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# The Relationship between Balance and Foot Pressure in Fatigue of the Plantar Intrinsic Foot Muscles of Adults with Flexible Flatfoot

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**Abstract.** [Purpose] This research investigated whether fatigue of intrinsic muscles plays an important role in support of the medial longitudinal arch, affecting foot pressure and balance. [Subjects] The study subjects were 20 adults with flatfoot who did not exhibit musculoskeletal disorders, disease of the lower limbs, or lower back pain. [Methods] The subjects were instructed to perform 75 isotonic contractions of the intrinsic foot muscles, flexing the metatarsophalangeal joints through the full range of motion with an elastic band. This exercise was repeated until a drop in median frequency (MedF) of at least 10% was observed. Before and after exercise, balance and foot pressure were measured with the subject standing on one leg. [Results] After the exercise, the middle forefoot area and midfoot medial area showed a significant difference in foot pressure. In the middle forefoot area, the pressure increased from 21.83 ± 4.56 psi to 25.95 ± 2.92 psi. In the midfoot medial area, the pressure increased from 5.52 ± 1.97 psi to 12.75 ± 2.56 psi. Although the anterior/posterior index, medial/lateral index, and overall stability index of balance increased significant differences were not observed. [Conclusion] Increased pronation of the subtalar joint was seen in people with flatfoot after intrinsic muscle fatigue.
**Key words:** Flatfoot, Intrinsic muscle, Foot pressure

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## INTRODUCTION

The posture of the feet in standing may have an influence on pelvic alignment[1)] and on spinal posture[2, 3)]. Pronation of the subtalar joint is a triplanar motion that, in a closed kinematic chain, is characterized by adduction and plantar flexion of the talus, and eversion of the calcaneus[4)]. The adduction of the talus leads to the internal rotation of the lower limb[4)], while the eversion of the calcaneus, associated with the plantar flexion of the talus, leads to a functional reduction of lower limb length[4)]. Calcaneal eversion is a measure that is commonly used to assess excessive foot pronation[1, 5, 6)]. Flatfoot may affect one or both feet, and not only increases the load acting on the foot structure, but also interferes with the normal foot function[7)]. As a result, the plantar fascia may be overstretched, with the subtalar joint excessively pronated, causing a rearfoot valgus posture in which the calcaneus is everted away from the midline. The forefoot is usually abducted, and the talus and navicular bones are depressed[8)]. The bony structure, ligaments, and extrinsic and intrinsic foot muscles contribute to supporting the medial longitudinal arch (MLA) and play a role in controlling pronation during gait. If one of these structures contributing to the MLA fails, excessive pronation may occur, and injuries may result[9)]. In particular, active forces from intrinsic muscles may be needed to compensate for the lack of tension produced in overstretched connective tissues[8)]. However, fatigue through prolonged tightness of the intrinsic muscles increases the load on the MLA.

Typical flatfoot symptoms include a tenderness of the plantar fascia, patella tendinitis, a rapid tiring of the foot, pain under stress, and instability of the medial side foot structure[10–12)]. Over time, the mechanical overloading resulting from the flattened MLA is transferred to proximal areas such as the knees, hips, and lower back[13)]. Therefore, plantar intrinsic muscles play an important role in supporting MLA[14)]. Increased tension from the intrinsic muscles and increased weight across the tibiotalar joint lead to flattening of the arch[15)]. Long-term fatigue of the intrinsic muscles results in pain, connective inflammation, and other symptoms. However, the effect of fatigue of the plantar intrinsic muscles on body balance and foot pressure has not been studied.

## SUBJECTS AND METHODS

Twenty people with flatfoot participated in this study. None of the subjects suffered from any neurological disorder that might have interfered with the goals of the research. Informed consent was obtained in writing from all subjects.

The general characteristics of the subjects were: 2 men, 18 women; age: 21.3 ± 2.2; height: 165.3 ± 2.3 cm; weight:

60.2 ± 4.2 kg; body mass index (BMI): 22.5 ± 3.0; and navicular drop test: 1.57 ± 0.21 cm.

Measures of balance using the Balance System SD (Biodex Medical System, New York, USA) and foot pressure (FSA, Vista Medical, Canada) while standing on one leg were taken before and after exercising the foot intrinsic muscles.

Balance System SD measures the balance index of subjects which is presented as anterior/posterior, medial/lateral, and overall indexes. A lower score on the balance index represents better balance. Foot pressure was defined using seven areas to identify the pressure distribution of the sole, including one toe area, three forefoot areas, two midfoot areas, and one rearfoot area. The forefoot area located below the metatarsal head was divided into three areas: the medial forefoot area, below the 1st metatarsal head; the middle forefoot area, below the 2nd and 3rd metatarsal heads; and the lateral forefoot area, below the 4th and 5th metatarsal heads. The two midfoot areas were divided into the medial and lateral sides.

We used an elastic band (Theraband, USA) to generate fatigue in the intrinsic muscles, which are important for supporting the MLA, as clarified by Headlee et al.[9]. The subjects were seated on a chair with the hip, knee, and ankle joint at approximately 90°, and the test foot was placed against the elastic band, which was set vertically. The muscle belly of the abductor hallucis on the test foot was palpated, debrided with fine sandpaper, and cleaned thoroughly with isopropyl alcohol. Two EMG electrodes were placed on the skin approximately 2 cm apart and parallel to the muscle fiber orientation of the abductor hallucis muscle[16]. A ground electrode was placed over the lateral malleolus. The foot was fixed to the platform using a Velcro strap to prevent movement of the ankle joint. A block was placed in front of the platform to allow the subject to perform MVC. The subjects were instructed to push their toes straight down toward the floor without bending them and not to tighten any other muscles in the legs or trunk. The tester also demonstrated how the toes should perform on the floor for the subject to see. Subjects then performed three maximum voluntary isometric contractions so that the baseline median frequency (MedF) could be determined. The subjects were instructed to gradually build up to their maximum contraction in two seconds, then hold the contraction for 2–3 s before relaxing. Verbal cues were used to encourage maximal contraction. There was a 60 s rest period between each of the three trials. The MedF calculated from the MVC trial with the greatest peak amplitude was used as the baseline from which the percent of fatigue was calculated[9]. The stationary platform was removed and the subjects placed all of their toes on the elastic band. Each subject was instructed to perform 75 isotonic contractions of the intrinsic foot muscles, flexing the metatarsophalangeal joints through the full range of motion.

The purpose of the 75 isotonic contractions of the intrinsic foot muscles was to generate fatigue in the muscles supporting MLA, similar to that from would arise from walking for a long period. We used the method suggested by Headlee et al.[9]. Following each set of 75 contractions, MVC was recorded again, and MedF was calculated. We were able to calculate MedF in less than 15 s in order to track the percent of downward MedF shift as an index of muscular fatigue. This was repeated until a drop in MedF of at least 10% was observed. For example, if the baseline MedF was 100 Hz, then the subject was instructed to stop the exercise once the MedF from a repetition fell to approximately 90 Hz after exercise. We again measured balance and foot pressure while standing on one leg after a drop in MedF of at least 10% was observed.

SPSS 12.0 was used for all statistical analyses. Balance and foot pressure measurements were compared with the dependent t-test. The correlations between the pre-post change in MedF and the pre-post change in balance and foot pressure were determined. A level of significance of $p<0.05$ was chosen for all analyses.

**Table 1.** Comparison of foot pressure after pre- and post-exercise

| | pre exercise | post exercise |
|---|---|---|
| Hallux | 12.15 ± 4.11 | 11.76 ± 3.95 |
| Medial forefoot area | 22.90 ± 4.56 | 25.75 ± 5.31 |
| Middle forefoot area* | 21.83 ± 4.56 | 25.95 ± 2.92 |
| Lateral forefoot area | 8.32 ± 0.21 | 9.10 ± 1.78 |
| Midfoot lateral | 21.60 ± 4.01 | 22.67 ± 4.76 |
| Midfoot medial* | 5.52 ± 1.97 | 12.75 ± 2.56 |
| Hindfoot | 30.00 ± 0.00 | 30.00 ± 0.00 |

unit: psi

## RESULTS

After the exercise, the middle forefoot area and midfoot medial area showed significant differences in foot pressure ($p<0.05$) (Table 1). In the middle forefoot area, the pressure increased from 21.83 ± 4.56 psi to 25.95 ± 2.92 psi; in the midfoot medial area, the pressure increased from 5.52 ± 1.97 psi to 12.75 ± 2.56 psi. Although the anterior/posterior index, medial/lateral index, and overall stability index showed increases in balance, these increases were not statistically significant (Table 2).

## DISCUSSION

This research investigated whether fatigue of intrinsic muscles plays an important role in support of the MLA, affecting foot pressure and balance. We employed EMG MedF measures as a means of assessing fatigue[18]. This technique is commonly used to measure muscular fatigue, since it can describe a shift in motor unit recruitment from highly fatiguable to less fatiguable motor units[19, 20].

Significantly different pressure distributions at the middle forefoot area and midfoot medial area were found in foot pressures after a drop in MedF of at least 10% induced by exercise of the intrinsic muscles. These results reinforce recent findings that the intrinsic muscles provide substantial support to the MLA in static stance[16]. We suggest that increased pronation was seen in subjects after intrinsic

**Table 2.** Comparison of balance after pre- and post-exercise

| | pre exercise | post exercise |
|---|---|---|
| Anterior/Posteior index | 1.42 ± 0.31 | 1.43 ± 0.38 |
| Medial/lateral index | 1.41 ± 0.30 | 1.49 ± 0.31 |
| Overall index | 1.49 ± 0.25 | 1.53 ± 0.32 |

unit: score

muscle fatigue. As a result, the plantar fascia may have been overstretched, with the subtalar joint excessively pronated, causing a rearfoot valgus posture, in which the calcaneus is everted away from the midline. In this position, the forefoot is usually adducted, and the talus and navicular bones are depressed[8]. Furthermore, although the anterior/posterior index, medial/lateral index, and overall stability index increased after the exercises, the increases were not significant. Flatfoot has been associated with increased plantar peak forces, increased forefoot supination, and increased knee internal rotation[17].

Fatigue of the intrinsic muscles did not affect the hip, knee, and ankle strategy which would have had a direct impact on balance. We speculate that the subjects control their balance using a hip/knee strategy, although they lacked an ankle strategy. Walking for a long time and impact on the foot reduce the ability of people with flatfoot to support the MLA, which increases the pressure on the middle forefoot area and midfoot medial area.

We suggest that people with flatfoot should wear proper insoles to support the MLA when engaged in activities such as extended walking or experiencing impacts on the foot, and should follow a course of exercises to strengthen the intrinsic muscles for ankle stability. If people with flatfoot use proper supporting insoles, they would be able to walk comfortably and avoid rapid fatigue of the muscles around the ankle.

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