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Original Article

Children with flat feet have weaker toe grip strength than those having a normal arch

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Abstract. [Purpose] This study investigated the relationship between toe grip strength and foot posture in children. [Subjects and Methods] A total of 619 children participated in this study. The foot posture of the participants was measured using a foot printer and toe grip strength was measured using a toe grip dynamometer. Children were classified into 3 groups; flatfoot, normal, and high arch, according to Staheli's arch index. The differences in demographic data and toe grip strength among each foot posture group were analyzed by analysis of variance. Additionally, toe grip strength differences were analyzed by analysis of covariance, adjusted to body mass index, age, and gender. [Results] The number of participants classified as flatfoot, normal, and high arch were 110 (17.8%), 468 (75.6%), and 41 (6.6%), respectively. The toe grip strength of flatfoot children was significantly lower than in normal children, as shown by both analysis of variance and analysis of covariance. [Conclusion] A significant difference was detected in toe grip strength between the low arch and normal foot groups. Therefore, it is suggested that training to increase toe grip strength during childhood may prevent the formation of flat feet or help in the development of arch.

Key words: Flatfoot, Toe grip strength, Children

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INTRODUCTION

Foot misalignment (flatfoot and high arch) is one of the common orthopedic issues in pediatric health[1–3)] and it causes many injuries in the foot, knee, and lower back[3–5)]. Almost all children are born with flatfoot and normal foot posture develops during the first decade of life[6, 7)]. However, some children have misaligned feet even after10 years of age. An estimated 19.1% of children, aged 10–13 years, have flatfoot[8)]. The incidence of high-arched foot is reportedly 14.6–25.8%[9, 10)]. If normal foot posture does not develop created during the elementary school period, foot misalignment continues to during adolescence and into adulthood. Therefore, development of normal foot posture during childhood is important.

Flatfoot and high arch are caused by many factors such as neurological disorders, congenital conditions, and structural anomalies[1, 3)]. However, flatfoot and high arch can also be found in otherwise healthy individuals, and in the absence of injury, they can be caused by structural issues such as ligament tension and muscle strength[1, 3)]. Ligament laxity typically improves as bones lengthen with age, and the majority of children develop an arch in the first decade of life[11)]. In early childhood, the intrinsic and extrinsic foot muscles are usually strengthened through walking and running. However, if the intrinsic and extrinsic foot muscles are not used enough in early childhood, they remain weak. Therefore, improving muscle strength in the foot is one method of treating foot misalignment.

Recently it was revealed that toe grip strength is related to foot posture. Toe grip strength is the strength of the toe flexor muscles, such as the flexor hallucis longus and flexor digitorum longus. These muscles are related to the creation of the foot arch. Hashimoto et al.'s study revealed that toe grip strength training can increase the foot arch in adolescents[12)]. Toe grip strength is related to foot posture in adolescents[13)]. However, it is not known if the same relationship between toe grip strength and foot posture is present in children. The authors hypothesized that there was a relationship between toe grip strength and foot posture in children. The demonstration of a relationship between foot posture and toe grip strength would highlight the importance of toe grip strength

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in creation normal foot posture during childhood. Therefore, the authors investigated the relationship between toe grip strength and foot posture in this study.

SUBJECTS AND METHODS

A total of 619 children (boys, n = 311, age = 11.2 ± 0.7 years; girls, n = 308, age = 11.3 ± 0.7 years; age expressed as mean ± SD) participated in this study. Signed consent was obtained from the principals of five elementary schools in Nara Prefecture in Japan for inclusion of their schools in the study. Demographic data were collected from the returned consent forms, as were the inclusion (age 10–12 years) and exclusion (no history of foot surgery or congenital disorders) criteria. The purpose and methods of the current study were explained to the participants and elementary school teachers in detail in a verbal statement and document. The local ethics committee approved the study (H26-6).

Foot posture was measured using a foot printer (Bauerfeind Co. LTD, Germany). A static footprint was obtained as each child stood barefoot on the foot printer, with weight normally distributed between both feet. The dominant foot was identified as that preferred for kicking a ball and we used the posture of the dominant foot in the analysis. Children stood with their feet shoulder width apart and placed their foot at whatever angle they preferred. The width of the foot at the arch and the width of the heel were measured. The arch index for each foot was calculated by dividing the former number by the latter, as described by Staheli et al[14].

Toe grip strength was measured using a T.K.K.3362 toe-grip dynamometer (Takei Scientific Instruments, Niigata, Japan) (Fig. 1). The protocol for measuring toe grip strength was as described in the studies by Uritani et al[15, 16]. Participants sat upright on a chair without leaning on the backrest throughout the toe grip strength measurements. Both of the hips and knees were flexed at about 90° and the ankles were placed in a neutral position and fixed with a strap. The first proximal phalanx was positioned at the grip bar, and the heel stopper was adjusted to fit the heel of each participant. The bar was then gripped with the toes using maximal effort, for about 3 seconds. Toe grip strength of the dominant foot was measured twice. The maximum strength from the two measurements was recorded.

At first, participants were classified into flatfoot, normal, and high arch categories, based on the arch index, as measured by their footprint. An arch index value between 0.44 and 0.89 was defined as a normal foot, an index <0.44 was classified as a high arch, and an index, >0.89 was classified as a low arch[14]. Differences in age, body mass index (BMI), toe grip strength, and gender between the three groups were examined using analysis of variance (ANOVA) and a χ^2 test. Differences in toe grip strength among the 3 groups were examined using analysis of covariance (ANCOVA) adjusted for age, BMI and gender. When a significant effect was found, differences were determined using the Turkey-Kramer post-hoc test for ANOVA, and the Bonferroni post-hoc test for ANCOVA. Statistical analysis were carried out using the SPSS version 20.0 software package (SPSS, Chicago, IL, USA), with a p value < 0.05 accepted as significant.

Fig. 1. T.K.K.3362 toe-grip dynamometer

RESULTS

Table 1 shows the characteristics of the participants. The ANOVA results showed that there was a significant difference in toe grip strength among the 3 groups ($p < 0.01$). The values for toe grip strength were 11.0 ± 3.9 kg in flatfoot, 12.6 ± 4.1 kg in normal, and 11.4 ± 3.6 in high arch (Table 2). The toe grip strength of the low arch group was significantly lower than the normal group ($p < 0.01$) and that there was no significant difference between the high arch group and other groups. In addition, ANCOVA showed a significant difference in toe grip strength among the 3 groups when adjusted for age, BMI, and gender ($F = 5.22$, $p = 0.01$). Post-hoc tests indicated that the toe grip strength of the low arch group was significantly lower than in the normal group ($p < 0.01$).

DISCUSSION

Our study revealed that toe grip strength was related to foot posture in children and that the toe grip strength of the flatfoot group was weaker than that of the normal group. However, there was no significant difference between high arch group and the other groups. In addition, toe grip strength was related to foot posture after adjustment for BMI, age, and gender.

Foot posture of children is related to BMI, age, and gender[17, 18], however in this study toe grip strength was related to foot posture, when measurements were adjusted for these factors. Moreover, muscle strength and physique differ with age and gender as children go through their growth period[19], as does the prevalence of flatfoot[17]. Foot posture in children is flexible, so the foot arch can easily be decreased by the body weight load. Evan found that foot posture was not related to weight in children[20]; nevertheless, many other studies have identified a correlation between BMI and foot posture[17, 18, 21, 22]. Pfeiffer et al.'s study revealed that flatfoot was present in 62% of obese, 51% in overweight, and 42% of young children with normal body weight[17]. In the present study, toe grip strength was related to foot posture adjusted for BMI, age, and gender.

Two possible explanations for the relationship between toe grip strength and foot posture are proposed here. First, toe flexor muscles lift up the navicular and make a medial longitudinal arch. Toe grip strength comes from the toe flexor muscles, such as the flexor hallucis longus and flexor digito-

Table 1. Subject characteristics by foot posture group

	All subjects (N = 619)					
	Flatfoot (n = 110)	SD	Normal (n = 468)	SD	High arch (n = 41)	SD
Age (yrs)	11.1	0.8	11.3	0.7	11.1	0.7
BMI (kg/m^2)	17.9	3.0	17.4	2.6	16.8	2.3
Gender (n boy / %)	66 / 60.0		225 / 48.1		20 / 48.8	

The parameters above were analyzed by ANOVA and χ^2 test, * $p < 0.05$
There were no significant differences between any of these parameters between groups

Table 2. Toe grip strength differences by foot posture group

	All subjects (N = 619)						
	Flatfoot (n = 110)	SD	Normal (n = 468)	SD	High arch (n = 41)	SD	Post-hoc
Toe grip strength (kg) *†	11.0	3.9	12.6	4.1	11.4	3.6	a

[a]significant differences between flatfoot and normal
*analyzed for ANOVA ($p < 0.01$, post-hoc; a)
†adjusted for subject age, BMI and gender (ANACOVA) ($p = 0.01$, post-hoc; a)

rum longus, and these muscles pass under the navicular. The navicular height is the index of the longitudinal medial arch and by definition, flatfoot children have a diminished or absent longitudinal medial arch. Osseous structures, ligaments, tendons, and muscles create navicular height[23, 24], and toe grip strength is one of the factors in creating the foot arch. This is supported by Hashimoto's study, which revealed that toe grip strength training increases the foot arch height in adolescents[12]. Therefore, toe grip strength is related to foot arch, and toe grip strength is different between flatfoot and normal children.

Second, toe flexor muscles are stretched in flatfoot children, so the muscles cannot contract with maximal strength. Muscles contraction strength exhibits a length-tension relationship[25–27], where optimal contraction occurs when the muscle is at the appropriate length and not overly stretched or compressed. In our study, toe grip strength of flatfoot children was lower than that of normal children. When the foot arch is low, toe flexor muscles are stretched. Therefore, toe flexor muscle cannot contract at maximum strength. Conversely, toe flexor muscles are looser in high arch children. However, subjects who had severe high arch due to neurological disorders were excluded from our study, and no significant differences were seen between the high arch group and the other groups. This is the second reason why toe grip strength of low arch feet was low.

The present study revealed that there was a significant difference in toe grip strength between flatfoot and normal children. A recent systematic review of current research demonstrated that there is very limited evidence for the efficacy of nonsurgical interventions in children with flatfoot[28]. Usually, a shoe or insole is used to treat symptomatic flatfoot in children. However, these treatments cannot permanently correct foot alignment[1, 29]. Flatfoot in children is caused by ligament laxity or foot muscle weakness, and ligament laxity is not changeable after foot posture develops. However, muscle strength is changeable, so increasing toe grip strength has the possibility to improve flatfoot. This idea is supported by the present study, which reveals that toe grip strength is related to foot posture in children. Therefore, training to increase toe grip strength during childhood may prevent flatfoot and improve foot posture.

There were several limitations in the present study. First, this study was a cross-sectional design, so the relationship between cause and effect is unknown. Therefore, further research is needed to reveal whether correlated change in grip strength and foot posture can be seen with individuals. Second, foot postures were measured using only a foot printer. The foot is a complex structure, so more detailed measurements of foot posture should be evaluated. Third, foot posture is related to genetics and ethnicity, but these factors were not considered. Despite these limitations, the findings from the present study provide valuable information and illustrate the importance of toe grip strength.

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