is inserted through this guide.

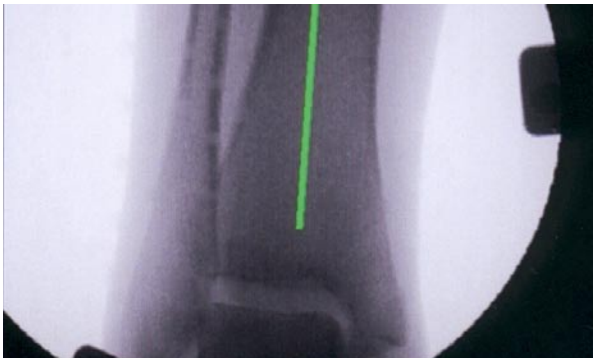

Figure 3. Nail length measurement. After navigation of the entry point, a distal tibial anteroposterior view is taken, and the green beam is lengthened until it reaches the desired position. Beam length is estimated nail length.

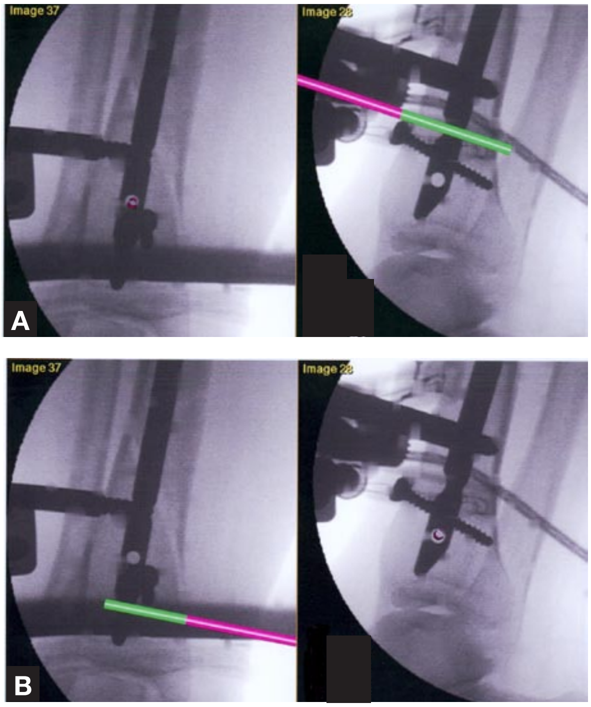

Figure 4. **(A)** Anteroposterior (AP) distal tibial nail locking screw is navigated. With the “perfect circle” technique, the beam appears as a circle within the hole on the AP view while length is being measured in the lateral view. The screw can now be drilled and inserted. Note the blocking screw inserted previously. **(B)** Using the same fluoroscopic images, the surgeon inserts the distal mediolateral locking screw in similar fashion. Note that both locking screws were inserted using only these 2 images.

Nail length and width can be determined by means of 2 plain films of the 2 adjacent joints between which the nail is to be placed. The images are simultaneously stored in the computer and displayed on the screen. In placing the tracked drill guide at the entry point, a virtual projected beam is extended from

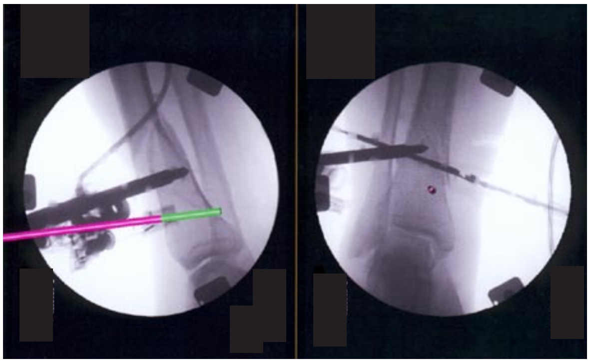

Figure 5. Planning to use a blocking screw to reduce a distal metaphyseal tibial fracture (anteroposterior and lateral views). This anteromedial screw is placed to prevent varus malalignment of the distal fragment.

the entry point toward the estimated end of the nail. The length of the beam on the screen indicates the required length (Figure 3). Similarly, screw length can be determined by measuring the trajectory beam (Figures 4A, 4B).

Freehand locking is relatively easy to perform, and radiation exposure is minimal. The bone tracker is fixed near the desired location of locking screws. With the "perfect circle" technique, an AP view of the locking hole is obtained; the lateral view can be optionally taken for screw-length measurement. Sometimes, as in the case of the tibial nail, the same AP and lateral views can be used for insertion of 2 or even 3 adjacent locking screws (Figures 4A, 4B). Usually, after that point, no further fluoroscopy is needed. The tracked drill guide is then approximated to the locking screw area and is navigated until a circle within the hole appears on the computer screen (Figures 4A, 4B). Drilling through the tracked drill guide and inserting the locking screw complete the process.

Blocking screws, also known as *Poller screws,* can be used to correct bone alignment while nailing metaphyseal fractures.[19,20] These screws can now be precisely placed with a technique like that used for locking screws. Virtual fluoroscopy-based AP and lateral images enable easy and precise locating of blocking screws, such as anteromedial blocking screws for preventing varus in a distal oblique tibial metaphyseal fracture (Figure 5).

After intramedullary nail insertion, additional AP and lateral images of the proximal femur can be obtained so the cross-neck screw can be placed without interfering with the inserted nail. The navigation system allows determination of the precise position of the "miss-a-nail" cross-neck screws and careful navigation through the narrow safe zone (Figure 6).

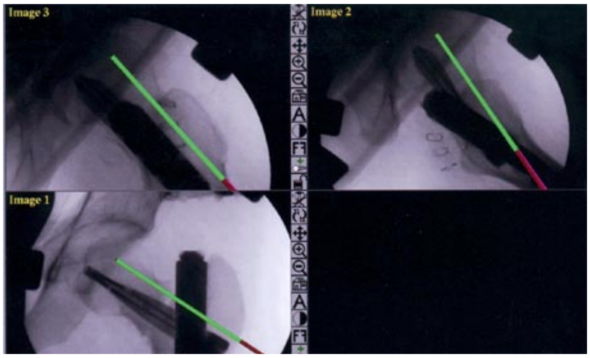

Figure 6. Virtual trajectory of a navigated "miss-a-nail" screw through a femoral neck fracture after insertion of a femoral nail with a spiral blade.

Discussion

Use of computerized navigation in orthopedic surgery has recently been increasing in popularity.[10,18] Computerized image guidance systems can achieve maximal accuracy with minimal radiation exposure.

It is now possible to use real-time 3-dimensional imaging to guide instrument insertion, and the accuracy of nail placement is increased. Determining the exact entry point for a nail is critical, as misplaced nails are among the main sources of morbidity in intramedullary nailing. A too-medial entry point in antegrade femoral nailing can lead to complications of femoral head osteonecrosis and femoral neck fractures,[21] while incorrect tibial nail insertion can cause significant cartilage and ligamentous damage as well as malalignment.[5,22,23] With computerized navigation systems, precise nail entry points can be determined, and soft-tissue dissection can be minimized—particularly helpful in special cases, such as obese patients, in whom anatomic landmarks are obscure. Working with several images simultaneously can also help surgeons avoid making unnecessary drill holes and reduce tissue damage and cartilage perforation, as all targeting is done before the instrument is introduced. Insertion of locking screws in certain nails poses a potential hazard to neurovascular structures. Classic examples are locking screws for retrograde femoral and antegrade humeral nails.[24] This hazard can be reduced by minimizing the number of drilling attempts and increasing precision. Additional improvement in nailing techniques is achieved by facilitating insertion of blocking screws. When screws are precisely placed, angular correction of metaphyseal fractures is improved. Precise measurement of nail and screw lengths can also reduce the complication of protruding ends.

"Working with several images simultaneously can also help surgeons avoid making unnecessary drill holes and reduce tissue damage and cartilage perforation...."

Exposure to ionizing radiation is probably an underappreciated risk for both trauma surgeons and patients.[25] Suhm and colleagues[18] found a 20-fold reduction in fluoroscopy time for distal locking in intramedullary nailing. It should also be noted that a single minute of fluoroscopy around the pelvis equals the radiation dose administered by 250 chest plain films or 1 computed tomography scan of the pelvis.[16] Undoubtedly, reduced radiation exposure is a significant and tangible advantage of using computer-assisted technique rather than standard fluoroscopy.[1,13]

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Time required for insertion of locking screws may actually be longer when using computerized navigation.[18] As our surgical team has performed more of these surgeries, however, the time needed for setup and installation of the system has shortened considerably. Recently, more surgeons in our team have been using the system and become proficient.

Further developments in computerized navigation and virtual fluoroscopy will allow surgeons to reduce fractures. Although current systems do allow direct tracking of 2 fragments simultaneously, further modifications of the software may facilitate navigated fracture reduction.[3] However, this issue is beyond the scope of this article.

A computerized fluoroscopic navigation system has proved useful in intramedullary nailing, though further case–control or randomized studies are required to prove its efficacy.

Authors' Disclosure Statement

Dr. Liebergall is a consultant for Medtronic Surgical Navigation Technologies, Inc. The other authors report no actual or potential conflict of interest in relation to this article.

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