Effects of Foot Muscles Training on Plantar Pressure Distribution during Gait, Foot Muscle Strength, and Foot Function in Persons with Flexible Flatfoot

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Objective: *To investigate the effects of a foot-muscle training program on plantar pressure distribution, foot muscle strength, and foot function in persons with flexible flatfoot.*

Material and Method: *Participants received foot-muscle training 3 times weekly, over 8 weeks. Training consisted of gastrosolues muscle stretching and strengthening the muscles around the ankle and the intrinsic muscles. The contact area and peak pressure under the hallux, first metatarsal, and medial midfoot were assessed by the Force Distribution Measurement Platform while walking. Strength of the tibialis posterior and peroneus longus muscles were assessed by handheld dynamometer. Foot function regarding difficulty in activities of daily living was assessed. All measures were assessed at pre-training, intermediate-training, and post-training. Friedman ANOVA was used for testing mean differences among the variables.*

Results: *Five participants with flexible flatfoot were recruited in the study. Results demonstrated significant increases in tibialis posterior (p = 0.018) and peroneus longus muscles strength (p = 0.007), and significant decrease in foot function score (p = 0.021). In addition, no significant difference in contact area and peak pressure was observed among testing periods.*

Conclusion: *Foot-muscle strength and foot function in persons with flexible flatfoot can be improved significantly after receiving foot-muscle training.*

Keywords: *Flexible flatfoot, Plantar pressure distribution, Foot-muscle training*

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Human feet are the organs that receive body weight and allow movement. One essential component of the foot is the arch that provides body weight support and force distribution. The medial longitudinal arch plays a role for shock attenuation and its flexible component enables proper function. Consequently, disorders of the medial longitudinal arch may affect foot function.

Flatfoot, pes planus or fallen arch is a common disorder that arises from a decrease of the medial longitudinal arch. This deformity induces calcaneus bone in the valgus position and talus bone in plantar flexion with adduction producing excessive pronation of the foot when bearing full weight(1). Flatfeet can be categorized as flexible and rigid types(2). Rigid flatfoot is defined as the permanent medial longitudinal arch flat in both weight bearing and non-weight bearing situations. Flexible flatfoot occurs when the arch is flat only during weight bearing situations and the arch appears during non-weight bearing situation. Flexible flatfoot is caused by many reasons such as tibialis posterior dysfunction, abnormalities of the foot bones, ligament laxity, shortened Achilles tendon, calf muscle tightness or contracture, and weakness of the foot muscles(3-5). Murley et al(5) investigated muscle activation in normal subjects and people with flatfoot. They found more muscle activity of the tibialis posterior and tibialis anterior muscles in persons with flatfoot compared with normal persons. Lee et al(6) reported that increased foot pronation may occur in persons with flatfoot who have intrinsic muscle fatigue. When people have suffered from flatfoot for a long time without receiving proper treatment, the disorder may progress to several problems such as hallux valgus, plantar fasciitis, metatarsalgia, knee pain, back pain, knock-knee posture, Achilles tendinitis, and foot bone

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transformation[7-9].

Treatment techniques for flatfoot include taping, orthoses, shoe modification, surgery, and foot-muscle training[10-14]. Taping, orthoses and shoe modification are conservative treatments that provide short-term effects and do not adjust foot structure[10,11]. Surgery can improve pain, function, and foot alignment but is vulnerable to complications after surgery and requires time for recovery[12]. Foot-muscle training can reduce over pronation, assist in restructuring the foot, is easy to perform, cost-free, and provides long-term effect. However, it requires time to improve symptoms and must be performed continuously and consistently[13,14].

No previous study has been conducted on the effect of exercise alone concerning pressure distribution while walking among persons with flexible flatfoot. Only a few studies have indicated that persons with flexible flatfoot had greater pressure at the sub-hallux and middle areas of the foot compared with persons with normal feet[15,16]. Plantar pressure distribution can help therapists diagnose lower extremity problems and evaluate disorder of gait. Thus, the present study aimed to evaluate the effect of foot-muscle training on plantar pressure distribution during gait, foot-muscle strength, and foot function in persons with flexible flatfoot.

Material and Method

Participants

Characteristics of the participants are presented in Table 1. Five volunteer participants were screened using the following criteria: age 18 to 50 years, ability to walk without using assistive device, full range of motion of forefoot inversion and eversion, and no weakness of the gluteus muscles (manual muscle test $\geq$4). Flexible flatfoot is defined as a depressed or absent medial longitudinal arch of the foot while standing and the arch is restored when standing on toes[1]. Exclusion criteria included the flexible flatfoot secondary to neuromuscular disorder, diabetes mellitus, hypertension (blood pressure $\geq$140/90 mmHg), obesity (body mass index $\geq$25 kg/m^2), rheumatoid arthritis, gouty arthritis, pain at the lower extremity (numeric pain scale $\geq$4/10), operation at lower extremity, and leg length discrepancy >1 cm. Data were analyzed on one foot among participants who had one or both sides of flatfoot and evaluation was performed on the side with more symptoms. All participants signed an informed consent form approved by the Mahidol Institutional Review Board (MU-IRB COA. NO. 2013/136.3010) before being recruited in the study.

Outcome measures

Outcome measures consisted of contact area and peak pressure of the foot, strength of the tibialis posterior and peroneus longus muscles, and foot function score. All measures were collected at pre-training, intermediate-training, and post-training by the same examiner. Intermediate-training and post-training data were collected in the 4th and 8th weeks.

Contact area and peak pressure of the foot

The contact area and peak pressure of the foot while walking were assessed by force distribution platform (The zebris FDM-System-Gait Analysis) with 100 Hz sampling frequency synchronized with one video camera (Zebris Medical Gmbh, SC-1 SYNCCam, S/N 1850300002171224, Germany). During gait data collection, the video camera was placed in front of the participants to assist phase identification. Participants were asked to stand at the edge of the platform, then walk barefoot along the walkway platform at usual speed, hands beside the body, and look

Table 1. Characteristics of the participants (n = 5)

Variables	n (%)	Mean (SD)	Minimum	Maximum
Age (years)	-	28.30 (11.46)	19.0	50.0
Sex (male)	3 (60)	-	-	-
Side of flexible flatfoot (left)	4 (80)	-	-	-
Weight (kg)	-	62.80 (11.00)	49.0	75.0
Height (cm)	-	165.60 (11.60)	153.0	180.0
Leg length (cm)				
Left	-	85.80 (6.30)	78.5	91.0
Right	-	86.00 (6.50)	78.0	92.0

straightforward. Three walking trials were recorded for calculating the average contact area and peak pressure. The values of contact area and peak pressure under three areas of the foot [contact areas of the hallux (1), the first metatarsal (2), and medial midfoot (3)] were analyzed by MATLAB software (S/N: 891627).

Strength of the tibialis posterior and peroneus longus muscles

Before collecting data, the examiner trained how to assess the strength of the tibialis posterior and peroneus longus muscles using a handheld dynamometer (Lafayette Manual Muscle Test System, Model 01165, IN, US). High intra-rater reliability was demonstrated for the strength of the tibialis posterior ($ICC_{3,1}$ = 0.95) and peroneus longus ($ICC_{3,1}$ = 0.93). Each muscle was assessed three times and the average data were calculated.

Foot function score

Pain and difficulty of foot were assessed by foot function questionnaire containing 10 items with the score from 0 (no pain or difficulty) to 10 (worst pain or difficulty). It consisted of 1) pain of foot that occurred during activity; 2) pain of foot when walking barefoot; 3) pain of foot when standing barefoot; 4) pain of foot when standing with shoes; 5) pain of foot when walking with shoes; 6) pain of foot at the end of the day, 7) difficulty level while standing tiptoe; 8) difficulty level while fast walking; 9) activity restriction due to abnormalities of the foot; and 10) difficulty in walking continuously for 30 minutes.

Procedure

Participants received a foot-muscle training program three times weekly over two months with a physical therapist. Around 45 minutes was spent for each exercise. The training program comprised calf muscles stretching exercise, strengthening the tibialis posterior, peroneus longus, flexor digitorum longus, ankle dorsiflexors and intrinsic muscles as well as co-contraction of the invertors and evertors. Stretching exercise was performed in approximately 10 repetitions or until the calf muscles were relaxed. Strengthening exercises of each muscle were performed in 10-15 repetitions each set for 3 sets. Participants used various resistive exercise bands (peach, orange, green, blue and purple) according to individual muscle strength.

Data analysis

The data were analyzed using SPSS version 18.0. The variables were compared among pre-training, intermediate-training and post-training by Friedman ANOVA test and pairs of differences were tested by Wilcoxon Signed-Ranks test. Statistically significant differences were set at $p<0.05$.

Results

Table 2 presents comparisons of the contact areas and peak pressures at the hallux, first metatarsal, and medial midfoot, foot function score, and tibialis posterior and peroneus longus muscle strengths among pre-training, intermediate-training, and post-training. No significant differences were found in all contact areas and peak pressures at the hallux, first metatarsal, and medial midfoot areas among training periods. Significant differences were found in the foot function score (p = 0.02) and muscle strengths of the tibialis posterior (p = 0.02) and peroneus longus (p = 0.007). Pairwise comparisons of the foot function score and strengths of the tibialis posterior and peroneus longus are presented in Table 3.

Fig. 1 shows the contact areas and peak pressures of the hallux, first metatarsal, and midfoot for each participant. All of these variables, improvements were found in 3 of 5 participants. Participants ID 1, 2, and 4 demonstrated reduced contact area of the hallux, contact area of medial midfoot, peak pressure of the hallux area, and peak pressure of the first metatarsal area. Reduction of the contact area of the first metatarsal was found in participants ID 1, 2, and 5. In addition, reduced peak pressure of the medial midfoot area was found in participants ID 1, 2, and 3.

Discussion

Our results showed that eight weeks of foot-muscle training was effective in an increase of the tibialis posterior and peroneus longus muscle strengths for persons with flexible flatfoot. Foot function score was significantly decreased implying that persons with flexible flatfoot had better foot functional ability. However, no significant difference was found in the contact areas and peak pressures at the hallux, first metatarsal, and medial midfoot among training periods. We found minimal reduction of the contact area of the medial midfoot at intermediate-training and post-training when compared with pre-training. Decreased accentuation at the medial part of the midfoot implied that the degree of flatfoot decreased.

Considering these results, the authors aimed to correct the weakness of the ankle and foot muscles. This correction might adjust the alignment of the foot

Table 2. Contact areas (cm^2) and peak pressures (N/cm^2) at the hallux, first metatarsal, and medial midfoot, foot function score (score), and tibialis posterior and peroneus longus muscle strengths (N) at pre-training, intermediate-training, and post-training

Variables	Pre-training				Intermediate-training				Post-training				*p*-value
	Mean ± SD	Percentiles			Mean ± SD	Percentiles			Mean ± SD	Percentiles			
		25th	50th	75th		25th	50th	75th		25th	50th	75th	
Contact area-hallux	3.17±3.30	0.42	2.00	6.50	1.33±1.61	0.00	0.66	3.00	2.86±4.30	0.00	1.66	6.33	0.800
Contact area-first metatarsal	36.50±50.65	10.66	16.66	72.25	15.06±4.11	10.66	16.66	18.67	15.40±2.34	13.00	16.66	17.17	0.850
Contact area-medial midfoot	25.40±13.99	15.67	20.00	37.83	16.60±4.41	13.16	14.33	21.17	15.93±6.80	9.66	16.66	21.83	0.450
Peak pressure-hallux	2.03±2.55	0.11	0.83	4.55	0.68±0.75	0.00	0.54	1.43	0.81±0.78	0.00	1.00	1.52	0.800
Peak pressure-first metatarsal	3.73±2.18	2.34	2.69	5.63	3.34±1.81	2.06	2.97	4.82	2.85±1.34	1.74	2.89	3.94	0.550
Peak pressure-medial midfoot	3.40±1.11	2.66	2.87	4.42	2.75±0.49	2.34	2.87	3.10	2.96±0.52	2.65	2.76	3.35	0.550
Foot function score	26.28±12.28	15.35	24.70	38.00	22.33±17.36	7.78	18.10	39.00	16.16±13.54	4.20	11.40	30.50	0.020*
Strength-tibialis posterior	37.69±28.56	15.84	35.38	60.69	56.95±36.41	23.50	68.93	84.42	75.64±46.40	37.17	88.66	107.60	0.020*
Strength-peroneus longus	56.83±31.09	32.62	40.64	89.14	95.29±56.91	53.15	62.33	153.90	141.26±34.69	116.17	130.00	171.99	0.007*

* *p*-value <0.05 analyzed by the Friedman ANOVA test

during the midstance event of the gait and thereby lead to more lateral weight distribution. No improvement was observed in the contact area and foot pressure after exercise in the present study probably caused by the small number of subjects and variability of plantar pressure pattern. The contact area and peak pressure data were analyzed individually. Three of five participants demonstrated improvements of these variables. Participants ID 1 and 2 showed improvements of foot pressure variables in all three areas of measurement after training. The improvements were also captured in participant ID 5, who had reduced contact area of the first metatarsal. Participant ID 3 also demonstrated better peak pressure of the medial midfoot area, which decreased after training.

However, flatfoot symptom improvements also included an increase in muscle strength, decreased pain level, and increased ability to function[14]. The present findings demonstrated improved muscle strength, reduced pain, and increased foot function after exercise. Alteration of the foot structural level may require varied time depending on the severity of flatfoot symptom. The limitations of enrolling only five subjects and a variety of plantar pressure distribution patterns among subjects may have resulted in no significant difference of plantar pressure distribution found in the study.

Regarding the exercise program used in the present study, the authors stretched the calf muscle and strengthened the tibialis posterior, peroneus longus, tibialis anterior, intrinsic, flexor digitorum, and co-contracted invertors and evertors. Recommendation of the target muscles followed previous studies[17,18]. Kamiya et al in 2012[17] reported that the tibialis posterior muscle was the essential muscle used for maintaining the medial longitudinal arch during dynamic weight bearing condition. In addition, Gray in 1969[18] found that the tibialis anterior, tibialis posterior, peroneus longus and soleus muscles play a role in sustaining the medial longitudinal arch in persons with flatfoot.

Conclusion

The present study showed that a foot-muscle training program for eight weeks was sufficient to improve foot muscle strength and foot function in persons with flexible flatfoot. To enhance foot function more effectively, this foot-muscle training program is recommended for persons with flexible flatfoot.

What is already known on this topic?

Several treatment techniques have been recommended to manage problems in persons with

Table 3. Pairwise comparisons of the foot function score and strengths of tibialis posterior and peroneus longus muscle

Outcomes	*p*-value		
	Pre vs. intermediate	Intermediate vs. post	Pre vs. post
Foot function score	0.5	0.068	0.043*
Strength-tibialis posterior	0.068	0.068	0.068
Strength-peroneus longus	0.043*	0.043*	0.043*

* *p*-value <0.05 analyzed by the Wilcoxon signed-ranks test
Pre = pre-training; Intermediate = intermediate-training; Post = post-training

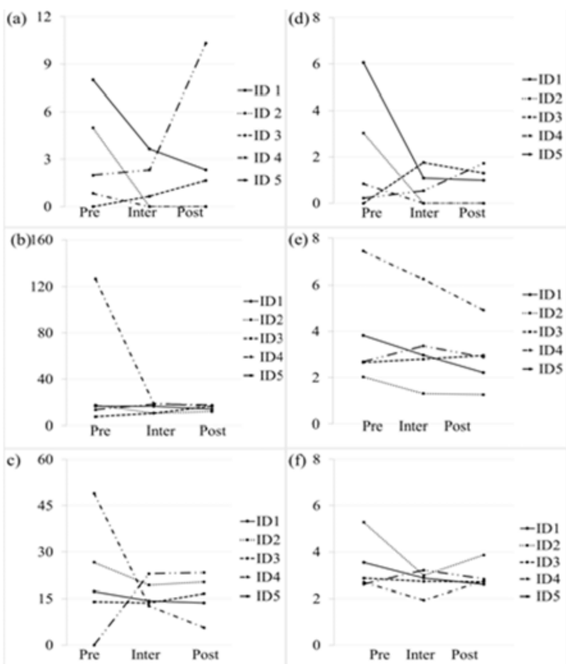

Fig. 1 Graphs representing contact areas (cm^2) of A) hallux, B) first metatarsal, C) medial midfoot and peak pressure (N/cm^2) of D) hallux, E) first metatarsal, and F) medial midfoot during pre-training (Pre), intermediate-training (Inter), and post-training (Post) for each participant (n = 5).

flatfoot. However, effects of foot-muscles training on weight distribution, strength, and function in persons with flexible flatfoot is still controversial.

What this study adds?

Foot-muscle training programs can be used to improve muscle strength and foot function significantly in persons with flexible flatfoot. Tendency of improvement in weight distribution was demonstrated with decreased contact areas at the hallux, first metatarsal, and medial midfoot after training.

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Potential conflicts of interest

None.

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ผลของการฝึกกล้ามเนื้อเท้าต่อการกระจายแรงกดใต้ฝ่าเท้าขณะเดินความแข็งแรงของกล้ามเนื้อเท้าและการทำงานของเท้าในบุคคลที่มีภาวะเท้าแบนแบบปรับตัวได้

ชุติมน พานิชวิทย์, สุนีย์ บวรสุนทรชัย, รุ่งทิวา วัจฉละฐิติ, คมปกรณ์ ลิมป์สุทธิรัชต์

วัตถุประสงค์: *เพื่อเปรียบเทียบผลของการออกกำลังกล้ามเนื้อเท้าต่อการกระจายแรงกดใต้ฝ่าเท้า ความแข็งแรงของกล้ามเนื้อเท้า และการทำงานของเท้าในผู้ที่มีภาวะเท้าแบนแบบปรับตัวได้*

วัสดุและวิธีการ: *ผู้เข้าร่วมการวิจัยได้รับการออกกำลังกล้ามเนื้อเท้า 3 วัน ต่อสัปดาห์ เป็นเวลา 8 สัปดาห์ การฝึกประกอบด้วยการยืดกล้ามเนื้อ gastrosolues และการเพิ่มความแข็งแรงของกล้ามเนื้อรอบข้อเท้าและในฝ่าเท้า โดยการประเมินพื้นที่สัมผัสและแรงกดสูงสุดใต้ตำแหน่งนิ้วหัวแม่เท้า กระดูกเท้าชิ้นที่ 1 และฝ่าเท้าส่วนกลางด้านในด้วยแผ่นวัดแรงกดใต้ฝ่าเท้าขณะเดิน ความแข็งแรงของกล้ามเนื้อ tibialis posterior และ peroneus longus ประเมินด้วย hand held dynamometer การทำงานของเท้าซึ่งเกี่ยวข้องกับความยากลำบากในการทำกิจกรรม ถูกประเมินด้วยแบบประเมินการทำงานของเท้า ตัวแปรทั้งหมดถูกประเมินก่อนรับการฝึก ระหว่างการฝึก และหลังการฝึก ทำการเปรียบเทียบค่าเฉลี่ยของตัวแปรด้วยสถิติ Friedman ANOVA ระดับนัยสำคัญทางสถิติตั้งที่ $p<0.05$*

ผลการศึกษา: *ผู้เข้าร่วมการวิจัยเป็นผู้ที่มีภาวะเท้าแบนแบบปรับตัวได้จำนวน 5 ราย เข้าร่วมในการศึกษานี้ พบความแตกต่างอย่างมีนัยสำคัญทางสถิติของความแข็งแรงของกล้ามเนื้อ tibialis posterior ($p = 0.018$) กล้ามเนื้อ peroneus longus ($p = 0.007$) และคะแนนของแบบประเมินการทำงานของเท้า ($p = 0.021$) นอกจากนี้ไม่พบความแตกต่างอย่างมีนัยสำคัญทางสถิติของพื้นที่สัมผัสและแรงกดสูงสุดระหว่างช่วงเวลาที่ทดสอบ*

สรุป: *การออกกำลังกล้ามเนื้อเท้าสามารถช่วยเพิ่มความแข็งแรงของกล้ามเนื้อเท้าและประสิทธิภาพของการทำงานเท้า ในผู้ที่มีภาวะเท้าแบนแบบปรับตัวได้*