Ultrasonography features of the intrinsic foot muscles in patients with and without plantar fasciitis: A novel case-control research study

Type
Research paper

Keywords
ultrasonography, foot, musculoskeletal diseases, ankle, plantar fascia

Abstract
Introduction
Plantar fasciitis (PF) is the most common cause of heel pain. This condition was described as a degenerative syndrome associated with pain, lack of functionality and stiffness on the plantar fascia. The aim of the present study was to compare with ultrasound imaging (USI) the thickness and cross-sectional area of the intrinsic foot muscles between individuals with and without plantar fasciitis (PF).

Material and methods
A total of 64 volunteers from 18 to 55 years were recruited for the present study. The sample was divided in two groups: A group, composed of participants diagnosed by PF (n = 32) and B group, composed by healthy participants (n = 32).

Results
USI measurements for FBH CSA (p = 0.035) was decreasing showing statistically significant differences for the PF group, while the QP CSA (p = 0.40) was increasing reporting statistically significant differences for the PF group with respect the healthy group. The rest of the IFM did not show statistically significant differences, however in FHB, FDB, QP and AHB thicknesses and FDB CSA a slightly decrease for the PF group have been observed.

Conclusions
USI measurements showed that the CSA of the FHB muscle is reduced in patients with PF while the CSA of the QP muscle is increased in patients with PF.
Ultrasonography features of the intrinsic foot muscles in patients with and without plantar fasciitis: A novel case-control research study

Abstract:
Objective: the aim of the present study was to compare by ultrasound imaging (USI) the thickness and cross-sectional area of the muscles flexor hallucis brevis (FHB), flexor digitorum brevis (FDB), abductor hallucis brevis (AHB) and quadratus plantae (QP) between individuals with and without plantar fasciitis (PF). Methods: a case-control study was developed in 64 participants and divided in two groups: A, PF group (n = 32) and B, healthy group (n = 32). Results: USI measurements for FBH CSA (p = 0.035) was decreasing showing statistically significant differences for the PF group, while the QP CSA (p = 0.40) was increasing reporting statistically significant differences for the PF group with respect the healthy group. The rest of the IFM did not show statistically significant differences, however in FHB, FDB, QP and AHB thicknesses and FDB CSA showed a slightly decrease for the PF group have been observed. Conclusions: USI measurements showed that the CSA of the FHB muscle is reduced in patients with PF while the CSA of the QP muscle is increased in patients with PF.

Keywords: ultrasonography, musculoskeletal diseases, plantar fascia.
Introduction

Plantar fasciitis (PF) is the most common cause of heel pain. (1) This condition was described as a degenerative syndrome associated with pain, lack of functionality and stiffness on the plantar fascia. (2) In addition, the calcaneal insertion and mid-foot area were the identified as the most common injured locations. Thus, is frequent to find literature with terms: neuritis, subcalcaneal bursitis, calcaneal periostitis or heel spur syndrome. (3) Lemont et al. reported that PF episodes could be associated with or without inflammation. (4) Several authors argued that PF was developed by a repeated trauma, therefore considering an overuse injury. (5) To-date, this condition presented an estimated prevalence of 7% in the general population, reporting bilateral affectation in 30% of the affected patients.

The origin of this condition remains unclear despite an intrinsic and extrinsic risk factors were described, such as an excessive body mass index (BMI), a reduced ankle dorsiflexion, pes panus, pes cavus, Achilles tendon disturbances, overpronation which produce an additional stress and weakness of the intrinsic foot muscles and plantar muscles (6) – intrinsic risk factors – and excessive physical activity, low-quality footwear, inadequate surfaces, walking barefoot (6) – extrinsic factors-. Patients with PF experienced severe pain at the first steps in the morning or after non-activity long periods, such as sleeping or sitting. If this symptoms persists on time, this condition could be developed onto chronic PF which leads an important decreasing in quality of life, negative socially impact and a limited daily activities. (7)

McKeon et al. proposed a concept drawing the parallelism between the intrinsic foot muscles (IFM) and the trunk core muscles, giving the importance of these small foot muscles for the biomechanics and foot structures (arches) stabilization. (8) The IFM and extrinsic foot muscles (EFM) work in a coordinated manner to provide movement and stability of the three flexible arch structures. In this line, the PF and the IFM - hallucus brevis (AHB), flexor hallucis brevis (FHB), flexor digitorum brevis (FDB) and quadratus plantae (QP) - modify the foot stiffness in order to dissipate external forces or transmit the internal force of the EFM to the foot. (9) Thus, these muscles have been subject of study for the diagnosis and treatment of foot disorders, such as PF.

Ultrasound imaging (USI) has been employed to evaluate the muscle architecture, such as thickness and cross-sectional (CSA), related with fascial and muscular disorders.
Regarding the foot and ankle area, Wu et al. reported that USI was a reliable method for the PF assessment. In the same line, Romero et al. showed that the thickness of the plantar fascia at the insertion was reduced in individuals with Achilles tendinopathy compared with healthy subjects. Calvo-Lobo et al. reported thickness alterations of the intrinsic plantar muscles in post-stroke survivals. Furthermore, Calvo-Lobo et al. observed a thickness and CSA reduction of the FHB and AHB in patients diagnosed by hallux valgus evaluated by USI. Moreover, Angin et al. reported an increase in the PF thickness in patients with pes pannus. Franettovich-Smith et al. showed that the assessment of the IFM by USI had high reliability within and between test sessions and thus, was a reliable and clinically feasible method to assess the IFM morphology in weight bearing.

To the authors knowledge, the thickness and CSA of the IFM have not been evaluated in individuals with PF. Thus, the purpose of the present study was to compare the thickness and CSA of the AHB, FHB and QP in participants with and without PF. Our hypothesis suggests that these muscles structures were altered in patients with PF.

Methods

Design

An observational study was developed following the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) specifications from May to August 2021.

Participants

A total of 64 volunteers from 18 to 55 years were recruited for the present study. The sample was divided in two groups: A group, composed of participants diagnosed by PF (n = 32) and B group, composed by healthy participants (n = 32). The enrollment of the participants was developed by a specialized medical doctor with more than 10 years of experience in sport medicine. For the A group participants were recruited if the met the following inclusion criteria: heel pain at least 1 month, pain with tenderness on palpation located in the middle of the plantar fascia or at the medial calcaneal tubercle, pain during the first septs in the morning or after non-weight bearing activities. Exclusion criteria were as follows: fracture, back or lower limb surgery, participants with any systemic disease, pregnancy, infection, plantar orthoses, length discrepancy greater...
than 1 cm, corticosteroid interventions, and also lower limb disturbances within the last year (e.g. ankle sprain, tendinopathy or tarsal tunnel syndrome)(18)

**Sample size calculation**

The sample size calculation was carried out by the G*Power software to measure the difference between the PF and healthy group using the FHB CSA variable of a pilot study (n = 10) that was divided into two groups (mean ± SD): 5 participants with PF (1.46 ± 0.29) and 5 participants for the healthy group (1.65 ± 0.51). For the sample size calculation, a power of 0.80, an α error of 0.05 and an effect size of 0.63 with a one-tailed hypothesis, a power of 0.80, an α error of 0.05 and an effect size of 0.86 with a one-tailed were employed. In conclusion, a sample of 64 was calculated.

**Ethics**

The research ethics committee of Universidad Europea issued a favorable authorization with code number CIPI/20/166 for the present study. All the participants signed an informed consent form before the study participation. In addition, thorough the procedure the Helsinki Declaration for human experimentation has been respected.

**Ultrasonography assessment**

For the ultrasonography assessment an ultrasound system with a high-quality Mindray DC-60 with a 6 to 14 MHz linear transducer (L14-6NE) in B-Mode was employed. All the USI evaluations were performed by the same clinician with more than 3 years of experience in ultrasound imaging. In accordance with the Mickle et al. procedure, for the AHB, FDB, QP and FHB evaluations, subjects were laid in supine position with the knee slightly flexed. (19) Crofts et al. reported a high intra- and inter-rater reliability agreement for the aforementioned USI protocol. (20) The FHB thickness was measured longitudinally along the 1st metatarsal bone at the thickest portion of the muscle (Fig 1A), and after that the transducer was rotated 90° for the CSA at the same location. (Figure 1B). (19) The FDB thickness was measured longitudinally along a line from the medial calcaneal tubercle to the third toe at the thickest part of the muscle (Figure 1C) and, for the CSA the transducer was also rotated 90° at the same location (Figure 1D). (19) In this line, the QP muscle thickness (Figure 1E) and CSA (Figure 1F) were evaluated with the transducer in the same place of FDB and located intimately under the FDB muscle. For the AHB assessment the transducer was placed in the middle line between the origin of the muscle on the calcaneal tuberosity and the navicular
tuberosity (Figure 2A). For the AHB CSA the transducer was placed perpendicular to the longitudinal scanning axis of the foot and the anterior plane of the medial malleolus. (Figure 2B)(19) The final scores were recorded by the mean of 3 repeated values for each measurement with the ImageJ software (Bethesda, MD, USA).

**Statistical analysis**

Statistical analysis was performed by IBM SPSS v.22.0 statistical package (SPSS, Inc. Chicago, IL, USA). To check the normality distribution the Kolmogorov-Smirnov test was employed. A descriptive analysis for the sample was developed. A comparative analysis between the PF and the healthy group was carried out. Mean and standard deviation (SD) and Student t test for independent samples were used for the parametric data. In addition, Levene’s test was developed to evaluate the equality of variances. For non-parametric data, median and interquartile range (IR) and Mann-Whitney U test were developed.

A multivariate analysis was developed employed a linear regression to predict the influence of the descriptive data on the statistically significant outcome measurements. The dependent variables were FHB and QP CSA. The independent variables were group, sex, age, weight, height, and BMI. An α error of 0.05 (95% CI) and a desired power of 80% (ß error of 0.2) were used.

**Results**

According to the table 1, sociodemographic data showed significant differences (p < 0.05) in age, weight, and body mass index (BMI) between the PF and healthy group. Regarding the IFM, USI measurements for FBH CSA (p = 0.035) was decreasing showing statistically significant differences for the PF group, while the QP CSA (p = 0.40) was increasing reporting statistically significant differences for the PF group with respect the healthy group. The rest of the IFM did not show statistically significant differences, however in FHB, FDB, QP and AHB thicknesses and FDB CSA a slightly decrease for the PF group have been observed.

Regarding to the linear regression analysis (Table 3), the prediction model for FHB CSA ($R^2 = 0.122$) and QP CSA ($R^2 = 0.112$) was not determined by the sociodemographic variables.

**Discussion**
The results of this research show that individuals with PF have a decrease of FDB CSA and an increase of QP CSA. In addition, for the PF group FHB, FDB, QP and AHB thicknesses showed a decrease for the PF group with respect to the healthy group. To our knowledge, this is the first study to analyze by USI the differences between PF and healthy participants. Plantar muscles were considered of interest for clinicians and researchers due to the influence in the ankle and foot complex and their relationship with lower limb structures and biomechanics, such as the Achilles tendon.(14) Regarding the IFM and lower limb disturbances, such as Achilles tendinopathy, Romero et al. reported an increase of the FDB thickness, as well as FDB and FHB CSA in subjects diagnosed with Achilles tendinopathy assessed by USI.(21) However, the results of the present study showed a decrease for the FDB CSA muscle that might be explained due to these participants presents a functional deficit in the FDB muscles that had to compensate by the QP muscle (which increases it´s CSA). Plantar fascia was described as a structure capable of works with efficiency with greater loads. Therefore, in cases when there are heavy mechanical load fluctuations, the plantar fascia could be affected, for example, showing changes in the thickness of the plantar fascial in subjects with pes planus.(22) In the same line, Romero et al. reported that the thickness of the plantar fascia at the insertion was reduced in participants with Achilles tendinopathy.(11) Considering the FHB muscle, Calvo-Lobo et al. in a previous research showed a decrease in both thickness and CSA variables in participants with hallux valgus.(23) Nevertheless, our results reported similar values with a smaller thickness and CSA in participants with PF. The fact of soft tissues and muscle alterations were described in IFM were intimately related with disturbances on the ground reaction forces around the joints of the ankle and foot complex, such PF, hallux valgus, Achilles tendinopathy or pes planus. The present work highlighted the importance of the plantar muscles in the foot and ankle complex, however it’s should be considered a very important issue the foot structure, such as the foot arch, who acts a passive system which works in a coordinated manner with the IFM muscles to provide stability in weight bearing positions. Based on this criterion, Mickle et al. argued that disturbances on the medial longitudinal arch could be related with PF, foot overpronation or navicular drop situations.(19) Results of the present study suggest that a decrease of the CSA of the FHB muscle could develop an imbalance on the ankle and foot biomechanics which
The present study might be a starting point to integrate the use of the USI inside the physiotherapist battery test for the musculoskeletal conditions diagnostic and to track the implementation of training and rehabilitation programs. In this line, the assessment by USI of the intrinsic and extrinsic plantar musculature play an important role in patients with PF. According with the aforementioned concept, in the Huffer et al. systematic review, the fact of defined the IFM as a therapeutic target, for example with an exercise program could be benefits on pain and functionality in patients with PF. (24)

**Clinical applications**

The results of the present study do not pretend to provide a cause or explanation about the PF etiology or symptomatology. According to the aforementioned PF, several authors consider the PF a multifactorial musculoskeletal condition. (6)(7) Therefore, the measurement of the IFM by USI as a conventional assessment procedure could be beneficial for the diagnosis and management programs in individuals with PF.

**Study limitations and future studies**

This study has some limitations. First, ultrasonography measurements were not developed by a blinded researcher to the groups. Second, BMI variable was measured by the Quetelet’s formula reporting differences between groups, thus the results of the present study could be influenced. (25) In this line, the weight and BMI differences might be explained by the Quetelet’s index calculation and also that the heaviest participants could load more and increase their connective tissues work (e.g. muscles or tendons). (26)

Additional studies will be needed to gain a better knowledge about the role of the plantar muscles in individuals with PF. Electromyography or dynamometer tools could be clarifying the muscle activation and their influence on the balance and posture. The assessment with M-mode of the muscular activation and inhibition could be useful for to extract more information.

**Conclusions**

USI measurements showed that the CSA of the FHB muscle is reduced in patients with PF while the CSA of the QP muscle is increased in patients with PF. Therefore, the
assessment of the IFM by USI could be beneficial for the diagnosis and management programs in individuals with PF.

References

Fascia Complex in Patients with Chronic Non-Insertional Achilles Tendinopathy: A Case-Control Study. Sensors (Basel). 2019 May;19(9).


**Figure legends**

Figure 1. Ultrasound imaging of the FHB, FDB and QP in longitudinal and transversal view.

Figure 2. Ultrasound imaging of the AHB in longitudinal and transversal view.
Table 1. Sociodemographic data of the sample

<table>
<thead>
<tr>
<th>Data</th>
<th>Plantar fasciitis (n = 32)</th>
<th>Controls (n= 32)</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>43.00 ± 11.00†</td>
<td>31.00 ± 9.50†</td>
<td>.001*</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>76.00 ± 27.00‡</td>
<td>73.00 ± 25.50‡</td>
<td>.028‡</td>
</tr>
<tr>
<td>Height, m</td>
<td>1.71 ± 6.3 *</td>
<td>1.70 ± 9.68 *</td>
<td>.465‡</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>28.02 ± 5.56 *</td>
<td>24.69 ± 5.45 *</td>
<td>.031‡</td>
</tr>
</tbody>
</table>

Abbreviations: BMI, body mass index

* Mean ± standard deviation (SD) was applied.

** Student’s t-test for independent samples was performed.

† Median ± interquartile range (IR) was used.

‡ Mann-Whitney U test was utilized.
Table 2. Ultrasound imaging measurements of the intrinsic muscles thickness and CSA

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Plantar fasciitis (n=32)</th>
<th>Controls (n=32)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Distance (unit)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FHB CSA (cm²)</td>
<td>1.43 ± 0.65 (1.25-1.72) *</td>
<td>1.76 ± 0.56 (1.56-1.96) *</td>
<td>0.035**</td>
</tr>
<tr>
<td>FHB Th (cm)</td>
<td>1.13 ± 0.30 (1.09-1.26) *</td>
<td>1.17 ± 0.15 (1.11-1.22) *</td>
<td>0.552**</td>
</tr>
<tr>
<td>FDB CSA (cm²)</td>
<td>1.57 ± 0.56 (1.48-1.76) *</td>
<td>1.66 ± 0.34 (1.53-1.78) *</td>
<td>0.416**</td>
</tr>
<tr>
<td>FDB Th (cm)</td>
<td>0.68 ± 0.21 (0.64-0.77) *</td>
<td>0.71 ± 0.14 (0.66-0.76) *</td>
<td>0.457**</td>
</tr>
<tr>
<td>QP CSA (cm²)</td>
<td>1.23 ± 0.25 (1.00-1.17) *</td>
<td>1.08 ± 0.33 (1.14-1.33) *</td>
<td>0.040**</td>
</tr>
<tr>
<td>QP Th (cm)</td>
<td>0.74 ± 0.24 (0.69-0.84) *</td>
<td>0.76 ± 0.18 (0.70-0.83) *</td>
<td>0.643**</td>
</tr>
<tr>
<td>AHB CSA (cm²)</td>
<td>2.03 ± 0.72 (1.91-2.36) *</td>
<td>2.01 ± 0.40 (1.86-2.15) *</td>
<td>0.841**</td>
</tr>
<tr>
<td>AHB Th (cm)</td>
<td>1.01 ± 0.28 (0.97-1.11) *</td>
<td>1.02 ± 0.24 (0.96-1.12) *</td>
<td>0.782**</td>
</tr>
</tbody>
</table>

Abbreviations: AHB, Abductor hallucis brevis; CSA, cross sectional area; FDB, flexor digitorum brevis; FHB, flexor hallucis brevis; QP, quadratus plantae.

* Mean ± standard deviation (SD) (minimum- maximum) was applied.

** Student’s t-test for independent samples was performed.

† Median ± interquartile range (IR) (minimum- maximum) was used.

‡ Mann-Whitney U test was utilized.
Table 3 – Multivariate predictive analysis for FHB and QF CSA for patients with plantar fasciitis and controls.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Model</th>
<th>P value</th>
<th>Model R²</th>
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</thead>
<tbody>
<tr>
<td>FHB CSA (cm²)</td>
<td>3.430</td>
<td>0.122</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.140 * Sex</td>
<td>0.348</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.125 * Age</td>
<td>0.077</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.25 * Weight</td>
<td>0.344</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.010 * Height</td>
<td>0.476</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.084 * BMI</td>
<td>0.287</td>
<td></td>
</tr>
<tr>
<td>QP CSA (cm²)</td>
<td>1.351</td>
<td>0.315</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.077 * Sex</td>
<td>0.364</td>
<td>0.112</td>
</tr>
<tr>
<td></td>
<td>-0.125 * Age</td>
<td>0.745</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.25 * Weight</td>
<td>0.545</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.010 * Height</td>
<td>0.961</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.084 * BMI</td>
<td>0.513</td>
<td></td>
</tr>
</tbody>
</table>

*Abbreviations: FHB, flexor hallucis brevis; QP, quadratus plantae
*Multiplay: Group (control = 0; Tendinopathy = 1); Sex (women = 0; men = 1)
Figure 1. Ultrasound imaging of the FHB, FDB and QP in longitudinal and transversal view.
Figure 2. Ultrasound imaging of the AHB in longitudinal and transversal view.