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Dimensional Changes of the Tibial Nerve and Tarsal Tunnel in Different Ankle Joint Positions in Asymptomatic Subjects

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ABSTRACT

The tarsal tunnel is a clinically important fibrous osseous conduit for the tibial nerve and associated tendons. It is mechanically dynamic, and normal ankle movements appear to change the tunnel shape, potentially having an impact on the tibial nerve. The objective of this study was to measure changes in the tibial nerve and tarsal tunnel dimensions in plantarflexion and dorsiflexion of the ankle joint in healthy subjects. A cross-sectional study with 13 volunteer subjects and a total of 18 records was designed. The cross-sectional area, anterior-posterior distance, transverse distance, and flattening ratio of the tibial nerve were measured by using ultrasound in plantarflexion and dorsiflexion of the ankle joint. The anterior-posterior distance of the tarsal tunnel was also measured. The tunnel anterior-posterior distance significantly increased during plantarflexion ($p < .001$) and decreased during dorsiflexion ($p = .027$) of the ankle. From plantarflexion to dorsiflexion of the ankle, the tibial nerve cross-sectional area significantly decreased ($p = .035$). The anterior-posterior distance also decreased significantly ($p < .001$), whereas the transverse distance increased ($p < .001$), thus decreasing the flattening ratio of the tibial nerve ($p < .001$). Ankle joint position determined significant changes in the shape and dimensions of the tibial nerve at the tarsal tunnel.

The tarsal tunnel is a fibrous osseous tunnel situated posteriorly and inferiorly to the medial malleolus, and it presents a proximal and distal floor (1). The proximal retromalleolar floor is limited by the flexor retinaculum and contains the flexor tendons, posterior tibial tendon, flexor digitorum longus, flexor hallucis longus, and tibial neurovascular bundle (1). In this narrow passage, the tibial nerve is vulnerable to compression. Involvement of the tibial nerve or its branches in the tarsal tunnel at the ankle is known as tarsal tunnel syndrome (TTS) (2–6). This syndrome was first described by Keck (5) and Lam (6) in 2 separate reports in 1962. Although this syndrome is a common form of entrapment syndrome of the lower extremity, it is not as common as carpal tunnel syndrome (7) in the upper extremity. TTS affects women more than men (3,8), but its prevalence and incidence are unknown (9,10).

Patients with TTS present with pain, paresthesia, hypoesthesia, hyperesthesia, muscle cramps, and/or numbness affecting the heel and/or the sole of the foot, and the symptoms may spread to the toes (11). These symptoms mainly occur while walking, during exercise, and at night when the patient is at rest (8,11). Symptoms are commonly unilateral and rarely bilateral (3). Although its true incidence is unknown, the specific cause of TTS can be identified in 60% to 80% of patients (2,3,7,9,11–13). The causes can be broadly classified into trauma, space-occupying lesions, and deformities of the foot (13).

Bone disorders linked to static foot disorders, including compression to the medial process of the talus in valgus flat foot, which leads to pushing and stretching of nerves, have been described as a contributing factors in TTS (11,12). Cadaveric studies have demonstrated that increased eversion, dorsiflexion, or combined dorsiflexion-eversion significantly increases tibial nerve tension (14–16). The strain on the tibial nerve is even greater when the nerve bed is elongated at both the hip and the knee before dorsiflexion (16,17). In vivo studies have suggested that benign joint hypermobility is a potential causal mechanism in patients with TTS (18) and that activities that apply a heavy burden on the ankle joint, such as sprinting or jumping, are related to the development of TTS (12).

In addition to increasing the tension on the tibial nerve, the ankle eversion and dorsiflexion can decrease the tarsal tunnel size (19,20) and increase compression on the nerve. It is believed that the valgus heel and abducted forefoot in a pes planus deformity can contribute to the development of TTS by compressing and increasing tension to the

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tibial nerve (13). A similar mechanism has been described for the carpal tunnel and the medial nerve at the wrist (21–23). Several studies have shown morphological and dimensional changes in the carpal tunnel and median nerve during different positions of the carpal bones, and it has been suggested that movements that increase the carpal tunnel cross-sectional area (CSA) could decrease median nerve compression and be useful as treatment techniques for patients with carpal tunnel syndrome (21–23).

To our knowledge, several studies have measured the CSA of the tibial nerve at the ankle in asymptomatic subjects (24,25) and patients with TTS (4,7,11,24–26) in anatomical position of the ankle joint. However, no researchers have measured the potential changes in the morphology of the tibial nerve and tarsal tunnel in different ankle positions in asymptomatic subjects. We were interested in determining if the ankle movements change the tibial nerve and tarsal tunnel dimensions in asymptomatic subjects. We hypothesized that ankle dorsiflexion would reduce the dimensions of the tarsal tunnel, making the tibial nerve more flattened, whereas ankle plantarflexion would increase the dimensions of the tarsal tunnel, making the tibial nerve less flattened. Our primary aim was to quantify changes in the tibial nerve and tarsal tunnel dimensions in different ankle joint positions in healthy subjects, and our secondary aim was to determine the amount of change between ankle positions in both the tibial nerve and the tarsal tunnel.

Participants and Methods

Study Design

A cross-sectional (ie, a series of subjects) study was designed (E.B.) to document and analyze the dimensional changes of the tarsal tunnel and tibial nerve in different ankle joint positions in asymptomatic individuals. The study was conducted at the research laboratory of the Universidad de Zaragoza, from January 1, 2018, to April 30, 2018. The Ethics Committee of Clinical Research of Aragón approved the protocol of this study.

Participants

The sample size calculation was made for all ultrasound measurements (E.E.), estimating a level of significance of .05 and a power of .8. The highest value (18 cases) was obtained with data of the anterior-posterior distance (APD) of the tarsal tunnel, calculated from a previous pilot study with 8 ankles and selected to be sufficient to detect at least a 5% between-positions difference.

Potential participants were excluded by a researcher (E.S.) if any of the following was present: history of plantar heel (24) pain, neurologic signs, range-of-motion limitation in ankle joint, or lumbar or lower limb surgery. All subjects were required to read an information sheet and sign a consent form before participation.

Experimental Procedure

Each participant was in standing position. The hip and knee of the examined lower extremity were flexed 90 degrees, and the foot was placed on a step. Then, the ankle joint was placed at 3 different positions using a standard goniometer: anatomical position (0 degrees of dorsiflexion), 30 degrees of dorsiflexion, and 30 degrees of plantarflexion. Subjects were asked not to load the body weight on the examined extremity during the 3 measurements (Fig. 1).

Ultrasonographic examinations were obtained by using LOGIC-e Basic ultrasound system and a 13-MHz linear array transducer. Images were evaluated by an evaluator (J. S.) with >10 years of experience in musculoskeletal ultrasonography. Depth, gain, and dynamic range were adjusted appropriately for optimal differentiation between nerves and other soft tissue structures. The probe was positioned perpendicular to the tibial nerve at the level of the tarsal tunnel on the medial aspect of the ankle, and the scans were made by placing the probe on the malleolar calcaneal axis (7,25,27) (Fig. 1).

APD of the tarsal tunnel at the proximal tunnel was measured. The tunnel APD was measured from the deepest part of the tarsal bones to the dorsal aspect of the transverse tarsal ligament. Tibial nerve distances were also measured. The APD and the transverse distance (TD) were the minor axis and the major axis of the nerve, respectively (Fig. 2). The indirect method was used to calculate the CSA of the tibial nerve (28,29). In this measurement, the formula of ellipsoid area was used (APD × TD × 3.14/4). Finally, the flattening ratio (TD:APD) of the tibial nerve was also calculated. The flattening ratio provided an indication of the tibial nerve roundness (23) and of the possible changes in its morphology during the mobilization.

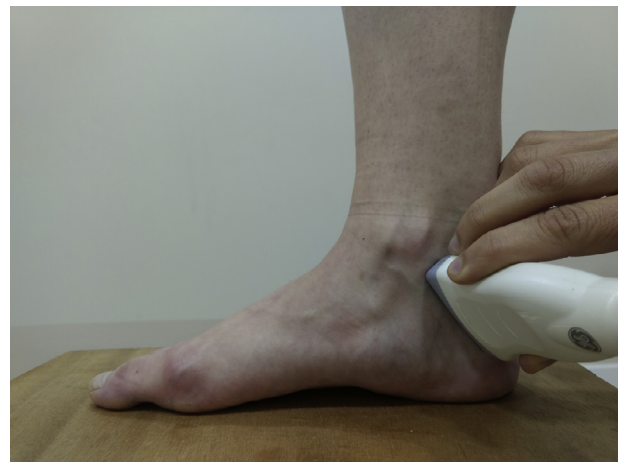

Fig. 1. Probe position for ultrasound imaging at the malleolar-calcaneal axis.

Preliminary to the primary component of the study, intrarater reliability of the ultrasound measurements of the tarsal tunnel and the tibial nerve was determined (E.E.). All these measurements were performed on 8 subjects, twice at each ankle joint angle, with a 10-minute interval between measurements (J.S.). Time between repetitions was similar to that of previous intrarater reliability studies (17). Interrater reliability was not measured in the present study.

Statistical Analysis

SPSS statistical software, version 20.0 for Windows was used for all statistical analyses (E.E.). Mean and standard deviation values were calculated for all the measurements.

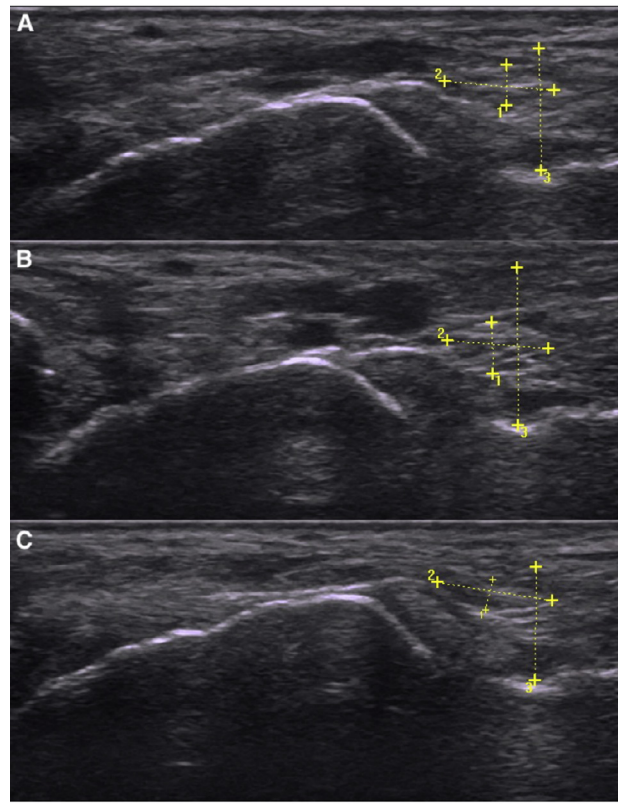

Fig. 2. Ultrasound measurements of the tarsal tunnel and tibial nerve. (*A*) Anatomical position of the ankle. (*B*) Plantarflexion. (*C*) Dorsiflexion. Line 1, anterior-posterior distance of the tibial nerve. Line 2, transverse distance of the tibial nerve. Line 3, anterior-posterior distance of the tarsal tunnel.

Table 1
Demographic characteristics of the sample population (N = 18 feet in 13 subjects)

Characteristics of Participants	Overall (N = 13)
Number of females (%)	9 (69.23)
Age (years)	33.23 ± 11.09
Body mass index (kg/m^2)	21.07 ± 7.74

The intraclass correlation coefficient (ICC) at a 95% confidence interval (CI) were calculated to determine the relative reliability. Interpretation of ICCs followed Portney and Watkins (30) and included values of 0.00 to 0.25 indicating little to no relationship; 0.26 to 0.50, fair degree of relationship; 0.51 to 0.75, moderate to good relationship; and 0.76 to 1.00, good to excellent relationship. Differences in ultrasound measurements between ankle joint positions were calculated by using the Friedman test, and the post hoc pairwise comparisons were calculated by using the Wilcoxon test. Statistical significance was defined at the 5% ($p = .05$) level.

Cohen's d (31) was computed as a measure of the pre-post effect sizes. Effect size was defined as the mean difference between baseline and post-technique scores for each measure divided by the standard deviation of difference (31). A d-value of .20 indicates a small effect size; 0.50, medium effect size; and 0.80, large effect size (32). Effect size provides an estimate of the magnitude of between-group differences on a standard scale. Large effect sizes are more likely to demonstrate clinically relevant improvement at the endpoint. Effect size is a unitless measure and thus is appropriate for comparisons involving scales with different metrics (33).

Results

The initial sample consisted of 13 volunteers (26 ankles: 9 [69.23%] females and 4 [30.77%] males). Eight (30.79%) ankles were excluded due to previous pathology, so the final sample consisted of 13 volunteers (18 ankles). The mean age of the volunteers was 33.23 ± 11.09 years, and the mean body mass index (BMI) was 21.07 ± 7.74 kg/m^2 (Table 1). Intrareliability of tunnel and nerve measurements that were obtained with ultrasound was excellent. The ICCs ranged from 0.91 to 0.99 for all measurements.

In the anatomical position, the mean values for the APD, TD, and CSA of the tibial nerve were 2.17 ± 0.71 mm, 7.50 ± 1.44 mm, and 13.24 ± 5.71 mm^2, respectively. The tarsal tunnel APD was 11.27 ± 2.18 mm (Table 2) and significantly increased in ankle plantarflexion ($p < .001$) and decreased in dorsiflexion ($p = .027$). Specifically, the tunnel APD increased by 0.78 ± 0.65 mm during the plantar phase and decreased by 0.37 ± 0.65 mm in the dorsal phase. The tibial nerve dimensions were significantly affected by plantarflexion (plantar phase). The nerve CSA varied by 1.30 ± 3.47 mm^2. This variation in the nerve CSA was accompanied by significant increases in the nerve APD ($p = .007$) and significant decreases in the nerve TD ($p < .001$). The plantarflexion of the ankle also influenced the tibial nerve flattening ratio ($p < .001$), and the tibial nerve increased in roundness as shown by its decreasing flattening ratio, from 3.64 ± 0.83 to 2.85 ± 0.62. For the tibial nerve descriptors during the dorsal phase (from the anatomical position to dorsiflexion of the ankle), only the tibial nerve TD was significantly modified ($p = .002$). The nerve TD increased by 0.49 ± 0.63 mm (Table 2).

From plantarflexion to dorsiflexion, both the tunnel and the tibial nerve shape descriptors were significantly modified ($p \leq .05$), except the tibial nerve CSA. The tarsal tunnel APD decreased by 1.14 ± 0.80 mm ($p < .001$); the tibial nerve TD and the flattening ratio decreased ($p < .001$) by 1.51 ± 1.29 mm and 1.24 ± 0.74, respectively; and the APD increased by 0.59 ± 0.58 mm ($p = .002$) (Table 3).

Medium to large effect sizes ($d \geq .50$) were found during the plantar phase, whereas small to medium effect sizes (d 0.20 to 0.49) were found in the dorsal phase. Finally, all the measurements between plantarflexion and dorsiflexion showed a large effect size ($d \geq .80$), except the tibial nerve CSA (Table 4).

Discussion

This study investigated the effects of ankle joint position on the tibial nerve and tarsal tunnel dimensions in asymptomatic subjects. Ultrasonography was used to capture changes at this level because it has proved to be a good tool for measuring the tibial nerve at the tarsal tunnel (11,24–27). Initial values for the tibial nerve at anatomical position were similar to those of other studies (24–26). It was shown that the ankle joint position resulted in morphologic changes in both the tibial nerve and the tarsal tunnel. The APD of the tunnel significantly

Table 2
Tarsal tunnel and tibial nerve descriptors (N = 18 feet in 13 subjects)

	Anatomical Position	Plantarflexion	Dorsiflexion
APD tunnel (mm)	11.31 ± 2.18	12.09 ± 2.31	10.95 ± 2.15
APD nerve (mm)	2.07 ± 0.54	2.25 (2–2.90)*	1.97 ± 0.33
TD nerve (mm)	7.51 ± 1.45	6.99 ± 1.35	7.30 (6.9–9.1)*
CSA nerve (mm^2)	11.05 (9.5–14.1)*	12.97 (9.9–15.3)*	11.55 (9.7–15.5)*
Flattening ratio	3.74 ± 0.76	2.93 ± 0.70	4.08 ± 0.61

Abbreviations: APD, anterior-posterior distance; CSA, cross-sectional area; TD, transverse distance.
* Median (interquartile range).

Table 4
Effect size outcomes for plantarflexion, the dorsal phase, and the difference between phases (N = 18 feet in 13 subjects)

	Plantarflexion Effect Size	Dorsiflexion Effect Size	Difference in Effect Size
APD tunnel (mm)	1.20	–0.55	1.43
APD nerve (mm)	0.98	–0.24	0.89
TD nerve (mm)	–1.42	0.78	–1.42
CSA nerve (mm^2)	0.61	0.03	0.40
Flattening ratio	–1.12	0.42	–1.48

Abbreviations: APD, anterior-posterior distance; CSA, cross-sectional area; ES, effect size with Cohen's.; TD, transverse distance.

Table 3
Differences and comparison between the plantar phase and the dorsal phase (N = 18 feet in 13 subjects)

	Difference From Anatomical Position		Difference From Anatomical Position		Difference From Plantarflexion to Dorsiflexion	
	Mean	p-Value	Mean	p-Value	Mean	p-Value
APD tunnel (mm)	0.78 ± 0.65	<.001	–0.36 ± 0.64	.029	1.14 ± 0.80	<.001
APD nerve (mm)	0.43 ± 0.44	0.007	–0.09 ± 0.39	.318	0.53 ± 0.59	.002
TD nerve (mm)	–0.80 (–1.4, – 0.5)*	<.001	0.35 (0.05 –0.9)*	<.002	–0.80 (–1.4, –0.5)*	<.001
CSA nerve (mm^2)	1.64 ± 2.66	.311	0.10 ± 2.54	.948	1.55 ± 3.84	.085
Flattening ratio	–0.82 ± 0.73	<.001	0.34 ± 0.79	.084	–1.15 ± 0.78	<.001

Abbreviations: APD, anterior-posterior distance; CSA, cross-sectional area; TD, transverse distance.
* Median (interquartile range).
$p \leq .05$ = significant difference.

decreased from plantarflexion to dorsiflexion of the ankle joint, whereas a change in the morphology of the tibial nerve was also observed.

Previous studies have analyzed the effect of ankle joint motions on the tarsal tunnel pressure (12,34) and symptom provocations in TTS (35,36). It has been shown that when the foot and ankle are positioned in full eversion or full inversion, tarsal tunnel pressure increases up to 30 mm Hg and 17 mm Hg in cadavers, respectively (34). These results provide an explanation for the observed aggravation of symptoms with the Phalen-type test and relief of symptoms with immobilization in the neutral position in TTS (34). Also, passive and maximal dorsiflexion combined with maximal eversion of the ankle has been shown to reproduce clinical symptoms in surgically proven TTS (35). This combination of movements has been proposed as the dorsiflexion-eversion test for TTS (35). In the present study, a decrease in the APD of the tarsal tunnel was observed in dorsiflexion of the ankle compared with the anatomical position. This decrease in the APD could indicate an increase in the tunnel pressure in dorsiflexion, supporting the hypothesis that the dorsiflexion-eversion test could increase pressure on the tibial nerve inside the tarsal tunnel, thus producing symptoms in patients with TTS. In addition, a decrease in the CSA of the tibial nerve was also observed during the dorsiflexion. This reduction in the CSA of the nerve could be explained by the change in its morphology and reflected in the increase of the flattening ratio. The nerve shape is often quantified by the flattening ratio, and this descriptor has been suggested for use as a diagnostic criterion for compressive neuropathies such as carpal tunnel syndrome (37,38). Recently, several studies have found that when the CSA of the carpal tunnel increases, the median nerve becomes rounder, reflected by a decrease in flattening ratio (21–23).

Opposite the dorsiflexion, the APD of the tarsal tunnel significantly increased from the anatomical position to plantarflexion in the current study. According to the hypothesis, this could indicate a decrease in tarsal tunnel pressure and, consequently, pressure on the tibial nerve. The tibial nerve shape became rounder, reflected by a decrease in the flattening ratio. Previous studies have analyzed the effect of plantarflexion and inversion on the tarsal tunnel pressure (34,39,40), but results are contradictory. These studies have reported an increase in the tunnel pressure during both plantarflexion and inversion. Accordingly to these findings, the “triple compression test” has been proposed for the diagnosis of TTS (40).

The apparent contradictory effects for the tunnel APD found between the current study and previous studies could be explained by several factors. In previous studies (34,36), it was hypothesized that reproduction of symptoms by inversion of the foot and ankle in TTS could be a result of narrowing of the tarsal tunnel in the inverted position. Also, the calcaneal gutter is brought closer to the medial malleolus in plantarflexion position, narrowing the tunnel floor (36). However, the tarsal tunnel area could be affected not only by the shape of the bony structures but also by the slack of the tarsal ligament and the distance between such ligament and the calcaneus. A similar mechanism has been described for the carpal tunnel during the mobilization of the carpal bones in modeling (41), in vitro studies (42,43), and asymptomatic subjects (21,23). It has been shown that when compression is applied transversely on the carpal tunnel, the carpal bones are brought closer, thus decreasing the TD. In addition, the transverse carpal ligament is slackened and the APD increases; there is an effect of rounding the tunnel and thus increasing the CSA (21–23,41,42). In the present study, the APD of the tunnel increased during plantarflexion. This increase could produce an increase in the tunnel area, thus decreasing the pressure inside the tunnel, and the opposite mechanism occurs during the dorsiflexion of the ankle joint. However, because the tarsal tunnel width exceeds the length of the ultrasound probe, the TD of the tarsal tunnel was not measured in the present study.

In an anatomical study, Nayagam et al (39) found elevated pressures in maximal plantarflexion, inversion, eversion, and dorsiflexion compared with the neutral position at the tarsal tunnel in cadavers. In that study, maximal ankle joint movements were performed and pressure inside the tarsal tunnel was recorded, but pressure at intermediate ankle plantarflexion or dorsiflexion angles was not measured. In the carpal tunnel, pressure has been observed to increase in maximal carpal flexion and maximal dorsiflexion of the wrist, in both control subjects and patients with carpal tunnel syndrome (44). However, a reduction in the pressure was reported from the neutral position of the wrist to 30 degrees of extension (45). In the present study, ultrasound measurements were performed at 30 degrees of plantarflexion of the ankle, which is not the maximal movement of the ankle joint (46). A similar mechanism could exist for the tarsal tunnel, and mid-range plantarflexion may produce a decrease in tunnel pressure but maximal flexion could increase the pressure inside the tunnel. However, because APD of the tarsal tunnel was not measured at maximal plantarflexion, more studies are needed to validate this hypothesis.

The results of this study may suggest that dorsiflexion and plantarflexion of the ankle produce dimensional changes in both the tibial nerve and tarsal tunnel. This could be particularly important to understand the etiology in patients with compressive pathology of the tarsal tunnel. However, future studies are needed to measure the dimensions of the tarsal tunnel at different angles of the ankle, specifically the TD of the tunnel.

There are several limitations to consider with this study. First, in our study, the TD of the tarsal tunnel was not measured. Because the width of the tunnel exceeds the length of the ultrasound probe, a measurement of the tunnel width was not recorded in this study. Thus, the total area of the tarsal tunnel in different ankle joint positions was not measured. Second, the measurements were performed only at the proximal tarsal tunnel level and just bidimensional with ultrasound. Effects of the technique that could have occurred at other levels of the tunnel, such as the longitudinal glide of the tibial nerve at the tarsal tunnel or the medial and lateral plantar nerves at the anterior and posterior calcaneal canals to abductor halluces, respectively, were not evaluated. Third, because ankle dorsiflexion and plantarflexion are triplanar motions, when moving into 30 degrees of dorsiflexion or plantarflexion, a significant amount of midfoot/rearfoot eversion is also likely to occur. However, these potential movements that could have occurred during plantar and dorsiflexion of the ankle were not controlled. We also realize that our sample size was small, and as such, our findings are relatively preliminary in nature. Finally, interrater reliability was not analyzed in our study. Therefore, future studies are needed to control all these parameters. Also, it would be interesting to know how the medial and lateral plantar nerves change with motion and weightbearing, deep to the abductor halluces, in the calcaneal tunnels distal to the porta pedis, which could be the focus of future studies.

In conclusion, this study demonstrated in vivo and noninvasively (ultrasound) in healthy subjects that ankle joint position determined significant changes in the shape and dimensions of the tibial nerve at the tarsal tunnel. The APD of the tarsal tunnel increased during the plantarflexion and decreased during dorsiflexion of the ankle. The effects reached the tibial nerve, whose morphology was altered at both plantarflexion and dorsiflexion. A decrease in the CSA of the tibial nerve was observed during the dorsiflexion, whereas CSA of the nerve increased during the plantarflexion. We also believe that the results of this investigation could be used in the development of future studies that focus on the same or similar conditions.

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