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Original Article

Gender difference in factors affecting the medial longitudinal arch height of the foot in healthy young adults

Katsuhito Nagano, RPT, PhD[1)*], Risako Okuyama, RPT[2)], Natsuki Taniguchi, RPT[3)], Tomoki Yoshida, RPT[4)]

[1)] *Division of Physical Therapy, Department of Rehabilitation, Faculty of Health Science, Fukui Health Science University: 56 Egami-cho 13-1, Fukui City, Fukui 910-3190, Japan*
[2)] *Department of Rehabilitation, Nakamura Hospital, Japan*
[3)] *Department of Rehabilitation, Fukui General Hospital, Japan*
[4)] *Department of Rehabilitation, Geriatric Health Services Facility Alma Senju, Japan*

Abstract. [Purpose] Medial longitudinal arch (MLA) height is associated with various injuries and diseases and gender differences, if any. This study aimed to examine factors affecting the MLA height associated with gender differences in healthy subjects with no orthopedic disorders. [Subjects and Methods] This study included 36 healthy adults (19 males, 17 females; mean age, 21.8 ± 3.6 years; body mass index, 21.1 ± 2.0 kg/m^2). Their height, body weight, foot length, muscle strength of the tibialis posterior muscle (TPM), toe-gripping strength, hallux valgus angle, inversion microdactylia angle, angle of leg–heel alignment, femoro-tibial angle, and navicular height were measured. Correlation between the ratio of arch height and other measurement parameters was examined. [Results] In females, the ratio of arch height was significantly positively correlated with muscle strength of the TPM and toe-gripping strength and negatively correlated with the hallux valgus angle and the leg-heel alignment, whereas in males, only a positive correlation between the ratio of arch height and muscle strength of the TPM was observed. [Conclusion] These results reveal that etiological mechanisms determining MLA height are different between males and females. Overall, the present results indicate that further studies identifying causes of MLA height variation must include gender-based analysis.
Key words: Medial longitudinal arch, Tibialis posterior muscle, Toe-gripping strength

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INTRODUCTION

The medial longitudinal arch (MLA) height of the foot is associated with various injuries, diseases, and disability of lower extremities, including anterior cruciate ligament injuries[1)], medial tibial stress syndrome[2, 3)], plantar fasciitis[4)], rheumatoid arthritis[5)], and cavus foot deformity[6)].

The MLA has an important role as shock absorber for mechanical shock and load during walking and for body weight during static movement. It has a protective role not only in foot ankle joints but also in osteoarthritis of the knee and hip and in soft tissue injuries near the proximal lower extremities[7)]. Factors influencing MLA include constructional factors involving ligaments and bones and functional factors involving foot and lower leg muscles that form the support structure for the MLA, which is as follows:

The bone structure of the MLA is formed by the calcaneus, talus, navicular bone, medial cuneiform bone, and first metatarsal bone. The spring ligament complex is connected with the navicular bone of the foot, and thus the navicular bone

*Corresponding author. Katsuhito Nagano (E-mail: nagano@xg8.so-net.ne.jp)

serves as an important constructional factor for the MLA and has a role as an indicator and stabilizer determining height of the foot arch[8, 9].

The tibialis posterior muscle (TPM) originates from the interosseous membrane, the posterolateral tibia, and the posteromedial fibula; passes through the rear of medial malleolus; and connects with the lower inner surface of the navicular, cuneiform, and cuboid bones and the base of the 2–5 metatarsal bones. It serves as a functional factor for the MLA and has a role in inversion and plantar flexion of the foot and elevation of the medial longitudinal arch.

From these functions, TPM dysfunction is considered the most common cause of adult-acquired flatfoot and has been reported as a major functional factor supporting formation of the foot arch[10].

Although the plantar intrinsic foot muscles and the extrinsic foot muscles are widely thought to be associated with formation of the foot arch, electrical activity of these muscles is undetectable when weight is applied on the knee in a sitting position. The TPM is unable to sufficiently compensate for insufficiency of the arch under sectioning of the spring ligament complex. Therefore, the spring ligament complex is considered the major stabilizer of the arch and not the TPM[11]. Therefore, the role of the TPM in MLA height must be further examined to explain the contrasting results.

In contrast, toe flexor strength, which is caused by the action of the flexor digitorum longus, flexor hallucis longus, and flexor digitorum brevis muscles, is considered to be an important factor involved in walking and standing ability, risk of falling, and balance stability[12–16]. Moreover, toe flexor strength has been reported to be associated with the foot arch, and it is recognized that short foot exercises for intrinsic muscles of the foot to improve the MLA in flatfoot result in improved results in the arch height index[17].

However, it is reported that toe flexor strength in children is not correlated with foot arch height and that foot arch height did not decrease even due to experimentally fatigued abductor halluces and flexor hallucis brevis muscles, which are considered to be associated with toe flexor strength[18, 19]. Based on these differing results, the association between foot arch height and toe flexor strength remains unclear.

MLA height in children has been reported to be correlated with overweight, obesity, and genu valgum, which also causes flatfoot[20–22]. However, little has been reported on the association between MLA height and digitus minimus varus.

Previous studies have arrived at differing or unclear results due to differences between patients and healthy subjects, based on the age and gender of subjects. Therefore, the present study was designed to normalize age and health status and examine factors influencing MLA height.

SUBJECTS AND METHODS

All subjects agreed to participate in this study after receiving an explanation of its purpose and content and all the risks involved. The study was conducted in accordance with the principles of the Declaration of Helsinki for experimentation with humans and was approved by the Ethics Committee for Human Experiments of the Nittazuka Medical Welfare Center (No. 27-128).

The subjects of the study included 36 healthy adults (19 males and 17 females; 72 feet) whose mean age was 21.8 ± 3.6 years. Subjects were excluded if they had central nervous system disease, peripheral nerve disease, or orthopedic disorders.

Body mass index (BMI) was calculated as weight (kg) divided by height (m^2). Navicular height was measured as the distance of the navicular tuberosity from the floor surface, and foot length was measured as the distance from the rear edge of the heel to the tip of the longest of the first and second toes. The ratio of arch height was calculated as the height of navicular bone divided by the actual length of the foot. For the ankle plantar flexion and inversion strength, the peak torque (Nm) at an angular speed of 60° was measured in the supine position using CYBEX NORM (Cybex International, Inc., USA.) according to the method described by Yildiz et al[23]. Muscle strength was measured thrice, and an average was obtained and used as the muscle strength of the TPM, which is one of the muscle groups of ankle plantar flexor and inverter. Time interval between measurements was 30 s. Toe-gripping strength was measured as per a toe-grip measurement method developed by Miura et al. Number of measurements and time interval were identical to those in the above sthenometry.

The hallux valgus angle was measured as the angle formed between the axis of the proximal phalanx of the big toe and the axis of the first metatarsal bone. The inversion microdactylia angle was measured as the angle formed between the axis of the fifth proximal phalanx and the axis of the fifth metatarsal bone. While subjects were in a standing position with their full weight bearing on both legs, the leg-heel alignment (LHA) was measured as the angle formed between the long axis of the lower leg and the straight line bisecting the calcaneus. The femoro-tibial angle (FTA) was assessed by measuring the lateral angle between the femoral and tibial anatomical axes while standing.

All data were expressed as mean ± standard deviation. Pearson's correlation analysis was applied to determine the relationships of the ratio of arch height with strength of the TPM, toe-gripping strength, the hallux valgus angle, the inversion microdactylia angle, LHA, and FTA. All statistical analyses were performed using the software Statcel4 (OMS Inc., Saitama, Japan). $P<0.05$ was considered statistically significant for each two-tailed analysis.

Table 1. Correlation between foot arch ratio and other parameters in male subjects (n=19)

Measurement items	Mean value	Correlation coefficient
Ratio of foot arch height (%)	11.6 ± 2.2	
Height (cm)	171.0 ± 5.4	0.2511
Weight (kg)	62.4 ± 4.6	0.1974
BMI (kg/m^2)	21.3 ± 1.7	−0.0495
Hallux valgus angle (°)	9.7 ± 3.5	0.1396
Digitus minimus varus (°)	13.8 ± 3.9	0.2628
Tibialis posterior muscle strength (Nm)	20.3 ± 6.3	0.4155**
Toe grip strength (kg)	12.4 ± 3.2	−0.0379
Leg-heel alignment (°)	6.4 ± 3.1	−0.0246
Femoro-tibial angle (°)	177.1 ± 1.7	−0.2831

Data are expressed as mean ± SD.
**Significant difference p<0.01.

Table 2. Correlation between foot arch ratio and other parameters in female subjects (n=17)

Measurement items	Mean value	Correlation coefficient
Ratio of foot arch height (%)	11.2 ± 2.6	
Height (cm)	160.4 ± 6.2	0.4116
Weight (kg)	53.8 ± 7.9	0.3130
BMI (kg/m^2)	20.9 ± 2.3	0.1297
Hallux valgus angle (°)	11.0 ± 4.0	−0.3707*
Digitus minimus varus (°)	15.9 ± 6.2	−0.1507
Tibialis posterior muscle strength (Nm)	14.2 ± 4.6	0.3561*
Toe grip strength (kg)	9.0 ± 2.7	0.3770*
Leg–heel alignment (°)	6.6 ± 2.9	−0.4688**
Femoro-tibial angle (°)	175.4 ± 2.1	0.1172

Data are expressed as mean ± SD.
*Significant difference p<0.05. **Significant difference p<0.01.

RESULTS

A total of 36 participants completed all measurements in this study. The male and female participant characteristics, mean value of the arch height ratio, and values of the six parameters potentially influencing MLA height are shown in Table 1 and 2.

Correlation analysis in male subjects (Table 1) showed that ratio of arch height in males was significantly positively correlated with TPM strength (r=0.42, p<0.01) and TPM strength relative to body weight (r=0.35, p<0.05). No significant correlations were found between ratio of arch height and any of the other parameters. In contrast, correlation analysis in female subjects showed that ratio of arch height was significantly positively correlated with TPM strength (r=0.36, p<0.05) and toe-gripping strength (r=0.38, p<0.05) and was significantly negatively correlated with the hallux valgus angle (r=−0.37, p<0.05) and the LHA (r=−0.47, p<0.01). No significant correlations were found between ratio of arch height and any of the other parameters.

DISCUSSION

Interpretation of the Pearson's coefficient r is a measure of correlation ranging from 0.25 to 0.50, which suggests a fair degree of relationship; a value of 0.5 to 0.75 indicates moderate to good correlation, whereas a value greater than 0.75 indicates good to excellent correlation[24]. The results of the present study revealed a fair positive correlation between foot arch ratio and TPM strength in both males and females, a fair positive correlation between foot arch ratio and toe grip strength only in females, and fair negative correlations between foot arch ratio and the hallux valgus angle and LHA only in females. This indicated gender-based differences in the effect of the various parameters on MLA height. Further, no statistical correlations were found between foot arch ratio and body weight, BMI, body height, digitus minimus varus, or FTA indicating that the correlation was poor to fair in either males or females.

Kovaleski et al. reported that college-age females have a higher ankle inversion-eversion range of motion than males[25].

Similarly, analysis of foot radiographic images has shown that the magnitude of angular change of the medial longitudinal arch under both static and dynamic weight-bearing conditions compared with non-weight bearing conditions was greater in females than in males[26]. These results demonstrate that females have greater joint mobility of the foot than males and that foot ligaments in females have higher flaccidity than those in males; the foot arch in females can thus be presumed to be higher influencing factors other than ligaments which support the foot arch. Toe grip strength is a compound movement produced due to activity of the flexor digitorum brevis, flexor hallucis brevis, lumbricals pedis, flexor digitorum longus, and flexor hallucis longus muscles[27]. The toe flexor muscles contribute to the support of foot arch height[28, 29]. The ratio of MLA height was found to be positively correlated with toe grip strength only in females in the present study, probably because toe flexor muscles contribute to foot arch height in females owing to weaker support of foot ligaments of the foot arch in females compared with that in males.

Although the ratio of arch height in females was positively correlated with the hallux valgus angle in the present study, hallux valgus occurs more frequently in females, and several factors have been reported to be associated with hallux valgus including genetic factors, gender, age, BMI, foot pain, and high-heeled shoes[22]. In contrast, several studies have reported that the hallux valgus angle is associated with pronation deformity of the first metatarsal; in addition, first metatarsal pronation affects the MLA heigh[30, 31]. Results obtained in females in this study were in good agreement with the above reports, implying that MLA height in females is more likely to be influenced by the hallux valgus angle compared with that in males.

Overall, our results suggested that support mechanisms for MLA height are likely to differ between males and females. Gender-based analysis is necessary for further studies identifying causes of MLA height variation.

Conflict of interest

None.

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