J. Phys. Ther. Sci.
27: 3089–3092, 2015

Original Article

An analysis on muscle tone of lower limb muscles on flexible flat foot

Gi-Mai Um, PT, PhD[1)], Joong-San Wang, PT, PhD[1)*], Si-Eun Park, PT, MD[2)]

[1)] *Department of Physical Therapy, Yeoju Institute of Technology: 338 Sejong-ro, Yeoju-si, Gyeonggi-do, Republic of Korea*
[2)] *Department of Physical Therapy, Yongin University, Republic of Korea*

Abstract. [Purpose] The aim of this study was to examine differences in the muscle tone and stiffness of leg muscles according to types of flexible flat foot. [Subjects and Methods] For 30 subjects 10 in a normal foot group (NFG), 10 in group with both flexible flat feet (BFFG), and 10 in a group with flexible flat feet on one side (OFFG), myotonometry was used to measure the muscle tone and stiffness of the tibialis anterior muscle (TA), the rectus femoris muscle (RF), the medial gastrocnemius (MG), and the long head of the biceps femoris muscle (BF) of both lower extremities. [Results] In the measurement results, only the stiffness of TA and MG of the NFG and the BFFG showed significant differences. The muscle tone and stiffness were highest in the BFFG, followed by the OFFG and NFG, although the difference was insignificant. In the case of the OFFG, there was no significant difference in muscle tone and stiffness compared to that in the NGF and the BFFG. Furthermore, in the NFG, the non-dominant leg showed greater muscle tone and stiffness than the dominant leg, although the difference was insignificant. [Conclusion] During the relax condition, the flexible flat foot generally showed a greater muscle tone and stiffness of both lower extremities compared to the normal foot. The stiffness was particularly higher in the TA and MG muscles. Therefore, the muscle tone and stiffness of the lower extremity muscles must be considered in the treatment of flat foot.
Key words: Flexible flat foot, Muscle tone, Stiffness

(This article was submitted May 29, 2015, and was accepted Jul. 6, 2015)

INTRODUCTION

A flexible flat foot refers to a structural deformity in which the medial longitudinal foot arch has become abnormally depressed under weight-bearing conditions[1, 2)]. Due to the flat foot, the loading on the foot cannot be properly distributed, and more activities of the intrinsic and extrinsic muscles are needed[1)]. In a pronation deformity, where the valgus position is combined with the pronation of the subtalar joint, the talus, navicular, and first cuneiform bone are placed downward and medially[3)], and a biomechanical change occuress[2)]. Furthermore, flat foot causes the hyper-adduction of the knee joint as well as the foot deformity, leading to the general structural deformity of the lower extremity[4)].

Among the lower extremity muscles, the medial gastrocnemius (MG) and the long head of the biceps femoris muscle (BF) located in the posterior part on the frontal plane, and the tibialis anterior muscle (TA) and the rectus femoris muscle (RF) are located in the anterior part. As they have the continuity of myofascial meridian, they are mutually involved in posture and balance[5)] and are activated during walking[5, 6)]. However, due to the influence of the flat foot, the lower extremity muscle activity becomes higher or lower than that of the normal foot during walking or when standing on one leg[6, 7)].

Most studies on the flexible flat foot have used electromyography (EMG) to investigate the structural deformities[2–4)] of feet and changes in the activities of the lower extremity muscles during walking[7–9)]. Recently, studies have used myotonometry to compare muscle tone and stiffness between healthy subjects and neurologically impaired patients[10–12)]. However, no studies have investigated the differences in muscle tone and stiffness of the flexible flat foot.

In this study, therefore, differences in the muscle tone and stiffness in both the flexible flat foot and the one-side flexible flat-foot types of both lower extremities, compared to the normal foot type in adults in their twenties, were analyzed to provide basic data for physical therapy and evaluation.

SUBJECTS AND METHODS

This study was conducted with 30 subjects in their twenties who were students of the Yeoju Institute of Technology in Yeoju, Gyeonggi-do. The subjects consisted of 10 in the normal foot group (NFG), 10 in the group with both flexible flat feet (BFFG), and 10 in the one-side flexible flat-foot group (OFFG). Those who had no problem in the vestibular system and the neurological and musculoskeletal system

*Corresponding author. Joong-San Wang (E-mail: king9655@empas.com)

Table 1. General characteristics of subjects

Characteristics		Normal foot goup (n = 10)	Both flexible flat foot (n = 10)	One side flexible flat foot (n = 10)
Gender	Male	3	5	4
	Female	7	5	6
Age (years)		21.2 ± 1.1	21.10 ± 1.4	21.1 ± 1.5
Weight (kg)		60.2 ± 10.3	69.0 ± 9.1	62.3 ± 11.6
Height (cm)		165.6 ± 9.4	168.02 ± 7.0	167.0 ± 10.8
Foot calibration (pixel/pixel)		Dominanant: 0.3 ± 0.0 Non-dominant: 0.3 ± 0.0	Dominant: 0.41 ± 0.0 Non-dominant: 0.41 ± 0.0	Flexible flat foot: 0.3 ± 0.0 Normal foot: 0.3 ± 0.0
Dominant leg		Right (10)	Left (3), Right (7)	Right (10)
Flexible flat foot		Left (0), Right (0)	Left (10), Right (10)	Left (6), Right (4)

mean±SD

and who had not done any regular exercise for the last six months were selected. We explained the purpose and method of this study to the subjects, and only those who consented to participate were included in this study (Table 1). The study protocol was approved by the local ethics committee of the Namseoul University of Cheonan (NSU-150429-7).

In this study, the Global Posture System 400 (GPS 400, Redbalance, Italy) was used to determine the flexible flat foot. The plantar region was photographed using a camera with the GPS system. If the length of the narrowest region of the foot exceeded 0.37 (pixel/pixel) of the length of the widest region in the GPS system, the foot was classified as a flat foot[13]. Based on previous studies[7, 14], the feet were also analyzed using Strake's line and Marie's line. Strake's line refers to the line from the medial line of the fore-foot to the medial line of the rear foot. If the line of the medial sole falls inside Marie's line (the line from the center of the third metatarsal bone to the center of the rear foot), it is a flat foot. When both of these two conditions are met, the foot is classified as flexible flat foot and Marie's line. Strake's line refers to the line from the medial line of the fore-foot to the medial line of the rear foot. If the line of the medial sole falls inside Marie's line (the line from the center of the third metatarsal bone to the center of the rear foot), it is a flat foot. When both of these two conditions are met, the foot is classified as flexible flat foot.

The Myoton®PRO (MyotonAS, Estonia) was used measure the muscle tone and stiffness of the subjects. This device can quickly and safely measure the muscle tone, elasticity, and stiffness of various body regions with high reliability[10, 11, 15]. Every measurement was made in a quiet, isolated room, and the room temperature was 25.5 °C. Before measurement, the highest regions of the muscle belly of the BF, MG, RF, and TA were marked with a skin marker. The muscle tone and stiffness were measured with the measurement device positioned vertically on the skin marker in a relaxed condition in a prone position for the BF and MG and in a supine position for the RF and TA[12]. All measurements were made twice, and their averages were used.

All the data were encoded and analyzed using the statistical analysis program SPSS WIN (ver. 21). The average and standard deviation of the general characteristics (age, weight, and height) were calculated using descriptive statistics for each foot type. The homogeneity was tested with one-way ANOVA, and no significant differences were found ($p > 0.05$).

For each foot type, the OFFG was reclassified into a flexible flat-foot side and a normal foot side, and the BFFG was reclassified into dominant foot and non-dominant foot. In the case of the OFFG, the Wilcoxon signed-rank test was used to compare the differences between the flexible flat-foot side and the normal foot side, and the differences in the muscle tone and stiffness of the dominant foot and non-dominant foot, compared to the BFFG and the NFG. In addition, the Kruskal-Wallis H test was used to analyze the difference in muscle tone and stiffness between the dominant leg of the BFFG and NFG and the flexible flat-foot side of the OFFG. The statistical significance level was set to $\alpha=0.05$.

RESULTS

To investigate the differences in muscle tone and stiffness by foot type, the dominant leg of the NFG and BFFG and the flexible flat-foot side of the OFFG (one-side flexible flat foot) were compared. In the measurement results, only the TA and MG stiffness of the NFG and BFFG showed a significant difference ($p < 0.05$). Although it was insignificant, the muscle tone and stiffness was highest in the BFFG, followed by the OFFG and NFG. Furthermore, in the NFG, the non-dominant leg showed greater muscle tone and stiffness, on average, than the dominant leg, although the difference was not significant. The comparison in muscle tone and stiffness between the normal foot side and the flexible flat-foot side in the OFFG showed no significant difference (Table 2).

DISCUSSION

The flat foot causes generally negative changes to the body due to the structural deformity[4] of the lower extremity joint, changes in muscle activity[7–9], biomechanical changes[2], and decreased muscular strength and balance[16].

Caillet et al.[17] claimed that the stiffness of the ankle dorsiflexor was associated with difficulty during walking due to an asymmetric posture and the loss of balance and motor control. Therefore, an examination of the stiffness of muscles in the flexible flat foot is a critical part of treatment

Table 2. Muscle tone and stiffness on each foot types

Type	Muscle	Side	Muscle tone (Hz)	Stiffness (N/m)
Normal Foot	Rectus femoris	Dominant leg	14.1 ± 0.3	245.5 ± 9.0
		Non-dominant leg	14.0 ± 0.2	240.2 ± 7.3
	Tibialis anterior	Dominant leg	19.0 ± 0.8	380.6 ± 17.5
		Non-dominant leg	19.3 ± 0.6	393.5 ± 14.3
	Medial gastrocnemius	Dominant leg	15.6 ± 0.4	253.7 ± 10.7
		Non-dominant leg	15.7 ± 0.5	254.3 ± 10.9
	Biceps femoris (long head)	Dominant leg	14.7 ± 0.5	236.7 ± 15.8
		Non-dominant leg	15.1 ± 0.7	244.5 ± 19.1
Both flexible flat foot	Rectus femoris	Dominant leg	15.3 ± 0.4	269.3 ± 10.3
		Non-dominant leg	15.2 ± 0.5	264.1 ± 13.1
	Tibialis anterior	Dominant leg	20.6 ± 0.8	436.7 ± 17.7*
		Non-dominant leg	20.5 ± 1.0	450.5 ± 26.1
	Medial gastrocnemius	Dominant leg	16.6 ± 0.3	277.0 ± 6.7ǂ
		Non-dominant leg	16.5 ± 0.3	279.4 ± 6.8
	Biceps femoris (long head)	Dominant leg	15.9 ± 0.4	274.8 ± 12.8
		Non-dominant leg	16.0 ± 0.3	281.7 ± 11.2
One side flexible flat foot	Rectus femoris	Flexible flat foot	14.3 ± 0.3	248.9 ± 10.2
		Normal foot	14.5 ± 0.3	253.5 ± 9.6
	Tibialis anterior	Flexible flat foot	19.4 ± 0.6	416.3 ± 24.3
		Normal foot	19.5 ± 0.8	421.9 ± 27.9
	Medial gastrocnemius	Flexible flat foot	15.8 ± 0.5	263.1 ± 8.5
		Normal foot	15.6 ± 0.5	254.9 ± 11.0
	Biceps femoris (long head)	Flexible flat foot	15.3 ± 0.4	258.9 ± 16.3
		Normal foot	15.5 ± 0.3	260.9 ± 11.4

Values are means ± SE
*Significant difference between normal foot and both flexible flat foot in tibialis anterior of dominant leg
ǂSignificant difference between normal foot and both flexible flat foot in medial gastrocnemius of dominant leg

and evaluation.

In this study, a comparison of the muscle tone and stiffness of both lower extremity muscles by foot type indicated a significant difference in the stiffness of the TA and MG muscles of the dominant leg between the NFG and the BFFG ($p < 0.05$). The muscle tone and stiffness was the highest in the BFFG, followed by the OFFG and NFG, although the differences were insignificant. This means that the muscle tone and stiffness of the flat foot are higher than those of the normal foot. Furthermore, a comparison of the muscle tone and stiffness of the normal foot side and the flexible flat-foot side in the OFFG revealed that the muscle tone and stiffness of the MG were higher on the flexible flat-foot side, whereas the muscle tone and stiffness of the RF, TA, and BF were higher on the normal foot side, although the differences were insignificant. It seems that the differences were insignificant because the muscle tone and stiffness were measured in a relaxation condition. The differences in muscle tone and stiffness could increase during physical activities such as standing or walking. In the case of the NFG, the muscle tone and stiffness of the RF were higher on average in the dominant leg, and those of the TA, MG, and BF were higher in the non-dominant leg, however, the differences were insignificant. The reason for this seems to be that the frequency of raising the dominant leg with the support of the non-dominant leg is higher.

Among the studies on EMG, Lee et al.[4] compared the muscle activity between the normal foot and the flat foot when standing on one leg and found that the muscle activities of the MG, TA, and vastus medialis (VL) of the flat foot were lower, whereas the muscle activity of the RF of the flat foot was higher, however, the differences were insignificant. Only the muscular activity of the abductor hallucis muscle of the normal foot was significantly higher than that of the flat foot, suggesting the importance of the intrinsic foot muscles. Therefore, more research on the intrinsicfoot muscles is required in the future.

In a study that analyzed the muscle activity of the flexible flat foot using the root mean square (RMS) of the EMG, Vittore et al.[18] mentioned that the TA needs to be strengthened during the rehabilitation of flat foot, because the more severe the flexible flat foot was, the lower the muscle activity of TA in the supine and orthostatic position became. In this study, however, the muscle tone and stiffness of the lower extremity muscles of the flat foot were higher compared to those of the normal foot. The reason for this seems to be that the lower muscle activity increased the muscle tone and stiffness.

In this study, only the stiffness of the TA and MG muscles of the NFG and BFFG showed significant differences, but on average, the muscle tone and stiffness of both the lower extremity muscles of the flexible flat foot were higher than those of the normal foot. These changes will be a negative factor in walking or other physical functions, and in cases of older age or injury to the lower extremity, the function of the lower extremity will become lower, and more neuromuscular control will be required.

For the limitations of this study, the findings cannot be generalized to all ages, because the subjects were in their 20s, and differences by gender were not examined. Furthermore, this study could not be compared to many previous studies, because there were few previous studies about the muscle tone and stiffness of the flexible flat foot.

However, the findings of this study reveal the need for an adjustment of the muscle tone and stiffness of a flexible flat foot during physical therapy, and the results of this study can be used as basic data for various physical therapies such as strengthening exercise, therapeutic massage, and myofascial release.

REFERENCES

1) Neumann DA: Kinesiology of the musculoskeletal system (Foundations for rehabilitation). St Louis: Mosby, 2010.
2) Leung AK, Mak AF, Evans JH: Biomedical gait evaluation of the immediate effect of orthotic treatment for flexible flat foot. Prosthet Orthot Int, 1998, 22: 25–34. [Medline]
3) Otman S, Basgöze O, Gökce-Kutsal Y: Energy cost of walking with flat feet. Prosthet Orthot Int, 1988, 12: 73–76. [Medline]
4) Lee SY: The effect of on CTA and Q-angle with the different position of the foot in the standing status, Daegu University Rehabilitation Science Graduate School, a Master’s degree, 2002.
5) Myers TW: Anatomy Trains: Myofascial Meridians for Manual and Movement Therapists. Churchill Livingstone, 2001.
6) Murley GS, Landorf KB, Menz HB, et al.: Effect of foot posture, foot orthoses and footwear on lower limb muscle activity during walking and running: a systematic review. Gait Posture, 2009, 29: 172–187. [Medline] [CrossRef]
7) Kim MK, Lee YS: Kinematic analysis of the lower extremities of subjects with flat feet at different gait speeds. J Phys Ther Sci, 2013, 25: 531–533. [Medline] [CrossRef]
8) Lee JE, Park GH, Lee YS, et al.: A comparison of muscle activities in the lower extremity between flat and normal feet during one-leg standing. J Phys Ther Sci, 2013, 25: 1059–1061. [Medline] [CrossRef]
9) Hunt AE, Smith RM: Mechanics and control of the flat versus normal foot during the stance phase of walking. Clin Biomech (Bristol, Avon), 2004, 19: 391–397. [Medline] [CrossRef]
10) Aird L, Samuel D, Stokes M: Quadriceps muscle tone, elasticity and stiffness in older males: reliability and symmetry using the MyotonPRO. Arch Gerontol Geriatr, 2012, 55: e31–e39. [Medline] [CrossRef]
11) Marusiak J, Jaskólska A, Budrewicz S, et al.: Increased muscle belly and tendon stiffness in patients with Parkinson’s disease, as measured by myotonometry. Mov Disord, 2011, 26: 2119–2122. [Medline] [CrossRef]
12) Mullix J, Warner M, Stokes M: Testing muscle tone and mechanical properties of rectus femoris and biceps femoris using a novel hand held MyotonPRO device: relative ratios and reliability. Working Papers in Health Sciences, 2012, 1: 1–8.
13) Global posture system 400 manual.
14) Clarke HH: Application of measurement to Health and Physical Education, 5th ed. Prentice-Hall, 1976, p 96.
15) Bailey L, Samuel D, Warner M, et al.: Parameter representing muscle tone, elasticity and stiffness of biceps brachii in healthy older males: symmetry and within-session reliability using the myotonPRO. J Neurol Disord, 2013, 1: 1–7. [CrossRef]
16) Riemann BL, Myers JB, Lephart SM: Sensorimotor system measurement techniques. J Athl Train, 2002, 37: 85–98. [Medline]
17) Caillet F, Mertens P, Rabaséda S, et al.: [Three dimensional gait analysis and controlling spastic foot on stroke patients]. Ann Readapt Med Phys, 2003, 46: 119–131. [Medline] [CrossRef]
18) Vittore D, Patella V, Petrera M, et al.: Extensor deficiency: first cause of childhood flexible flat foot. Orthopedics, 2009, 32: 28. [Medline] [CrossRef]