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Role of high-resolution ultrasonography and electromyography in the evaluation of patients with flat foot

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Abstract

Objective: The present work aimed to assess the abductor hallucis (AH) muscle changes using sonographic and electrophysiologic studies in flatfoot patients.

Patients and methods: This study included 60 patients with flatfoot deformity (group I) and 20 age and sex-matched healthy individuals as a control group (group II). The patients were subjected to full history taking, clinical assessment, foot x-ray examination, high-resolution ultrasound, and surface electromyography (EMG) of AH muscle. Using a plain x-ray, Meary’s angle was measured, and severity grading was categorized for the patient group.

Results: The AH ultrasonography revealed a significant difference between patient and control groups regarding cross-sectional area (CSA) (P < 0.05). The EMG of the AH muscle showed a statistically significant reduction in the amplitude of motor unit action potential (MUAP) in patients with flat foot compared with the control group (P < 0.05). No statistically significant differences were found between different severity of the deformity regarding both ultrasound measurements and surface EMG. The AH CSA was significantly correlated with muscle activity (P < 0.05), while there was no significant correlation between AH CSA and severity of deformity (P > 0.05).

Conclusion: Patients with flatfoot showed significant structure and function changes regarding AH muscle. These changes could be assessed using sonographic and electrophysiologic studies.

Keywords: Abductor hallucis muscle, Flatfoot, High-resolution ultrasound, Surface EMG

1. Introduction

Flatfoot (FF) (pesplanus) is one of the most commonly encountered foot deformity; it is a chronic condition in which the medial longitudinal arch (MLA) is reduced, the rearfoot is everted, and the midfoot is abducted and dorsiflexed [1]. FF is reported to be prevalent among about a quarter of the general population [2], with a relatively higher prevalence among females, individuals with obesity [3], and those with large feet [2].

Thus, FF and its associated relatively low MLA have been reported to be associated with common overuse lesions such as Achilles tendonitis, plantar fasciitis, patellofemoral pain syndrome, and posterior tibialis tendon dysfunction [4,5]. The medial longitudinal arch is mainly supported by passive structures such as the plantar ligament and plantar fascia [6]. Nevertheless, the intrinsic and extrinsic foot muscles provide local dynamic support. The intrinsic foot muscles with a small cross-sectional area (CSA) and small moment arms are principally involved in the stabilization of foot arches [7].

The abductor hallucis (AH) muscle is one of the foot muscles that is located most medially in the first layer of plantar intrinsic muscles. With its tendon being located underneath the transverse axis of the

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first metatarsal, AH conduct plantar flexion and abduction of the first metatarsalphalangeal joint [8], and it acts as a longitudinal arch dynamic stabilizer. The AH muscle demonstrates activity in the late stance phases of gait [9]. The structure and function of AH may be negatively impacted by musculoskeletal disorders, such as FF and hallux valgus [8,10].

Such an effect on the AH muscle can change day-to-day activities, workplace productivity, injury risk, and athletic performance. Early detection, application, and appropriate care of flatfeet are therefore crucial [11].

To examine soft tissue structures, a variety of noninvasive procedures are available. In the imaging of skeletal muscle, ultrasonography has been demonstrated to be an accurate and valid diagnostic method, generating qualitative and quantitative data about muscle architecture [12]. Skeletal muscle activity has also been measured using electromyography (EMG) [13].

This article aimed to evaluate AH muscle characteristics using high-resolution ultrasonography and to assess its activity with surface EMG in patients with FF.

2. Patients and methods

This study included 60 patients with FF who were enrolled from the outpatient clinic of Physical Medicine, Rheumatology and Rehabilitation and age and sex-matched 20 healthy control subjects. The study was approved by the ethical committee.

Patients with clinically diagnosed FF deformity whose plain x-ray examination revealed a more than 4° Meary’s angle (MA) on standing lateral radiograph were eligible to the study.

Patients who had a distal lower limb injury within six months prior to the study, a history of lower limb operation, severe foot deformity, inflammatory arthritis, or diabetes were excluded from the study. Informed written consent was obtained from the study participants.

All included participants underwent the following:

(1) Full history taking and clinical assessment, including general, locomotor, and neurological examination. Data collection and patient characteristics were recorded, including age, sex, and BMI.

(2) Foot x-ray: in the patients’ group, lateral weight-bearing foot radiographs were performed, and the MA (lateral talus-first metatarsal angle) was measured between the first metatarsal axis and a line drawn along the talus longitudinal axes. Meary’s angle is typically measuring 0°. Angle measures higher than 4° were considered abnormal (pes planus). The condition was considered mild if the angle was <15°, moderate if the angle ranged between 15° and 30°, and severe if it was >30° [14].

(3) Ultrasonography assessment of the AH CSA was performed. Blinded to the clinical data, ultrasound imaging was conducted using a high-resolution ultrasound machine (Toshiba, Aplio 400, Japan) by a linear array transducer (18/7 MHz). The patients were lying supine with the ankle in a neutral position. The medial aspect of the foot is scanned in transverse axis orientation from the calcaneus posteriorly to the level of the hallux anteriorly. Greyscale images were acquired for the AH muscle at the mid-belly level and the cross-sectional area was calculated using the machine’s tracing function [15].

(4) Surface EMG of AH muscle using [Neuro-EMG-Micro] Neurosoft apparatus. At EMG examination, the time is based on 10 ms/D and sensitivity of

**Fig. 1.** B-mode transverse view of the Abductor hallucis muscle of case (A) and control (B) subjects showing a smaller cross-sectional area of the case subject as compared to the control muscle using manual tracing.
recording at 200 μV/D. The frequency of 10 KHz upper and 10 Hz lower filters of the recorder amplifier were used. In order to eliminate sensory artifacts and stimulators that interfere with the environment, the noise was filtered at 60 Hz (fluorescence bulbs, wall plugs, etc.).

The Active electrode was applied to the muscle belly (1–2 cm posterior to navicular tuberosity), and the reference electrode was placed 3 cm distal to the active electrode and the ground electrode on the distal third of the leg [16]. Muscle activity was recorded during abduction on minimal and maximal volition to measure the amplitude of MUAP measured in μV and the interference pattern of MUAP.

2.1. Statistical analysis

The participants’ data were analysed using the statistical software SPSS V17. The quantitative data were expressed as mean and standard deviation and compared using the student-t test. The qualitative variables were presented as numbers and percentages and compared with the Chi-square test. Linear correlations between variables using Pearson correlation were done.

3. Results

The patients’ group were 12 males (20%) and 48 females (80%) patients, and their ages ranged between (25–55) years old, with a mean age of 42.7 ± 8.2. Their mean BMI was 30.9 ± 3.9 ranged (25.3–39.6 kg/m²), 35 (58.3%) were overweight and 25 (41.6%) were obese. The control group was 20 healthy subjects, five males (25%) and 15 females (75%). Their ages ranged between (24–52) years old, with a mean age of 40.8 ± 10. Eleven (55%) subjects were overweight and nine (45%) were obese. No statistically significant differences were noted between patients and control groups concerning age (P = 0.1) and sex (P = 0.9) (Table 1).

Depending on (MA), 38 patients had a mild degree (MA<15°) and 22 with a moderate degree (MA 15–30°).

Table 1. Demographic data of patient and control groups.

<table>
<thead>
<tr>
<th>Age (y)</th>
<th>Group I (60)</th>
<th>Group II (20)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ± SD</td>
<td>43.3 ± 9</td>
<td>40.8 ± 10</td>
<td>0.1</td>
</tr>
<tr>
<td>Range</td>
<td>25–55</td>
<td>24–52</td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>12 (20%)</td>
<td>5 (25%)</td>
<td>0.9</td>
</tr>
<tr>
<td>Female</td>
<td>48 (80%)</td>
<td>15 (75%)</td>
<td></td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>30.9 ± 3.9</td>
<td>30.6 ± 3.2</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Ultrasound results of AH muscle showed a significant difference between group I and group II regarding CSA (P < 0.001). The mean CSA of group I was (1.8 ± 0.5 cm) ranged (1–2.7 cm), while the mean CSA of group II was (2.5 ± 0.7 cm), ranged (1.2–3.6 cm) (Table 2, Fig. 1).

Surface EMG results of AH muscle showed a significant decrease (P < 0.05) of MUAP amplitude during abduction in group I compared with group II. The mean amplitude of group I was 384 ± 206 uv, while the mean amplitude of group II was 689 ± 141 uv (Table 3).

Table 2. Comparison between group I and group II regarding US measurement (CSA) of AH muscle.

<table>
<thead>
<tr>
<th></th>
<th>Group I (60)</th>
<th>Group II (20)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abductor Hallucis CSA (cm²)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>1.8 ± 0.5</td>
<td>2.5 ± 0.7</td>
<td>0.005</td>
</tr>
<tr>
<td>Range</td>
<td>1–2.7</td>
<td>1.2–3.6</td>
<td></td>
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</tbody>
</table>

P value < 0.05 Significant.

Table 3. Comparison between group I and group II regarding MUAP amplitude measurements of AH muscle.

<table>
<thead>
<tr>
<th></th>
<th>Group I (60)</th>
<th>Group II (20)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abductor Hallucis MUAP (uv)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>325.9 ± 130.6</td>
<td>680.3 ± 152.1</td>
<td>0.045</td>
</tr>
<tr>
<td>Range</td>
<td>200–640</td>
<td>350–870</td>
<td></td>
</tr>
</tbody>
</table>

P value < 0.05 Significant.

4. Discussion

The AH muscle has the capacity to control foot posture. It has a crucial role in the medial longitudinal arch (MLA) support, and it is the largest and most medially located plantar intrinsic foot muscle. Through isometric contraction, it maintains first metatarsophalangeal (MTP) joint stability and prevents abnormal transverse plane motion. In an over-pro- nated foot, there is a loss of the anatomical relationship between the AH muscle and the 1st MTP joint; the muscle, therefore, loses its abductory force [17].

The structural changes that occur make the AH muscle, which provides dynamic stability to the MLA, do not activate well when they are needed in subjects with FF.

Although the AH muscle is involved in the deformity pathomechanical changes, the AH muscle with FF have been investigated by a few studies [18,19].
The aim of this study was to investigate the AH muscle CSA using ultrasound and assessment of the muscle activity with surface EMG in patients with FF.

Sixty patients with flat foot type (group I) and 20 healthy individuals as a control group (group II) participated in this study. There was no significant difference between FF and normal foot in age, sex, and BMI.

In this work, females were more predominant (90%), and the patients had a mean BMI of 32.4 ± 4.29. This was consistent with the data reported in the literature that the prevalence of FF is higher in the female gender [2,3] and individuals with obesity [3].

In this study, a significant decrease was found in CSA of the AH muscle in group I compared with group II. These results agree with previous studies [18,19]. Angin et al. [18] concluded that FF versus normal foot patients display smaller CSA and thickness in AH, while flexor digitorum brevis did not show any difference. The authors thought this could be related to the proximity of the AH muscle to the medial arch. Also, Zhang et al. [19] reported smaller CSA in symptomatic pronators than in their asymptomatic counterparts.

Contrary to our results, other authors reported a higher AH thickness in patients with FF. This thickness was explained by Tas et al. [20] to be related to its functional and anatomical characteristics, which are different from the other intrinsic foot muscles since there is increased loading on the AH muscle that may lead to AH muscle hypertrophy. Zhang et al. [21] stated that recreational runners with pronated foot had larger AH than those with a normal foot and attributed this to higher strength capacity and adaptation to control foot overpronation during dynamic activity by increasing the muscle morphology of AH.

These findings regarding associations between AH CSA and their relationships with FF [18,21] were also reported in previous studies that examined the size of intrinsic foot muscle with foot deformity (e.g., Hallux valgus, claw toe) [22,23]. These muscles’ morphological features can serve as a key indicator of muscle physiological function, such as the strength of the muscle [24,25]. Our findings suggest that FF is associated with a reduced AH activity. As surface electromyography (sEMG) has been used to describe activation of the AH [26,27], so (sEMG) was done to assess muscle activity in FF patients.

The results of surface electromyography of AH muscle showed that the mean amplitude of MUAP in group I was 463.1 ± 260.4 while in group II was 911.4 ± 424.1 with a significant decrease in group I. These results are similar to other authors [28] where they found that, in FF, the activity of AH was significantly decreased than in normal subjects.

Previous EMG research has shown that the height of the navicular and the morphology of the MLA are affected by changes in or dysfunction of the plantar foot intrinsic muscles. Fiolkowski et al. [26] and Headlee et al. [27] showed that a decrease in AH muscle activity could cause the navicular drop to increase.

These previous findings regarding the activity of AH in patients with FF are also noted in studies [29,30] examining AH in Hallux valgus feet, where the activity of AH during abduction was markedly decreased, and that AH loses abductory activity associated with structural deformities.

Studies conducted on participants with flatfeet or asymptomatic feet have shown that foot training can activate the AH muscle [31,32]. Furthermore, Jung et al. [10] showed that exercising the AH muscle for eight weeks enhanced the AH CSA in pes planus-affected feet.

Our study demonstrated a significant correlation between muscle CSA and muscle activity, which is similar to previous studies [33,34]. There has been a significant association between the AH CSA and the strength of great toe flexion. This proposes that the AH CSA could be helpful for the early recognition of foot muscle weakness [15].

The present study results did not show any relationship between the severity of the FF deformity assessed by Meary’s angle and the thickness of the AH muscle, which was similar to Okamura et al. [35]. However, Angin et al. reported a correlation between the severity score and the size of AH [18]. These contradictory findings may be a result of the differences in the patients severity score range.

4.1. Conclusion

AH muscle function has been compromised by altered foot structure. Musculoskeletal ultrasound and surface EMG are a noninvasive and utilisable method of assessing AH muscle morphology and activity in FF patients, with a significant correlation between cross-sectional area and muscle activity of AH.
4.2. Limitation of the study

Lack of FF patients with different severity, so further studies are needed with various levels.

Conflict of interest

None declared.

Institutional Review Board (IRB) Approval Number

INM00035.

References