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Original Article

The effects of hip external rotator exercises and toe-spread exercises on lower extremity muscle activities during stair-walking in subjects with pronated foot

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Abstract. [Purpose] The purpose of the present study was to examine the effects of toe-spread (TS) exercises and hip external rotator strengthening exercises for pronated feet on lower extremity muscle activities during stair-walking. [Subjects and Methods] The participants were 20 healthy adults with no present or previous pain, no past history of surgery on the foot or the ankle, and no foot deformities. Ten subjects performed hip external rotator strengthening exercises and TS exercises and the remaining ten subjects performed only TS exercises five times per week for four weeks. [Results] Less change in navicular drop height occurred in the group that performed hip external rotator exercises than in the group that performed only TS exercises. The group that performed only TS exercises showed increased abductor hallucis muscle activity during both stair-climbing and -descending, and the group that performed hip external rotator exercises showed increased muscle activities of the vastus medialis and abductor hallucis during stair-climbing and increased muscle activity of only the abductor hallucis during stair-descending after exercise. [Conclusion] Stair-walking can be more effectively performed if the hip external rotator muscle is strengthened when TS exercises are performed for the pronated foot.

Key words: Abductor hallucis, Foot arch, Hip joint

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INTRODUCTION

One of the most important roles of feet is weight-bearing, which requires stability and resilience for absorbing impact, and the medial longitudinal arch (MLA) and transverse arch provide this stability and resilience[1)]. In particular, the MLA is the primary structure absorbing the impact of the weight-bearing that occurs during the physical activities of walking or running[2)]. The condition in which the MLA becomes chronically or abnormally low is called flatfoot[3)], and it is divided into spastic flatfoot and flexible flatfoot[4, 5)]. The reported causes of flexible flatfoot include excessive extension of the plantar muscle, which provides stability to the MLA, and poor function of the tibialis posterior muscle[4)]. Some researchers have reported that hip external rotator weakening internally rotates the hip joint while inducing foot pronation[6)].

Hip external rotator strengthening exercises, performed by extending the hip joint when it is in external rotation and the knee joint is at 90° flexion, have been reported to have the greatest effect when performed in the prone position[7)].

The results of one study showed that as the activity of the abductor halluces (AbdH) increased, the angle of the MLA decreased, indicating that AbdH exercises are helpful for the maintenance and enhancement of the MLA[8)]. In a study of various exercises for strengthening the AbdH, toe-spread (TS) exercises and short-foot exercises performed in the sitting position did not elicit any significant difference in AbdH activity, but the muscle activity value was shown to be higher during

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TS exercises[9].

Although many studies have been conducted of the various exercises for MLA correction[10, 11], studies examining exercises that also strengthen the hip external rotator muscle are insufficient. Therefore, the purpose of the present study was to investigate the effect of hip external rotator strengthening and TS exercises in subjects with pronated feet, and to evaluate their effects on lower extremity muscle activities during stair-walking.

SUBJECTS AND METHODS

A total of 20 healthy adults were selected after excluding those with present or past arthritis, those who had undergone foot or ankle surgery, and those with diabetes, cuts on the lower extremities, or foot abnormalities. The subjects were selected from among those with foot pronation (>10 mm) based on navicular drop (ND) tests[9, 12]. The participants were provided with a written informed consent form in accordance with the ethical principles of the Declaration of Helsinki. The mean age, height, and weight of the study subjects who performed both hip external rotator and TS exercises were 21.8±1.62 years, 162.9±6.9 cm, and 59.3±14.6 kg respectively, and the mean age, height, and weight of the study subjects who performed only TS exercises were 22.3±1.95 years, 165.0±8.1 cm, and 63.2±11.8 kg, respectively.

A surface EMG DTS system (TeleMyo DTS, Noraxon Inc., AZ, USA) was used to record and process the electromyographic (EMG) signals from the gluteus maximus, the vastus medialis, the tibialis anterior, and the AbdH in order to measure the muscle activities of these muscles. Single electrodes were used for the surface EMG. The collected surface EMG signals were processed using the MyoResearch Master 1.07 XP program (Noraxon Inc., AZ, USA). The signals were digitally sampled at a rate of 1,500 Hz and noise was removed using a 20–500 Hz bandpass filter and a 60 Hz notch filter. The EMG data were normalized using the maximal voluntary contraction (%MVC) values.

The study subjects performed exercises five times per week for four weeks: two times per week at home and three times per week in the laboratory. The subjects who performed both hip external rotator exercises and TS exercises performed three sets of 20 repetitions of hip external rotator exercises in the prone position along with 100 repetitions of TS exercises in the sitting position while maintaining both the hip joints and the knee joints at 90° flexion. The subjects in the other group performed only 100 repetitions of TS exercises.

ND tests[12, 13] were conducted before and after the four weeks of exercises and the mean values of the groups were compared using the independent t-test. Before stair-climbing and -descending, foot switches were attached to the center of the heel, below the first metatarsal, and below the fifth metatarsal to divide the phases of weight bearing in order to measure the muscle activity of the gluteus maximus, the vastus medialis, the tibialis anterior, and the AbdH during the individual phases. The paired t-test was used to analyze changes in lower extremity EMG during stair-walking before and after the exercise period within each exercise group. The results were statistically analyzed using SPSS version 18.0 (SPSS Inc., Chicago, IL, USA) and significance was accepted for values of $p<0.05$.

RESULTS

The ND of the group that performed both hip external rotator and TS exercises was 5.66±1.58 mm and that of the group that performed only TS exercises was 7.52±2.16 mm after the intervention. These results indicate that the ND of the group that performed both hip external rotator and TS exercises decreased significantly more than the group that performed only TS exercises (Table 1). According to EMG measurements taken during stair-walking before and after the intervention, the %MVC values of the vastus medialis (5.56±7.27%) and the AbdH (11.05±10.54%) during stair-climbing and the %MVC values of the AbdH (7.9±6.23%) during stair-descending were significantly different in the group that performed both hip external rotator and TS exercises (Table 2). In the group that performed only TS exercises, the %MVC values of the AbdH during stair-climbing (11.58±13.46%) and stair-descending (11.87±10.78%) were significantly different between before and after the exercise treatment (Table 2). After the 4-week intervention, there was no significance different between hip external rotator and TS exercise and only TS exercise (Table 3).

DISCUSSION

The present study was conducted to compare changes in lower extremity muscle activities during stair-walking between subjects with flatfoot who performed only TS exercises and subjects who additionally performed hip external rotator exercises, in order to present basic evidence for exercise treatment. Since many studies set the criterion for flatfoot as 10 mm or greater ND[12–14], the present study's subjects were selected based on that criterion.

In the case of flatfoot, valgus stress is created in the knee joints during gait due to the pronation and extroversion of the hind foot, the supination of the fore foot and the mid foot, and the internal rotation of the lower extremities, leading to kinematic sway of the lower extremities and compensatory actions[1]. Under the assumption that femoral anteversion contributes to hip joint internal rotation, some researchers have reported that the muscle activity of the vastus medialis and the hip adductor are decreased by hip internal rotation and 40° knee flexion[15]. Based on these previous study results, in the

Table 1. Comparison of navicular drop test results between the group that performed both hip external rotator exercises and TS exercises and the group that performed only TS exercises (n=20)

		Hip external rotator exercise and TS exercise Mean (SD)	TS exercise Mean (SD)
Pre	ND (mm)	11.8 (1.9)	11.4 (1.4)
4 weeks	ND (mm)	5.7 (1.6)	7.5 (2.2)*

ND: navicular drop, SD: standard deviation
*p<0.05

Table 2. EMG activities: %MVC values pre- and post-intervention (n=10)

		Hip external rotator exercises and TS exercises		TS exercises only	
	Muscle	Pre Mean (SD)	4 weeks Mean (SD)	Pre Mean (SD)	4 weeks Mean (SD)
Stair up	GM	22.1 (7.8)	24.4 (9)	22 (9.1)	25.8 (10.4)
	VMO	31.1 (12.5)	36.7 (12.9)*	45.5 (17)	48.7 (5.7)
	TA	21 (12.8)	19 (11.3)	17.2 (5.5)	15.7 (6.1)
	AbdH	27.1 (4.7)	38.18 (8.8)*	23.9 (7.3)	37.3 (11.5)*
Stair down	GM	13.6 (9)	12 (5.1)	15.4 (14.2)	22.3 (12.8)
	VMO	35.8 (21.7)	32.5 (8.9)	37.1 (15.5)	41.2 (9.5)
	TA	20.1 (10.7)	19.8 (16)	17.2 (10.2)	20 (9.1)
	AbdH	32 (6.8)	39.9 (9.6)*	25 (11.1)	36.9 (9.7)*

GM: gluteus maximus, VMO: vastus medialis, TA: tibialis anterior, AbdH: abductor hallucis, SD: standard deviation
*p<0.05

Table 3. Comparison of EMG activities (%MVC) between the group that performed both hip external rotator and TS exercises and the group that performed only TS exercises after the 4-week intervention (n=20)

	Muscle	Hip external rotator exercises and TS exercises Mean (SD)	TS exercises only Mean (SD)
Stair up	GM	24.4 (9)	25.8 (10.4)
	VMO	36.7 (12.9)	48.7 (5.7)
	TA	19 (11.3)	15.7 (6.1)
	AbdH	38.2 (8.8)	37.3 (11.5)
Stair down	GM	12 (5.1)	22.3 (12.8)
	VMO	32.5 (8.9)	41.2 (9.5)
	TA	19.8 (16)	20 (9.1)
	AbdH	39.9 (9.6)	36.9 (9.7)

GM: gluteus maximus, VMO: vastus medialis, TA: tibialis anterior, AbdH: abductor hallucis, SD: standard deviation

present study, hip external rotator muscle strengthening is considered to have increased hip joint external rotation, leading to increased muscle activity of the vastus medialis during stair-climbing. The decrease in ND height that occurred after hip external rotator strengthening exercises would be explained by the internal rotation of the lower extremity, as described by Neumann[1)].

Limitations of the present study include the fact that gait perse is an activity with large variations among individuals, and stair-walking also has limitations for generalization because individuals' stair-walking characteristics are different. In addition, muscle activity levels and joint angles at different time-points could not be identified during motion, as the changes in muscle activity and the joint angles were evaluated together. The issues discussed here should be addressed in future studies to present evidence for exercise treatment through kinetic and kinematic analyses.

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