Article

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Position of the Posteromedial Ankle Structures in Patients Indicated for Total Ankle Replacement

Matthew S. Conti, MD[1], Jonathan H. Garfinkel, MD[2], Harry G. Greditzer IV, MD[1], Carolyn M. Sofka, MD[1], Kristin C. Caolo, BA[1], Jonathan T. Deland, MD[1], Constantine A. Demetracopoulos, MD[1], and Scott J. Ellis, MD[1]

Abstract

Background: The posteromedial ankle structures are at risk during total ankle replacement (TAR). The purpose of our study was to investigate the distance of these structures from the posterior cortex of the tibia and talus in order to determine their anatomy at different levels of bone resection during a TAR and whether plantarflexion of the ankle reliably moved these structures posteriorly.

Methods: Ten feet in 10 patients with end-stage tibiotalar arthritis indicated for a TAR were included. Preoperative magnetic resonance images were obtained with the foot in a neutral position as well as in maximum plantarflexion to measure the distance of posteromedial ankle structures to the closest part of the posterior cortex of the tibia or talus. Wilcoxon signed-rank rests were used to investigate differences in these distances.

Results: The mean distance from the posterior tibial cortex to the tibial nerve at 14 and 7 mm above the tibial plafond was 8.7 mm (range 5.0-11.8 mm) and 6.7 mm (range 2.7-10.6 mm), respectively, which represented a statistically significant movement anteriorly ($P = .021$). The posterior tibial artery was, on average, 8.0 mm (range 3.6-13.9 mm) and 7.2 mm (range 3.1-9.4 mm) from the posterior tibial cortex at 14 and 7 mm above the tibial plafond, respectively. Distal to the tibial plafond, the posterior tibial artery and flexor digitorum longus tendons moved posteriorly by less than 1 mm in plantarflexion (all $P <$ .05); otherwise, plantarflexion of the ankle did not affect the position of the tibial nerve, posterior tibial tendon, or flexor hallucis longus.

Conclusion: In patients with end-stage ankle arthritis, the tibial nerve and posterior tibial artery lie, on average, between 6.5 and 10 mm from the posterior tibial and talar cortices. Plantarflexion of the ankle did not reliably move the posteromedial ankle structures posteriorly.

Level of Evidence: Level IV, case series, therapeutic

Keywords: total ankle replacement, tibial nerve anatomy, magnetic resonance imaging

Introduction

Among patients with common foot and ankle diagnoses, patients with end-stage ankle arthritis consistently report the very high pain and low physical function preoperatively and have patient-reported quality of life measures similar to patients with severe hip arthritis.[3,4] Options for surgical management of end-stage ankle arthritis include ankle arthrodesis or total ankle replacement (TAR). TARs for the treatment of end-stage ankle arthritis are becoming increasingly more common, and their indications are being expanded to include a greater number of patients.[12]

As orthopedic foot and ankle surgeons more frequently use replacements to manage severe tibiotalar arthritis, complications unique to TARs such as injury to the posteromedial

[1] Hospital for Special Surgery, New York, NY, USA
[2] Cedars Sinai Medical Center, Los Angeles, CA, USA

Corresponding Author:
Scott J. Ellis, MD, Hospital for Special Surgery, 535 East 70th St, New York, NY 10021, USA.
Email: elliss@hss.edu

structures of the ankle during the tibial and talar bone cuts may become more prevalent. Numerous structures in the posteromedial ankle including the tibial nerve, posterior tibial tendon (PTT), posterior tibial artery, and flexor hallucis longus (FHL) have been reported as being injured during a TAR.[8,10,11,16] The tibial nerve can be injured in a TAR due to prolonged retraction, excessive nerve stretching, improper release during surgery, or laceration.[11] In a study of 150 patients who underwent TAR, 9 patients (6%) had an injury to the tibial nerve, with 2 patients who had lacerations of the tibial nerve as a result of the saw blade.[11] A recent cadaveric study demonstrated that pin placement for the tibial cutting guides put the posteromedial ankle structures at risk and demonstrated that the flexor digitorum longus (FDL) tendon and tibial nerve were the structures most vulnerable to harm.[13]

Because of the potential for injury to the posterior ankle structures, anatomic studies looking at the position of these structures in patients with end-stage tibiotalar arthritis may decrease the rate of iatrogenic injury. At our institution, surgeons typically plantarflex the ankle when making bone cuts, which has the potential to decrease tension on the structures behind to the medial malleolus and move them more posteriorly away from harm from the saw. It has not been shown, however, that this actually decreases the incidence of surgical injury.

Consequently, the primary purpose of our study was to investigate the distance of the tibial nerve, PTT, FHL, FDL, and posterior tibial artery from the posterior cortex of the tibia at discrete heights above and below the tibial plafond and superior talus in order to determine their anatomy at different levels of bone resection during a TAR. A secondary outcome was to determine if these structures reliably moved posteriorly during plantarflexion at the tibiotalar joint. A better understanding of the anatomy of the tibial nerve may result in fewer injuries during TAR.

Methods

Patient Enrollment

Institutional review board approval from the investigators' institution was obtained in order to prospectively enroll patients in this study. Patients were eligible to be included in this study if they were over the age of 18 years old, had end-stage osteoarthritis, were indicated for TAR by the senior authors (C.A.D, S.J.E.), and had at least 20 degrees of clinical plantarflexion in order to determine movement of the posteromedial ankle structures with plantarflexion of the ankle. Patients were excluded if these had severe coronal plane deformities defined as greater than 20 degrees of varus or valgus deformity, current hardware in their ipsilateral ankle, or contraindications to magnetic resonance imaging (MRI). Patients with severe deformity (greater than 20 degrees of varus or valgus of the tibiotalar joint) were excluded as these patients represent outliers who may have especially aberrant anatomy of the posteromedial ankle structures because of the magnitude of their deformities. Patients were identified and recruited for the study by the treating surgeons (C.A.D, S.J.E.), who indicated the patient for a TAR. Data including age and gender were obtained from the patients' medical records.

An a priori power analysis was performed in order to detect a 3-mm change in the location of the tibial nerve in neutral and at least 10 degrees of plantarflexion. de Leeuw et al published a cadaveric study using 10 specimens that demonstrated that the superficial peroneal nerve moved 2.4 mm (SD 0.9 mm) when the ankle was positioned in neutral compared with 10 degrees of plantarflexion and maximal inversion.[1] Thus, our sample size calculation using a nonparametric matched pairs design in G*Power[2] indicated that for 80% power and P value of .05, a total of 4 patients would need to undergo neutral and maximal plantarflexion MRIs in order to detect a difference of 3 mm with an SD of 0.9 mm. Three millimeters was chosen based on the movement of the superficial peroneal nerve in the de Leeuw et al study as this amount of movement was reported to be clinically significant.[1] A total of 10 patients were then enrolled in order to minimize the risk of underpowering the study.

Eight of 10 patients had no prior procedures on the ipsilateral ankle. One patient previously had an irrigation and debridement of her tibiotalar joint through an anterior approach approximately 19 years prior to her planned TAR. The second patient had an open reduction and internal fixation of an ipsilateral trimalleolar ankle fracture and subsequent removal of hardware with irrigation and debridement 8 years before her planned TAR. She also had an anterior ankle debridement 1 year prior to her planned TAR. Neither patient had evidence of scarring of the posteromedial ankle structures on MRI. Six patients had osteoarthritis of the tibiotalar joint secondary to chronic ankle sprains. The 2 remaining patients had ankle arthritis attributable to severe rheumatoid arthritis in one patient and primary osteoarthritis in the other.

MRI and Measurements

Preoperative MRIs with 3.5-mm slices were obtained for all patients with the foot in a neutral position as well as in maximum plantarflexion. Patients were positioned by a research assistant (J.H.G.) in a neutral tibiotalar position clinically using a goniometer, and the first sequence of MRI images were obtained. Subsequently, the research assistant placed a bump under the calf and patients were asked to maximally plantarflex their foot. This maximum plantarflexion was then measured on a goniometer and recorded. Patients then held this maximally plantarflexed position while the second set of MRI images were obtained.

The position of the tibiotalar joint was then measured in neutral and maximal plantarflexion on sagittal MRI slices. Dorsiflexion and plantarflexion of the ankle were measured using an angle between the axis of the tibia, which was measured using a line that bisected the tibia at 25 mm and 50 mm above the tibial plafond, and the axis of the talus, which was

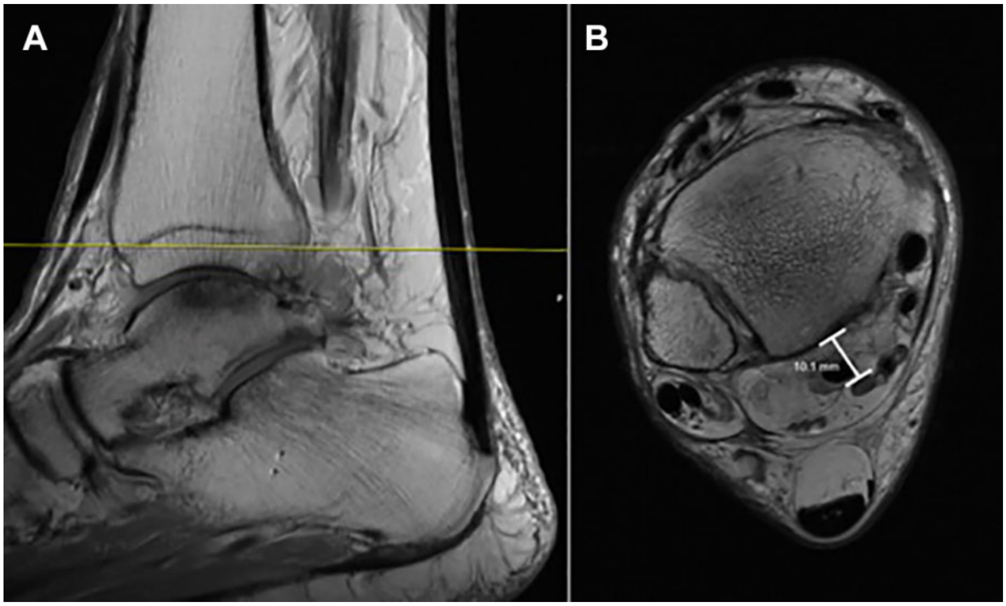

Figure 1. Technique to measure tibial nerve above and below the tibial plafond. The tibial nerve was measured from the posterior cortex of the tibia and talus at multiple levels above and below the tibial plafond, respectively. (A) The sagittal image was used to determine the level. (B) The axial image was then used to measure the distance from the tibial nerve to the closest posterior cortex.

measured using a line that bisected the narrowest part of the talar neck and the articular surface of the talar head. The distance of the tibial nerve, posterior tibial tendon (PTT), flexor digitorum longus (FDL), flexor hallucis longus (FHL), and posterior tibial artery to the closest part of the posterior cortex of the tibia or talus was measured by a board-certified musculoskeletal radiologist (H.G.G.) on the Sectra IDS7 PACS System at 7 mm and 14 mm above the tibial plafond as well as 3.5 and 7 mm below the tibial plafond at the level of the talus (Figure 1). These measures were repeated in both neutral and maximum plantarflexion of the tibiotalar joint. The distances above and below the tibial plafond were chosen as they represented typical bone cuts in a TAR.

There were 7 men and 3 women with a mean age of 65.2 years (range, 56-77 years) who were included in the study. The average clinical plantarflexion as measured by a goniometer for these 10 patients with end-stage osteoarthritis indicated for a total ankle replacement was 29.5 degrees (SD 10.1 degrees, range, 20-46 degrees). Maximum plantarflexion at the tibiotalar joint measured on MRI imaging was 37.1 degrees (SD 11.4 degrees, range 17.4-56.2 degrees).

Statistical Analysis

SPSS, version 22 (IBM Corp, Armonk, NY), was used by one of the authors (M.S.C.). for all statistical analyses. Descriptive statistics are reported as means and SDs. To determine if posteromedial ankle structures moved closer to the posterior cortices of the tibia and talus as they moved more distally, Wilcoxon signed-rank tests were used to evaluate for differences in posteromedial ankle structures between 14 and 7 mm above the tibial plafond and 3.5 and 7 mm below the tibial plafond. All statistical tests were 2-sided, and significance was set to $P = .05$. Wilcoxon signed-rank non-parametric tests, in place of their parametric equivalent, the paired t test, due to the small sample size ($n = 10$), were also used to calculate differences between neutral and maximally plantarflexed ankle position for the distance of the posteromedial ankle structures to the posterior tibial or talar cortices on each MRI slice above and below the tibial plafond.

Results

The mean distance from the posterior tibial cortex to tibial nerve at 14 mm above the tibial plafond was 8.7 mm (SD 2.6, range 5.0-11.8 mm) (Table 1). At 7 mm above the tibial plafond, the average distance of the tibial nerve from the posterior tibial cortex was 6.7 mm (SD 2.7 mm, range 2.7-10.6 mm), which represented a statistically significant movement anteriorly when compared with its location 14 mm above the tibial plafond ($P = .021$) (Figure 2). The tibial nerve was located, on average, 8.5 mm (SD 2.6 mm, range 4.5-12.7 mm) and 8.4 mm (SD 3.2 mm, range 4.6-14.8 mm) posterior to posterior cortex of the talus at 3.5 and 7 mm below the tibial plafond, respectively ($P = .358$). Maximum plantarflexion at the ankle joint did not result in statistically significant changes in the position of the tibial nerve compared with the posterior cortices of the tibia or talus (all P values $> .05$) (Table 1). However, in maximum plantarflexion, there was a trend for the tibial nerve to be closer to

Table 1. Mean Distance (range) of the Tibial Nerve and Posterior Tibial Artery from the Tibial and Talar Posterior Cortices in Neutral and Plantarflexion.[a]

	Neutral Ankle				Maximum Ankle Plantarflexion			
	Distance *Above* Tibial Plafond		Distance *Below* Tibial Plafond		Distance *Above* Tibial Plafond		Distance *Below* Tibial Plafond	
	14 mm	7 mm	3.5 mm	7 mm	14 mm	7 mm	3.5 mm	7 mm
Tibial nerve	8.7 * (5.0-11.8)	6.7 * (2.7-10.6)	8.5 (4.5-12.7)	8.4 (4.6-14.8)	7.7 (5.0-11.5)	6.6 (2.7-10.6)	8.6 (4.6-11.8)	9.7 (5.6-13.1)
Posterior tibial artery	8.00 (3.6-13.9)	7.2 (3.1-9.4)	9.1 † (5.5-18.6)	9.7 (5.9-17.6)	8.0 (4.2-10.5)	7.2 (4.9-10.0)	10.6 † (7.6-22.1)	11.4 (7.1-17.0)

[a]Cells with the same symbol after the mean distance (ie, * or †) had a statistically significant difference when compared to a cell with the same symbol. *$P = .021$ and ‡$P = .047$. All values are in millimeters.

the posterior tibial cortex at 14 mm above the tibial plafond (mean 7.7 mm, SD 2.6 mm, range 5.0-11.5 mm, $P = .066$).

The posterior tibial artery was, on average, 8.0 mm (SD 3.62 mm, range 3.6-13.9 mm) and 7.2 mm (SD 2.14 mm, range 3.1-9.4 mm) from the posterior tibial cortex at 14 and 7 mm above the tibial plafond, respectively, and 9.1 mm (SD 4.0 mm, range 5.5-18.6 mm) and 9.7 mm (SD 4.04 mm, range 5.9-17.6 mm) from the posterior talar cortex at 3.5 mm and 7 mm below the tibial plafond (Table 1). Additionally, in maximal plantarflexion, the posterior tibial artery moved, on average, 1.5 mm posterior at 3.5 mm below the tibial plafond ($P = .047$), and there was a trend for the posterior tibial artery to move approximately 1.6 mm posterior at 7 mm below the tibial plafond ($P = .059$).

The flexor tendons similarly did not move reliably in a posterior direction at the level of the tibial cortex in plantarflexion (Table 2). In fact, the flexor hallucis longus (FHL) tendon moved anterior in maximal plantarflexion from a mean of 8.0 mm (SD 2.7 mm, range 4.6-13.8 mm) posterior to the tibial cortex at 14 mm above the tibial plafond to 6.8 mm (SD 2.1 mm, range 4.5-12.0 mm) at the same level in maximal plantarflexion ($P = .028$). Similar to the tibial nerve, the FHL moved anteriorly to 5.2 mm (SD 2.5 mm, range 2.4-11.1 mm) at 7 mm above the tibial plafond, which represents a statistically significant difference anteriorly from 14 to 7 mm above the tibial plafond ($P = .005$). In contrast, the flexor digitorum longus (FDL) tendon moved further posteriorly to the talar cortex in maximal plantarflexion by approximately 0.8 mm at 3.5 mm and 7 mm below the tibial plafond ($P = .024$ and .005, respectively) (Table 2). Otherwise, there was no significant anterior-posterior movement of the flexor tendons.

Discussion

The tibial nerve lies, on average, between 6.5 and 9 mm from the posterior cortices of the tibia and talus; however, in one patient, the tibial nerve was as close as 2.7 mm from the posterior cortex of the tibia. As the tibial nerve courses distally above the tibial plafond, it moves closer to the posterior tibial cortex, which may put the tibial nerve at greater risk of injury with tibial bone cuts that take less bone. Although we hypothesized that the tibial nerve would move posterior with the ankle in plantarflexion, plantarflexing the tibiotalar joint actually resulted in the trend of the tibial nerve moving closer to the posterior tibial cortex at 14 mm above the tibial plafond ($P = .066$). The posterior tibial artery lies, on average, between 7 and 10 mm from the posterior tibial and talar cortices. Maximal plantarflexion of the ankle resulted in only the posterior tibial artery and FDL moving posteriorly less than 1 mm distal to the tibial plafond, but plantarflexion of the ankle did not affect the position of the tibial nerve, PTT, or FHL.

Although damage to the posteromedial neurovascular structures is uncommon, it does occur in a small percentage of patients who undergo TAR.[7,8,11,16] A recent study of 148 consecutive TARs reported that 2 patients had tibial nerve lacerations, and the rate did not differ between patients with severe (>20 degrees) and moderate coronal plane deformity.[7] In a separate study, 9 of 150 patients who had undergone a TAR had an injury to their tibial nerve, and of these 9 patients, 5 patients had incomplete or no recovery of the nerve.[11]

Additionally, there have been case reports of injuries to the posterior tibial artery as well as the FHL tendon during a TAR.[10,16] Wooster et al described a case of an iatrogenic arteriovenous fistula and pseudoaneurysm of the posterior tibial artery after a revision TAR in a 62-year-old man.[16] The authors hypothesized that this may have occurred during placement of a cannulated screw, provisional Kirschner wire fixation, or from penetration of the vessels by the cutting block pins.[16] The patient required a return to the operating room with ligation of the arteriovenous fistula and excision of the pseudoaneurysm with a saphenous vein graft.[16] Previous work demonstrated that the posterior medial and dorsal medial pins for the InBone II total ankle system (Wright Medical Technology, Inc, Memphis, TN) encountered the tibial artery or vein in up to 3 of 10 cadaveric ankle specimens.[13] Peters and Miller reported a case of a 45-year-old woman who suffered a laceration of her FHL tendon as a result of the bone cuts during a TAR.[10] She was treated with primary repair of the tendon.[10] Our work found that

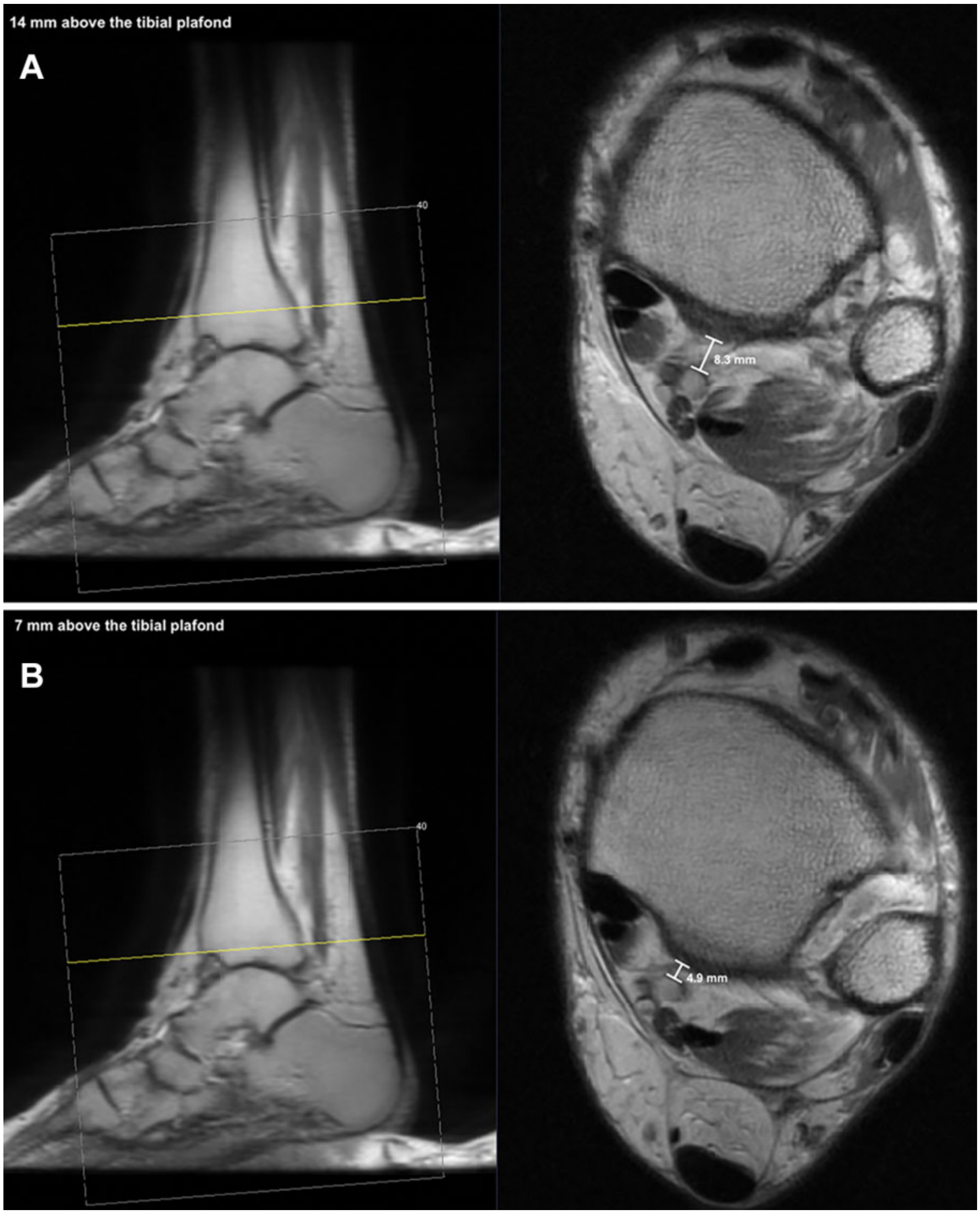

Figure 2. Position of the tibial nerve (A) 14 and (B) 7 mm above the tibial plafond. The tibial nerve moved closer to the posterior tibial cortex as it coursed distally from 14 to 7 mm above the tibial plafond ($P = .021$). In this patient, the tibial nerve was (A) 8.3 and (B) 4.9 mm from the posterior tibial cortex at 14 and 7 mm above the tibial plafond, respectively.

plantarflexion of the ankle would not prevent this complication as, at 14 mm above the tibial plafond, the FHL tendon moved closer to the tibia in plantarflexion.

The amount of bone resected during a TAR depends on the system, and different systems may result in the tibial and talar cuts putting certain structures more at risk for injury. The Exactech Vantage (Gainesville, FL) system, for example, resects 7 mm of bone from the tibia and between 2 and 4 mm of bone from the talus.[9] In contrast, the Wright InBone II system resects between 10.5 and 14 mm from the tibia and between 6 and 8 mm from the talus.[5] The Wright Infinity (Wright Medical Technology, Inc) requires an 11-mm tibial bone cut and a 5- to 6-mm talar cut.[6] Revision TARs often require tibial and talar bone resections that are greater than primary TARs. Depending on the level of tibial and talar resection, the tibial nerve may lie closer to the posterior tibial cortex. Surgeons should be aware that TAR systems that preserve more bone may put the tibial nerve at greater risk.

To the authors' knowledge, this is the first study to investigate the distance of the tibial nerve and

Table 2. Mean Distance (range) of the Posterior Tibial Tendon (PTT), Flexor Digitorum Longus (FDL), and Flexor Hallucis Longus (FHL) from the Tibial and Talar Posterior Cortices in Neutral and Plantarflexion. [a]

	Neutral Ankle				Maximum Ankle Plantarflexion			
	Distance *Above* Tibial Plafond		Distance *Below* Tibial Plafond		Distance *Above* Tibial Plafond		Distance *Below* Tibial Plafond	
	14 mm	7 mm	3.5 mm	7 mm	14 mm	7 mm	3.5 mm	7 mm
PTT	0.3 (0.0-1.8)	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.1 (0.0-0.8)	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.1 (0.0-0.9)
FDL	3.2 (1.0-5.9)	3.0 (0.0-4.9)	3.2 * (0.0-4.6)	3.1 † (1.2-4.7)	3.7 (1.9-5.3)	3.6 (0.7-6.0)	4.0 * (1.6-5.6)	4.0 † (1.8-6.3)
FHL	8.0 ‡,§ (4.6-13.8)	5.2 ‡ (2.4-11.1)	4.7 (2.1-8.5)	4.9 (2.4-10.8)	6.8 § (4.5-12.0)	5.3 (1.8-10.2)	4.6 (1.6-9.3)	4.6 (3.3-6.0)

[a]Cells with the same symbol after the mean distance (ie, *, †, ‡, §) had a statistically significant difference when compared to a cell with the same symbol. *$P = .024$, †$P = .005$, ‡$P = .005$, and §$P = .028$. All values are in millimeters.

posteromedial structures from the posterior tibial and talar cortices in neutral and maximal ankle plantarflexion. One study looked at the movement of the superficial peroneal nerve at the ankle joint in neutral and plantarflexion in order to avoid iatrogenic injury to this nerve through the anterolateral ankle portal during ankle arthroscopy.[1] The authors found that the superficial peroneal nerve moved 2.4 mm laterally when the ankle was moved from plantarflexion to neutral and 3.6 mm laterally when the ankle was moved from 10 degrees plantarflexion to 5 degrees dorsiflexion.[1] Other studies have used MRI to evaluate the anatomy of neurovascular bundles at different joint positions, especially in the knee.[14,15,17] MRIs have been used to determine the distance from the posterior horn of the lateral meniscus to the popliteal neurovascular bundle in adolescents in order to avoid damage to these structures during an all-inside meniscus repair.[14] In a study of 9 volunteers, MRI was used to investigate the distance of the popliteal artery from the posterior tibial cortex in extension and 90 degrees of knee flexion.[15] The authors found that the popliteal artery moved farther away from the posterior tibial cortex by 2.3 mm although they did not report if this was statistically significant.[15] In a similar study of 30 knees positioned in extension and 90 degrees of knee flexion, the popliteal artery was measured on MRI scans to move posteriorly by 4.5 mm in flexion at 1 cm distal to the joint line.[17] The present study in the ankle, in contrast to previous studies in the knee, did not find significant movement of the neurovascular or tendinous structures of the posteromedial ankle.

This study was limited by the small number of patients enrolled in the study. Our study was powered to detect a 3-mm change in distance of the tibial nerve from the posterior tibial cortex in maximal ankle plantarflexion, and therefore, movements of the posteromedial ankle structures less than 3 mm may not have reached statistical significance. However, the tibial nerve tended to move closer to the posterior tibial cortex in maximal plantarflexion, so it is unlikely that increasing the number of patients in the study would have significantly changed the result. This study was also limited by the selection bias created by the inclusion and exclusion criteria. In order to have adequate plantarflexion of the ankle to replicate that which may be achieved in an operating room under anesthesia, our study selected only patients with good plantarflexion of the ankle (greater than 20 degrees), which may have excluded patients with severe osteoarthritis of the tibiotalar joint. Additionally, most of the patients in this cohort had tibiotalar arthritis due to chronic ankle sprains ($n = 6$) rather than secondary to post-traumatic osteoarthritis ($n = 1$). Patients with post-traumatic tibiotalar osteoarthritis who have undergone an open reduction and internal fixation of an ankle fracture may have more scarring in the posterior ankle, and this may affect the anatomy of the posteromedial ankle structures by moving them either closer to or farther away from the posterior cortices of the tibia and talus. Finally, the present study did not directly evaluate instrumentation of any TAR system, and consequently, no conclusions can be drawn about how to avoid injuring the posteromedial ankle structures during TAR.

In conclusion, in patients with end-stage ankle arthritis, the tibial nerve and posterior tibial artery lie, on average, between 6.5 and 10 mm from the posterior tibial and talar cortices. In some patients, these structures are less than 3 mm away from the bone. Plantarflexing the ankle during the bone cuts for a TAR does not result in the posteromedial structures moving reliably away from the posterior tibial cortex, and therefore, it may be safer to perform the tibial bone cuts in a neutral ankle position. Knowledge of the anatomy of the posteromedial ankle structures may help surgeons avoid iatrogenic injuries to the neurovascular bundle and flexor tendons during TAR.

Declaration of Conflicting Interests

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ORCID iD

Matthew S. Conti, MD, https://orcid.org/0000-0003-3313-2520
Jonathan A. Garfinkel, MD, https://orcid.org/0000-0001-5884-3009
Scott J. Ellis, MD, https://orcid.org/0000-0002-4304-7445

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