

Morphological characteristics of intrinsic foot muscles among flat foot and normal foot using ultrasonography

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Purpose: The purpose of this study was to compare the morphology of the intrinsic foot muscle between typical foot and flat foot with the use ultrasound. *Methods:* Thirty-seven healthy participants were recruited in this study. Foot types were classified using the Foot posture index 6-item version. A total of 43 flat feet and 31 typical feet were examined. Using B-mode ultrasound imaging, the morphology of the abductor hallucis, oblique head of adductor hallucis, abductor digiti minimi, and flexor digitorum brevis muscles were measured. Morphology of all muscles measured was normalized by body height. The independent Student's *t*-test was used to examine the differences in the thickness and the cross-sectional area (CSA) of the intrinsic foot muscle among the two groups. *Results:* The thickness of abductor hallucis was significantly larger in flat foot group. The thickness and CSA of abductor digiti minimi and the thickness of oblique head of adductor hallucis were significantly smaller in flat foot group. *Conclusions:* Our results showed hypertrophied adductor hallucis, atrophied abductor digiti minimi, and atrophied oblique head of the adductor hallucis in individuals with flat feet, suggesting a possible tendency to hypertrophy in muscles that are located in a medial position and a possible tendency to atrophy in muscles that are located in a lateral position in flat feet.

Key words: ultrasound, flat foot, foot muscle

1. Introduction

The medial longitudinal arch (MLA) of the human foot is formed by the calcaneus, talus, navicular and first metatarsal bones. It is able to buffer impact force and it contributes to forward propulsion [10]. Flat foot is a postural deformity in which the MLA is lower than usual, and it is generally characterized by an everted rearfoot and abducted forefoot. Flat foot is associated with the development of overuse injuries, such as medial tibial stress syndrome, patellofemoral pain, plantar fasciitis, and Achilles tendinopathy [8], [15], [22]. Therefore, it is important to clarify the function and anatomical characteristics of the structures supporting MLA for a deeper understanding of the flat feet pathology.

The MLA supporting system is divided into two major structures, the static and the dynamic ones. The static supporting structure is formed by the spring

ligament and the long plantar ligament [23]. The dynamic supporting structure includes the tibialis posterior, the tibialis anterior, and the intrinsic foot muscles (IFM) such as the abductor hallucis [21]. The activity of these muscles is important for controlling the collapse of the MLA [5], [7]. The IFM is a small volume muscle and is located directly below the MLA. Mckeon et al. [12] indicated that the IFM has a role in supporting the MLA, similarly as local muscles in the back that contribute to supporting the lumbopelvic complex. Therefore, the muscle volume and strength of the IFM might be reduced in the flat foot with collapsing of the MLA. However, the literature assessing the characteristics of individual intrinsic foot muscles in the flat is lacking [5], [7], [12].

Ultrasonography (US) is a versatile method often used as a non-invasive method to assess muscle morphological features. IFM can be assessed separately by using the US. Some studies compared the IFM

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between flat foot and typical foot [1], [18], [23], but the results obtained so far are controversial. In addition, morphological features such as thickness and CSA are affected by physical characteristics such as height, body weight, and foot length, but previous studies have not taken this variability into account. The purpose of this study was to compare IFM thickness and CSA between the typical foot and flat foot by taking the physical characteristics of participants into account.

2. Materials and methods

Thirty-seven healthy participants (21 male, 16 female) volunteered to participate in this study, for a total of 74 feet. None of the participants reported recent lower limb pain, and none had injuries during the last 3 months before measurement. The Foot Posture Index 6-item version (FPI-6) was used to divide foot type into typical and flat [15]. Specifically, the flat foot was defined as FPI-6 score higher than or equal to 6 points, whereas typical foot was defined as FPI-6

score lower than or equal to 5 points. In total, typical feet were found in 31 individuals (17 male, 14 female) and flat feet in 43 (25 male, 18 female). Only one participant had one typical foot and one flat foot. Participants' characteristics are summarized in Table 1. All participants provided informed consent before participation. The present study was reviewed and approved by the ethical committee (No. 2017-002) at our institution.

Table 1. Baseline characteristics of the flat and normal feet groups

| | Flat feet group (Mean \pm SD) | Typical feet group (Mean \pm SD) |
|----------------------|------------------------------------|---------------------------------------|
| Number [feet] | 43 | 34 |
| Gender [Female/male] | 18/25 | 17/14 |
| Age [years] | 21.7 \pm 3.2 | 20.9 \pm 0.4 |
| Weight [kg] | 58.4 \pm 8.7 | 58.2 \pm 7.1 |
| Height [cm] | 166.1 \pm 9.8 | 165.7 \pm 9.1 |
| Foot length [cm] | 25.5 \pm 1.5 | 24.2 \pm 1.9 |
| FPI-6 score | 8.0 \pm 1.7 | 1.9 \pm 2.6 |

All US measurements were performed with the use of B-mode US imaging system (Aplio300, Canon medical corporation, Tokyo, Japan) with an 18 MHz

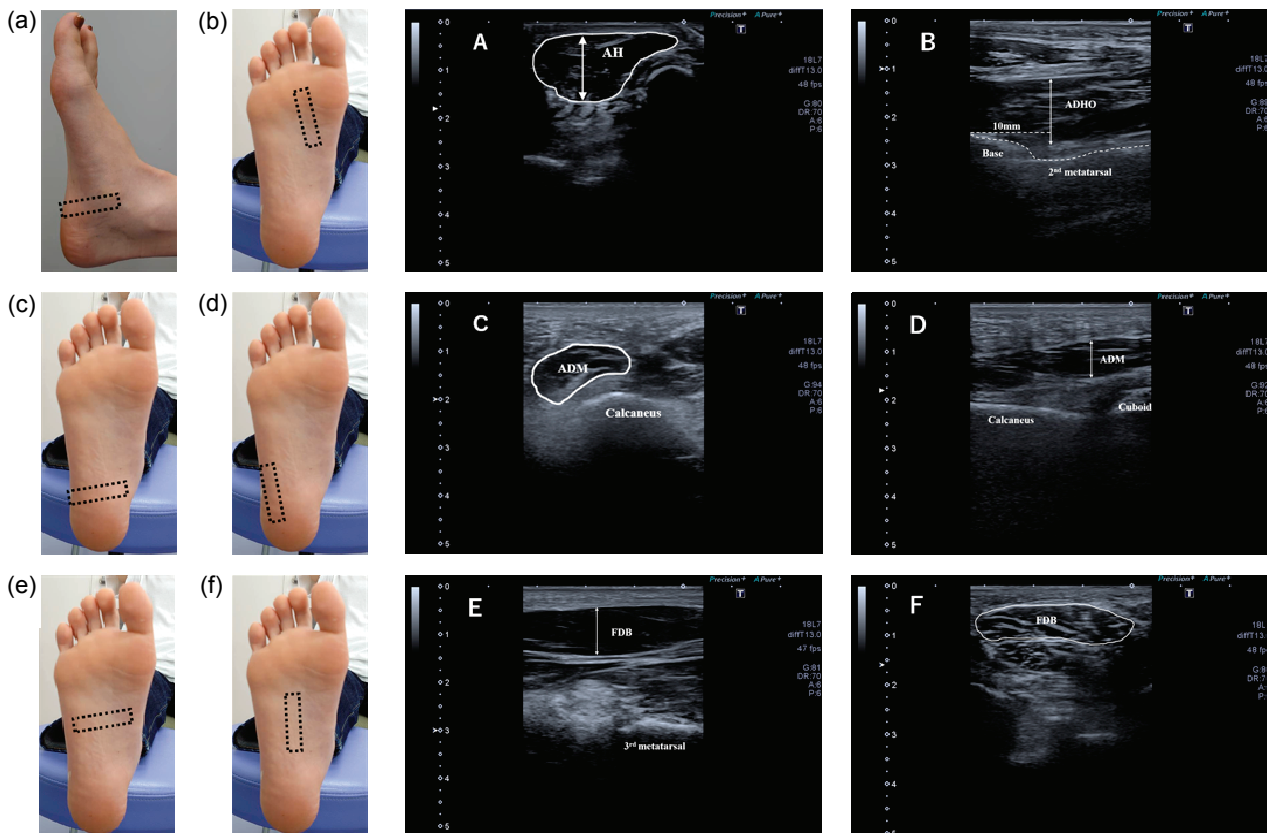


Fig. 1. Transducer position and ultrasound images of the intrinsic foot muscles. AH – abductor hallucis; ADM – abductor digiti minimi; FDB – flexor digitorum brevis; ADHO – oblique head of abductor hallucis. Transducer position of AH at thickness and CSA (A), ADHO at thickness (B), ADM at CSA (C) and thickness (D), and FDB at CSA (E) and thickness (F)

linear transducer (PLT-1204BT). The thickness and CSA of the abductor hallucis (AH), the abductor digiti minimi (ADM) and the flexor digitorum brevis (FDB) muscles were measured while the participants were in the supine position with neutral ankle position and knee extended, according to Mickle et al. [12]. Also, we measured the thickness of the oblique head of the adductor hallucis (ADHO). The CSA of ADHO was not included in the measurement parameters due to the unclear boundary between it and the surrounding tissues. For the AH, the US transducer was placed along a line perpendicular to the long axis of the foot at the anterior aspect of the medial malleolus. The thickness and CSA of AH were measured at the thickest part of the muscle (Fig. 1A). For the ADM, the transducer was placed parallel to the line joining the lateral calcaneal tuberosity and the tuberosity of the 5th metatarsal. Thickness was measured at the calcaneocuboid joint, whereas to obtain the CSA, the transducer was rotated through 90° (Figs. 1B, C). For the FDB, the transducer was placed parallel to the line joining the medial calcaneal tuberosity and the third toe. Thickness was measured on the Lisfranc joint, whereas to measure the CSA, the transducer was rotated through 90° (Figs. 1D, E). The ADHO was imaged by aligning the transducer along the line joining the lateral sesamoid and the 2nd metatarsal base. ADHO thickness, defined as the distance from the superficial fascia to the deep fascia of the ADHO, was measured at 10 mm distal to the 2nd metatarsal base (Fig. 1F). All measurements were repeated three times, and the thickness and CSA were estimated as the average of the three measurements. We also examined test-retest reproducibility in seven of the participants.

All statistical analyses were performed using SPSS statistics version 25 (IBM). The Shapiro–Wilk test showed that all the parameters were normally distributed. Intraclass correlation (ICC) was used to assess the test-retest reliability of the measurement. Specifically, as the same investigator measured the thickness and CSA of muscle in separate sessions at least three days apart, ICC (1, 3) was identified by comparing the measured values on session 1 and session 2. The minimal detectable change with a confidence level of 95% (MDC95) was calculated as follows: $MDC_{95} = \text{the standard error of measurement (SEM)} \times \sqrt{2} \times 1.96$. Before comparing the morphology of IFM, the Pearson's product moments correlation was used to assess the degree of the linear relationship between thickness and CSA of IFM and physical characteristics, including height, body weight, foot length, and truncated foot length (TFL). The thickness and CSA of all mus-

cles were normalized by the body height as it is significantly correlated with all muscle thickness and CSA. The independent samples Student's *t*-test was used to assess possible differences in thickness and CSA of IFM between typical and flat feet. The analysis of group differences and test-retest reliability was performed on both the measured values and the normalized values. A *P*-value < 0.05 was considered statistically significant.

3. Results

The ICC, 95% confidence intervals, and MDC computed across multiple measurement sessions for all muscles, is shown in Table 2. The table shows that the ICC was high for all the measured morphological features (range of 0.87–0.99).

Table 2. ICC and MDC95 of the ultrasound measurement

| | ICC | 95% CI | | Standard error | MDC ₉₅ |
|-------------------------|------|-------------|-------------|----------------|-------------------|
| | | Lower limit | Upper limit | | |
| Measured value | | | | | |
| AH-CSA | 0.99 | 0.03 | 0.02 | 0.05 | 0.08 |
| AH-Thickness | 0.99 | 0.04 | 0.04 | 0.12 | 0.33 |
| ADHO-Thickness | 0.95 | 0.23 | 0.17 | 0.35 | 0.63 |
| ADM-CSA | 0.96 | 0.07 | 0.15 | 0.07 | 0.19 |
| ADM-Thickness | 0.86 | 0.1 | 0.07 | 0.17 | 0.27 |
| FDB-CSA | 0.99 | 0.05 | 0.04 | 0.08 | 0.15 |
| FDB-Thickness | 0.98 | 0.2 | 0.14 | 0.3 | 0.54 |
| Normalized value | | | | | |
| AH-CSA | 0.99 | 0.99 | 0.99 | 0.04 | 0.37 |
| AH-Thickness | 0.99 | 0.99 | 0.99 | 0.13 | 0.10 |
| ADHO-Thickness | 0.94 | 0.83 | 0.98 | 0.12 | 0.25 |
| ADM-CSA | 0.97 | 0.92 | 0.99 | 0.02 | 0.06 |
| ADM-Thickness | 0.87 | 0.65 | 0.96 | 0.09 | 0.25 |
| FDB-CSA | 0.98 | 0.94 | 0.99 | 0.03 | 0.10 |
| FDB-Thickness | 0.99 | 0.98 | 0.99 | 0.09 | 0.33 |

95% CI – 95% confidence interval; ICC – intraclass correlation coefficient; SEM – standard error of measurement; MDC₉₅ – the minimal detectable change with a confidence level of 95%; CSA – cross-sectional area; AH – abductor hallucis; ADHO – oblique head of adductor hallucis; ADM – abductor digiti minimi; FDB – flexor digitorum brevis. The procedure with ultrasound measurements was performed on two different days in seven participants.

Pearson's correlation coefficients between the morphological features (thickness and CSA) of IFM and physical characteristics (height, body weight, foot length, and TFL) are collected in Table 3 and show

that only height had a significant linear correlation with all the muscle morphological features.

Table 3. Correlation coefficient between height, body weight, foot length, TFL, and the muscle thickness and CSA

| | Height | Body Weight | Foot length | TFL |
|----------------|--------|-------------|-------------|------|
| AH CSA | 0.63** | 0.51** | 0.13 | 0.01 |
| AH Thickness | 0.39** | 0.43** | 0.01 | 0.04 |
| ADHO Thickness | 0.27* | 0.21 | -0.26* | 0.20 |
| ADM CSA | 0.36** | 0.21 | 0.04 | 0.13 |
| ADM Thickness | 0.36* | 0.21 | 0.13 | 0.01 |
| FDB CSA | 0.53** | 0.55** | 0.17 | 0.10 |
| FDB Thickness | 0.44** | 0.57** | 0.17 | 0.05 |

Statistical significance: * $P < 0.05$, ** $P < 0.01$.

AH – abductor hallucis; ADHO – oblique head of adductor hallucis; ADM – abductor digiti minimi; FDB – flexor digitorum brevis; CSA – cross-sectional area.

Table 4. Differences (mean \pm standard deviation) in measured thickness and CSA between flat feet and normal foot (upper table: measured values; lower table: normalized values)

| parameters | Typical feet group | Flat feet group | p -value |
|------------------------------|--------------------|------------------|------------|
| Measured value | | | |
| AH-CSA [cm ²] | 2.14 \pm 0.64 | 2.36 \pm 0.51 | 0.13 |
| AH-thickness [mm] | 11.25 \pm 1.94 | 12.86 \pm 1.91 | <0.01 |
| ADHO-thickness [mm] | 13.39 \pm 1.64 | 12.61 \pm 1.71 | 0.06 |
| ADM-CSA [cm ²] | 1.15 \pm 0.33 | 0.95 \pm 0.25 | <0.01 |
| ADM-thickness [mm] | 8.23 \pm 1.16 | 6.68 \pm 1.11 | <0.01 |
| FDB-CSA [cm ²] | 1.96 \pm 0.57 | 1.92 \pm 0.45 | 0.78 |
| FDB-thickness [mm] | 8.18 \pm 1.65 | 8.16 \pm 1.47 | 0.96 |
| Normalized value | | | |
| AH-CSA [cm ² /m] | 1.28 \pm 0.35 | 1.42 \pm 0.26 | 0.08 |
| AH-thickness [mm/m] | 6.78 \pm 1.08 | 7.74 \pm 1.08 | <0.01 |
| ADHO-thickness [mm/m] | 8.10 \pm 1.03 | 7.59 \pm 0.95 | <0.05 |
| ADM-CSA [cm ² /m] | 0.69 \pm 0.19 | 0.57 \pm 0.14 | <0.01 |
| ADM-thickness [mm/m] | 4.97 \pm 0.65 | 4.02 \pm 0.61 | <0.01 |
| FDB-CSA [cm ² /m] | 1.17 \pm 0.32 | 1.14 \pm 0.25 | 0.73 |
| FDB-thickness [mm/m] | 4.92 \pm 0.85 | 4.89 \pm 0.77 | 0.9 |

The muscle morphological features measured in the two groups are shown in Table 4. The thickness of the AH was significantly larger in the flat feet group than the typical feet group for both the measured and the normalized values. The thickness and CSA of the ADM were significantly smaller in the flat feet group compared to the typical feet group for both measured and normalized values. The thickness of ADHO was significantly smaller in the flat feet group for only the normalized values. Further supporting these group differences, the differences in mean values for the AH thickness, ADHO thickness, and the thickness or CSA

of ADM between the two groups were higher than corresponding MDC95. No significant differences in other muscle morphological features were observed between the two groups.

4. Discussion

The findings of this study were that the morphological parameters being measured and body height had significant positive correlation and that IFM morphologies were different between flat feet and typical feet.

This study examined the effects of physical parameters (height, weight, foot length, and BMI) of the subjects on IFM morphology. Tas et al. [19] reported higher weight and BMI related to increased thickness and CSA of IFM (AH, FDB, and flexor hallucis brevis). Larger IFM morphology may be an adaptation to the increased loading caused by higher weight and height. However, the previous study did not examine the effect of height on IFM morphology and did not include ADHO and ADM as measurement parameters. Our results demonstrated significant positive correlations between all the measured morphological parameters and height and therefore suggested that the morphology of IFM is affected not only by weight but also by height. As a result, our study shows that it would be important to consider the physical characteristics of subjects, including their height, to properly address the IFM morphology.

Overall, hypotrophy of the AH and atrophy of the ADM and ADHO in the flat feet group were observed. The difference in morphological parameters of IFM between foot types is still controversial. Angin et al. [1] reported that the thickness and CSA of the AH (which is known to be a strong dynamic stabilizer of the MLA [22]) was smaller in flat feet than in typical feet. In contrast, Zhang et al. [23] and Tas et al. [18] showed that flat feet had larger AH thickness than typical feet. Also, Zhang et al. [23] reported that individuals with flat feet had smaller ADM thickness and CSA than the individual with typical feet. These findings seem to be confirmed by the current study. Moreover, this study showed that the ADHO thickness in flat feet was smaller compared to typical feet.

The AH muscles, which are situated in the most medial side of the plantar surface of the foot, insert proximally on the medial tubercle of the calcaneus and insert distally on the base of the proximal phalanx of the first toe, the medial sesamoid bone, and medial side of the capsula of the first metatarsophalangeal

joint [2]. Therefore, the AH muscles are estimated not only to be abductor of the greater toe, but also forefoot adductor, such as the tibialis posterior. Murley et al. [13] showed an increase in tibialis posterior activity during gait in flat foot. Flat foot deformity was characterized by an everted rearfoot and abducted forefoot. Therefore, the antagonists of forefoot abduction are likely to be required a greater work to resist the collapse of MLA because of flat feet undergo greater loading compared to the typical foot. These mechanisms might contribute to thickened AH and increased tibialis posterior muscle activity.

In the current study, atrophy of the ADM and ADHO were observed in the flat feet group. The ADM inserts proximally on the medial and lateral tubercles of the calcaneus, courses proximal to distal on the lateral foot, and inserts distally on the lateral base of the fifth proximal phalanx [6]. The ADHO inserts proximally on the base of the second through fourth metatarsals and traverses distal medial to insert onto the base of the first proximal phalanx [6]. Therefore, the ADM and ADHO are considered to be the abductor of the forefoot. A previous study reported that the peroneal longus activity decreased during gait in flat feet [13]. In addition, the thickness and CAS of peroneal longus muscle were smaller in flat feet than in typical feet in the previous study. These findings suggest that the forefoot abduction with flattening MLA may result in a reduced activity of the peroneal longus, the forefoot abductor, which may lead to muscle atrophy due to inactivity. Similarly, muscle atrophy resulting from inactivity may occur in ADM and ADHO in flat feet. Also, some previous studies suggested that atrophy of the ADM may be caused by entrapment of the inferior calcaneal nerve, which is the first branch of the lateral plantar nerve [3], [4], [16]. The inferior calcaneal nerve typically arises as a branch of the lateral plantar nerve and posterior tibial nerve, which runs among the AH and quadratus plantar muscle, changes direction vertically, passes the anterior 5 mm of the calcaneal tubercle and innerves the ADM [3], [4], [16]. Entrapment of the inferior calcaneal nerve might be introduced by rearfoot eversion.

In our study, the thickness and CAS of IFM were used as measured parameters. Muscle morphology can be an important indicator of muscle strength. McKeon et al. [11] considered that the IFM are advantageously positioned to provide immediate sensory information via the stretch response about changes in the MLA posture, although the IFM has little mechanical support of the MLA. It is known that muscle morphology affects muscle tension. Morphological changes of the IFM with flattening of the MLA may alter the tension

on the muscle-tendon of the IFM and may affect sensory feedback function. It is important to investigate the relationship between IFM morphology and sensory-motor interaction further.

This study has a few limitations. In this study, only morphological features, such as the thickness and CSA, were described. Thus, we did not assess muscle activity during gait. Moreover, the present study did not evaluate the extrinsic foot muscles. Adding assessment of muscle activity and extrinsic foot muscles in future studies may help understand the pathophysiology of flat feet more clearly. Another limitation is that the study is cross-sectional. Therefore, a causal relationship between flat foot and morphological changes of the IFM cannot be demonstrated. A longitudinal study would be important to examine the relationship between the foot arch and IFM morphology for a deeper understanding of the pathogenesis of flat feet.

In conclusion, our results showed a statistically significant positive correlation between all the measured morphological parameters and body height, increased AH thickness, decreased ADM thickness and CSA, and decreased ADHO thickness in individuals with flat feet. There is the possibility that differences in morphology of IFM are related to their function relative to forefoot.

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