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Sonographic assessment of extrinsic foot muscles in patients with plantar fasciitis: A case-control study

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ABSTRACT

Purpose: Plantar fasciitis (PFS) is the most common cause of plantar heel pain and is reported to affect 10% of the general population at any point in their lifetime. The objective of this study was to determine the differences in thickness and cross-sectional area (CSA) of the tibialis anterior (TA), extensor digitorum longus (EDL), peroneus (PER) muscles and the plantar fascia (PF) thickness between individuals with plantar fasciitis (PFS) and healthy subjects.

Materials and Methods: A total of 80 subjects were collected and divided into two groups: the PFS group (n=40) and the healthy group (n=40). The EDL, TA, and PER muscles thickness and CSA, as well as the PF thickness at calcaneal insertion, 2 cm and 4 cm distal to the insertion, were evaluated by ultrasound in both groups.

Results: EDL thickness (p=0.007) and CSA (p=0.015) as well as PER muscles thickness (p=0.021) and CSA (p=0.005) showed statistically significant differences for a decrease in favour the PFS group. Furthermore, PF thickness (p<0.001) measured at: calcaneal insertion, 2 cm, and 4 cm distal to the insertion showed an increase in the PFS group, showing statistically significant differences.

Conclusion: The thickness and CSA of both the EDL and PER muscles were reduced in the patients with PFS. Moreover, the PF thickness 4 cm distal to the insertion is increased in the patients with PFS and is reported to be greater than 4 mm at calcaneal insertion.

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Introduction

Plantar fasciitis (PFS) is the most common cause of plantar heel pain and is reported to affect 10% of the general population at any point in their lifetime [1]. In United States, 1 million patients with PFS have visited healthcare centers during the period from 1995 to 2000 [2]. PFS is characterized by severe pain over the medial calcaneal tubercle with the first step in the morning or after rest and increases with prolonged weightbearing [3–6]. It affects both genders; however, females are slightly more affected than males [7]. It also affects both athlete and non-athlete subjects [8]. There is controversy about the nature of PFS, which can be either inflammatory or degenerative [9, 10]. It is categorized into two main types according to the locations: insertional (at the calcaneal tubercle) and non-insertional, 1–3 cm distal to the calcaneal tubercle [11].

Although the mechanism of PFS is still unclear, several previous studies revealed that alterations in thickness and echogenicity of PF are observed in patients with PFS [12–15]. Moreover, it is still unknown if the surrounding muscles, such as extrinsic foot muscles, are affected by PFS, despite the fact that Chiquet [16] and Galloway et al. [17] showed that alterations in these muscles are very common in patients with Achilles tendinopathy. Those alterations include changes in the muscles, such as thickness and cross-sectional area (CSA).

The extrinsic foot muscles involving the tibialis anterior (TA), extensor digitorum longus (EDL), and peroneus muscles (PER) play a key role in the foot and ankle biomechanics. For instance, the TA and EDL muscles act in an early stance to allow and control the gradual plantarflexion of the foot [18], whereas the PER muscle has an important role in the ankle joint, acting as plantar-flexor muscles and stabilizers of the subtalar joint [19]. Besides, the PER muscles provide the eversion required to balance the opposing inversion actions [20].

As ultrasound is considered a non-invasive, safe, portable, tolerable, available, and lower cost method as compared to MRI and CT [21–26], it was used to evaluate the thickness and CSA of numerous muscles related to the lower limbs' conditions [24]. For example, Lobo et al. [27] found a reduced PER CSA in subjects with ankle sprains. Moreover, the thickness and CSA of the abductor hallucis brevis and flexor hallucis brevis have been reduced in patients with hallux valgus [28]. In the same context, the vastus medialis muscle was also examined by ultrasound, showing a reduction in thickness in patients with knee osteoarthritis [29]. For the PFS, ultrasound imaging has focused on fascia thickness measurement in patients with and without pathology. Nevertheless, reports of sonographic measurements of the thickness and CSA of the muscles surrounding the PF in patients suffering from PFS are very limited in the literature. Thus, this study was designed to evaluate and quantify with ultrasound imaging the thickness and CSA of the EDL, TA, PER muscles and the thickness of PF between patients with PFS and healthy controls. We hypothesized that in the presence of PFS, the thickness and CSA of the extrinsic foot muscles are reduced.

Materials and Methods

Study design

A matched case-control design was carried out in this study from January 2022 to September 2022. The healthy subjects were matched by age (± years), gender, and BMI (±2 kg/m^2).

Study population and Sampling

A sample of 80 subjects aged 18 years and older was included in the study. Two groups were included in the study: the PFS group (subjects) and the control group (subjects). For the PFS group, the patients were included if they were clinically diagnosed with PFS by an orthopedist or a rheumatologist, had pain on the medial tubercle of the calcaneus > 3 on a visual analogue scale (VAS), had first-step pain after prolonged rest or after waking up in the morning, had pain increase after weight bearing, or had pain in the proximal attachment of the PF or PF thickness measured > 4mm on ultrasound. For the

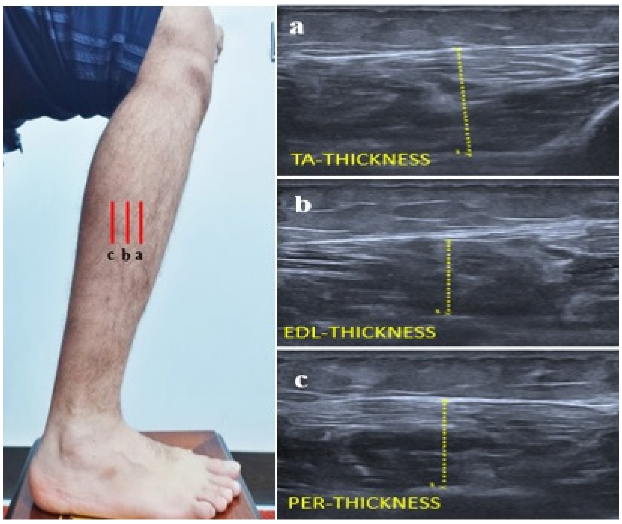

Fig. 1: A longitudinal ultrasound imaging for measuring the thicknesses of the TA (a), EDL (b) and PER (c) muscles.

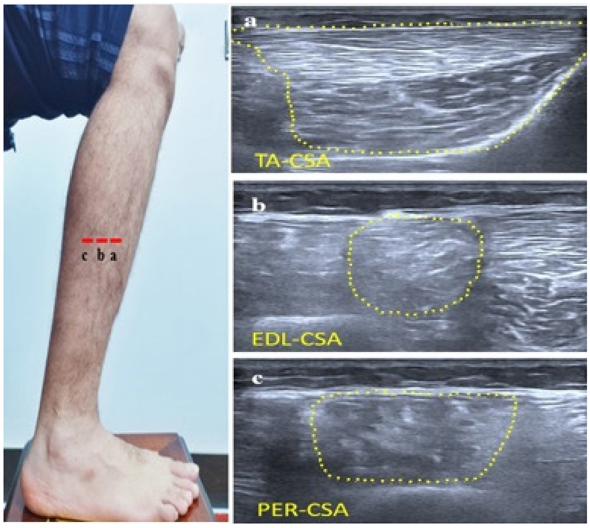

Fig. 2: A transverse ultrasound imaging for measuring the cross-sectional areas of the TA (a), EDL (b) and PER (c) muscles.

control group, subjects who had no symptoms of PFS on clinical examination and had not undergone any type of physiotherapy or any other relevant treatment during the last month. This group includes the visitors to the ultrasound department, academic staff, hospital staff, and relatives. The exclusion criteria included patients with previous surgery or fractures in the foot or ankle joint, pregnancies, patients with fibromyalgia syndrome, patients with tarsal tunnel syndrome, patients with neurologic diseases such as Parkinson's disease and multiple sclerosis, patients with rheumatologic disorders, patients who had received nonsteroidal anti-inflammatory drugs or physiotherapy, patients who had a plantar calcaneal spur, patients who have consumed protein supplements, patients who intake growth hormone supplements, and patients who had weightlifting or squat exercise at least once/week on the last month prior the ultrasound examination.

Sample size calculation

The sample size was calculated based on the equation ($2[(Z_{\alpha/2}+Z_{\beta})\sigma/\Delta]^2$) of mean differences between tendinopathy and control groups using the thickness of the abductor hallucis brevis (AHB) in mm from a previous study. In the tendinopathy group, the mean thickness of AHB was 8.60 mm, and in the control group, it was 7.58 mm. The AHB thickness in the study population had a standard deviation of 1.65 mm. An $_{\alpha}$-error of 0.05 (2-sided), a power (1-$_{\beta}$) = 0.80, $Z_{\alpha/2} = Z_{0.025} = 1.96$, and $Z_{\beta} = Z_{0.2} = 0.842$. Finally, a total sample size of 40 was estimated for each group. However, we could recruit 80 subjects for both groups.

Ethical Approval

Ethical approval from the Educational Medical City Department, Training and Human Development Centre, Ministry of Health, Baghdad, has been obtained (reference number 370 on January 4, 2022). Each respondent was verbally informed about the study, and consent forms were signed by all participants before the start of the study.

Ultrasound imaging and measurements

Two radiologists who have more than 10 years of experience in musculoskeletal ultrasound imaging examined all subjects. ALPINION E-CUBE-15 Platinum, Korea, equipped with a linear probe (3–12 MHz) was used to carry out grey-scale ultrasound imaging. With respect to the extrinsic foot muscles, ultrasound imaging was applied with the subject lying in a supine position. The TA muscle was assessed by placing the probe longitudinally at the midpoint between the head of the fibula and the inferior border of the lateral malleolus (Figure 1a) to measure the thickness, and then the probe was

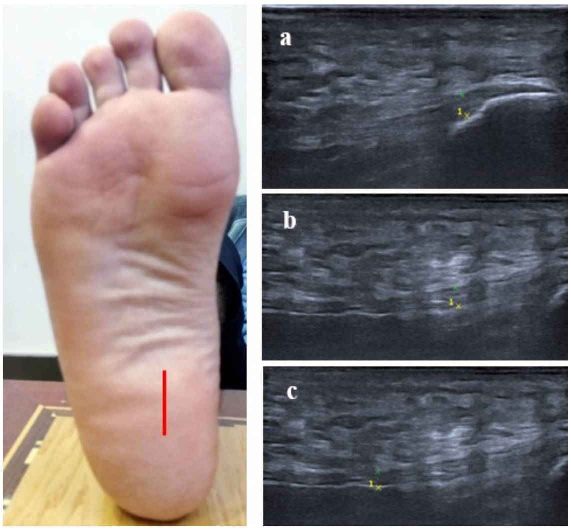

Fig. 3: A longitudinal ultrasound imaging for measuring the thickness of the PF at calcaneal insertion (a), at 2 cm (b) and 4 cm distal to the insertion (c).

turned 90 degrees to this plane to document the CSA (Figure 2a) [30].

For EDL muscle thickness measurement, the probe was placed longitudinally lateral to the TA muscle at the midpoint between the insertion and origin of the muscle (Figure 1b). At the same location, the probe was turned transversely in order to measure the CSA of the muscle (Figure 2b) [22]. For measuring the thickness of PER muscle, the probe was longitudinally placed at the midpoint between the lateral malleolus and the head of the fibula (Figure 1c). After that, the probe was turned 90 degrees in order to measure the CSA of the muscle (Figure 2c) [30].

The PF was scanned in prone position. The PF thickness was measured on the longitudinal scan by placing the probe on the plantar surface of the foot along the line between the medial tuberosity of the calcaneus and the second toe over the PF (Figure 3) [31]. The examiner flexed and extended the subject's big toe while the PF was palpated in order to accurately identify the calcaneal tubercle [32]. The measurement was done at three points: at the calcaneus insertion, 2 cm, and 4 cm distal to the calcaneus. The distance measured from the anterior to posterior edge of the PF was indicated as the thickness of the PF. The thickness in mm and CSA in cm^2 was measured on a frozen image. The final measurement for each muscle was obtained by calculating the average of three repeated measurements.

Statistical analysis

Data were analyzed using the Statistical Package for Social Science (SPSS) programme version 22.0. Continuous variables were reported as mean ± standard deviation (SD) or median (interquartile range, "IQR"), whereas categorical variables were reported as numbers where appropriate. The normal distribution of data was tested by a Kolmogorov-Smirnov test. When the data were normally distributed, independent-samples t-test was used. However, when data were not normally distributed, the Mann-Whitney U test was used. A chi-square test was used to determine the association between categorical variables. A *P*-value of less than 0.05 was considered statistically significant.

Results

Demographic and anthropometric data are shown in Table 1. Statistical analysis demonstrated no significant differences in age (), gender (), weight (0.740), height (0.257), BMI (), and WC () between the PFS group and the healthy group.

For extrinsic foot muscles, data analysis revealed that EDL thickness (), EDL-CSA (), PER thickness (), and PER-CSA () were increased, showing statistically significant differences for the PFS group compared to the healthy group. On the contrary, differences in the TA thickness () and CSA () were not observed to be statistically significant between the two groups. Considering the PF thickness, our results showed an increase in the PF thickness at calcaneal insertion (), 2 cm (), and 4 cm () distal to the insertion for the PFS group, showing statistically significant differences. Besides that, the mean PF thickness in the PFS group was noted to be the greatest (4.8 ±1.4 mm) at calcaneal insertion, followed by (3.8 ±1.6 mm) at 2 cm distal to the insertion, whereas the lowest thickness was (3.3 ±1.8 mm) at 4 cm distal to the insertion (Table 2).

Discussion

The purpose of the present study was to find out if the PFS patients would show differences in PF thickness measured at three main sites: at calcaneal insertion, 2 cm, and 4 cm distal to the calcaneal insertion. Moreover, this study was designed to detect any pos-

Table 1: Comparison of demographic data, anthropometric measures, examined foot and clinical scores between PFS and healthy groups (n=80 patients)

Variables	PFS group (n=40)	Healthy group (n=40)	P-value	Statistic
Age (years)	43.2±12.0 [a]	44.8±11.0 [a]	0.556 [c]	t = -0.591
Gender (male/female)	12/28 [e]	13/27 [e]	0.809 [f]	X^2= 0.058
Weight (Kg)	73.0 ±12.5 [a]	73.8 ±8.7 [a]	0.740 [c]	t=0.333
Height (cm)	169.5 ±17.0 [b]	170.0 ±8.0 [a]	0.257 [d]	U=682.500
BMI (Kg/m2)	25.4 ±4.7 [a]	25.0 ±3.1 [a]	0.650 [c]	t=0.456
WC (cm)	100.0 ±15.0 [b]	95.0 ±17.5 [b]	0.368 [d]	U=707.000
Examined foot (right/left)	21/19 [e]	20/20 [e]	0.823 [f]	X^2 =0.050
VAS - R	7.6 ±1.9 [b]	N/A		
VAS - A	8.2 ±1.8 [a]	N/A		

BMI: Body Mass Index, WC: Waist Circumference, VAS-R: Visual Analog Scale- Rest, VAS-A: Visual Analog Scale-Activity

[a] *mean ± standard deviation (SD) was applied.*

[b] *median ±interquartile range (IQR) was used.*

[c] *independent – samples student's t-test was utilized.*

[d] *Mann-Whitney U test was performed.*

[e] *sample (n)*

[f] *Chi square test was applied*

Table 2: Comparison of ultrasound measurements between PFS and healthy groups (n=80 subjects)

Variables	PFS group (n=40)	Healthy group (n=40)	P-value	Statistic
PF thickness				
at calcaneal insertion (mm)	4.8 ±1.4 [a]	2.6 ±0.5 [a]	<0.001 [c]	t = 9.382
at 2 cm distal to insertion (mm)	3.8 ±1.6 [a]	2.2 ±0.4 [a]	<0.001 [c]	t = 6.075
at 4 cm distal to insertion (mm)	3.3 ±1.8 [a]	2.1 ±0.4 [a]	<0.001 [c]	t = 4.421
EDL thickness (mm)	15.5 ±2.9 [b]	17.0 ±2.3 [b]	0.007 [d]	U=517.500
EDL – CSA (cm^2)	1.85 ±1.06 [b]	2.18 ±0.50 [b]	0.015 [d]	U=548.000
TA thickness (mm)	25.8 ±3.5 [a]	24.7 ±3.9 [a]	0.192 [c]	t = 1.315
TA – CSA (cm^2)	7.00 ±2.17 [a]	6.40 ±1.84 [a]	0.184 [c]	t = 1.340
PER thickness (mm)	15.8 ±2.8 [a]	17.5 ±3.6 [a]	0.021 [c]	t = 2.362
PER – CSA (cm^2)	3.61±1.48 [a]	4.56 ±1.43 [a]	0.005 [c]	t = 2.918

PF: Plantar Fascia, EDL: Extensor Digitorum Longus, TA: Tibialis Anterior, PER: Peroneus muscles, , CSA: Cross Sectional Area, mm: Millimeter, cm^2: Centimeter square,

[a] *mean ± standard deviation (SD) was applied.*

[b] *median ±interquartile range (IQR) was used.*

[c] *independent – samples student's t-test was utilized.*

[d] *Mann-Whitney U test was performed.*

sible differences in the thickness and CSA of the extrinsic foot muscles between patients with PFS and healthy subjects. Thus, this may be considered the first study to compare the morphology of EDL, TA, PER, and PF between patients with PFS and healthy subjects. The foot and ankle biomechanics closely relate to these structures of interest. A previous study by Calhoun et al. [33] showed that the tibia and ankle complex transmitted 83% of the load and the fibula transmitted 17% of it. Therefore, EDL, TA, and PER muscles that are anatomically related to this area are more susceptible to changes in patients with PFS [34]

Regarding the reliability of the ultrasound measurements for EDL, our measures showed that both thickness and CSA were valid to assess the EDL morphology. Similar findings from previous studies showed that extrinsic foot muscles were promptly measured and evaluated with ultrasound imaging [30] [18] [22]. In this context, our results showed a decrease in the thickness and CSA for the PFS group. Carlos Romero-Morales reported a decrease in the thickness and CSA of the EDL in patients with Achilles tendinopathy as compared with healthy subjects. The differences, however, were only noted to be significant for the CSA [22].

For the TA thickness and CSA, our findings showed an increase for the PFS group with no significant differences between the two groups. Resulting from load changes, the TA may act as a compensatory muscle caused by the PFS symptoms and biomechanical alterations due to disturbances at the ankle and foot (e.g., excessive pronation and muscle weakness) in patients with PFS. For example, Maffulli et al. [35] showed that alterations in the foot and ankle biomechanics, such as PFS, could be developed by excessive pronation. Those findings were consistent with findings from a recent study [22], which showed an increase in the TA thickness due to response to excessive loads and mechanical stress in patients with Achilles tendinopathy. Furthermore, Angin et al. [18] revealed an increased thickness and CSA of the extrinsic foot muscles in individuals with pes planus. Besides that, Carlos Romero-Morales [22] showed an increase in thickness and a smaller CSA of the TA in patients with Achilles tendinopathy. Moreover, those adaptations could be explained by the injury site. Lorena Canosa-Carro [34] observed a reduced thickness and CSA in the tibialis posterior in the PFS group with respect to the healthy control group.

The thickness and CSA of the PER muscles were also examined. Our data demonstrated a decrease in the thickness and CSA in favor of the PFS group. Lobo et al. [27] revealed a decrease in the PER-CSA in patients with ankle sprains. Furthermore, Murley et al. [19] found a reduction in the PER muscle in patients who suffered from pes planus. With the presence of pathology in the PER muscles, the ankle supinator muscles enhance their action [19]. Carlos Romero-Morales [22] stated that PER thickness and CSA were decreased in patients with Achilles tendinopathy. Therefore, it could be an important structure for the treatment and diagnosis of patients with foot and ankle pathology such as PFS and Achilles tendinopathy. The present study confirmed that conventional ultrasound is reliable for diagnosing PFS. Our results were compatible with the previous reviews in which the PF thickness greater than 4 mm was considered to be indicative of PFS [36, 37]. In this line, the present study showed an increase in PF thickness in those with PFS not only at calcaneal insertion but also along the first 4 cm distal to the insertion. However, the thickness at the calcaneal insertion was observed to be more increased than at other sites. As there are no particular guidelines about how metatarsophalangeal joints should be positioned during a PF scan [38], a lack of standardization in ultrasound imaging can limit measurements. Therefore, the patients were instructed to put the foot under examination in a relaxed position to reduce the errors caused by muscle tension [39]. In the meantime, the PF thickness was noted to reduce in patients with Achilles tendinopathy [40, 41].

The present study was not designed to explain the etiology of the PFS. There are several studies that consider the causes of this condition multifactorial [42], proposing to provide an ultrasound-based method of evaluating and quantifying the soft tissue structures surrounding the PF in patients with PFS. Many authors documented the role played by clinicians in the diagnosis of PFS combined with complementary diagnostic imaging such as ultrasound [22, 43, 44]. Moreover, due to the observational study design, this study only provided knowledge about the differences and does not support the idea that the results could be caused by PFS. Thus, an additional cohort study design is needed to determine the cause-and-effect relationship.

There are some limitations in this study. First, this study did not use M-mode, which is useful in providing more information about soft tissue and muscle features. Second, the individuals in this study suffered from PFS, and this condition could limit our possibility of generalizing the present findings to patients with other lower limb conditions. Further studies are required to use elastography to quantify and evaluate muscle elasticity [45]. Lastly, future studies also need to develop our knowledge about the importance of the extrinsic foot muscles in PFS.

Conclusion

The thickness and CSA of the EDL and PER muscles were significantly decreased in PFS patients. Regarding TA muscle, thickness and CSA were slightly increased in patients with PFS, showing no statistically significant differences. The mean thickness of PF was increased in patients with PFS, reported to be greater than 4 mm at calcaneal insertion. **R**

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