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Original Article

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Comparison of Abductor Hallucis Contractility between Regular and Flat Feet during SFE with SLSKB Test

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| Abstract |

Purpose: This study compared and analyzed the contractility of the abductor hallucis (AbdH), an intrinsic foot muscle, between flat feet and normal feet during a movement control test (single-leg small knee band test) using ultrasonography.
Methods: A total of 23 subjects with (n = 11) and without (n = 12) flatfoot were included in the study. Each subject performed the short foot exercises (SFE) with a single-leg small knee bend (SLSKB) test, which is a functional movement. An ultrasound device was used to collect data regarding the changes in the contractility of the AbdH.
Results: Intergroup comparison showed that dorsoplantar thickness was significantly reduced at baseline and during the SFE with SLSKB in the flatfoot group ($p < 0.05$). Intragroup comparison showed that the cross-sectional area significantly improved when the SFE was performed with SLSKB in the control group ($p < 0.05$).
Conclusion: In this study, it was observed that the AbdH had inadequate contractility during the SLSKB test in subjects with flatfoot; therefore, it is important to train the contraction of the AbdH via functional movements during clinical interventions for subjects with flatfoot.

Key Words: Movement Control Test, Abductor hallucis, Flat feet, Ultrasonography

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Ⅰ. Introduction

The medial longitudinal arch (MLA) of the foot is supported by both passive and active structures (Jung et al., 2011). The passive structures comprise the 1st metatarsal bone, tarsal bones, plantar ligament, and plantar fascia (Cheung et al., 2004; Jennings et al., 2008). The foot contracts the intrinsic and extrinsic muscles, maintaining the MLA to adapt to various environments during weight-bearing, standing, and walking (Jung et al., 2011; Taş et al., 2018). Interest regarding the contribution of the intrinsic muscles of the foot in human locomotion and postural control has increased, as demonstrated by recent studies; it has been reported that a reduction in the size of intrinsic muscles, including the abductor hallucis (AbdH), causes hallux valgus deformity and pes planus (Battaglia et al., 2016).

Pes planus; a representative chronic foot disease; refers to deformity of the foot, causing flattening of the MLA, eversion of the rear foot, and abduction of the midfoot with respect to the rear foot (Pinney, 2006). Maintaining the MLA height of the foot is therefore important to prevent foot deformity; this requires the contractile forces of the intrinsic foot muscles, such as the AbdH, flexor digitorum brevis, and flexor hallucis brevis (Battaglia et al., 2016; McKeon et al., 2015; Taş et al., 2018). Short foot exercises are recommended to train these muscles in clinical practice (Lynn et al., 2012). Short foot exercises (SFE) increase MLA by contracting the intrinsic foot muscles (IFM) without overactivation the extrinsic foot muscles, including the tibialis anterior and gastrocnemius muscles (Jung et al., 2011; Lynn et al., 2012).

In previous studies, various methods have been used to evaluate intrinsic foot muscles; ultrasonography has been suggested as the most efficient method to assess intrinsic foot muscles, which are small in size and difficult to access (Nakayama et al., 2018; Soysa et al., 2012). Although direct comparisons cannot be made, ultrasonography has been used to assess morphological structures, such as thickness and cross-sectional area (Crofts et al., 2014; Mickle et al., 2013); however, ultrasonography of the intrinsic foot muscles has several limitations. Evaluation is dependent on the observer, while the resolution of fat-rich muscles is poor. Additionally, high reliability is only observed in large intrinsic foot muscles (Kuo & Carrino, 2007; Severinsen & Andersen, 2007; Soysa et al., 2012). Such limitations led to inconsistent results between previous studies that assessed morphological structures of intrinsic foot muscles in patients with flatfoot (Crofts et al., 2014; Taş et al., 2018). Moreover, previous studies performed ultrasonographical evaluations of intrinsic foot muscles by focusing on only the increase and decrease of morphological aspects; since evaluation of muscle contractions and use of muscles during functional movements were not performed (Crofts et al., 2014; Stewart et al., 2013; Taş et al., 2018), this may have led to contradictory results.

Recent studies have assessed the contraction of intrinsic foot muscles during both the functional single-leg stance, and weight-bearing (Battaglia et al., 2016; Nakayama et al., 2018; Taş et al., 2018). Specific movements were performed in healthy subjects to evaluate the ability of intrinsic foot muscles to contract; however, there is a lack of studies regarding the contractility of intrinsic foot muscles during functional motion in subjects with flatfoot. Therefore, this study evaluated the contractility of the intrinsic foot muscles of subjects with flatfoot versus those with normal feet; subjects performed the short-foot exercise (SFE) via a single leg small knee bend (SLSKB) test, which assesses functional movement. Additionally, we aimed to provide basic information to supplement exercise programs and improve contractility in patients with flatfoot.

Ⅱ. Materials and method

1. Participants

An a priori power analysis using G*Power software ver. 3.1.5 (Franz Faul, University of Kiel, Germany) was utilized to estimate the sample size. A pilot study with eight volunteers (flatfoot: n=4; normal: n=4) was used to achieve an alpha level of 5% and power of 95%; the estimated sample size was 20. This study was approved by the Ethics Review Committee of the institution. In total, 23 (11 male and 12 female) college students, currently attending our institution, were recruited; written, informed consent was obtained from each participant.

All 23 subjects underwent the foot posture index-6 (FPI-6) test. Eleven (5 male and 6 female) subjects, who all scored 6 points or higher, were assigned to the flatfoot group; the remaining 12 subjects, who scored 0-5 points, were assigned to the control group (Redmond et al., 2006). Selection criteria included those with no evidence of foot or ankle joint-related disease, and no prior history of surgery. General characteristics of the participants in the flatfoot group were an age of 22.27±2.41 years, height of 166.27 ±9.42 cm, and body weight of 60.00±13.40 kg. General characteristics of the participants in the control group were an age of 23.00±2.69 years, height of 166.50 ±9.23 cm, and body weight of 62.08±12.93 kg.

2. Measures

1) Ultrasonographic examinations

An ultrasonography device (Mylab class ultrasound system; ESAOTE, Italy) and a linear probe of 7.5 MHz were used to assess the AbdH. Baseline data were collected in the single leg stance (SLS). To perform the SLSKB test, subjects were asked to flex their knees

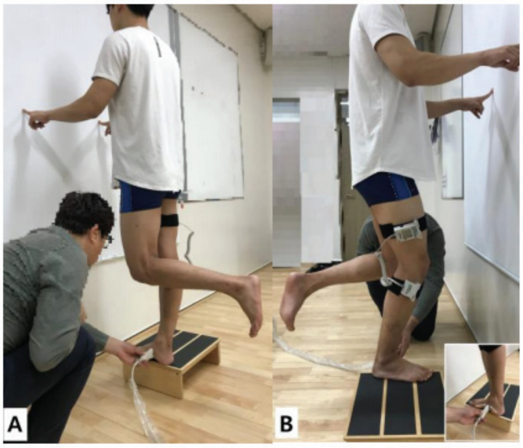

Fig. 1. Measurement position. (A)single leg stance (SLS), (B) short foot exercise with single leg small knee bend (SFE with SLSKB).

at 30 degrees, using their index finger against the wall to maintain balance (Fig. 1); this was taught to the subjects in advance. As the subjects performed the SFE with SLSKB, the AbdH was evaluated using an ultrasonography device. Mediolateral width thickness, dorsoplantar thickness (DP thickness), and cross-sectional area (CSA) were measured to ensure reliable measurement of the AbdH; three measurements were determined for each item, as described in previous studies (Cameron et al., 2008; Latey et al., 2018; Stewart et al., 2013) (Fig. 2).

A line was drawn on the anterior edge by stimulating the medial malleus; the ultrasound probe was placed 1 cm behind the navicular tubercle, which was anterior to the drawn line (Jung et al., 2011; Lynn et al., 2012). The image processing and analysis software Image J version 1.44 (National Institute of Health, Bethesda, USA), was used to measure the thickness (cm) and CSA (cm^2) of the AbdH through images acquired using the ultrasonography device (Stewart et al., 2013).

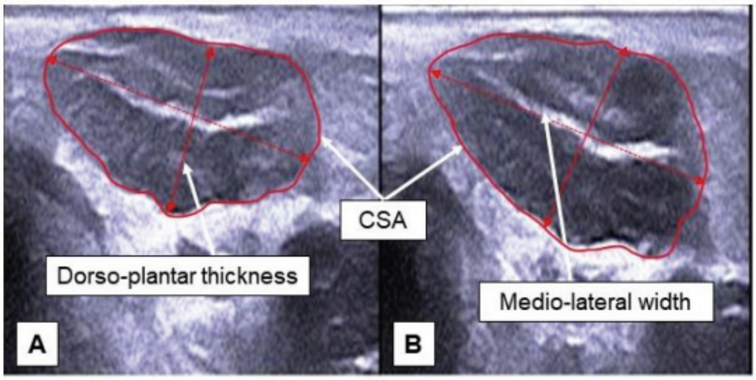

Fig. 2. Ultrasonography images of abductor hallucis muscle with short foot exercise (SFE); (A) starting position, (B) ending position.

3. Procedures

Baseline thickness and CSA of the AbdH muscle in the SLS were measured in all 23 participants. In subjects who received training 7-10 times in advance, the SFE with SLSKB was performed; at the same time, the thickness and CSA of the AbdH muscle were measured using the ultrasonography device. All analysis has performed three times, and the average value of the measured values during the total of three analyses was used as the result value. The SFE is a movement that shortens the length of the front and rear foot while pointing the 1st metatarsal bone head toward the heel, without bending the big toe. Therefore, the subjects were instructed to place their forefoot and heel on the ground, shorten the foot through isometric contraction for 5 s without raising the heel or bending the distal phalanges of the foot, and let the big toe touch the floor as much as possible (Jung et al., 2011).

4. Statistical analysis

To determine the intrarater reliability for measurements of the thickness of the AbdH muscle, intraclass correlation coefficients (ICCs) were used. The $ICC_{(3,1)}$ model was selected to test the intrarater reliability, and good reliabilities were demonstrated for measuring the thickness of the AbdH (ICC3,1: 0.68; 95% CI: 0.11-0.91; SEM: 0.028 cm) within the two trials.

The general characteristics of the participants in this study were analyzed via the average and standard deviation, or frequency, using SPSS 21.0 software (SPSS, Inc., USA). The Kolmogorov–Smirnov test was performed to determine whether continuous data approximated a normal distribution, and the independent t-test was used to compare the differences between the flatfoot and control groups. The paired t-test was used to compare the mean difference between the baseline and during the SFE with SLSKB for each group, and an independent t-test was used to compare the difference between each group. The level of significance was set at α =0.05.

Ⅲ. Results

In the intergroup comparison, there was a significant difference between D-P thickness and M-L width at the baseline and during the SFE with SLSKB test. However, the mean difference between the two groups was not significant. ($p<0.05$). Intragroup comparison, the flat feet

Table 1. Comparison of muscle thickness and cross section area between each group

Variable	Group	Baseline (SLS)	SFE with SLSKB	Mean difference	t	p
D-P thickness (cm)	Flat feet	0.87±0.19	0.88±0.19	0.00±0.06	-0.22	0.82
	Control	1.46±0.75	1.50±0.79	0.03±0.09	-1.25	0.23
	t	-2.59	-2.60	-0.86		
	p	0.02*	0.02*	0.39		
M-L width (cm)	Flat feet	2.59±0.24	2.68±0.24	0.08±0.12	-2.11	0.06*
	Control	2.13±0.80	2.22±0.82	0.09±0.17	-1.75	0.10
	t	1.89	1.82	-0.13		
	p	0.08*	0.09*	0.89		
CSA (cm^2)	Flat feet	1.82±0.58	1.88±0.52	0.05±0.17	-1.07	0.30
	Control	2.10±0.62	2.22±0.52	0.12±0.19	-2.21	0.04*
	t	-1.07	-1.53	-0.82		
	p	0.29	0.14	0.41		

Mean±SD, D-P: Dorso-plantar, M-L: Medio-lateral, CSA: Cross-section area, SLS: Single leg stance, SLSKB: Single leg small knee bend, SFE: Short foot exercise

group was a significant change between M-L width at the baseline and during the SFE with the SLSKB test, but the control group exhibited a significant increase in CSA when the SFE was performed with SLSKB ($p<0.05$; Table 1).

Ⅳ. Discussion

The AbdH, one of the representative intrinsic muscles of the 1st ray, supports the MLA along with the extrinsic muscles and is a major factor that differentiates pes planus from normal foot types (Crofts et al., 2014; Taş et al., 2018). However, studies regarding ultrasound analysis of the AbdH in pes planus show inconsistent results (Crofts et al., 2014; Taş et al., 2018; Zhang et al., 2017). Previous studies have suggested that muscle size measurement using ultrasound technology may be affected by the operator's skill, as well as related to the position and level of pressure of the probe, lowering the reliability of the test (Stewart et al., 2013; Zhang et al., 2017). In addition, evaluation of foot kinematics is necessary. Therefore, our study compared changes in the contractility of the AbdH in subjects with pes planus and normal feet during the SFE with SLSKB, performed to increase the MLA of the foot.

The SFE is defined as a series of movements that activates the AbdH; used in a previous study, it repositions elongated foot intrinsic muscles to neutral positions, changing the alignment of the foot (Jung et al., 2011). When DP thickness was compared between the flatfoot and control groups in our study, there were significant differences at the baseline and during the SFE with SLSKB. This suggests that the foot muscle's anatomical position had changed, and that its ability to mobilize the muscles involved in abduction of the hallux had decreased in the flatfoot group, whose MLA was lower (Stewart et al., 2013). Moreover, the altered position of the AbdH with respect to the active length-tension curve caused mechanical insufficiency and inadequate overlap of actin and myosin filament fibers, leading to insufficient contraction of the AbdH (Comerford & Mottram, 2012).

It is thought that this may have caused insignificant changes in DP and mediolateral thickness in the flatfoot group.

On the other hand, significant changes were seen during SFE with SLSSKB at baseline in the flat feet group. However, as a result, the result value of CSA was higher at normal feet, confirming that the value of CSA changed according to the increase in D-P thickness rather than M-L width. In addition, although not significantly different between the two groups, the mean CSA in the flatfoot group was lower than that of the normal group, which was consistent with the reports of previous studies (Angin et al., 2014). Our findings support these prior results, showing that contraction of the AbdH decreased, leading to compensatory increases in contractility of the extrinsic muscles (flexor digitorum and flexor hallucis longus) in pronated flatfoot subjects (Angin et al., 2014; Kirane et al., 2008; Wacker et al., 2003).

Additionally, recent studies have assessed the sensory-motor interaction of foot intrinsic muscle disorder in patients with flatfoot (McKeon et al., 2015), focusing on the delivery of altered sensory information caused by problems regarding sensory-motor interactions, rather than the relationship with muscle morphology, or strength of intrinsic muscles (Taş et al., 2018). The stretch response in the normal alignment and anatomic position of intrinsic foot muscles immediately induces changes in foot posture; however, delivery of altered sensory information in individuals with over-pronated flatfoot and decreased MLA height, induces abnormal foot posture control (McKeon et al., 2015). To confirm this finding, we performed the SFE in subjects with flatfoot, as well as those without, to assess altered sensory-motor interactions.

The SFE is widely used for rehabilitation purposes, both to increase afferent input on the sole of the foot and improve postural alignment (Liebenson, 2007). In this study, we hypothesized that subjects with flatfoot who received altered sensory information during functional movements, such as SLSKB, would show poor performance during the SFE. The changes observed within each group in our study support our hypothesis. In the flatfoot group, the CSA both at baseline and during the SFE with SLSKB did not significantly change. It is thought that the sensory input, altered by intrinsic muscles that were over-stretched by the over-pronated foot and decreased MLA height, had greater effects on muscle contraction response in the flatfoot group than in the control group. On the other hand, in the case of flat feet, because the foot is pronated by weight support, the MLA descends, and the weight is distributed to the inside of the foot (Kim et al., 2020).

To induce this environment, in this study, we were instructed to perform the SLSKB motion, and during the SLSKB motion, we were required not to bend or overextend the toes and to lift the MLA to the heel with the first metatarsal head. However, AbdH thickness's ultrasound results showed that the contractile ability to produce MLA during weight-bearing conditions was reduced in subjects with flat feet. The importance of sensory-motor training, in addition to improvement of intrinsic muscle strength, should therefore be considered in future intrinsic muscle training regimens for patients with flatfoot.

This study compared the contractility of intrinsic muscles during functional motions between subjects with flatfoot and those without. This differs from previous studies that have assessed the morphological differences of intrinsic muscles in a static posture. In clinical practice, evaluation of the foot's intrinsic muscles has always been performed in a static posture. However, many people spend many of their lives in a weight-bearing state, such as walking daily, and these movements work differently than the muscles of the foot in the OKC situation. Therefore, when evaluating the intrinsic muscles of the foot, it is considered an important part to evaluate the contractile force of the muscles while carrying out tasks similar to daily activities in a weight-supported state.

A limitation of this research is that the relationship between intrinsic and extrinsic muscles was not assessed. Additionally, changes in other intrinsic muscles, such as the flexor hallucis brevis and flexor digitorum brevis, were not evaluated. It is therefore necessary to investigate the interaction between intrinsic and extrinsic muscles, as well as the actions of various intrinsic muscles during functional motions, in future studies.

Ⅴ. Conclusion

In this study, morphological differences indicated by significant differences in DP thickness were observed between subjects with flatfoot, as well as those without, during the SFE with SLSKB. Insignificant changes in flatfoot subjects and significant changes in normal subjects during the SFE with SLSKB demonstrated altered sensory-motor interaction ability of the foot’s intrinsic muscles in flatfoot subjects. Therefore, this shows that the contraction of the AbdH via functional movements is important in clinical interventions for subjects with flatfoot.

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