

Ultrasound evaluation of intrinsic plantar muscles and fascia in hallux valgus

A case-control study

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Abstract

A cross-sectional area (CSA) and thickness reduction of the abductor hallucis (AbH) is shown in subjects with hallux valgus (HV). To date, other soft-tissue structures have not been researched in relation with HV. The aim of this study was to compare the CSA and thickness of the intrinsic plantar muscles and fascia (PF) between feet with and without HV. Therefore, a cross-sectional and case-control study was performed using B-mode with an iU22 Philips ultrasound system and a 5 to 17-MHz transducer. The CSA and thickness were measured for the AbH, flexor digitorum brevis (FDB) and flexor hallucis brevis (FHB), and also the thickness for the anterior, middle, and posterior PF portions. A convenience sample of 40 feet, 20 with HV and 20 without HV, was recruited from a clinical and research center. A multivariate regression analysis using linear regression was performed to evaluate the ultrasound imaging measurements ($\alpha = 0.05$). Consequently, statistically significant differences were observed between the groups ($P < 0.05$) for the AbH and FHB thickness, and CSA reduction, and also the plantar fascia thickness increase in favor of the HV group. On the contrary, the FDB thickness and CSA did not show statistically significant differences ($P \geq 0.05$). In conclusion, the CSA and thickness of the AbH and FHB intrinsic plantar muscles are reduced, whereas the thickness of the anterior, middle, and posterior PF portions are increased, in subjects with HV compared with those without HV.

Abbreviations: AbH = abductor hallucis, CSA = cross-sectional area, FDB = flexor digitorum brevis, FHB = flexor hallucis brevis, HV = hallux valgus.

Keywords: anatomy, cross-sectional, hallux valgus, physical therapy modalities, ultrasonography

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1. Introduction

The toe region comprises the 14% of the nontraumatic foot and ankle consultations in primary care. Indeed, hallux valgus (HV) is 1 of the 10 most frequently documented nontrauma conditions.^[1] The estimated prevalence for HV reaches the 23% in adults aged 18 to 65 years, and increases with age or female sex.^[2] Moreover, HV produces an impact in the quality of life and depression levels, which appears to be associated with their degree of deformity.^[3,4]

Furthermore, pronated foot posture and function are associated with the presence of HV.^[5] Therefore, this condition modifies foot loading and pressure patterns.^[6] The severity of the radiographic first metatarsophalangeal joint osteoarthritis increases with the prevalence of HV, among other demographic and clinical factors.^[7] HV shows a reduction in the cross-sectional area (CSA) and thickness of the abductor hallucis (AbH), independently of the degree of deformity. Consequently, morphological changes to the AbH muscle may occur early in the HV development.^[8] The toe-spread-out exercise is recommended for subjects with mild to moderate HV degree due to the angle reduction and AbH CSA increase.^[9]

Rehabilitative ultrasound imaging (RUSI) has been used to measure the CSA and thickness of the muscles and connective tissue in the locomotor system conditions which influence physical therapy evaluation.^[10] Regarding the intrinsic plantar muscles and fascia (PF), the CSA and thickness of the flexor hallucis brevis (FHB), flexor digitorum brevis (FDB), AbH, and fascia can be used to explain the relationship between foot function and clinical conditions (ie, pes planus).^[11,12] These RUSI measurements showed an excellent intraclass correlation coefficient (ICC) from 0.91 to 0.98.^[11]

To date, the decrease of the CSA and thickness of the AbH in subjects with HV were stated. Nevertheless, RUSI measurements need to be established in the other plantar muscles and fascia of patients with HV. Accordingly, the aim of this study was to compare the CSA and thickness of the FHB and FDB plantar muscles, and also the PF thickness, in feet with and without HV.

2. Methods

2.1. Sample

A convenience sample of 40 feet was recruited at the CARMASALUD clinical and research center, Madrid, Spain (20 feet with HV and 20 feet without HV).^[13] Subjects did not receive any treatment of the foot or forefoot regions in the 6 months before measurements.

The inclusion criteria comprised subjects aged 18 to 65 years with no pain in the leg, ankle, and foot regions (excluding HV region) over the past 6 months.^[11] The exclusion criteria were self-reported, or medical record included fractures, surgeries, tears, sprains, tendinopathies, neuropathies, rheumatoid or systemic conditions, and pharmacotherapy.^[11–13] Regarding the foot and forefoot region, other specific exclusion criteria included prior medical diagnosis of plantar orthoses use, pes planus and cavus, hallux rigidus, plantar fasciitis, heel spurs, Morton neuroma, Sever disease, tarsal tunnel syndrome, or tibial nerve entrapment.^[5,11–14] Considering the anatomical area from the low back to the leg, degeneration or inflammation of the tibial periosteum, meniscopathy, sprains, Baker cysts, bursitis, sciatic nerve entrapments or piriformis syndrome, labral impingement syndrome, or sacroiliac joint dysfunction were also excluded.^[5,11,12,14–20] Furthermore, exercise practice for less than 1 or more than 3 hours per week or high-intensity exercise was excluded due to lower limbs CSA modifications could be produced.^[21]

2.2. Ethical considerations

The Research and Ethics Committee of University of A Coruña (A Coruña, Spain; record number: CE 06/2014) approved the study. Consent informs were signed by all subjects before the beginning of the study. The ethical standards for human experimentation of the Declaration of Helsinki were respected.^[22] The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines were applied.^[23]

2.3. Sociodemographic and descriptive data

The sociodemographic descriptive characteristics were collected: sex (male or female), age (years), weight (kg), height (cm), body mass index (BMI, kg/m²), pain intensity (Numeric Rating Scale), HV side (left or right), HV angle (°), dominant side (left or right), and foot length (cm). These data were collected to assess their relationship with the CSA and thickness of the intrinsic plantar muscles and fascia.^[11,12]

2.4. HV degree

In addition, the same specialized researcher podiatrist (DRS) diagnosed the HV degree using the Manchester Scale.^[23] This scale is a noninvasive method of measuring the grade of HV deformity by means of a standardized photograph set, from grade I (no HV deformity) to grade IV (severe HV deformity). An excellent interexaminer repeatability (kappa coefficient $\kappa = 0.86$) was showed for this 4-point scale.^[24] A high inter-rater reliability

and validity of the HV angle between the photographic measurements and radiographs was demonstrated. Their ICC (>0.96) and Pearson correlation coefficient ($r = 0.96$) were excellent, and also their confidence interval (95% CI) limits of agreement were acceptable. Therefore, the cost and radiation exposure of radiograph use may be avoided.^[25]

2.5. Ultrasound imaging

All RUSI imagines were performed by the same physical therapist (CCL) with 4 years of specialization and experience. This rater was not blind to case or control group assignment during RUSI evaluation. A high-quality diagnostic ultrasound system (iU22; Philips Ultrasound, 22100 Bothell-Everett Highway; Bothell, WA), with a 7 to 17.0-MHz-range linear transducer (L 17–5 Broadband Linear Array type; 38-mm footprint), was used to perform resting B-mode ultrasound imaging.

The probe location (Fig. 1) was marked as proposed by Crofts et al.^[11] and Angin et al.^[12] On one hand, the PF was measured in a longitudinal direction between the medial calcaneal tubercle and the second toe. Three different regions were assessed: the calcaneous insertion (PF-1), navicular tubercle (PF-2), and second metatarsal head (PF-3). On the other hand, the thickness (longitudinal) and the CSA (perpendicular) in the thickest part of the AbH, FDB, and FHB were evaluated on 3 different scanning lines. First, the AbH scanning line was placed between the medial calcaneal tuberosity and the navicular tuberosity. Second, the FDB scanning line was drawn from the medial tubercle of the calcaneus to the third toe. Finally, the FHB scanning line was located longitudinally along the shaft of the first metatarsal.^[11,12] Subjects for whom the limits of the muscles and PF could not be differentiated were excluded.

The RUSI measurements were carried out by the same physical therapist (AGM) with 4 years of specialization and experience using the software (QLAB advanced quantification software; iSCAN 2D) provided with the ultrasound imaging system (iU22; Philips Ultrasound, 22100 Bothell-Everett Highway; Bothell, WA). The mean of 3 repeated values was obtained for each measure.^[11,12]

2.6. Data analysis

The statistical analysis was performed by the SPSS version 22.0 for Windows (IBM SPSS Statistics for Windows; Armonk, NY: IBM Corp) and an α error of 0.05 (95% CI), with a desired power of 80% (β error of 0.2). First, Shapiro-Wilks was carried out to assess normality. Second, all parametric data were analyzed to compare the RUSI measures and the descriptive data (age, weight, height, BMI, pain intensity, HV angle and foot length) by the Student *t* tests for independent samples. The Fisher exact test was used to compare the sex, HV, and dominant side, and also the chi-square test was used to analyze the HV degree. Box-plots were used to illustrate the CSA and thickness RUSI values from the case and control group characteristics.

In addition, a multivariate predictive analysis was carried out by linear regression. Linear regression was performed using the stepwise selection method and the R^2 coefficient to state the quality adjustment. Descriptive data, including age, sex (male = 0; female = 1), weight, height, BMI, pain intensity, foot length, dominant side (left = 0; right = 1), HV angle, HV side (left = 0; right = 1), HV degree (grade I = 0; grade II = 1; grade III = 2; grade IV = 3), and group (control = 0; HV = 1) were considered as dependent variables. The RUSI measures were considered as independent variables.

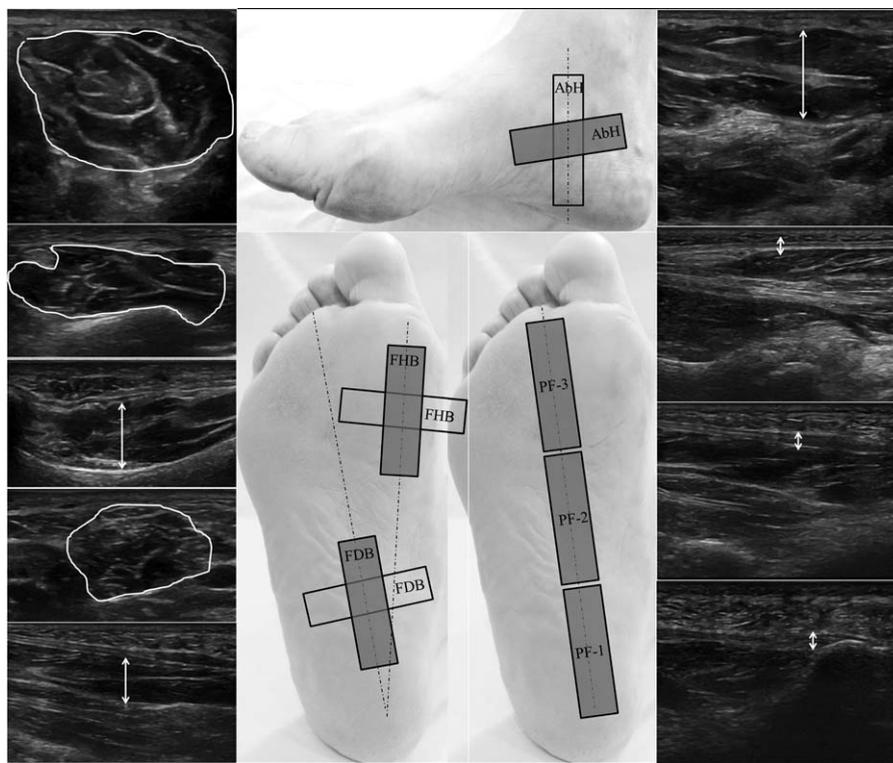


Figure 1. Probe location and ultrasound imaging measurements. AbH=abductor hallucis, CSA=cross-sectional area, FDB=flexor digitorum brevis, FHB=flexor hallucis brevis, HV=hallux valgus, PF-1=plantar fascia at the calcaneous insertion, PF-2=plantar fascia at the navicular tubercle, PF-3=plantar fascia at the second metatarsal head.

3. Results

The descriptive data of the sample characteristics are shown in Table 1. The groups did not differ in sex ($P=0.66$), age ($P=0.27$), dominant side ($P=0.52$), HV side ($P=0.52$), height ($P=0.65$), weight ($P=0.19$), BMI ($P=0.10$), or foot length ($P=0.85$). The pain intensity and HV angle mean \pm SD were 2.59 ± 0.58 and $24.35 \pm 6.09^\circ$ in subjects with HV, respectively. The numbers of grades I, II, III, and IV of HV were 20 (100% without HV), 14 (70% with HV), 5 (25% with HV), and 1 (5% with HV), respectively.

Table 1		
Demographic and baseline characteristics of the subjects *		
Characteristic	Controls (n=20)	HV (n=20)
Sex, female/male [†]	16 (80)/4 (20)	18 (90)/2 (10)
Dominant side, no/yes [†]	9 (45)/11 (55)	12 (60)/8 (40)
HV side, left/right [†]	9 (45)/11 (55)	12 (60)/8 (40)
Grade I HV [†]	20 (100)	N/A
Grade II HV [†]	N/A	14 (70)
Grade III HV [†]	N/A	5 (25)
Grade IV HV [†]	N/A	1 (5)
Pain intensity [‡]	N/A	2.59 ± 0.58
HV angle, $^\circ$ [‡]	N/A	24.35 ± 6.09
Age, y [‡]	42.13 ± 12.19	46.22 ± 11.25
Weight, kg [‡]	63.30 ± 12.18	68.88 ± 14.19
Height, m [‡]	1.65 ± 0.05	1.64 ± 0.10
BMI, kg/m ² [‡]	22.94 ± 3.50	24.76 ± 3.38
Foot length, cm [‡]	39.05 ± 2.32	38.90 ± 2.80

BMI=body mass index, HV=hallux valgus, N/A=not available.
 * Difference between the groups is not statistically significant ($P \geq 0.05$).
[†] Values are the n (%).
[‡] Values are the mean \pm SD.

3.1. Plantar muscles and fascia RUSI changes in subjects with HV

The descriptive data of the RUSI measurements for the CSA and thickness for the muscles and PF of both groups are summarized in Table 2. On one hand, statistically significant differences were observed between the groups ($P < 0.05$) for the AbH and FHB thickness and CSA reduction, and also the plantar fascia (PF-1, PF-2, and PF-3) thickness increase in favor of the HV group. On the other hand, the FDB thickness and CSA did not show statistically significant differences ($P \geq 0.05$). Box-plots to

Table 2			
Ultrasound parameter measurements.			
Parameter	Controls (n=20)*	HV (n=20)*	P
CSA, cm ²			
AbH	2.74 ± 0.64 (1.45–3.59)	2.22 ± 0.49 (1.27–3.16)	$<.01^\dagger$
FDB	1.93 ± 0.41 (1.30–2.87)	1.73 ± 0.41 (1.12–2.59)	.14
FHB	2.13 ± 0.65 (1.08–3.04)	1.57 ± 0.41 (0.75–2.27)	$<.01^\dagger$
Thickness, cm			
AbH	1.10 ± 0.26 (0.60–1.50)	0.91 ± 0.23 (0.54–1.40)	0.02^\dagger
FDB	0.83 ± 0.16 (0.57–1.05)	0.76 ± 0.14 (0.51–1.11)	0.19
FHB	1.09 ± 0.18 (0.81–1.18)	0.93 ± 0.14 (0.69–1.24)	$<.01^\dagger$
PF-1	0.35 ± 0.05 (0.28–0.47)	0.40 ± 0.05 (0.31–0.51)	.01 [†]
PF-2	0.17 ± 0.03 (0.13–0.23)	0.21 ± 0.06 (0.12–0.37)	.02 [†]
PF-3	0.11 ± 0.03 (0.08–0.17)	0.16 ± 0.05 (0.09–0.30)	$<.01^\dagger$

AbH=abductor hallucis, CSA=cross-sectional area, FDB=flexor digitorum brevis, FHB=flexor hallucis brevis, HV=hallux valgus, PF-1=plantar fascia at the calcaneous insertion, PF-2=plantar fascia at the navicular tubercle, PF-3=plantar fascia at the second metatarsal head.
 * Values are the mean \pm SD (minimum–maximum).
[†] Difference between the groups is statistically significant ($P < 0.05$).

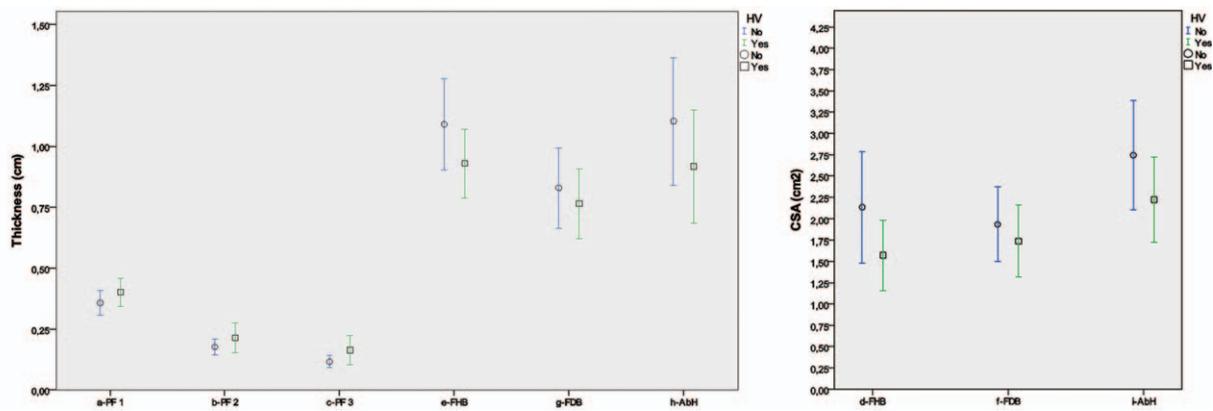


Figure 2. Box-plot to illustrate the thickness and CSA of the ultrasound imaging measurements of the control and HV groups. AbH= abductor hallucis, CSA= cross-sectional area, FDB= flexor digitorum brevis, FHB= flexor hallucis brevis, HV= hallux valgus, PF-1= plantar fascia at the calcaneous insertion, PF-2= plantar fascia at the navicular tubercle, PF-3= plantar fascia at the second metatarsal head.

illustrate the CSA and thickness of the ultrasound imaging measurements of the control and HV groups are shown in Fig. 2.

3.2. Multivariate predictive analysis of plantar muscles and fascia RUSI changes

Regarding the multivariate regression analysis, the linear regression model (Table 3) determined significant differences ($P < 0.05$) for each RUSI measurement. Furthermore, the large R^2 of the prediction model ranged from 0.224 to 0.595.

4. Discussion

To improve the anatomical knowledge, this is the first study that states the resting CSA and thickness of the intrinsic plantar muscles, such as the FDB and FHB, and fascia, at 3 different regions, in subjects with HV.

In addition, previous studies have researched the CSA and thickness of the AbH in this population.^[8,9] In addition, the AbH thickness and CSA (mean \pm SD) varied from 1.13 ± 0.17 to 1.19 ± 0.14 cm and 2.71 ± 0.61 to 3.00 ± 0.46 cm² for different HV degrees, respectively. Independently of the degree of deformity, the AbH thickness and CSA were decreased compared with subjects without HV (1.33 ± 0.2 cm and 3.39 ± 0.56 cm², respectively). Consequently, morphological alterations to the AbH muscle may be developed early in the HV condition. According to Stewart et al,^[8] these results and variation ranges are similar with the present study (Table 2 and Fig. 2).

For plantar muscles and fascia RUSI measurements in healthy subjects, the CSA means \pm SD of 3.03 ± 0.44 , 1.82 ± 0.54 , and 3.17 ± 0.50 cm² for the AbH, FDB, and FHB were determined. In addition, the thickness means \pm SD of 1.27 ± 0.14 , 1.05 ± 0.19 , 1.59 ± 0.29 , 0.29 ± 0.05 , 0.19 ± 0.03 , and 0.13 ± 0.01 cm for the AbH, FDB, FHB, PF-1, PF-2, and PF-3 were established. According to Crofts et al,^[11] these measurements coincide with our research (Table 2 and Fig. 2).

Using the same procedure, Angin et al^[12] found a similar AbH (2.75 ± 0.34 vs 2.36 ± 0.47 cm²), FDB (2.14 ± 0.59 vs 2.20 ± 0.57 cm²), and FHB (2.97 ± 0.46 vs 2.66 ± 0.48 cm²) CSA in subjects without and with pes planus, respectively. Furthermore, a similar AbH (1.27 ± 0.09 vs 1.18 ± 0.11 cm), FDB (0.89 ± 0.17 vs 0.86 ± 0.16 cm), FHB (1.43 ± 0.20 vs 1.30 ± 0.18 cm²), PF-1 (0.33 ± 0.04 vs 0.32 ± 0.05 cm), PF-2 (0.19 ± 0.03 vs 0.16 ± 0.03 cm), and PF-3

Table 3
Multivariate predictive analysis of plantar muscles and fascia ultrasound imaging.

Parameter	Model	R ² change [†]	Model R ²
CSA (cm ²)	AbH	1.087	0.563
		-0.572 sex*	0.201
		-1.033 group*	0.133
		+0.079 BMI*	0.165
		+0.302 HV degree*	0.063
	FDB	2.541	0.476
	-0.828 sex*	0.476	
FHB	1.463	0.548	
		-0.727 sex*	0.306
		-0.587 group*	0.154
		+0.054 BMI*	0.088
Thickness (cm)	AbH	0.214	0.382
		+0.038 BMI*	0.154
		-0.255 group*	0.228
	FDB	0.751	0.388
		-0.232 sex*	0.336
		+0.010 BMI*	0.052
FHB	1.287	0.547	
		-0.202 group*	0.198
		+0.005 weight*	0.209
		-1.350 height*	0.076
		+0.043 foot length*	0.064
PF-1	0.210	0.416	
		+0.001 weight*	0.259
		+0.026 HV degree*	0.157
PF-2	-0.009	0.595	
		+0.024 HV degree*	0.322
		+0.001 weight*	0.159
		+0.001 age*	0.124
PF-3	+0.117	0.224	
		+0.047 group*	0.224

AbH= abductor hallucis, BMI= body mass index, CSA= cross-sectional area, FDB= flexor digitorum brevis, FHB= flexor hallucis brevis, HV= hallux valgus, PF-1= plantar fascia at the calcaneous insertion, PF-2= plantar fascia at the navicular tubercle, PF-3= plantar fascia at the second metatarsal head.

* Multiplay: age (years); BMI (kg/m²); foot length (cm); sex (male = 0; female = 1); group (control = 0; HV = 1); height (m); HV degree (grade I = 0; grade II = 1; grade III = 2; grade IV = 3); weight (kg).

† P value < 0.05.

(0.13 ± 0.02 vs 0.10 ± 0.02 cm) thickness were found in subjects without and with pes planus, respectively. Consistent with Angin et al,^[12] who showed that the CSA and thickness of the AbH (-12.8% and -6.8%) and FHB (-8.9% and -7.6%) muscles were smaller in feet with pes planus, respectively, the AbH (-18.9% and -17.2%) and FHB (-17.2% and -14.6%) muscles CSA and thickness were also smaller in the feet with HV compared with feet without this condition (Table 2 and Fig. 2). In addition, neither pes planus nor feet with HV showed any statistically significant difference ($P \geq 0.05$) in the FDB thickness and CSA. Nevertheless, the middle (-10.6%) and anterior (-21.7%) PF portions were thinner in the pes planus,^[12] whereas the anterior (45.4%), middle (23.5%), and posterior (14.2%) PF regions were thicker in the feet with HV (Table 2 and Fig. 2). Consequently, these values may be used as the relevant clinical differences in the RUSI measurements obtained during clinical interventions of subjects with HV.

4.1. Future studies

Further studies are necessary to improve knowledge about the plantar muscles and fascia changes that may occur secondary to the clinical treatments, such as the therapeutic exercise, of subjects with HV. According to a current practice survey of Australian podiatrists, the nonsurgical management of HV is widely recommended.^[26] Indeed, the toe-spread-out exercise may reduce the HV angle at rest ($-3.41 \pm 3.17^\circ$) and actively ($-6.42 \pm 3.42^\circ$), and also increase the AbH CSA (0.48 ± 0.28 cm²) in subjects with mild to moderate HV degree.^[9]

4.2. Limitations

Several limitations should be considered in the present research. First, a blinded randomized controlled trial was not carried out. Nonsurgical interventional studies in subjects with HV should be considered.^[9,26] Second, different age ranges from 18 to 65 years have not been taken into account. Management strategies across patient age groups with updated clinical guidelines should differentiate between adult and juvenile HV.^[26] Furthermore, the plantar muscles and fascia RUSI measurements need to be stated in the older adults population due to the high HV prevalence.^[2] Third, the bilateral HV may have influenced the quality of life, pain, and related functional status.^[27] Fourth, the rater who carried out the ultrasound imaging was not blinded to case or control group. Nevertheless, the examiner who performed the RUSI measurements was blinded to avoid bias. Finally, more diverse subjects and a larger sample size may be useful to improve the research study strength and identify variation across countries.^[28]

5. Conclusions

The CSA and thickness of the AbH and FHB intrinsic plantar muscles are reduced, whereas the thickness of the anterior, middle, and posterior PF portions are increased in subjects with HV compared with subjects without HV.

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