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Safe Placement of Intramedullary Nail and Inter-Physician Variability in Guidewire Placement in Retrograde Tibiotalocalcaneal Fusions

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ABSTRACT

Retrograde tibiotalocalcaneal arthrodesis is a salvage procedure for severe arthrosis and deformity of both the tibiotalar and subtalar joints and requires image-confirmed placement of a retrograde guidewire. The anatomical shape of the calcaneus creates a situation in which guidewire placement can be skewed on imaging based on the angle of either internal or external rotation. As a result, the aims of our study were to (1) determine the optimal angle(s) of rotation required to accurately depict guidewire placement on imaging and (2) evaluate and describe the effects angle of rotation has on physician assessment of guidewire placement. Using a C-arm x-ray, images of cadavers with both correctly and incorrectly placed guidewires were taken at 5° increments of internal and external rotation of the cadaveric lower extremity and assessed for accuracy of guidewire depiction. The images revealed that the correctly placed guidewire appeared displaced medially at angles of 35° and 40° of external rotation. Conversely, the incorrectly placed guidewire appeared to be correctly placed at between 10° and 40° of external rotation. These images were then disseminated to various physicians including orthopedic surgeons and podiatrists to determine the ability of physicians to correctly appreciate guidewire placement. Using the responses from 35 physicians, it was found that certain angles of internal and external rotation preclude physicians from correctly determining guidewire placement. We found, based on chi-square analysis, that we were able to reject our null hypothesis with a p value of $<.001$ leading to the conclusion that indeed angle of rotation and guidewire placement can lead to false depictions of guidewire placement. In conclusion, our study gave objective measurements to guide foot placement during tibiotalocalcaneal fusion to decrease the risk incorrectly depicted medial guidewire placement and subsequent incorrect intramedullary nail placement.

Retrograde tibiotalocalcaneal (TTC) arthrodesis is a salvage procedure for severe arthrosis and deformity of both the tibiotalar and subtalar joints and is often used to reduce pain and improve function in patients with conditions such as posttraumatic arthrosis, avascular necrosis, neuropathic arthropathy, and neuromuscular disease (1–4). It also has uses as a revision procedure for nonunion and failed total ankle arthroplasty and as a salvage procedure for combined end-stage ankle and subtalar arthrosis (3).

The procedure involves a retrograde (calcaneus to tibia) insertion of an intramedullary nail which offers immediate rigid internal fixation, compression at the fusion site, and load-sharing capacity (5); however, before nail introduction, a guidewire must be used with fluoroscopy to determine correct placement. This serves as a vital step in preventing complications related to the procedure. Possible complications associated with TTC include those related to hardware, nonunion, and infection (6).

A 2014 study of compilations associated with TTC found that among 52 patients who underwent a total of 55 procedures, 13 experienced complications related to prominent hardware, 5 experienced complex regional pain syndrome, 1 experienced a periprosthetic joint infection, and 3 ultimately underwent below knee amputations following deep infection (7). This study highlights the importance of proper guidewire placement and ultimately intramedullary nail placement. Furthermore, complications associated with inappropriate placement of the intramedullary nail include damage to the neurovascular bundle that supplies the foot and travels medial to the calcaneus (8). This can result in neurovascular dysfunction and possible amputation (8).

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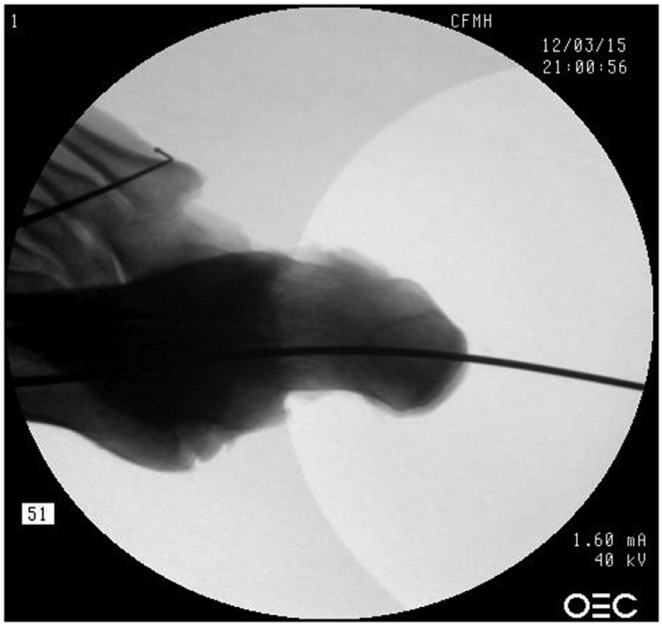

Fig. 1. Intrinsic C shape of the calcaneus as depicted in the calcaneal axial view.

Currently, the conventional method to assess correct placement of the guidewire is by using anteroposterior, lateral, and calcaneal axial images taken intraoperatively. The anteroposterior and lateral images

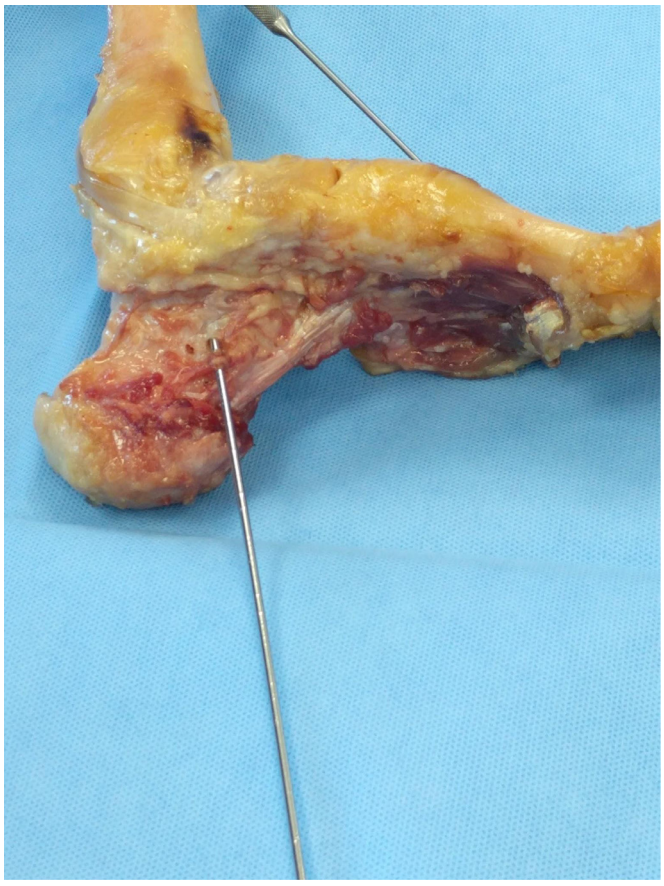

Fig. 2. Guidewire placement in a skeletonized below-the-knee cadaver.

Fig. 3. Positioning of a cadaver on the C-arm imaging device with a superimposed goniometer.

are able to accurately demonstrate proper alignment in the tibia and talus. In contrast, it is very difficult to surmise the correct placement of the guidewire in the axial field because of the intrinsic shape of the calcaneus (Fig. 1), which can cause internal and external rotation of the foot to falsely depict guidewire placement.

To that end, we sought to assess the effects of internal and external rotation of the foot on the accuracy of the calcaneal axial depiction of guidewire placement in the calcaneus and how that affected physician assessment of guidewire placement. More specifically, we aimed to (1) determine the optimal angle(s) of rotation required to accurately depict guidewire placement on imaging and (2) evaluate and describe the effects angle of rotation had on physician assessment of guidewire placement. We hypothesized certain angle(s) of internal and external rotation falsely depict guidewire placement and ultimately affect the accuracy of physician assessments of guidewire placement.

Materials and Methods

This study received exempt approval from our institutional review board. Our primary aim was to investigate the relationship between internal and external rotation of a patient's foot and subsequent depiction of TTC guidewire placement. Our secondary aim was to elucidate if physicians could determine correct versus incorrect guidewire placement based on calcaneal axial x-rays.

Obtaining the images necessary to assess both our primary and secondary aims required the use of two cadaveric specimens amputated below the knee, a standard full-size C-arm x-ray device, a goniometer, and a guidewire. To ensure the desired placement of the guidewire, the specimens were skeletonized by sharp dissection before insertion (Fig. 2). A guidewire was then placed correctly by the senior author (J.R.C.) (centered in tibia, talus, and calcaneus) into 1 of the specimens while another guidewire was placed incorrectly (centered in tibia and talus but external to the medial calcaneus) into the

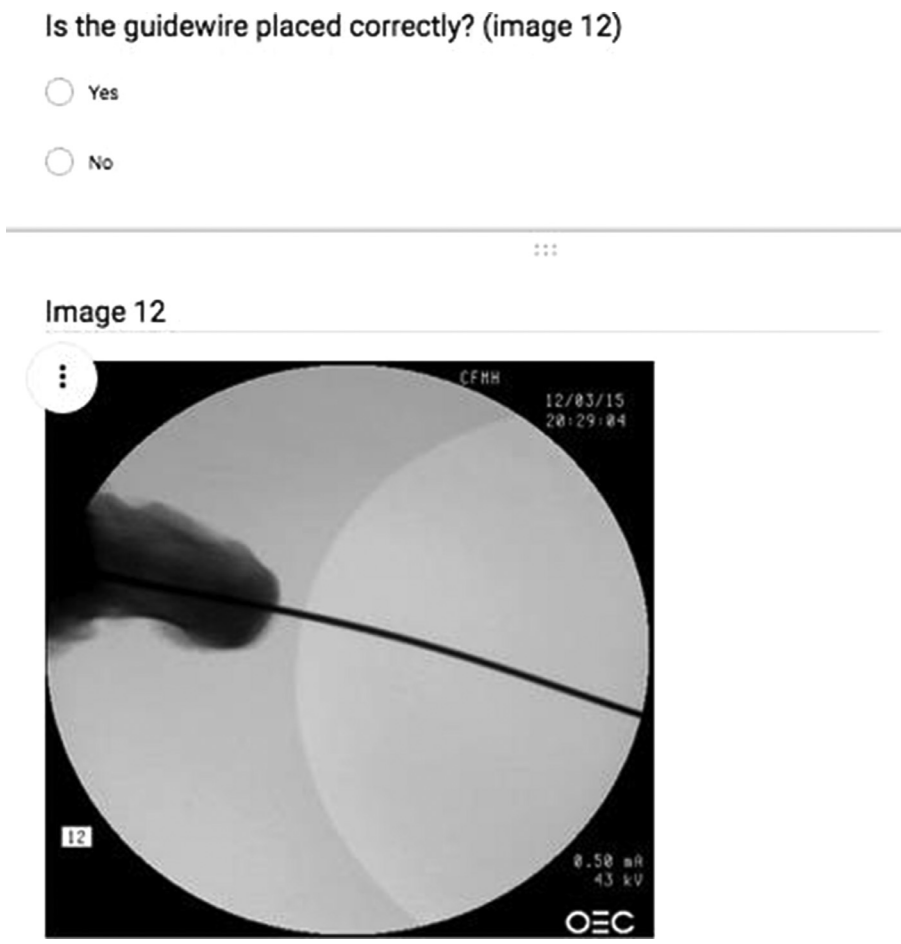

Fig. 4. Online questionnaire image with answer choices that was disseminated to attending physicians.

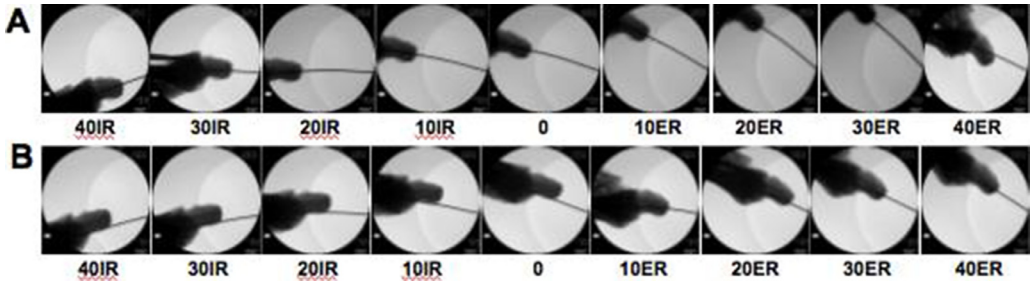

Fig. 5. C-arm x-ray images with a guidewire inserted at 5° intervals; 10° images were highlighted for image quality. (*A*) Correctly placed guidewire at 5° intervals. (*B*) Incorrectly placed guidewire at 5° intervals.

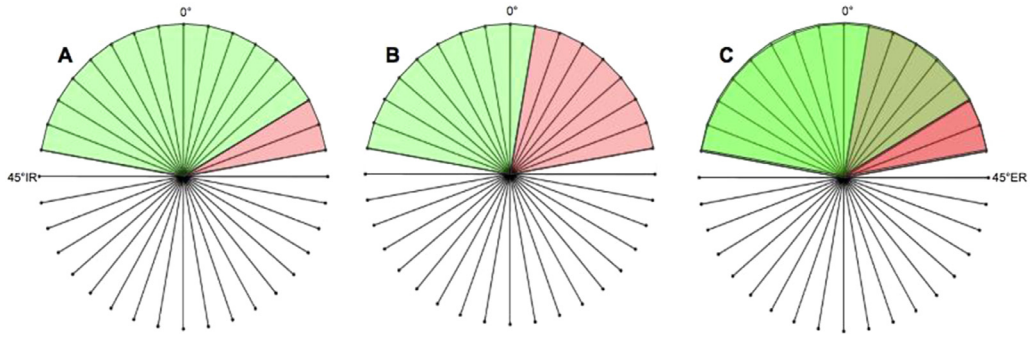

Fig. 6. Representation of true (green) and false (red) depiction of guidewire placement at 5° intervals. (*A*) Correctly placed guidewire. (*B*) Incorrectly placed guidewire. (*C*) Merged results.

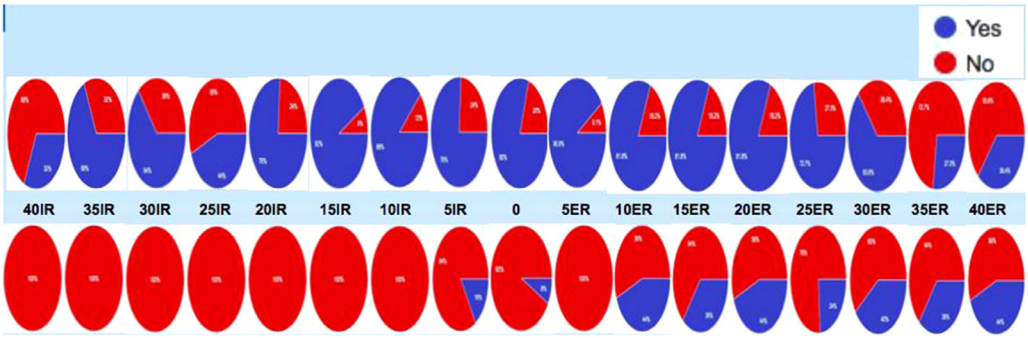

Fig. 7. Survey results, with yes and no representing the physicians' answer to the question "Is this guidewire correctly place?" (*Top*) Correctly placed guidewire. (*Bottom*) Incorrectly placed guidewire.

other.Imageswereta kenofthecadavericlegwiththe C-arminoptimalaxialposition.Thelegwas manipulated until optimal images of correct/incorrect placement were obtained. Although the manipulation of the isolated cadaveric leg is performed with greater ease than a patient, we simply wanted to obtain images that depicted the guidewire placement to the greatest accuracy.

To determine the optimal angle of rotation for accurate guidewire visualization, we took a series of images of both the correctly and incorrectly placed guidewire specimens using the C-arm x-ray device. Using a goniometer superimposed onto the device as a guide (Fig. 3), the images were taken at internal and external rotation angles from 0° to 40° in increments of 5°. To assess the variability in physician assessment of guidewire placement, 34 of these images were compiled and disseminated via an online survey program to 35 physicians including 7 orthopedic traumatologists, 18 foot and ankle orthopedic surgeons, and 10 podiatrists. Each image was paired with the following yes or no question: "Is the guidewire correctly placed?" (Fig. 4). The answers were recorded individually and compiled via the online survey program to give percentages of yes and no responses for each image.

Table 1
A 2 × 2 contingency table of data (N = 35) collected from an online survey

Guidewire Placement	Physician Response Yes	No
Correct	341	157
Incorrect	109	583
Total responses: 1190		

Table 2
Chi-square result for data (N = 35) collected from an online survey

Test	*p* Value
Chi-square	<.001

Assessors

The project involved 2 attending physicians and 2 Virginia Tech Carilion School of Medicine medical students. The initial aspect of the project, obtaining the cadaveric images, was performed under the guidance of the 2 attending physicians (J.C. and K.W.) whose input was needed for correct anatomical placement of the specimens during imaging. Additionally, K.W. was responsible for converting the images from the C-arm x-ray device to online images usable for the questionnaire. The medical students were responsible for image compilation and subsequent creation of the online questionnaire. Once the results of the questionnaire were obtained, M.R. was responsible for the statistical analysis and interpretation of the data collected.

Statistical Plan

Our null hypothesis was that correct/incorrect guidewire placement and a physician's ability to determine this placement were independent. Our alternative hypothesis was that the guidewire placement and the physician's ability to correctly determine placement were related. To determine the association between guidewire placement in images and physician ability to correctly determine placement a chi-square test of independence was performed given the categorical nature of our data. The level of significance was set at the conventional .05. Statistical analysis was performed using the statistical software program R (Free Software Foundation, Boston, MA).

Results

A total of 34 images were taken of the specimens: 17 images of the correctly placed guidewire and 17 of the incorrectly placed guidewire (Fig. 5). The cadaver with the correctly placed guidewire exhibited false depiction of wire placement (misalignment) between 35° and 40° of external rotation; however, in that same specimen, between 0° and 40° of internal rotation and 0°and 30° of external rotation correctly depicted wire placement. Conversely, in the cadaver with the incorrectly placed guidewire between 10° and 40° of external rotation falsely depicted the guidewire as being in the calcaneus when it was not. In that same specimen, between 0° and 40° of internal and 0°and 5° of external rotation correctly depicted the misalignment (Fig. 6).

Thirty-five physicians responded to our online email survey providing a total of 1190 responses for use in our analysis. The proportions of answers from the physicians in accordance with the images can be seen in Figure 7. A statistical analysis using the chi-square test based on the dichotomous outcomes of the table was performed in R giving us a *p* value <.001. A chi-square test was used to discern an associated between our 2 categorical values (Tables 1 and 2).

Discussion

Based on the results of our study, it can be concluded that a correctly or incorrectly placed guidewire in a retrograde TTC fusion can be made to look the opposite given a certain angle of rotation. This in turn affects physician assessments. The previous literature on retrograde TTC and proper x-ray depiction of guidewire placement to improve outcomes is limited. Many papers focus on such complications, functional outcomes, and techniques for nail placement (9–12).

The magnitude of rotation required to yield a false result differs depending on the actual alignment of the guidewire (i.e., in or outside of calcaneus) and the direction of rotation (i.e., internal or external). For instance, a relatively large amount of external rotation (35° to 40°) was required to depict the correctly placed guidewire as being out of the calcaneus. However, it only took 10° of external rotation to show the incorrectly inserted guidewire as correctly inserted. Additionally, it was also concluded that up to 40° of internal rotation did not falsely represent guidewire placement, regardless of whether it was correctly placed. Given these results, imaging with an angle of internal rotation between 0° and 40° and or an angle of external rotation between 0° and 5° would accurately depict guidewire placement. In lieu of the fact that a goniometer is not typically used intraoperatively to ensure 0°

alignment with the C-arm, favoring internal rotation (up to 40°) and thus avoiding all external rotation will minimize false results given the minimal amount of external rotation required to depict an incorrectly placed guidewire as inside the calcaneus.

Although these findings shed light on how foot position can falsely depict guidewire placement, we were interested to know how this affects a physician's ability to correctly determine guidewire placement intraoperatively. Our analysis of the survey results indicates there was indeed an association between angle of rotation and a physician's ability to accurately determine guidewire placement. The results of the survey show that as you move away from 0° of internal or external rotation the responses become less consistent among the correctly placed guidewire. Between 25° of external rotation and 20° of internal rotation, the majority of physicians were able to correctly determine placement of the correctly placed guidewire. With the incorrectly placed guidewire, the physicians had no difficulty in correctly determining incorrect placement at any angle of internal rotation. However, as the foot was externally rotated, it was observed that physicians were less likely to correctly determine that the guidewire was incorrectly placed.

This article, as with any study, has its limitations. With the use of cadaveric legs, the manipulation needed to obtain a reasonable image was easy to obtain. This would not be the case in the operating room, where there is far less of a degree of freedom with the appendage.

In conclusion, we found that the angle of rotation of the foot impacts the accuracy of guidewire depiction for both correctly and incorrectly placed wires and also affects physician assessment of guidewire placement. To that end, there are there are multiple applications for the findings of our study; for instance, a series of images can be taken at differing angles of rotation to rule in proper placement and/or rule out improper placement. Additionally, it is now known that certain rotations of the foot should be avoided altogether (i.e., external rotation) in the event that there is no access to a goniometer intraoperatively, because even a small amount of rotation can result in inaccuracies. As intended, these findings offer a quantitative approach to axial calcaneal imaging and provides physicians with the means to make more objective decisions regarding proper intraoperative foot placement, thus reducing the likelihood of inaccurate guidewire assessment, improper nail placement, and ultimately patient complications.

Acknowledgments

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