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Research Article

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Comparison of Subjects with and without Pes Planus during Short Foot Exercises by Measuring Muscular Activities of Ankle and Navicular Drop Height

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| Abstract |

PURPOSE: Despite the abundant literature available regarding the activity of intrinsic muscles, few studies have investigated the muscle activity of extrinsic muscles. Therefore, the present study compared the muscle activity of the peroneus longus, tibialis anterior, and abductor hallucis during short foot exercise in subjects with and without flat feet.

METHODS: Twelve subjects with and without pes planus participated in this study. During the short foot exercises, muscular activity of the tibialis anterior, fibularis longus, and abductor hallucis longus were measured in both groups. To identify the effects of short foot exercises, navicular drop height was also investigated in pre and post short foot exercises.

RESULTS: In a symptomatic group, the navicular drop height was significantly reduced at post measurement compared with pre-measurement. During the short foot exercise, the pes planus group showed significantly lower activities of the fibularis longus than the control group ($p<.05$).

CONCLUSION: Similar to previous studies and clinical literature, short foot exercise was effective for alleviating navicular drop for a population with pes planus. In addition, subjects with pes planus showed decreased muscular activities of the fibularis longus, which suggests that considering extrinsic muscles such as fibularis longus is also important for rehabilitation of pes planus patients.

Key Words: Balance, Flat foot, Peroneus longus, Short foot exercise

Ⅰ. Introduction

Flat foot affects approximately 20% of the young population (Bordin et al., 2001). Although the exact cause of flat foot has not been identified, genetic factors, acquired factors (e.g., wearing the wrong shoe type or extended periods of walking on asphalt or concrete surfaces), paralysis, pronated foot, or obesity may cause flat foot (Neumann, 2009). Flat foot refers to structural or functional changes in the foot, in which the foot arch is lost or excessively lowered when compared with a normal foot. In people with flat foot, shock absorption decreases, and

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balancing ability diminishes, resulting in decreased stability during walking or running, leading to walking impairment and reduced stamina (Harris et al., 2004). In cases of flat foot, pronation of the foot is delayed or exaggerated relative to normal protonation in the first 25% of the stance phase during walking (Okamura et al., 2018).

The feet and ankles play critical roles in maintenance of posture during weight shifts and walking (Murley et al., 2009). Pronation during walking, which is controlled by the bone structure of the feet, ligaments, and intrinsic and extrinsic muscles, plays a key role in maintenance of the medial longitudinal arch (MLA) (Okamura et al., 2018). The tibialis anterior, abductor hallucis, and peroneus longus are particularly important to this maintenance (Fiolkowski et al., 2003; Kura et al., 1997). The intrinsic muscles of the foot act as functional units to help support the MLA and provide dynamic stabilization. The peroneus longus muscle, which is located in the most lateral part of the calf, originates at the fibular head and inserts at the medial cuneiform bone (Kendall et al., 2005). In this way, this muscle stabilizes the ankle joint and induces the sole flexion in the front part of the foot. By contracting during the stance and toe-off phases of walking, the peroneus longus supports dynamic stabilization of the MLA (Okamura et al., 2018). Short foot exercise using an elastic band or towel is broadly implemented to reinforce intrinsic muscle strength, with exercise using a towel most frequently performed. Short foot exercise increases the height of the MLA by contracting the intrinsic muscles of the foot and decreasing the total length of the MLA (Jung et al., 2011). Intrinsic foot muscles play important roles in maintaining the MLA. Rothermel et al. (2004) reported that short foot exercise activated intrinsic foot muscles, with subjects lifting the MLA while keeping the front and rear parts of the foot on the ground. In the same study, short foot exercise ensured that the subjects actively maintained the longitudinal arch and transverse arch. The study of short foot exercise and foot function is currently an active area of research. McKeon et al. (2015) reported that short foot exercise strengthened not only intrinsic muscles, but also proprioceptive senses, through contact with the ground, such as a neutral location of the metatarsal head and calcaneus or spreading of the toes. Mulligan and Cook (2013) reported that short foot exercise led to an improved navicular drop and arch height index.

However, few studies have compared muscle activity during short foot exercise (Kim and Jung, 2017; Jung et al., 2011). Furthermore, despite abundant literature on the activity of intrinsic muscles, no studies have investigated the activity of extrinsic muscles. Therefore, the present study compared the muscle activity of the peroneus longus, tibialis anterior, and abductor hallucis during short foot exercise in subjects with and without flat foot. We expected that not only intrinsic muscles, but also extrinsic muscles would be weak in subjects with flat foot.

Ⅱ. Methods

1. Subject

The study group comprised 24 students enrolled in K University located in K City in Gyeongsangnamdo Province, South Korea. The subjects were divided into a flat foot group (n=12) and a normal foot group (n=12) based on the results of a navicular drop test. All subjects provided written informed consent after receiving a full explanation about the purpose and procedures of the study before the experiment.

2. Measurement device

1) Navicular drop test

This test was first introduced by Brody (1982). Previous research demonstrated that the test had high reliability for evaluating navicular height (interclass correlation coefficient [ICC]:>.94), with an ICC for intra- and inter-rater reliability of .83 and .73, respectively (Vicenzino et al., 2000). The height of the navicular tuberosity from the ground was measured with the subjects sitting on a chair with their knees flexed to 90° while maintaining a neutral foot position (a non-weight loading posture). The subjects then stood up with their feet shoulder width apart (weight-loading posture) and the vertical distance between the ground and navicular tuberosity was measured. The subject was placed in the flat foot group if the vertical height in the weight-loading and non-weight loading postures differed by more than 10 mm. Only the dominant foot of the subjects was used for the measurements. To determine the dominant foot, the subject was instructed to strike a ball that had been placed 10 m in front of them with their foot. The foot that touched the ball was considered the dominant foot.

2) Surface electromyogram measurements

A cable electromyogram device (LXM3204, Neuromedi, Deajeon, Korea) was used to measure electromyogram signals of the abductor hallucis, tibialis anterior, and peroneus longus. A disposable surface electrode made of argentum and silver chloride was used as the ground electrode. The electromyogram signals were recorded using a sampling frequency of 1,000 Hz and band pass filter of 20-500 Hz. The subjects wore shorts to facilitate the measurements. The electrodes were attached to the skin after wiping the skin with an alcohol swab to reduce resistance. For abductor hallucis measurements, the electrode was attached to a site 1-2 cm to the rear of the navicular tuberosity. For the tibialis anterior, the electrode was placed on the external part of the tibia at one fourth point in relation to the proximal thigh. For the peroneus longus, the distance between the fibular head and proximal thigh was divided into three points and the electrode was placed on the first point (Cram et al., 1998).

3) Procedure

The subjects were given an explanation of the exercise procedure and method. Before the experiment, the subjects were divided in an experimental group and a control group

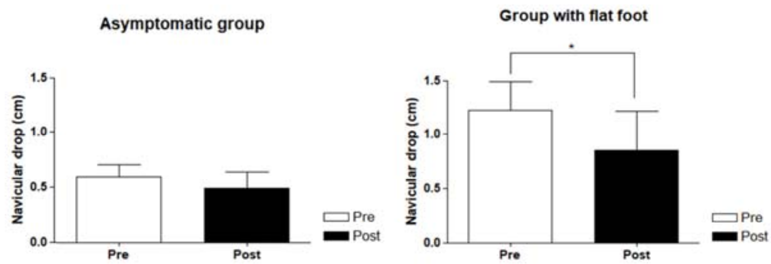

Figure 1. The normalized EMG data of the upper and lower trapezius, and serratus anterior in exercise variation
*Significant difference between conditions.

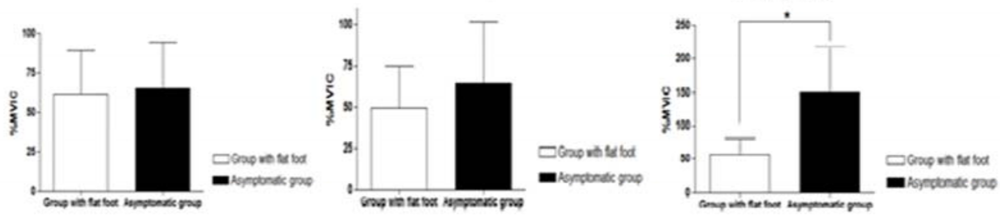

Figure 2. Normalized EMG data of the anterior deltoid and infraspinatus in exercise variation
*Significant difference between conditions

based on the results of a navicular drop test. For normalization of the measured muscle activity, muscle activity was measured at maximal voluntary isometric contraction (MVIC) in a posture that is broadly used in manual muscle tests (Kendall et al., 2005). After measuring the MVIC, the subjects performed five sets of short foot exercise 10 times. The navicular drop test was conducted immediately after the exercise and the test results before and after the exercise were compared. All electromyogram data were repeatedly measured three times for 5 seconds each, after which the data were RMS processed. The average electromyogram signal during the middle 3 seconds was used in the analysis.

The subjects made their foot as short as possible, without bending the metatarsophalangeal joint, as if bringing the head of the first metatarsal bone in front of the heel. In this way, the metatarsophalangeal joint and heel remained close to the ground, while the MLA was kept as high as possible. With a towel below the foot, the subjects maintained 90° flexion of the hip, knee, and ankle joints (Kim and Jung, 2017). They then performed five sets of 5-sec isometric exercise 10 times. The resting time between each set was restricted to 30 sec.

3. Statistical analysis

The SPSS statistical software (version 18.0; SPSS, Chicago, IL, USA) was used to evaluate differences in the %MVIC of each muscle and navicular drop height. Independent t-tests were performed to compare the %MVIC of each muscle. Two-way repeated measures analysis of variance (ANOVA) was performed to evaluate differences in navicular drop height, with one factor being the pre-post and the other factor the presence of pes planus. For pairwise multiple comparison, the Bonferroni correction was conducted to identify differences. A *p*-value of $<.05$ was considered to indicate statistical significance.

Ⅲ. Results

1. General characteristics of the research subjects

A total of 24 subjects participated in this study. The subjects were evenly divided into a control group (normal feet) and an experimental group (flat foot). Both groups performed the short foot exercise. In the normal foot group, the average age, height, and weight of the subjects was 21.2±1.64 years, 166.3±7.50 cm, and 61.5±10.50 kg, respectively. In the flat foot group, the average age, height, and weight was 22.02±2.75 years, 172.45±6.02 cm, and 72.5±10.44 kg, respectively. The results of an independent t-test revealed no significant differences between groups ($p<.05$).

2. Comparison of muscle activity

Table 1 shows the average muscle activity. The results of an independent t-test indicated that there was a significant difference in peroneus longus muscle activity, with that of the experimental group being significantly lower than that of the control group ($p<.05$).

Table 1. Descriptive Statics of Normalized EMG Values During Short Foot Exercise (Unit: %MVIC)

	Group comparison		p-value
	Group with flat foot	Asymptomatic group	
Tibialis anterior (TA)	61.40±28.02	65.38±28.96	.73
Abductor hallucis longus (AHL)	49.73±25.34	64.20±37.60	.28
Peroneus longus (PL)	56.27±25.01	150.40±67.86	.02*

*Significant difference between conditions.

Table 2. Comparison of Navicular Drop Test between Groups, and before and after Short Foot Exercise (Unit: cm)

	Pre and post	Group comparison		p- value	
		Group with flat foot	Asymptomatic group	Pre and post	Group
Navicular drop test	Pre	1.22±.27	.60±.11	.00*	.00*
	Post	.85±.36	.49±.15		

*Significant difference between conditions

3. Navicular drop before and after short foot exercise

Table 2 presents the results of the navicular drop test of the experimental and control groups before and after the intervention, including between-group differences. The results revealed that navicular height was significantly lower in both groups post-intervention when compared with pre-intervention (p<.05). According to the results of the navicular drop test, the experimental group showed a significant decrease from 1.22±.27 cm before the implementation of the short foot exercise to .85±.36 cm after the exercise (p<.05).

Ⅳ. Discussion

In this study, we conducted a navicular drop test to investigate the effects of short foot exercise. The navicular drop test described by Brody (1982) is generally used to check the extent of pronation (Del Rossi et al., 2004; Snyder et al., 2009; Vicenzino et al., 2005). A number of previous studies considered a value >10 mm as excessive protonation in the navicular drop test. In the present study, a normal foot was defined as pronation <10 mm, and an excessively pronated foot was defined as pronation >10 mm. After the short foot exercise, navicular height in the flat foot group significantly decreased from 1.22±.27 before the exercise to .85±.36 after the exercise. Similar to our study, Snyder et al. (2009) reported that short foot exercise was the best way of correcting flat foot, as it improved the abduction of the joint in lower parts of the body.

Previous studies that compared the effects of exercises aimed at flat foot relaxation mainly investigated the muscle activity of the abductor hallucis. Jung and Koh (2009) examined the muscle activity of the abductor hallucis during toe winding exercise intended to improve navicular drop. Jung et al. (2011) concluded that short foot exercise was a more useful strengthening exercise than towel grabbing exercise because it activated the abductor hallucis. In contrast, in the present study, the short foot exercise resulted in no significant difference in the abductor hallucis muscle activity of the normal foot group relative to the flat foot group. This discrepancy may be attributed to differences between study groups. Specifically, the aforementioned studies included only individuals with normal feet, whereas the present study included flat footed individuals.

In the present study, peroneus longus muscle activity during short foot exercise was significantly higher in the normal foot group (150.40±67.86) than the flat foot group (56.27±25.01). Although there were differences in measured activity between the present and previous studies, Murley et al. (2009) reported that tibialis anterior muscle activity increased, whereas peroneus longus muscle activity decreased in the contact phase during walking in a flat foot group. As in the study by Murley et al. (2009), peroneus longus muscle activation in the flat foot group was lower than that in the normal foot group in the present study. The peroneus longus originates at the external side of the fibula and inserts at the floor surface of the first metatarsal bone. The main function of the peroneus longus is to support the sole flexion. As the muscle is laterally attached, eversion of the ankle occurs during contraction. Because of weakening of the peroneus longus, people with flat feet can experience hyperextension or weakening of connective tissues, such as the plantar fascia and spring ligament (Neumann, 2009).

Murley et al. (2009) asserted that increased muscle activity of the tibialis anterior observed in cases of flat foot may act as a compensatory mechanism to decrease MLA overload. However, in the present study, we did not observe any increase in the muscle activity of the tibialis anterior of the experimental group (flat foot group) relative to the control group (normal foot group). The difference between the findings of the present study and those of Murley et al. (2009) may be attributed to the timing of the measurements. Murley et al. (2009) measured muscle activity during walking, whereas we measured muscle activity while the subjects performed short foot exercise. Functionally, the tibialis anterior helps support the MLA of the foot and acts as a synergic muscle together with the tibialis posterior muscle to maintain the height of the arch.

Both the tibialis anterior and peroneus longus anterior act as antagonistic muscles when performing pronation and supination (Neumann, 2009). The short foot exercise implemented in the current study did not involve dynamic movement, and the activity of the tibialis anterior muscle would be expected to increase in subjects with flat foot when conducting exercises that incorporated dynamic leg movements. It should be noted that this study has several limitations. First, it included only young individuals (i.e., those aged in their 20s). Hence, the results cannot be generalized to all age groups. Accordingly, further studies that include more diverse age groups and larger numbers of subjects are warranted. Second, because the duration of the intervention was short, it was not possible to determine the long-term effects of the exercise. We believe that the effects of short foot exercise should be examined in longer studies (e.g., 4 or 6 weeks) in the future. Finally, the %MVIC of the peroneus longus muscle activity was over 100%, which could generate a floor and ceiling effect on statistical analysis.

Ⅴ. Conclusion

We can draw two conclusions from this study. First, short foot exercise decreased navicular drop. Second, peroneus longus muscle activity was significantly lower in the flat group than the normal foot group during short foot exercise. These findings imply that the peroneus longus could not be sufficiently activated during short foot exercise in flat footed subjects; therefore, it is necessary to determine ways of selectively activating the peroneus longus. We suggest that reinforcement not only of the intrinsic muscles, but also the extrinsic muscles of the peroneus longus should be considered in rehabilitation programs aimed at correcting flat foot.

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