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Original Research

Intrinsic foot muscles morphological modifications in patients with Achilles tendinopathy: A novel case-control research study

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ABSTRACT

Objective: To compare the thickness and cross-sectional area (CSA) of the Abductor Hallucis Brevis (AHB), Flexor Digitorum Brevis (FDB) and Flexor Hallucis Brevis (FHB) in subjects with and without chronic mid-portion Achilles tendinopathy (AT).
Design: A case-control research study.
Setting: A private clinic.
Participants: A total sample of 143 subjects was recruited for the study and divided in two groups, such as chronic mid-portion AT group (n = 71) and healthy group (n = 72).
Main outcome measures: Ultrasound B-Mode imaging was used to measure the thickness and CSA of the AHB, FDB and FHB in subjects with and without chronic mid-portion AT at rest.
Results: USI measurements of the AHB ($p < .001$) and FDB ($p < .001$) thicknesses, as well as FDB ($p = .005$) and FHB CSA ($p = .048$), were increased for the tendinopathy group with respect to healthy group. However, FHB muscle thickness ($p < .001$) increases were showed for the control group with respect the tendinopathy group.
Conclusions: USI measurements of ABH and FDB thicknesses, as well as FDB and FHB CSA, were increased in patients who suffered from AT with respect to healthy group.

1. Introduction

Mid-portion Achilles Tendinopathy (AT) may be considered as a common overuse injury of the lower limb (Alfredson, 2003) and one of the most prevalent conditions in individuals who participated in jumping and running sports (Zafar, Mahmood, & Maffulli, 2009). Lopes et al. (Lopes, Hespanhol Junior, Yeung, & Costa, 2012) explain that AT comprised a clinical condition characterized by pain, stiffness, swelling and a lack of functionality in the lower extremity. Recently, this disease presented an incidence rate of 1.16–2.35 per 1000 individuals (Albers, Zwerver, Diercks, Dekker, & Van den Akker-Scheek, 2016). According to Li and Lua (Li & Hua, 2016), AT may be classified into 2 main types depending on its location: mid-portion AT (2–6 cm proximal to the Achilles insertion at the calcaneus) and insertional (at the calcaneus enthesis).

Current research showed that AT condition comprised a failed healing response of the tendon, with few signs of inflammation (Maffulli, Sharma, & Luscombe, 2004). Cook and Purdam (Cook & Purdam, 2009) defined an AT development model divided into 3 stages for a better understanding and management of the tendinopathy: 1) reactive tendinopathy, 2) tendon disrepair and 3) degenerative tendinopathy. These tendinopathy stages were constantly changing and could be influenced by an appropriate load management and exercise intervention programs (Cook & Purdam, 2009). In addition, several authors argued that exercise therapy (i.e.

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optimal loads) was crucial to improve the functions and symptoms in individuals with AT (Alfredson & Cook, 2007) (9). According to Cook and Purdam (Cook & Purdam, 2009), the etiology of the AT seemed to be multifactorial and for example recent studies found changes in the tendon thickness and surrounding structures (i.e. muscles) in response to degenerative mechanisms and loads alterations (Romero-Morales et al., 2019a, 2019b).

Structural alterations have been shown in subjects with AT. Indeed, Romero et al. (Romero-Morales et al., 2019b) observed a cross-sectional area (CSA) decrease in the extensor digitorum longus (EDL), tibialis anterior (TA) and peroneus muscles (PER) in individuals with AT. In addition, a recent study carried out by Romero et al. (Romero-Morales et al., 2019c) showed a plantar fascia (PF) decrease in subjects with AT. Regarding the Achilles tendon structure, an increase of the AT thickness and CSA at the mid-portion was observed in patients with chronic AT (Romero-Morales et al., 2019a).

Intrinsic foot muscles, including abductor hallucis brevis (AHB), flexor digitorum brevis (FDB) and flexor hallucis brevis (FHB), have shown a key role in foot and ankle biomechanics (Headlee, Leonard, Hart, Ingersoll, & Hertel, 2008). These intrinsic foot muscles maintained the medial longitudinal arch and provided a postural control during stance and gait (Chang, Kent-Braun, & Hamill, 2012). Therefore, alterations in these muscles, such as morphological changes, were associated with ankle and foot conditions (Lobo et al., 2016a; lobo et al., 2018; Calvo-lobo et al., 2018).

Ultrasound imaging (USI) has been used to assess the thickness and CSA of the muscles related to fascial and muscular conditions. Regarding the lower limb, Lobo et al. (Lobo et al., 2016a) reported a reduction in the thickness and CSA of the FHB and AHB in individuals with hallux valgus. Furthermore, Lobo et al. (Calvo-lobo et al., 2018) observed thickness changes in the intrinsic plantar muscles of post-stroke survivors with respect to healthy individuals assessed by USI. Lobo et al. (Lobo et al., 2016b) showed a reduction in peroneus longus CSA in subjects with ankle sprain. Angin et al. (Angin, Crofts, Mickle, & Nester, 2014) observed an increase in the PF thickness and CSA in individuals with pes pannus examined by USI. Moreover, Taniguchi et al. (Taniguchi et al., 2015) observed that thickness of the vastus medialis muscle was reduced in individuals with knee osteoarthritis.

To date, the thickness and CSA of the intrinsic plantar muscles have not been observed in patients with mid-portion AT. Therefore, the main purpose of the present study was to compare the thickness and CSA of the AHB, FDB and FHB in subjects with and without chronic mid-portion AT. We hypothesized that these muscle structures were altered in patients with AT.

2. Methods

2.1. Design

An observational cross-sectional study was performed in order to measure the USI intrinsic plantar muscles in patients with AT with respect to healthy matched controls from January to December 2017. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines were followed.

2.2. Sample

A total sample of 143 subjects was recruited for the study and divided in two groups: chronic mid-portion AT group ($n = 71$) and healthy group ($n = 72$). A specialized medical doctor with more than 10 years of experience in sport medicine carried out the enrollment of the participants. Inclusion criteria for the tendinopathy group comprised participants who reported tendon pain at least 3 out of 10 points in visual analogue scale (VAS), soreness and lack of functionality at the mid-portion of the Achilles tendon at least 3 months, participants who were not under physical rehabilitation or pharmacological intervention during the study course (Romero-Morales et al., 2019b). Exclusion criteria comprised surgeries, skin diseases, fractures, foot orthoses, sprains or any disturbance in the lower limb during the last 12 months (Alfredson & Cook, 2007).

2.3. Sample size calculation

G*Power software (21) was employed to calculate the sample size with the main outcome measurement of AHB thickness (mm) of a pilot study ($n = 22$) divided in 2 groups (mean ± SD): 13 subjects with mid-portion AT (9.04 ± 2.74) and 9 individuals for the healthy group (8.04 ± 1.09). The individuals recruited for the pilot study did not included in the full study. For the power calculation an α error of 0.05, an effect size of 0.48, a power of 0.80 and a 2 tailed-hypothesis were employed for the sample size calculation. Finally, a total sample of 140 individuals (70 per group) was calculated. In addition, for the present study we could recruit 143 subjects.

2.4. Ethical considerations

The Ethics Committee of La Princesa Hospital (Madrid, Spain), approved this study (2828A). Informed consent forms were signed by all the participants before the start of the study. The study considered and respect the ethical guidelines for human experimentation and the Declaration of Helsinki (Holt, 2014).

2.5. Data collection and measurements

All USI assessments were performed by the same clinician (P.M.L) with 3 years of specialization and experience. An ultrasound system with high-quality (LogiQ P7, GE Healthcare, UK) with a 4–13 MHz linear transducer (38-mm footprint) for musculoskeletal structures was employed to develop the ultrasound recordings in B-Mode. For the AHB, FDB and FHB measurements, participants were laid in supine position with the hip externally rotated and the knee slightly flexed. All the examinations were performed according to the standardized procedure proposed by Mickle et al. (Mickle, Angin, Crofts, & Nester, 2016) that has been shown to have high intra- and inter-rater reliability (Crofts, Angin, Mickle, Hill, & Nester, 2014). Gel for the ultrasound examination was applied all over the transducer and skin for each measurement place. The thickness of the FHB was measured longitudinally along the 1st metatarsal shaft at the thickest portion of the muscle (Fig. 1A), and for the CSA the transducer was rotated 90° in the same location (Mickle et al., 2016) (Fig. 1B). The thickness of the FDB muscle was longitudinally measured along a line from the medial tubercle of the calcaneus to the third toe at the thickest portion of the muscle (Fig. 1C), and for the CSA the transducer was rotate 90° in the same location (Mickle et al., 2016) (Fig. 1D). In order to measure the thickness for the ABH, the transducer was located between the muscle's origin on the medial calcaneal tuberosity and the navicular tuberosity in a longitudinal section (Fig. 2A). For the CSA measurement, the transducer was located on a scanning line perpendicular to the longitudinal axis of the foot at the anterior facet of the medial malleolus (Mickle et al., 2016) (Fig. 2B). The final measurements were obtained by the mean of 3 repeated values for each measurement. Muscle thickness (mm) and CSA (mm^2) were measured offline with Image J software (Bethesda, MD, USA).

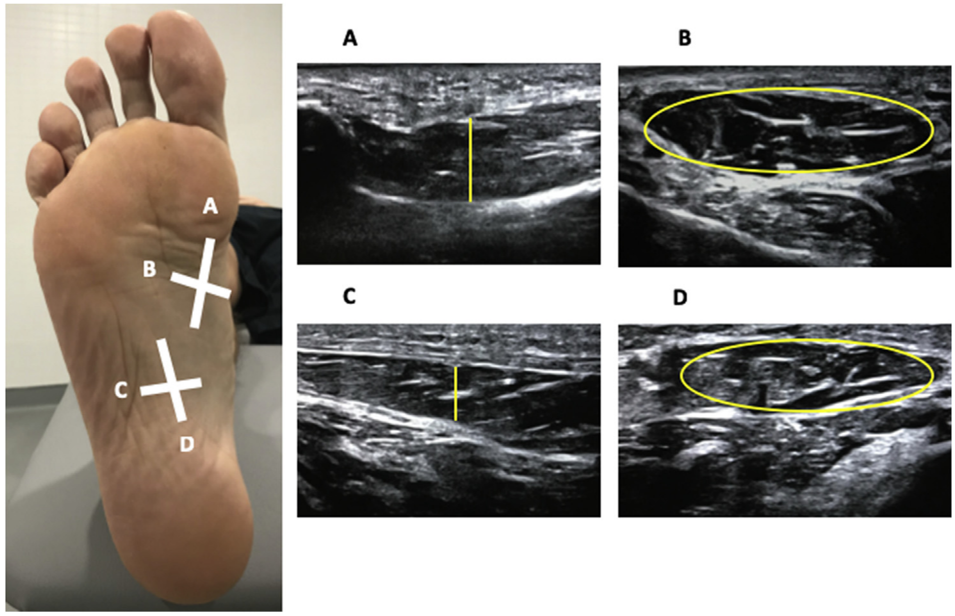

Fig. 1. Ultrasound imaging for the FHB and FDB muscles in longitudinal and transversal view.

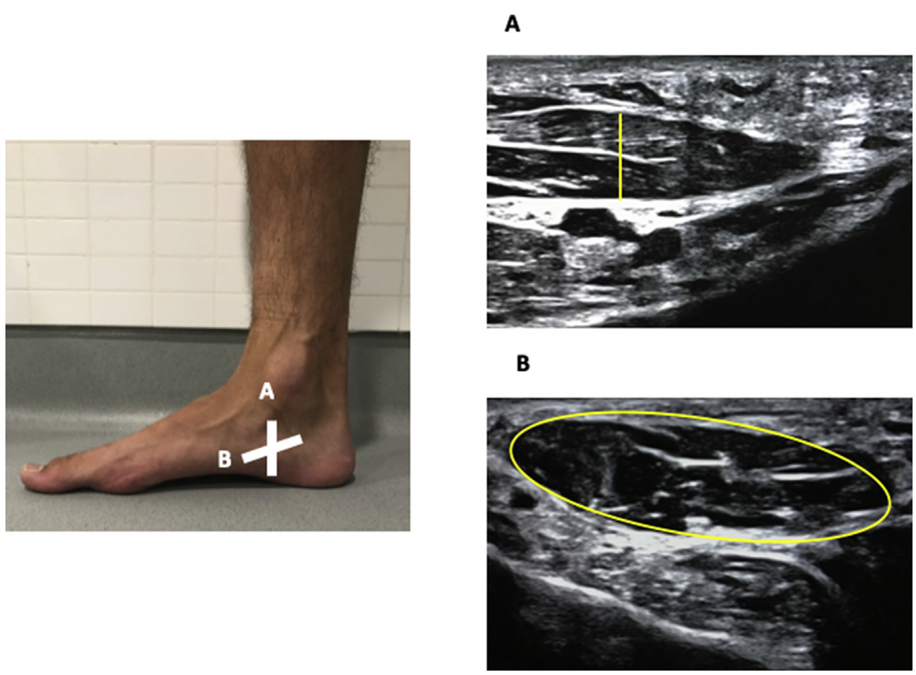

Fig. 2. Ultrasound imaging for the ABH muscle in longitudinal and transversal view.

2.6. *Data analysis*

Statistical analyses were performed by the SPSS software (v.22, IBM; Armonk, NY: IBM Corp.) considering an α error of 0.05 and a β error of 0.2 according to the sample size calculation.

Shapiro-Wilk test was performed to assess the normality (Ghasemi & Zahediasl, 2012). A descriptive analysis was performed for all the individuals and separately in the tendinopathy and healthy group. All data was described using mean, standard deviation, medians and interquartile ranges (IQR). Group differences were examined using an independent *t*-test for parametric data and Mann-Whitney *U* test for non-parametric data.

In addition, A multivariate analysis was carried out by linear regression (stepwise selection method; Pin = .05; Pout = .10) in order to predict the influence of the descriptive data and group (presence of Achilles tendinopathy) on the statistically significant outcome measurements (showed in the prior described analyses). The dependent variables were AHB, FDB and FHB thickness and CSA. The independent variables were group, sex weight, height, BMI and age.

3. Results

Demographic and descriptive data were shown in Table 1. Data

Table 1
Sociodemographic data, pain scores and VISA-A scale of the sample.

Data	Tendinopathy (n = 71)	Controls (n = 70)	*P*-value Cases vs Controls	Statistics	Total sample (n = 141)
Age, y	45.00 (13.00)[a]	35.00 (18.75)[a]	.000[b]	U = 1572.00	40.00 (18.00)[a]
Weight, kg	76.00 (12.00)[a]	75.00 (18.50)[a]	.412[b]	U = 2353.00	75.00 (15.00)[a]
Height, m	1.76 (0.11)[a]	1.76 (0.12)[a]	.566[b]	U = 2414.00	1.76 (0.11)[a]
BMI, kg/m^2	24.81 (2.13)[a]	23.88 (3.67)[a]	.012[b]	U = 1932.00	24.25 (2.96)[a]
VAS	2.00 (3.00)[a]	N/A	N/A	N/A	N/A
VISA-A	56.00 (14.00)[a]	N/A	N/A	N/A	N/A

Abbreviations: VAS, visual analogue scale.
*Mean (SD) was applied.
**Student's *t*-test for independent samples was performed.
[a] Median (IR) was used.
[b] Mann-Whitney *U* test was utilized.

Table 2
Ultrasound imaging measurements.

Measurement	Tendinopathy (n = 71)	Controls (n = 72)	*P*-value	*Statistics*
AHB Thickness (mm)	8.60 (1.88)[a]	7.58 (1.25)[a]	0.000[b]	t = 1.78
AHB CSA (mm^2)	213.99 (59.66)[†]	208.25 (51.13)[†]	0.277[b]	U = 2287.00
FDB thickness (mm)	8.70 (2.32)[a]	7.25 (1.21)[a]	0.000[b]	t = 4.67
FDB CSA (mm^2)	194.97 (42.01)[c]	178.42 (36.95)[†]	0.005[d]	U = 1.866
FHB thickness (mm)	10.11 (1.77)[c]	11.96 (2.97)[c]	0.000[d]	U = 1282.500
FHB CSA (mm^2)	173.53 (32.86)[a]	164.14 (22.22)[a]	0.048[b]	t = 2.00

Abbreviations: AHB, abductor hallucis brevis; FDB, flexor digitorium brevis; FHB, flexor hallucis brevis.
[a] Mean (SD) was applied.
[b] Student's *t*-test for independent samples was performed.
[c] Median (IR) was used.
[d] Mann-Whitney *U* test was utilized.

analysis showed statistically significant differences in age (p < .001) and body mass index (BMI) (p = .012) between the tendinopathy and healthy group, and weight and height did not show statistically significant differences. Considering the intrinsic plantar muscles, USI measurements of the AHB thickness (p < .001), FDB thickness (p < .001), FDB CSA (p = .005) and FHB CSA (p = .048) were increased showing statistically significant differences for the tendinopathy group with respect to healthy group. In addition, the thickness of the FHB muscle showed statistically significant differences (p < .001) for the control group with respect the tendinopathy group. The CSA for the AHB (p = .277) did not show statistically significant differences (Table 2).

According to the linear regression analysis (Table 3), the prediction model for FHB thickness ($R^2 = 0.123$) was determined by age and sex, and also the prediction model for the FHB CSA ($R^2 = 0.467$) was determined by group. The rest of the variables did not predict these statistically differences between AT and healthy group.

Table 3
Multivariate predictive analysis for FHB thickness and CSA for patients with Achilles tendinopathy and controls.

Parameter	Model	*P* value	Model R^2
FHB thickness (mm)	−3.274		0.123
	−0.047[a] Age	0.001	
	+1.419[a] Sex	0.041	
FHB CSA (mm^2)	7.371	0.040	0.467
	−536.069[a] Group		

Abbreviations: FHB, flexor hallucis brevis.
[a] Multiplay: Group (control = 0; Tendinopathy = 1); Sex (women = 0; men = 1).

4. Discussion

To the author's knowledge, this may be considered as the first study to compare the AHB, FDB and FHB between patients with and without chronic mid-portion AT. These structures were of interest, intrinsic foot muscles have a great influence in the ankle and foot complex generating an indirect relationship with the Achilles tendon and its biomechanical behavior (Angin et al., 2014) (24).

For the AHB thickness and CSA, our data showed an increase for the tendinopathy group. Nevertheless, Lobo et al. (Lobo et al., 2016a) reported a decrease for the thickness and CSA of AHB muscle in individuals with hallux valgus. Those findings could be explained by the injury location. Following the same line, Angin et al. (Angin et al., 2014) observed a smaller thickness and CSA of the AHB in individuals with pes planus suggesting that the intrinsic foot muscle may play an important role in the foot and ankle function. Regarding the FDB, the findings of the present study showed an increase of the thickness and CSA whereas previous studies did not shown statistically significant differences in individuals with hallux valgus and pes planus compared with healthy subjects (Angin et al., 2014; Lobo et al., 2016a). Considering the FHB, previous studies showed a decrease in the thickness and CSA in patients with pes planus and hallux valgus (Angin et al., 2014; Lobo et al., 2016a). Nevertheless, our findings showed a smaller thickness and an increased CSA in the tendinopathy group. Those findings were related to compensatory load changes caused for the AT symptoms and biomechanical adaptations due to disturbances at the foot and ankle complex.

There are multiple intrinsic and extrinsic soft tissue structures generating forces around the joints of the foot complex, and were implicated in many foot and ankle disturbances, such hallux valgus, pes planus or lower limb tendon diseases. For example, hallux valgus condition was related with a reduced CSA and thickness of the AHB producing gait disorders and intrinsic muscle compensations (Lobo et al., 2016a). In addition, the relationship between the plantar fascia and the Achilles tendon complex could be influenced in those individuals with pes planus condition (Angin et al., 2014) (12) Maffulli and Kader (Maffulli & Kader, 2002) reported that an excessive protonation was presented in individuals with AT.

Furthermore, foot over-pronation was deeply related to disturbances in the medial longitudinal arch, such as plantar fasciitis or a dropped navicular. In addition, the intrinsic musculature played a crucial role for supporting the medial longitudinal arch (Mickle et al., 2016).

Therefore, changes in the foot and ankle biomechanics were directly related to Achilles tendon disturbances caused by an excessive demand of the intrinsic foot muscles (Romero-Morales et al., 2019b). This research could be a starting point in order to contemplate the important role of the ABH, FDB and FHB muscles in patients with AT. Moreover, the rehabilitation and strengthening of these muscles could have benefits directly related to the AT symptoms (McKeon, Hertel, Bramble, & Davis, 2015).

4.1. Clinical relevance of the findings

According to the association findings of the present study, authors did not try to explain the cause or management for the patients with AT. Several authors consider a multifactorial etiology of the AT (Cook & Purdam, 2009) (8) providing an interesting approach in order to quantify the soft tissues, such as intrinsic foot muscles, in individuals with mid-portion AT by USI.

USI may be considered as a non-invasive, relatively inexpensive and portable technique which may provide a complete assessment of morphology and size of muscle tissue.

4.2. Limitations and future studies

Some limitations should be acknowledged regarding the present study. First, other ultrasonography modes, such as M-Mode were not used in the present study and could provide useful information about soft tissue. Second, elastography has not been included in the present study and may be useful to quantify the muscle stiffness (Karjalainen et al., 1997). Lastly, the participants of the present study were individuals with AT, and this issue may limit our capability to generalize our results with subjects who suffer from other dysfunctions in the lower limb.

5. Conclusions

USI measurements of the ABH and FDB thicknesses, as well as FDB and FHB CSA, were increased in patients who suffered from AT with respect to healthy group. Nevertheless, an increased thickness of the FHB muscle was shown for the control group with respect the tendinopathy group. Therefore, ultrasound abnormalities in the intrinsic foot muscles should be interpreted and explained within the clinical context in patients with AT.

Declaration of competing interest

There are no conflicts of interest or Source of Funding.

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