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The Effects of Foot Intrinsic Muscle and Tibialis Posterior Strengthening Exercise on Plantar Pressure and Dynamic Balance in Adults Flexible Pes Planus

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Abstract

Background: In previous studies regarding flexible pes planus, Foot orthosis, special shoes have been used as interventions for correcting malalignment and intrinsic muscles strengthening exercise have been regarded as interventions for foot function and supporting medial longitudinal arch during walking. However, some recent studies reported that strengthening extrinsic muscles as well as intrinsic muscles is more effective and active intervention for flexible pes planus. In particular, the tibialis posterior muscle of foot extrinsic muscles plays essential roles in maintaining the medial longitudinal arch during dynamic weight bearing and balance. In addition this muscle acts longer than other supination muscles during the stance phase in the gait cycle.

Objects: This study aimed to investigate the effect of foot intrinsic muscle and tibialis posterior muscle strengthening exercise for plantar pressure and dynamic balance in adults with flexible pes planus.

Methods: 16 young flexible pes planus adults (7 males, 9 females) were recruited and were randomized into two groups. The experimental group performed foot intrinsic muscle and tibialis posterior muscle strengthening training, the control group performed only foot intrinsic muscle strengthening training. All groups received strengthening training for 30 minutes five times a week for six weeks.

Results: The experimental group had significantly lower plantar pressure of medial heel area than the control group in stand ($p<.05$). The experimental group had significantly higher dynamic balance ability than control group ($p<.05$).

Conclusion: The results of this study provide evidence to suggest that foot intrinsic muscle and tibialis posterior muscle of extrinsic muscle strengthening exercises may improve plantar pressure distribution and dynamic balance ability in adults with flexible pes planus.

Key Words: Dynamic balance; Flexible pes planus; Plantar pressure; Tibialis posterior muscle.

Introduction

Among foot structures, the arches are important for foot stability and resilience. In particular, the medial longitudinal arch (MLA), consisting of the first metatarsal, medial cuneiform, navicular, talus, and calcaneus bones, is a primary weight-bearing and shock-absorbing structure (Neumann, 2011). Pes planus (or flatfoot) develops as the MLA decreases (Pandey et al, 2013) and is largely divided into rigid type and flexible type. Rigid type includes states in which the MLA has dropped regardless of bearing weight, while flexible types occur when the MLA is formed without bearing weight but disappears during weight bearing (Kuhn et al, 1999).

A flexible pes planus is caused by tibialis posterior dysfunction, foot bone malformation, ligament loosening, Achilles tendon shortening, and foot muscle weakness (Huang et al, 1993; Leung et al, 1998; Murley et al, 2009). These deformations lead to excessive prona-

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tion of the foot during weight bearing and cause plantar flexion and adduction of the talus bone and the valgus of the calcaneus bone (Pandey et al, 2013). Abnormal peripheral information from the foot affects muscle performance necessary for body posture and position control (Shumway-Cook and Horak, 1986) and stable maintenance on the base of support (Franco, 1987). Such abnormalities in the MLA leads to loss of the functional stability of the foot (Franco, 1987), which in turn causes balance problems (Hertel, 2002; Hillstrom et al, 2013; Tsai et al, 2006).

Pes planus treatments are divided into surgical and conservative treatments. Conservative treatments include taping, orthosis, special shoes, and foot muscle exercises. Among these treatments, foot muscle exercises have been reported to reduce excessive pronation, strengthen the foot muscles, and improve foot functions (Panichawit et al, 2015) and have the advantages of helping restructure the foot and being simple to perform (Jung et al, 2011; Lynn et al, 2012). Foot muscles are subdivided into intrinsic and extrinsic muscles. Intrinsic foot muscles assist standing postures and balance during gait and support the MLA during push-off in the stance phase (Neumann, 2011). Exercise interventions for intrinsic muscle strengthening include toe curls (TC), shin curls, picking up objects with the foot, unilateral balance activities, and short foot (SF) exercises (Anderson et al, 2004; Prentice, 2009). Among these exercises, TC and SF exercises are most commonly recommended (Abdo and Iorio, 1994; Freiberger et al, 2007; Liebenson, 2001).

Extrinsic foot muscles, such as the tibialis posterior and peroneus longus muscles, provide dynamic support to the MLA during the stance phase of gait and contribute to stabilization of the intertarsal joints (Jung et al, 2011). In particular, the tibialis posterior muscle plays essential roles in maintaining the MLA during dynamic weight bearing and balance (Kamiya et al, 2012; Kohls-Gatzoulis et al, 2004). In addition, this muscle provides foot adduction, supination, and plantar flexion, assists in controlled flattening of the MLA through eccentric contractions during the stance phase in the gait cycle, and acts longer than other supination muscles (Neumann, 2011). According to Prentice (2009), exercise interventions for selective strengthening of the tibialis posterior muscle include foot adduction, foot supination, and heel raises, with foot adduction and foot supination being the most effective for selective strengthening (Kulig et al, 2004).

In prior studies, the malignment of the foot due to flattening of the MLA has been corrected and excessive pronation of the subtalar joint has been adjusted using the orthosis and special shoes(Brown et al, 1995; Johanson et al, 1994; Nigg et al, 1998). Kelly et al (2014) stated that intrinsic foot muscles are important for foot arch postures while gait loads are applied, and other studies have reported that strengthening exercises targeting these muscles are necessary to maintain and enhance foot function. Foot muscle exercise interventions for the height of the MLA have been limited to intrinsic foot muscle strengthening exercises without considering extrinsic foot muscle strengthening (Jam, 2006; Won and Lee, 2010). Recent studies suggested that to correct foot pronation inducing MLA flattening, increasing the strength of the intrinsic and extrinsic muscles is the most effective method (Panichawit et al, 2015; Snyder et al, 2009). Currently, exercise interventions that combine both foot intrinsic muscle and foot extrinsic muscle are rare and studies of foot plantar pressure and dynamic balance in relation to the pes planus are lacking.

Therefore, the present study includes an examination of the effects of strengthening the tibialis posterior muscle, which maintains foot supination for the longest time among the extrinsic muscles that maintain the MLA, as well as effects on intrinsic muscles related to foot arch height, dynamic balance, and foot plantar pressure distribution in young adults with flexible pes planus. The hypothesis states that intervention methods combining foot intrinsic muscle strengthening exercise and tibialis posterior muscle strengthening exercise will affect flexible pes planus by decreasing foot arch height differences before and after weight bearing, increasing dynamic balance, and decreasing plantar medial column pressure.

Methods

Subjects

This study included 16 young adults (7 males and 9 females) with flexible pes planus residing in Daejeon City of Korea. After hearing sufficient explanations of the study, three participants were excluded during the selection process. The subjects were divided into an experimental group (foot intrinsic muscle and tibialis posterior muscle strengthening training; FTST) that performed intrinsic foot muscle and tibialis posterior muscle strengthening exercises and a control group that performed intrinsic foot muscle strengthening exercise (foot intrinsic muscle strengthening training; FST). The subjects were randomly assigned to the groups by having them draw a card indicating one of the two groups. The general characteristics of the study subjects are provided in Table 1, and selection criteria included foot arch height differences before and after weight bearing exceeding 10 ㎜ (Cote et al, 2005), normal weight with a body mass index ranging from 18.5~23.0 (Chang et al, 2010), and no use of insoles or orthoses. The exclusion criteria for the study subjects were those that had other neurologic, orthopedic, or cardiorespiratory system diseases. The subjects in the present study signed a written agreement related to the experiment and volunteered to participate in the study. The experimental procedure was approved by Daejeon University Institutional Review Board (approval number: 1040647-201506-HR-005-003).

Measurement tools

Foot arch heights measure

The navicular drop test (NDT) was used to select the subjects and measure foot arch heights before and after interventions (Shrader et al, 2005). This test is valuable for measuring and evaluating navicular heights with high reliability [Intraclass correlation coefficient (ICC)>0.94] (Cote et al, 2005; Vicenzino et al, 2000) and can evaluate damage to and weakening of the musculoskeletal system that changes MLA height (Allen and Glasoe, 2000). In a sitting position, subjects were asked to bend the knee joints to 90° and place their feet flat on the ground with a neutral posture of the ankles. In both sitting and standing positions, a sheet marked with navicular bone tuberosity was placed vertically on the floor, and the distance from the floor to the navicular bone tuberosity was marked. The difference between the distance measured in the sitting position and the distance measured in a state of weight bearing was measured using a tape measure (Picciano et al, 1993).

Plantar foot pressure measure

A Gaitview AFA-50 system (alFOOTs, Seoul, Korea) was used to measure foot plantar pressure dis-

Table 1. General characteristics of the subjects (N=16)

Characteristics	Experimental group[a] (n_1=8)	Contorl group[b] (n_2=8)
Gender (male/female)	4/4	3/5
Affected side (left/right)	6/2	3/5
Age (year)	24.9±2.9[c]	24.4±.7.0
Height (㎝)	169.5±7.0	170.5±5.9
Weight (㎏)	62.0±7.4	61.1±7.0
BMI[d] (㎏/㎡)	21.5±1.1	21.0±1.6

[a]foot intrinsic muscle and tibialis posterior muscle strengthening training, [b]foot intrinsic muscle strengthening training, [c]mean±standard deviation, [d]body mass index.

tributions in standing positions. The Gaitview is a pressure pad in the form of a footboard consisting of 2,304 (48×48 ㎟) sensors placed in an area of 410×410 ㎜, and it is highly reliable (Kim and Lee, 2012). The foot plantar pressure measurements were divided into eight zones: hallux, the second through fifth toes, first metatarsal (M1), second through fourth metatarsals (M24), fifth metatarsal, midfoot (MF), medial heel (MH), and lateral heel. To measure the foot plantar pressure distributions, the subjects were instructed to stand upright on the Gaitview for 30 seconds in a comfortable posture with eyes open and looking forward. The values were measured three times with a rest time of one minute after each measurement, and the average of the measured values was obtained. The measurement method was sufficiently explained to the subjects before the measurement so that the subject fully understood what was expected of them.

Dynamic balance test

The star excursion balance test (SEBT) was used to evaluate dynamic balance. This test evaluates balance ability by measuring the distances of the subject's non-weight-bearing leg stretched in eight directions while the weight is being borne on the other leg (Gribble et al, 2004). The eight directions drawn at intervals of 45° are anterior (SEBT-A), anterior-lateral, lateral (SEBT-L), posterior-lateral, posterior, posterior-medial, medial (SEBT-M), and anterior-medial (SEBT-AM). Each subject was instructed to place the leg with flexible pes planus on the center of a line and maximally stretch the other leg along the line. The distance from the center to the end of the big toe of the stretched leg was measured (Cote et al, 2005). During the measurements, subjects could only allow the stretched leg to slightly contact the bearing surface, which ensured that weight was not supported by the stretched leg. After stretching the leg as far as possible, measured values were calculated as a percentage (%) of the subjects' leg lengths (Gribble et al, 2004). Leg lengths were measured in three times as the distance from the medial malleolus bone to the anterior superior iliac spine (Beattie et al, 1990), at intervals of one minute, and the average of the measured values was obtained.

Intervention

The subjects in the experimental group performed selective tibialis posterior muscle strengthening exercises along with the intrinsic foot muscle strengthening exercise, while the subjects in the control group performed only the intrinsic foot muscle strengthening exercise. The interventions were implemented for 30 minutes per time, 5 times per week for 6 weeks.

Selected tibialis posterior muscle strengthening training

The selected tibialis posterior muscle strengthening exercises consisted of foot adduction resistance and foot supination resistance exercises (Kulig et al, 2004). After the exercises and to prevent shortening of the Achilles tendon, the subjects performed calf muscle stretching five times for approximately 7 seconds with a relaxation period of approximately 3 seconds (Hyong et al, 2009). For the foot adduction resistance exercise, each subject placed his or her feet on the floor, forearm length apart, and sat with knee joints bent at a flexion angle of 80°. For leg stability, the subjects placed their forearms on opposite sides of the leg, which strengthened between the legs and the leg being strengthened. Elastic bands were provided depending on each subject's muscle strength (Theraband, GmbH, Hadamar, Germany), which were wound around the medial and lateral sides of each subject's foot, tied up, and pulled laterally at an angle of 45° in relation to the floor (Kulig et al, 2004). During the exercise, the feet were maintained flat, in contact with the floor, and moved as it they were sweeping the floor. For the foot supination resistance exercise, each subject placed one leg on and stood at the lateral end of the footboard with the knee joint of placed on the footboard maintained a bend. The subject placed the medial part of the heel and foot at the base of the third metatarsal bones on the edge of the footboard to perform foot supination (Figure 1).

Foot intrinsic muscle strengthening training

The intrinsic foot muscle strengthening exercises consisted of TCs and an SF exercise (Abdo and Iorio, 1994; Freiberger et al, 2007; Liebenson, 2001) recommended for intrinsic foot muscle strengthening. For the TC, towels were prepared and placed below the feet of the subjects. While heels remained in contact, each subject bent the interphalangeal joint and metatarsophalangeal joint to hold the towel below the feet. During the SF exercise, without bending the toes, subjects shortened their feet in an anterior-posterior direction by moving the head of the M1 bone toward the heel. For TC and SF exercises in a sitting position, the subject sat on a chair to support the hip, knee, and ankle joints at 90° angles. The foot not being exercised was placed behind the foot being exercised. For TC and SF exercises in a one-legged standing position, the subject maintained the legs shoulder-width apart and slightly bent the knee joint. To maintain balance, the subject had the left and right index fingers gently come into contact with the wall.

All exercises were performed in a sequence from a sitting position, to a standing position, and finally a one-legged standing position (Jung et al, 2011). In addition, the researcher instructed the subjects to perform all exercises with maximum efforts.

Statistical analysis

The data collected from the experiments were analyzed using SPSS ver. 18.0 (SPSS Inc., Chicago, IL, USA) and the measured values were presented as means and standard deviations. Mann-Whitney U-tests were conducted to compare foot arch heights, foot plantar pressure and dynamic balance between the two groups, and Wilcoxon signed rank tests were conducted to compare foot arch heights, foot plantar pressure and dynamic balance between before and after interventions. To analyze statistical significance, significance level α was set to .05.

Results

Foot arch heights

The foot arch heights of the FTST and FST

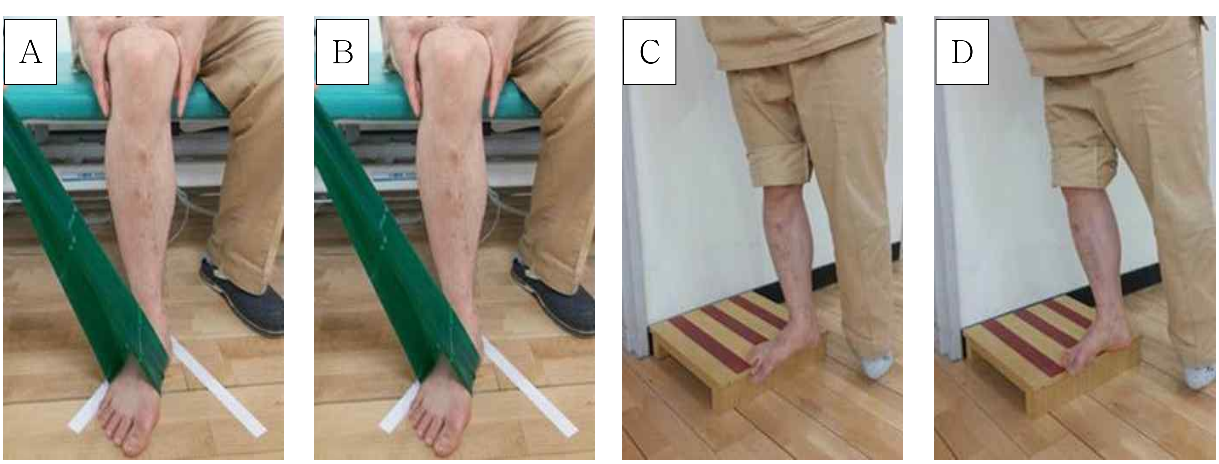

Figure 1. Tibialis posterior strengthening training: foot adduction resistance exercise (A: start position, B: end position), foot supination resistance exercise (C: start position, D: end position).

Table 2. Comparison of Foot medial longitudinal arch height outcomes within groups and between groups

NDT[c] (㎜)	Experimental group[a] (n_1=8)	Contorl group[b] (n_2=8)	p
Pre-test	1.03±.03[d]	1.07±.07	.25
Post-test	.68±.14	.78±.22	.33
p	.01*	.03*	
Change value	-.35±.15	-.29±.26	.44

[a]foot intrinsic muscle and tibialis posterior muscle strengthening training, [b]foot intrinsic muscle strengthening training, [c]navicular drop test, [d]mean±standard deviation, *p<.05.

groups before and after interventions were compared (Table 2). Both groups showed significant differences in foot arch heights before and after interventions (p<.05), but the two groups did not show any difference in foot arch heights (p>.05).

Plantar foot pressure

Plantar pressure distributions of the FTST and FST groups before and after interventions were compared (Table 3). The FTST group showed significant differences before and after interventions in the M1 bone, M24 bones, and MH (p<.05), while the FST group showed no significant difference (p>.05). In addition, the results from the two groups were significant different for the MH (p<.05).

Table 3. Comparison of foot plantar pressure outcomes within groups

Foot plantar pressure (㎪)	Experimental group[a] (n_1=8)	Contorl group[b] (n_2=8)	p
1st metatarsal bone			
Pre-test	108.45±24.93[c]	78.65±29.86	.06
t-test	60.74±41.84	65.10±39.25	.75
p	.02*	.09	
Change value	-47.71±40.46	-13.55±23.72	.17
2～4th metatarsal bone			
Pre-test	144.58±19.94	135.85±16.15	.53
Post-test	97.53±47.31	130.81±28.73	.25
p	.04*	.58	
Change value	-47.05±38.99	-5.04±25.90	.05
Midfoot			
Pre-test	54.16±20.54	56.93±34.62	.80
Post-test	56.61±22.40	57.35±36.19	.92
p	.77	.58	
Change value	2.45±21.45	.43±26.24	1.00
Medial heel			
Pre-test	141.58±13.01	156.08±10.37	.05
Post-test	140.5±15.19	157.06±12.10	.04*
p	.03*	1.00	
Change value	-1.08±14.92	.99±8.45	.60

[a]foot intrinsic muscle and tibialis posterior muscle strengthening training, [b]foot intrinsic muscle strengthening training, [c]mean±standard deviation, *p<.05.

Table 4. Comparison of dynamic balance ability outcomes within groups and between groups

SEBT[a] (㎝)	Experimental group[b] (n_1=8)	Contorl group[c] (n_2=8)	p
SEBT 1 (anterior)			
Pre-test	66.38±7.90[d]	73.34±10.40	.17
Post-test	85.70±10.00	75.67±7.70	.09
p	.01*	.33	
Change value	16.00±7.46	2.28±6.37	<.001*
SEBT 2 (anterior-medial)			
Pre-test	60.85±8.34	75.99±8.67	.01*
Post-test	87.91±10.70	85.68±11.29	.53
p	.01*	.07	
Change value	22.54±12.25	8.26±10.15	.05
SEBT 3 (medial)			
Pre-test	54.41±8.53	71.60±9.12	.01*
Post-test	64.32±5.10	75.53±8.06	.01*
p	.01*	.29	
Change value	8.31±4.57	3.36±7.22	.14
SEBT 4 (posterior-medial)			
Pre-test	63.85±12.42	70.94±9.56	.20
Post-test	88.92±10.91	88.10±8.81	.83
p	.01*	.02*	
Change value	20.79±15.25	14.64±9.71	.46
SEBT 5 (posterior)			
Pre-test	64.33±12.20	69.79±11.01	.28
Post-test	93.19±15.23	84.60±7.89	.25
p	.01*	.03*	
Change value	24.05±14.98	12.56±11.20	.14
SEBT 6 (posterior-lateral)			
Pre-test	66.29±9.62	66.96±12.47	1.00
Post-test	95.90±15.76	86.04±10.26	.17
p	.01*	.03*	
Change value	24.46±14.73	16.35±13.74	.46
SEBT 7 (lateral)			
Pre-test	68.57±6.46	53.68±8.17	.01*
Post-test	89.16±14.42	66.06±11.43	.01*
p	.01*	.03*	
Change value	16.90±12.05	10.28±7.65	.29
SEBT 8 (anterior-lateral)			
Pre-test	71.77±8.08	62.72±5.40	.04*
Post-test	90.17±14.28	73.25±10.59	.03*
p	.01*	.01*	
Change value	15.09±11.15	8.76±7.38	.23

[a]star excursion balance test, [b]foot intrinsic muscle and tibialis posterior muscle strengthening training, [c]foot intrinsic muscle strengthening training, [d]mean±standard deviation, *$p<.05$.

Dynamic balance ability

The dynamic balance ability of the FTST and FST groups before and after intervention were also compared (Table 4), using SEBT. The FTST group showed significant differences in balance before and after interventions in all eight directions ($p<.05$), while the FST group showed significant differences in balance before and after interventions in only five directions ($p<.05$). The two groups showed significant differences in medial, lateral, and anterior-lateral directions ($p<.05$).

Discussion

The purpose of the present study was to examine the effects of exercise to strengthen the tibialis posterior muscle, which is an extrinsic muscle, as well as intrinsic foot muscles on foot arch height, foot plantar pressure distribution and dynamic balance among young adults with flexible pes planus. According to the results, the FTST group, which combined strengthening exercises of the tibialis posterior muscle and intrinsic foot muscles, showed decreased foot arch height differences before and after weight bearing, improved dynamic balance, and significantly decreased foot plantar pressure in the M1 bone, M24 bones, and MH after intervention. In addition, this group showed significant decreases in MH pressure and significant increases in medial, lateral, and anterior-lateral SEBT stretching distances compared to the FST group, which performed only intrinsic foot muscle strengthening exercises ($p<.05$). NDTs were conducted to select subjects and measure foot arch heights. Both groups showed significant decreases in foot arch height differences before and after weight bearing after interventions ($p<.05$), but the two groups did not show any significant difference when compared to each other ($p>.05$). SEBTs were used to evaluate dynamic balance and have been conducted in previous studies as a highly reliable tool for measuring dynamic balance in pes planus patients (Cote et al, 2005; Hyong et al, 2009). According to the results of the present study, the FTST group showed significant increases in stretching distances in all directions, including SEBT-L (foot supination), SEBT-A (forward movement of the center of gravity similar to the propulsion stage in gait cycles), and SEBT-AM and SEBT-M directions (moving the center of gravity toward the medial side of the foot; $p<.05$). The FST group showed significant increases in only five of the eight directions, excluding SEBT-A, SEBT-AM, and SEBT-M ($p<.05$). Based on these results, rather than strengthen training only the intrinsic foot muscles, training that combines intrinsic muscle strengthening and strengthening of the tibialis posterior muscle should be considered to help patients move the center of gravity and during the propulsion stage of gait cycles, which affects gait speed.

Among prior studies, Hyong et al (2009) reported that when extrinsic foot muscle strengthening exercises were implemented with subtalar joint treatment, dynamic balance significantly increased, and Panichawit et al (2015) implemented intrinsic and extrinsic muscle strengthening exercises for flexible pes planus patients and reported that foot functions improved. In the present study, the FTST group performed foot intrinsic muscle strengthening exercise along with exercise to strengthen the tibialis posterior muscle, which allowed for longer gaits compared to other supination muscles that are used during the propulsion stage (Neumann, 2011). Thus, strengthening tibialis posterior muscle during sensory receptor activities and neuromuscular functions improves dynamic balance due to dynamic support of the foot medial area and static support of the intrinsic foot muscle. These strengthening exercises are capable of solving balance problems in flexible pes planus patients.

According to Ledoux and Hillstrom (2002), pes planus causes more weight to be applied to the area below the big toe compared to neutral feet, and when compared to pes cavus and neutral feet, pes planus has the most foot plantar pressure in the metatarsal bones and MF region and the least foot plantar pressure in the calcaneus region (Kim, 2013). During gaits, increased foot plantar pressure is distributed in the medial column (hallux, medial forefoot, medial MF, and medial rear foot), which is medial to the straight line that connects the center of the third metatarsal bone and the calcaneus center compared to normal feet (Sun et al, 2006). The FTST group showed significant decreases in foot plantar pressure in the M1 bone, M24 bones, and MH after the interventions ($p<.05$), while the FST group showed no significant difference ($p>.05$). A comparison between the groups revealed that the FTST group had significant decreases in MH pressure comparted to the FST group ($p<.05$), which is attributed to the strengthened tibialis posterior muscle function in the FTST group and posture changes that aligned the rear foot and normal foot arches recovered during weight bearing (Kitaoka et al, 1997; Niki et al, 2001). This led to reduction in foot plantar pressure in part of the medial column.

The MF did not show a significant difference after interventions for both groups ($p>.05$). Although the MF was divided into the medial and lateral parts when foot plantar pressure was evaluated in previous studies (Jonely et al, 2011; Tang et al, 2015), the Gaitview equipment used in the present study measured foot plantar pressure in eight zones, including the MF. When posture changed to recover a normal foot arch through exercise interventions, even if the pressure in the medial part of the MF decreased, the pressure in the entire MF increased or was maintained because of increases in the pressure in the lateral part of the foot caused by recovering foot arch.

This study has several limitations. First, the SEBT, which was used to evaluate dynamic balance, is closely related to the range of motion of joints and the forces of surrounding muscles because it requires compositive movements of the foot, ankle joint, knee joint, and hip joint (Cote et al, 2005; Won and Lee, 2010). Second, because young adults with flexible pes planus were selected as study subjects, generalizations of the results to diverse age groups does not apply. Third, pain in the foot during gait cycles or exercise caused by excessively pronated feet was not considered. When the feet are excessively pronated, pain occurs in the anterior tibialis muscle, the tibialis posterior muscle, the sole, and the plantar fascia, and the feet easily become tired causing. The present study did not consider cases for which subjects' weight was not balanced between the two feet due to foot arches and pain. Therefore, studies should be continuously conducted with subjects from diverse age groups and conditions to improve these limitations.

Conclusion

This study included 16 male and female adults with flexible pes planus divided into an intrinsic foot muscle and tibialis posterior muscle strengthening exercise group and a intrinsic foot muscle strengthening exercise group to examine the effects of the exercises on foot arch height, foot plantar pressure distribution, and dynamic balance. According to the results, the combined exercise group showed decreases in arch height differences before and after weight bearing, improvement of dynamic balance, and significant decreases in foot plantar pressure in the M1 bone, M24 bones, and MH after intervention. This group also showed decreases in MH pressure and significant increases in stretching distances during medial and lateral SEBTs, but as the center of gravity moving toward the medial side of the foot during the anterior-lateral SEBT, forward movement of the center of gravity was similar to the propulsion stage of the gait cycle and caused foot supination ($p<.05$). Therefore combining exercise interventions for flexible pes planus, rather than strengthening only the intrinsic foot muscles, to include strengthening exercises for the tibialis posterior muscle is more effective for medial foot plantar pressure decreases and dynamic balance ability improvement.

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