Plantar fascia is a major contributor to arch support. Foot function has been compared with the engineering structures of an arched beam and truss, with the plantar aponeurosis working as a resistive tie.\(^1,2\) Many in vitro studies\(^3-6\) on plantar fascia have consistently shown strong evidence of its importance in the stability of the foot. All of these studies have pointed to the plantar fascia as a major contributor to three-plane stability of different tarsal joints, although its contribution to arch stability was more substantial in some feet than in others. Computational models have also predicted a decrease in arch height after plantar fasciotomy,\(^7\) with dramatic increases in the tensile forces of the plantar ligaments and in the compressive forces in the dorsal aspect of foot bones.\(^8,9\)

Overload of the plantar fascia with increased tensile forces is the most widely accepted theory of plantar fasciitis. It is thought that repeated strain can produce microtears and subsequent inflammation on its insertion, commonly seen as an increased thickness of plantar fascia on ultrasonographic evaluation. Although it has identified some conditions that predispose to increased tension of the plantar fascia during weightbearing,\(^10,11\) plantar fascia biomechanics is not fully understood, and specific factors producing tensile overload of the plantar fascia are still unknown.
controversial. To address this issue, some studies have tried to quantify plantar fascia tension in different situations. However, because of the invasive technique of measuring plantar fascia in in vivo conditions, most studies have used specimens to measure plantar fascia strain. The load-bearing role of plantar fascia has been studied in vitro conditions dynamically, showing a gradual increase in plantar fascia tensile force during the stance phase, with a maximum tension that averages 0.96 times body weight. Ward et al also identified a peak of maximum strain on plantar fascia just after heel off during in vitro simulated walking. Plantar fascia tension has shown good positive correlation with Achilles tendon loading, and dorsiflexion of the toes tightens the plantar fascia, which increases the effect that the tensile forces in the tendo Achillis has on the tensile strain in the plantar fascia. Cheung et al estimated that the Achilles tendon load has approximately twice the straining effect on the plantar fascia as does the body weight. All of this research has added valuable information despite its limitations because of the cadaveric nature of the studies.

At the same time, sonography is now a widely accepted method for the diagnosis of plantar fasciitis. Several studies have consistently revealed significant differences in plantar fascia thickness in patients with plantar fasciitis compared with control groups. Some studies reveal no differences in plantar fascia thickness on the asymptomatic side of patients with unilateral plantar fasciitis compared with controls, although others do, showing a small but significant increase in thickness on the asymptomatic side of patients with unilateral plantar fasciitis compared with controls. The latter may suggest that the causative factors inducing plantar fasciitis, either anatomical or mechanical, might affect both heels and would explain the increased thickness on the asymptomatic side of patients with unilateral plantar fasciitis. Uzel et al also recently showed a moderate correlation between body mass index (BMI) and athletic activity with plantar fascia thickness at distal locations in healthy young adults; and in a previous study, we found weight to be an independent predictor of plantar fascia thickness in young healthy adults. Huang et al also showed that flexible flatfoot has great plantar fascia thickness compared with nonflatfooted control subjects. All of these studies suggest that overload of the plantar fascia could cause an increase in thickness. However, these increases are small compared with those in plantar fasciitis cases.

Body mass index, decreased ankle range of motion, and foot pronation have been proposed as factors that significantly contribute to increased plantar fascia stress. The aim of our study was to investigate whether these factors are related to increased plantar fascia thickness in asymptomatic subjects 1 and 2 cm distal to its insertion.

Methods

The study group consisted of 51 healthy, asymptomatic volunteers originally recruited from the undergraduate student population at Universidad Europea de Madrid, Madrid, Spain. All of the potential subjects were briefly interviewed to determine whether they met the inclusion criteria. The exclusion criteria for the study included the presence of pain on the heel before data collection, a previous diagnosis of plantar fasciitis, evidence of neural impingement with loss of sensory sensation, diabetes mellitus, inflammatory joint disease, a history of foot surgery, and current treatment with foot orthoses or braces. Written consent was obtained from all of the study participants after verbal and written explanation of the project.

Recruited subjects underwent ultrasonographic and physical examinations on the same day by two different clinicians (J.P.H. and J.M.A.G.). This study had a blinded design so that both clinicians were unaware of the condition of the subject during the examination. Subjects underwent the sonographic evaluation first and the biomechanical examination second. Data were recorded on different sheets and were put together at the end of the research.

All of the ultrasonographic examinations were performed by a radiologist (J.M.A.G.) with broad experience in foot and ankle sonography. Real-time ultrasound was performed with a 10-MHz linear array transducer (SSD-900; Aloka Inc, Wallingford, Connecticut). Patients were positioned prone with knees flexed 90° during the sonographic evaluation. Sonographic jelly was applied between the transducer and the plantar heel, and dorsiflexion of the toes was occasionally performed to stretch the plantar fascia and allow easier delineation of its margins. Longitudinal sonograms of the central band of the plantar fascia were obtained. The thickness of the plantar fascia was measured at two different locations in each subject: 1 and 2 cm distal to the insertion point of the plantar fascia on the calcaneus (Fig. 1). Alterations in echogenicity were also recorded.

The physical examination was performed to determine BMI (calculated as weight in kilograms divided by the square of the height in meters), ankle joint dorsiflexion range of motion, and degree of foot pronation in static stance. All of the examinations were performed by the same clinician (J.P.H.), with broad
pronated position in static stance (ie, $0^\circ$ means maximal pronation position in stance, $2^\circ$ means $2^\circ$ away from its maximal pronation position, etc). Foot pronation was also measured with a standard international goniometer marked in $1^\circ$ increments.

Results are expressed as mean ± SD. An unpaired Student $t$ test was used to calculate data analysis for age, mass, and height for men and women. A paired Student $t$ test was used to compare plantar fascia thickness 1 and 2 cm distal to the insertion locations. Pearson correlation analysis was used to determine the correlation between plantar fascia thickness at 1 and 2 cm distal and BMI, ankle dorsiflexion range of motion, and foot pronation in static stance. Differences were considered significant at $P < .05$. Statistical analysis was performed with a software program (SPSS version 12.0; SPSS Inc, Chicago, Illinois).

Results

A total of 102 feet of 51 healthy, asymptomatic subjects (17 men and 34 women) were enrolled in this study. The mean subject age was $26.82 ± 8.56$ years (range, 19–40 years). There was no significant difference in age between men and women ($P = .184$). Mean BMI values for men and women were $26.45 ±$
3.49 and 22.27 ± 2.58, respectively (P < .001). Differences in BMI between the two groups were significant (Table 1).

No statistically significant differences in plantar fascia thickness were found between 1 cm distal to the insertion (2.70 ± 0.68 mm; 95% CI, 2.56–2.83 mm) and 2 cm (2.62 ± 0.68 mm; 95% CI, 2.49–2.76 mm) (Table 2). Correlation analysis revealed a moderate positive correlation between BMI and plantar fascia thickness at the two locations 1 and 2 cm distal to the insertion. There was no correlation between ankle joint dorsiflexion and plantar fascia thickness at the 1- and 2-cm locations. Foot pronation had no correlation with thickness at 1 cm and an inverse weak correlation at 2 cm (Table 2). Qualitative changes in echogenicity and perifascial fluid collection were not found in any of the subjects.

**Discussion**

High-resolution ultrasonography is an ideal and noninvasive diagnostic imaging modality for the evaluation of plantar fasciitis because it provides objective evidence of the presence of inflammation in which increased thickness of plantar fascia is accepted as the diagnostic criterion. Research has shown average thicknesses that vary from 2.9 to 6.2 mm in symptomatic plantar fasciitis feet, although most of the studies have an average thickness of 5.2 to 5.9 mm. Control subjects and asymptomatic feet in unilateral plantar fascitis cases showed average thicknesses that vary from 2.2 to 3.9 mm. Thickness in the individuals in the present study was in accordance with that in the literature, with a mean of 2.70 ± 0.68 mm for the 1-cm location and 2.62 ± 0.68 mm for the 2-cm location. However, comparisons of these values are difficult because of differences in instrumentation and the lack of standardization of measurement points in the studies. In this study, plantar fascia thickness did not show differences in nonpainful subjects 1 and 2 cm distal to its insertion point. We also found a moderate correlation between plantar fascia thickness and BMI 1 and 2 cm distal to the insertion, no correlation with ankle joint dorsiflexion range of motion, and an inverse correlation with foot pronation at the 2-cm location.

The BMI was related to plantar fascia thickness at the 1-cm (P < .001; r = 0.444) and 2-cm (P < .001; r = 0.396) locations, with a moderate positive correlation (Table 2). The results of our study are in accordance with those of Uzel et al., who hypothesized that this correlation could be attributed to body height, which has a constitutional effect on plantar fascia thickness, more than the overload effect that a large BMI has on plantar fascia. However, a recent multivariate regression study found weight to be an independent predictor variable of plantar fascia thickness at different locations, whereas height did not emerge as an independent predictor. This study suggests that the correlation between BMI and plantar fascia thickness could be attributed to the overloading effect that weight has on plantar fascia. Although we found a positive moderate correlation between plantar fascia thickness and BMI, it is not possible from our study to know whether the relationship between BMI and plantar fascia thickness is the result of the constitutional effect that a large BMI has on plantar fascia or of the overloading effect that weight has on plantar fascia thickness.

Riddle et al. stated that limited ankle joint dorsiflexion plays a more important role in plantar fasciitis than BMI and prolonged weightbearing at work. So, subjects with decreased ankle dorsiflexion were supposed to have great tension of the plantar fascia during bipedal standing. In this study, we did not find a relationship between plantar fascia thickness at the 1- and 2-cm locations and decreased ankle joint dorsiflexion in healthy subjects. It seems that limited ankle joint dorsiflexion has no effect on plantar fascia thickness at distal locations in healthy subjects.

### Table 1. Age, Height, Weight, and BMI of the Study Subjects by Sex

<table>
<thead>
<tr>
<th></th>
<th>Men (n = 34)</th>
<th>Women (n = 68)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>28.4 ± 8.4</td>
<td>26.4 ± 3.5</td>
<td>.184</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>176.4 ± 6.6</td>
<td>162.4 ± 5.7</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>82.41 ± 12.61</td>
<td>58.90 ± 7.84</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>BMI</td>
<td>26.45 ± 3.49</td>
<td>22.27 ± 2.58</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

### Table 2. Correlation Between Measurements and Variables

<table>
<thead>
<tr>
<th></th>
<th>1 cm</th>
<th>2 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness (mean ± SD) (mm)</td>
<td>2.70 ± 0.68</td>
<td>2.62 ± 0.68</td>
</tr>
<tr>
<td>BMI</td>
<td>P &lt; .001*</td>
<td>&lt; .001*</td>
</tr>
<tr>
<td></td>
<td>r 0.444</td>
<td>0.396</td>
</tr>
<tr>
<td>Ankle motion</td>
<td>P .324</td>
<td>.467</td>
</tr>
<tr>
<td></td>
<td>r −0.046</td>
<td>0.098</td>
</tr>
<tr>
<td>Foot pronation</td>
<td>P .081</td>
<td>.031*</td>
</tr>
<tr>
<td></td>
<td>r 0.133</td>
<td>0.186</td>
</tr>
</tbody>
</table>

Abbreviation: BMI, body mass index (calculated as weight in kilograms divided by the square of the height in meters).

*P < .05.
Pronation has been proposed as a risk factor for plantar fasciitis. Hicks\textsuperscript{28} demonstrated that the windlass mechanism creates a subtalar joint supination moment. Ward et al\textsuperscript{13} confirmed this in their study showing that gradual sectioning of the plantar fascia decreases the supinating capacity of the foot, pointing out the supination moments created by the plantar fascia during the stance phase and propulsion. However, our study showed a weak inverse correlation between foot pronation and plantar fascia thickness 2 cm distal to the insertion of the plantar fascia \((P = 0.031; r = 0.186)\), which means that the more supinated the feet, the thicker the plantar fascia 2 cm from its insertion, and, conversely, the more pronated the feet, the lower the thickness at this location. No correlation was found at the 1-cm location. One possible explanation for this finding could be related to the effect that cross-sectional area of plantar fascia has on foot mechanics. Increased thickness of plantar fascia would increase tensile stiffness of the plantar fascia, would make the foot more resistant to pronation moments, and would make the foot rest in a more supinated position during static stance for the same given load. Decreased thickness of plantar fascia would decrease tensile stiffness of the plantar fascia, would make the foot less resistant to pronation moments, and would make the foot work in a more pronated position in static stance for the same given load.

It makes sense that plantar fascia with a thinner cross-sectional area would be more subjected to injury than a plantar fascia with a thicker cross-sectional area for the same given plantar fascia tensile load. Our study showed that the more pronated the foot in static stance, the thinner the plantar fascia in healthy young adults 2 cm distal to its insertion. From these results, we could hypothesize that for the same given plantar fascia tensile load, the plantar fascia of pronated feet tend to be more vulnerable than the plantar fascia of supinated feet. This hypothesis could explain the relationship shown in clinical practice between plantar fasciitis and foot pronation. However, this finding is contrary to our first hypothesis of the research that risk factors such as foot pronation increase plantar fascia thickness in healthy young adults because of increased plantar fascia tensile forces.

The main limitation of the study comes from the fact that plantar fascia thickness has been related to pathologic abnormalities of the plantar fascia in symptomatic subjects but not in healthy subjects. It does not seem that the first hypothesis could be supported from this study in that overloading factors of plantar fascia can cause an increase in thickness in asymptomatic subjects, except for the BMI factor. However, as we mentioned previously herein, the correlation seen between BMI and plantar fascia thickness could be attributed to the constitutional effect that body height has on plantar fascia thickness, as Uzel et al\textsuperscript{21} pointed out. More studies are needed to determine the effect of increased strain in the plantar fascia sonography in feet with and without plantar fasciitis.

Lemont et al\textsuperscript{20} pointed out that the histologic findings of plantar fasciitis are consistent with a degenerative process of a true tendinosis. At the same time, several sono graphic studies\textsuperscript{16, 17} have shown echogenicity changes of hypoechoic fascia. Hypoechoic fascia is analogous to that seen in tendinosis, and it is related to an underlying reparative process of microtears. In these asymptomatic subjects, we found no alterations in echogenicity in any subject. In addition, BMI and foot supination had an effect on plantar fascia thickness, but this effect induced only subtle changes in thickness in nonsymptomatic subjects. These results are in contrast with the hypoechoic images and the big increases in thickness seen in patients with symptomatic plantar fasciitis. From a sonographic view, it seems that no “subclinical forms” with hypoechoic and thicker plantar fascia seem to exist in asymptomatic subjects, although they can exhibit several etiologic factors that overload plantar fascia. We believe that the natural history of plantar fasciitis is that of an episode of small rupture or microrupture of the plantar fascia that starts a degenerative process, which is aggravated in individuals with great tensile overload of the plantar fascia. From this study, it could be hypothesized that echogenic changes and big increases in plantar fascia thickness are related to an abrupt, rapid increase in plantar fascia thickness in patients with symptomatic plantar fasciitis only, which is consistent with an incidence of microrupture that initiates a degenerative process that is rapidly aggravated by overload of the plantar fascia.

The clinical reliability of the measurements taken for ankle joint dorsiflexion and foot pronation in our study could be an issue. However, although intrarater reliability of the clinical measurements taken has been shown to be low, intrarater reliability has been shown to be high.\textsuperscript{27} Ample evidence exists for intrarater reliability for passive ankle joint dorsiflexion.\textsuperscript{30} Several studies\textsuperscript{27, 31-33} have demonstrated very good intrarater reliability for goniometric measurement of passive ankle joint dorsiflexion, irrespective of the subject sample, the characteristics of the clinicians, and the measurement technique used. Regarding the measurements taken for the calculation of foot pronation, both of them (maximally pronated off weightbearing and calcaneal stand position) have been shown to be reliable if taken by the same clinician within a short period.\textsuperscript{27, 33-36} Although our method of measurement

\[ P = \text{0.031; } r = 0.186 \]
cannot be considered true subtalar joint pronation, it may provide the examiner with a reliable method for ascertaining subtalar joint position in static stance and enable comparisons among feet. Because all clinical measurements were taken by the same physician, the reliability of the measurements should not be an issue.

**Conclusion**

The BMI has shown moderate correlation with plantar fascia thickness 1 and 2 cm from its insertion in healthy, asymptomatic patients, and foot supination showed weak correlation with plantar fascia thickness 2 mm from its insertion. Ankle range of motion showed no correlation with plantar fascia thickness at the 1- and 2-cm locations. Those changes are small, but they could play a role in plantar fascia strain and in the mechanical behavior of the foot. From the results of this study, it cannot be supported that the overloading factors of plantar fascia cause an increase in plantar fascia thickness seen in asymptomatic subjects. More studies are necessary to fully understand the role of these factors in plantar fascia strain in healthy individuals and in those with plantar fasciitis.

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**Conflict of Interest:** None reported.

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