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Original Article

Association between floating toe and toe grip strength in school age children: a cross-sectional study

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Abstract. [Purpose] This study investigated the association between floating toe and toe grip strength. [Subjects and Methods] A total of 635 Japanese children aged 9–11 years participated in this study. Floating toe was evaluated using footprint images, while toe grip strength was measured using a toe grip dynamometer. All 1,270 feet were classified into a floating toe group and a normal toe group according to visual evaluation of the footprint images. Intergroup differences in toe grip strength were analyzed using the unpaired t-test and logistic regression analysis adjusted for age, gender, and Rohrer Index. [Results] There were 512 feet (40.3%) in the floating toe group. Mean toe grip strength of the feet with floating toe was significantly lower than that of normal feet (floating toe group, 12.9 ± 3.7 kg; normal toe group, 13.6 ± 4.1 kg). In addition, lower toe grip strength was associated with floating toe on logistic regression analysis after adjustment for age, gender, and Rohrer Index (odds ratio, 0.954; 95% confidence interval, 0.925–0.984). [Conclusion] This study revealed that lower toe grip strength was significantly associated with floating toe. Therefore, increasing toe grip strength may play a role in preventing floating toe in school age children.
Key words: Floating toe, Toe grip strength, School age children

INTRODUCTION

The main functions of the toes involve prehensile strength and ambulatory ability[1]. The toes are in contact with the ground approximately three-quarters of the stance phase during walking and distribute the load[2]. Toes are also thought to play an important role in the ability to stand firmly on the ground by stabilizing the body[3]. Therefore, toe function is important to preserving healthy daily activities such as standing, moving, and walking.

Recently, "floating toe" received attention as a possible cause of toe dysfunction[3, 4]. Floating toe reportedly influences dynamic balance, stride length, and walking speed in studies from Japan. Previous studies concluded that floating toe results from excessive dorsiflexion[5] or a lack of plantarflexion[6] of the metatarsophalangeal joint (MTP). Fukuyama et al.[3] defined floating toe as a condition in which the toe did not contact the ground in the standing position and the weight did not shift to the toe during walking. Floating toe is one of the most common complications of Weil osteotomy, an effective treatment for metatarsal overload[7, 8]. In Japan, there is a high incidence of floating toe among infants and adults who have not undergone

Weil osteotomy[3, 4]. Despite the high incidence of floating toe in Japan, a precise etiology has not been identified.

Toe grip strength (TGS), an indication of toe flexor muscle strength, has also attracted attention as an important clinical indicator. TGS is related to foot structure, especially that of the foot arch[9, 10]. Mickle et al.[11] reported a correlation between toe flexor strength and toe deformities (e.g. hallux valgus, claw, or hammer toe). Therefore, it is possible that TGS is also associated with floating toe.

Previous studies reported the association between floating toe and differences in arch height percentage (sitting vs. standing) in adult females[3] and birth weight in infants[4]. However, no study has investigated school age children. Feet maintain an almost constant growth rate, which is the same in both genders, until 12 years of age[12]. Therefore, it may be easier to improve floating toe before 12 years of age using appropriate interventions. To implement appropriate interventions, it is first necessary to investigate the factors associated with floating toe in school age children. The aim of this study was to investigate the correlation between floating toe and TGS in school age children.

SUBJECTS AND METHODS

A total of 635 (1,270 feet) Japanese children (boys, n=334, age=10.2 ± 0.7 years; girls, n=301, age=10.3 ± 0.7 years; mean ± SD) participated in this study. The participants were recruited from five elementary schools in the Nara prefecture in Japan. Signed consent was obtained from the principals of these schools for inclusion of their students in this study. Exclusion criteria were a history of foot surgery and congenital disorders. We explained the purpose and methods of the study to the participants and teachers of each elementary school with a verbal statement and document. The methods and procedures of the study were in accordance with guidelines approved by the Kyoto University Graduate School of Medicine and the Declaration of Human Rights, Helsinki, 1975. The protocol of this study was approved by the ethical committee of the Kyoto University Graduate School of Medicine (R0109).

Information on age, gender, height, and weight was obtained with a questionnaire. The Rohrer Index, which has been validated in school age children[13], was calculated as body weight (kg)/height (m^3).

Images of each footprint were obtained using a foot printer (Bauerfeind AG, Zeulenroda, Germany) to screen for floating toe. Static footprint images were obtained as each participant stood barefoot on the foot printer in the resting position as described by Tashiro et al.[9] (with feet shoulder-width apart and in a neutral position). Footprint images were taken of both feet. The images for paper contact of each toe were reviewed. Floating toe was diagnosed if there was no visible toe imprint. A previous study[4] that used the same foot printer as used here, calculated the score according to the number of non-contacting toes and conducted a correlation analysis. However, there has been no established standard subgrouping of floating toe; hence, two categories and new analysis methods were used in the current study.

TGS was measured using a toe grip dynamometer (T.K.K.3362; Takei Scientific Instruments Co., Ltd., Niigata, Japan). TGS was measured in accordance with previous studies[9, 14, 15]. Participants sat on a chair without leaning on the backrest with both hips and knees flexed at 90° and with the ankles in a neutral position and fixed with a strap. The first proximal phalanx was positioned at the grip bar, while the heel was fixed by the heel stopper to prevent slipping during measurement. Participants gripped the grip bar using their toe with maximal effort for 3 seconds. The TGS measurements were carried out alternately in each foot and then repeated once. The maximum value of all measurements was used in the analysis.

A foot-based analysis of all 1,270 feet (both right and left feet of all 635 participants) was carried out. All feet were classified into the floating toe group or the normal toe group. The unpaired t-test was used to detect intergroup differences in TGS. A multivariate logistic regression analysis with generalized estimating equations adjusted for age, gender, and Rohrer Index was used to determine whether TGS was associated with floating toe. The dependent variable was with or without floating toe (floating toe group=1; normal toe group=0), while the independent variable was the TGS value. Results are presented as odds ratio (OR) with 95% confidence intervals (CI). The statistical analysis was performed using SPSS version 20.0 (IBM Corp., Armonk, New York, USA), and values of $p<0.05$ were considered significant.

RESULTS

The participants' demographic data are shown in Table 1. There were 512 feet (40.3%) in the floating toe group. The floating toe group had a lower mean TGS than the normal toe group (12.9 ± 3.7 kg vs. 13.6 ± 4.1 kg, respectively; p=0.001). Table 2 shows the results of the logistic regression analysis. A low TGS was independently associated with floating toe after the adjustment for age, gender, and Rohrer Index (OR, 0.954; 95% CI, 0.925–0.984; p=0.003).

DISCUSSION

This study investigated the association between floating toe and TGS in Japanese children aged 9–11 years. We found that a low TGS was associated with floating toe even after the adjustment for other factors. Although a causal relationship could not be determined between these two factors because of the current study's cross-sectional design, maintaining a normal toe position was found to be associated with a higher TGS.

A total of 512 feet (40.3%) in this study had more than one floating toe. Araki et al.[4] reported that at least one floating

Table 1. Participant characteristics

	All (N=635)	Male (N=334)			Female (N=301)		
		9Y (n=55)	10Y (n=143)	11Y (n=136)	9Y (n=49)	10Y (n=119)	11Y (n=133)
Age (years)	10.3 ± 0.7						
Height (cm)	141.5 ± 7.9	134.4 ± 5.3	139.3 ± 5.8	145.1 ± 7.3	133.6 ± 5.3	140.8 ± 6.8	146.5 ± 7.1
Weight (kg)	35.3 ± 7.9	31.0 ± 5.6	34.6 ± 6.9	37.5 ± 8.3	30.4 ± 7.6	33.9 ± 6.4	38.6 ± 8.6
Rohrer Index (kg/m^3)	12.4 ± 1.8	12.7 ± 1.5	12.7 ± 2.0	12.2 ± 1.8	12.6 ± 2.2	12.1 ± 1.5	12.1 ± 1.8

SD: standard deviation

Table 2. Logistic regression analysis

	Floating toe OR (95% CI)
Age (years)	0.982 (0.830–1.162)
Gender	-
Male	1 (reference)
Female	0.873 (0.696–1.096)
Rohrer Index (kg/m^3)	0.995 (0.989–1.001)
TGS (kg)*	0.954 (0.925–0.984)

OR: odds ratio; 95% CI: 95% confidence interval; TGS: toe grip strength; Rohrer Index: body weight (kg)/height (m^3). *$p < 0.01$

toe was observed in >87% of all 3–5 year-old children, while Fukuyama et al.[3] reported that 18 of 65 (27.7%) healthy adult females in their 20s had floating toes. While most studies have used different methods to evaluate floating toes, there is a tendency toward a decreasing incidence with age. This age-related difference may be due to differences in TGS. According to one footprint analysis[12], feet maintain an almost constant growth rate from 3 to 12 years of age. In the same way, TGS may also develop with age until age 12 years. Therefore, if someone has a floating toe in childhood, this may be corrected to normal with an increase in TGS. A previous study[14] investigated reference values for TGS among adults aged 20–70 years. TGS was decreased after 50 years of age. However, reference values for TGS among children and teenagers until 19 years of age have not been elucidated. Thus, further studies of TGS in this age group are necessary.

According to our logistic regression analysis, a low TGS was independently associated with floating toe. There could be two possible reasons for this association. First, a low TGS is associated with floating toe. Previous studies[6, 16] reported that the windlass mechanism may be responsible for post-osteotomy floating toe. TGS is exerted mainly by the plantar intrinsic and extrinsic muscles[17], which play a role in the windlass mechanism. The windlass mechanism relates extension of the toes with raising of the arch. The mechanism also works in reverse, such that increased body weight tends to flatten the arch, with associated flexion of the toes[18]. Therefore, it is possible that a low TGS indicates immaturity of the reverse windlass mechanism, which may lead to floating toe.

Second, floating toe is associated with a low TGS. It is possible that the toe flexor muscles are stretched by the condition of floating toe with the resulting toe extension. Optimal muscle length is needed to exert maximum strength of the plantar flexors at a certain angle of the ankle[19]. In floating toe, individuals cannot exert a maximum TGS owing to insufficient toe flexor length. Other factors may cause floating toe as well. Fukuyama et al.[3] asserted that various lifestyle factors are involved in the occurrence of floating toe, such as play in childhood, exposure to sports, and footwear. Future studies should include these factors.

Our finding implies that increasing TGS may be a key factor in preventing floating toe. Hashimoto et al.[10] studied strength training of the intrinsic flexor muscles of the foot. However, the training studied therein, which involved joint-flexing exercises of 200 repetitions once per day three times per week for 8 weeks with a 3-kg load, is too heavy a burden for children. Therefore, longitudinal studies that investigate effective methods of increasing TGS in children and preventing floating toe are needed. It was previously shown that toe flexor muscle strength is consistently associated with dynamic balance[20]. Accordingly, early prevention of floating toe with increasing TGS may improve dynamic balance ability in daily life.

This study had some limitations. First, owing to its cross-sectional design, a definite causal relationship between floating toe and TGS cannot be concluded. Further research to investigate the association between floating toe and TGS is needed. Second, our evaluation of floating toe was done using a foot printer, which is limited to evaluations of the stationary posture. Toe function is important in both static and dynamic situations. Therefore, a new attempt to evaluate whether floating toe can be seen in dynamic motion, such as walking, is necessary. Because the foot printer is a simple and convenient piece

of portable equipment, a wider clinical application is anticipated. In addition, the influence of weight bearing could not be considered. TGS and footprint images were measured as described by previous studies; however, it may be necessary to investigate TGS measurements in weight-bearing positions in the future. Finally, a simple visual evaluation of the presence of floating toe was performed. Despite these limitations, our findings suggest a significant correlation between floating toe and TGS in school age children. For the first time, an association between the number of floating toes and TGS was shown. Further studies are necessary to support our findings.

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