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Original Article

Relationship between the floating toe and the center-of-pressure position in an upright posture among students

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Abstract. [Purpose] The incidence of floating toes in children is increasing. Although the anteroposterior center of pressure in children is present posteriorly, its relationship with the floating toe is unclear. This study aimed to clarify the relationship between the position of the anteroposterior center of pressure and the floating toe in an upright posture in children. [Participants and Methods] In this cross-sectional study, a Win-Pod (Medicapteurs) platform was used to measure the position of the anteroposterior center of pressure in 208 boys and 195 girls from Japanese elementary schools. Using images of the plantar footprint, floating toes were assessed and the floating toe score was calculated. [Results] The anteroposterior center of pressure position was situated 32.3 ± 8.2% from the heel. The floating toe score of all the participants was 3.5 ± 2.4, with a very high rate of 98%. The floating toe score had a significant, moderate correlation with age, height, weight, and the anteroposterior center-of-pressure position. Multivariate analysis revealed an association between the floating toe score and the anteroposterior center-of-pressure position, height, and weight. [Conclusion] There is significant relationship between the anteroposterior center-of-pressure position and the floating toe score in an upright posture in Japanese elementary school students.
Key words: Floating toe, Center of pressure position, Elementary school children

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INTRODUCTION

In recent years, researchers have observed changes in children's bodies, one of which is the occurrence of floating toes[1)]. Although there is some disagreement in the scientific community regarding the definition of "floating toes", it is generally understood to be a condition in which the toes do not make adequate contact with the ground when standing and do not bear weight while walking[2)]. Toes are considered pivotal in stabilizing the body and ensuring a firm foothold[2)].

A recent study investigated the prevalence of floating toes in 396 Japanese children (aged 8 years) and reported a prevalence of 97.7%[1)]. Since floating toes do not cause pain or deformity, they are less commonly recognized than other toe deformities (e.g., hammertoe, hallux valgus). Furthermore, no reports currently exist on the relationship between floating toes and adverse conditions, e.g., musculoskeletal problems, in children. However, as noted above, floating toes affect the maintenance of an upright posture, and research has shown that walking with floating toes results in significant acceleration

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of the lumbar and knee joints[3]. Therefore, we believe that this increased acceleration can place excessive stress on the tissues of these joints, potentially leading to musculoskeletal issues.

Researchers have documented the etiology of floating toes in adults as a complication of Weil osteotomy[4, 5]. Despite the absence of Weil osteotomies, the frequency of floating toes remains high in Japanese children, and its exact etiology continues to elude researchers.

Measurement of the center of gravity (COG) or center of pressure (COP) helps evaluate postural control. In a static condition, the COP is regarded as the point at which a perpendicular line from the COG intersects the ground and slightly deviates from it. In a highly stable static condition, as exemplified by the upright posture, the lateral displacement of the COG is nonexistent; thus, this deviation can be completely ignored. In other words, the COG and COP can be deemed equivalent. Among the various COP parameters, the anterior-posterior COP (AP-COP) is expressed as a percentage of the foot length from the heel (0%) to the toe (100%), with the foot length serving as 100% (% foot length). A higher AP-COP value indicates that the COP is located on the anterior side (toe side).

A previous study investigated the predictive postural adjustments in children before the onset of walking by measuring the position of the AP-COP according to age. The results showed that approximately 31% of children were aged 5–6 years, 32% were aged 7–8 years, and 37% were aged 9–10 years[6]. This suggests that the AP-COP position in children is notably posterior (toward the heel) when standing and gradually shifts toward the anterior (toe direction) as they age. Koyama et al. found that in children from the current generation aged 6–12 years, the COP position while standing was 30.3 ± 8.9% from the heel, indicating a shift toward the heel (backward) compared to the findings of a previous study[7]. The relationship between the position of the AP-COP and floating toes in children is unknown, but the posterior position of the AP-COP may be a factor in the development of floating toes. We hypothesize a significant correlation between the AP-COP position and the floating toe score when children maintain an upright posture.

The purpose of this study was to clarify the relationship between the position of the AP-COP and the floating toe in children in an upright posture. The results of this study are expected to identify one of the factors associated with floating toes that are prevalent in elementary school children.

PARTICIPANTS AND METHODS

The study protocol of this cross-sectional study was approved by the Ethical Committee of Tokyo Ariake University of Medical and Health Sciences (No. 320) and complied with the ethical standards of the Declaration of Helsinki 1964 and per subsequent revisions. This study was conducted in the Kanto area of East Japan. Participants were recruited from three elementary schools in the Kanto area. We emailed parents through the children's elementary school, inviting them to participate in the study. Written informed consent was obtained from all elementary school children and their parents before participation. Information regarding the purpose of the study, potential risks, and protection of the participants' rights were provided to all elementary school children and parents. The measurements were conducted from November 2021 to February 2023.

The participants included 403 Japanese elementary school children (208 boys and 195 girls). Table 1 presents the tabulated data for the grade distribution of the participants. Yanagiya et al. reported that the position of AP-COP is modulated by engagement in competitive sports[8]. Hence, the eligibility criteria for the present study included children who did not engage in routine athletic activities. Additionally, the participants did not have any musculoskeletal ailments at the time of evaluation.

The physical characteristics of the participants (height and weight) were determined. Information on the grade, age, and current musculoskeletal condition was obtained using questionnaires. The Rohrer index was calculated as (weight (kg)/height (cm)^3 × 10^7).

A foot pressure distribution-measuring device (Win-Pod, MediCaptures, Inc., Balma, France) was used to measure the position of the AP-COP. The measurement process followed a procedure similar to that described by Fujimaki et al., who utilized a similar measuring device[1].

1. The environment was designed to ensure minimal sensory interference, with the ambient noise level kept to a minimum and illumination maintained at a uniform level. Furthermore, the flooring was sturdy enough to preclude any disturbances to bodily posture that might result from auditory or visual stimuli.

2. The foot length under load was measured using a foot gauge (MAMORU, Inc., Tokyo, Japan).

3. The participants' feet were bare and were positioned on a foot pressure distribution-measuring device. The participants were instructed to stand in an upright position such that the medial edge of their foot was parallel to the anteroposterior axis of the device. Furthermore, 50% of the foot length, as measured by the foot gauge and marked using a water-based pen, was aligned with the horizontal line drawn at the center of the device that measures foot pressure distribution.

4. The participants were positioned in a stable and ergonomically suitable stance, similar to their habitual standing position, with a fixed inter-foot distance of 10 cm. Additionally, the participants were instructed to keep their eyes open and fixate their gaze on an index located at a distance of 2 m and aligned with their eye level. The measurement time was 20 seconds from the point when the participant's sway became stable.

5. The position of AP-COP was the average value in the Y-axis (anterior-posterior) direction for 20 seconds, and the relative ratio was expressed as a percentage of the heel with the foot length at 100% (Fig. 1).

In previous studies, the floating toe score was calculated using images of the plantar footprint obtained from the measurement of the AP-COP position[1, 9]. In this study, images of the footprints captured 10 seconds after the start of the child's stable standing posture were used. For each of the 10 toes on both feet, a score of 2 was assigned if the toes were visible in the image (indicated by red to green), 1 if they were partially visible (indicated by blue), and 0 if they were not visible (Fig. 2). The floating toe score was obtained by summing all the points thus scored. Therefore, a smaller score indicated a higher degree of floating toes. If the floating toe score was 18 points or higher and both big toes had an increase of 2 points each, the patient was classified as the "contact toe" group; if the score was 11 to 17 points, the patient was classified as the "incomplete contact toe" group; and if the score was 10 points or lower, the patient was classified as the "floating toe" group.

The AP-COP position and floating toe score were analyzed using the Mann–Whitney's U test. To investigate the correlation between the floating toe score and each parameter, we employed Spearman's rank correlation coefficient. Furthermore, we conducted a multiple regression analysis to identify factors associated with the floating toe scores. A multiple regression analysis was conducted using the forced entry method with the floating toe score as the dependent variable, and the parameters were found to be significantly related to the floating toe score in the univariate analysis as independent variables. Considering the problem of multicollinearity, we analyzed the correlations among the independent variables using Spear-

Table 1. Number of participants at each grade level

Grade	Boy (n=208)	Girl (n =195)	Total (n=403)
1st	35	32	67
2nd	36	32	68
3rd	34	32	66
4th	31	31	62
5th	34	28	62
6th	38	40	78

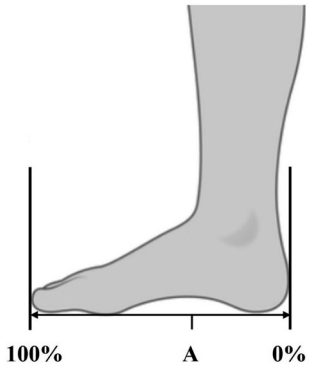

Fig. 1. AP-COP position.
A: The relative ratio is expressed as a percentage, with the heel representing 0% and the full foot length representing 100%.
AP: anterior-posterior; COP: center of pressure.

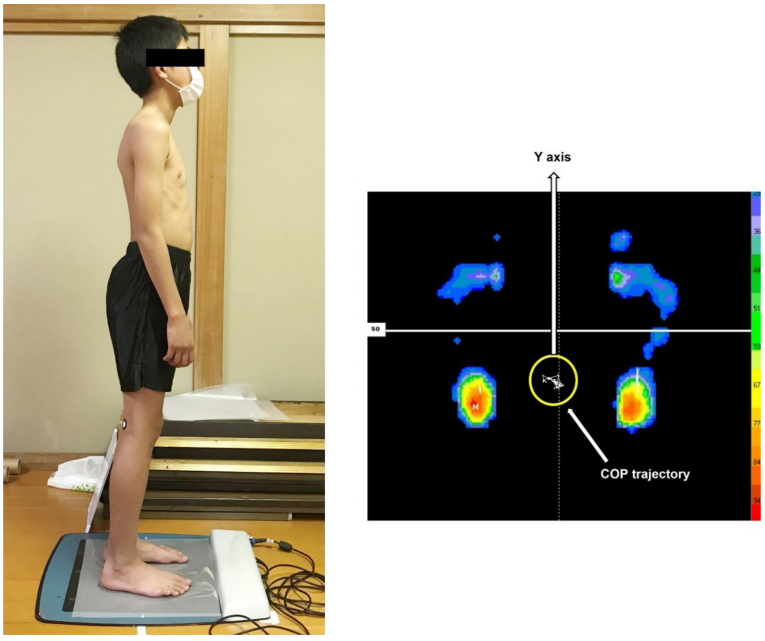

Fig. 2. An examination of the AP-COP position in the standing posture and footprints for floating toe score.
AP: anterior-posterior; COP: center of pressure.

man's rank correlation coefficient to check for the presence of excluded items with a correlation coefficient of 0.8 or higher. A p-value of <0.05 was considered statistically significant. All statistical analyses were performed using SPSS Statistics 23 software for Windows (SPSS; IBM Japan Inc., Tokyo, Japan).

RESULTS

The physical characteristics and AP-COP position of the 403 children are summarized in Table 2. There were no significant sex differences in height, weight, Rohrer index, or AP-COP position.

The mean floating toe score of all participants was 3.5 ± 2.4. According to the criteria proposed by Fujimaki et al. (a score of 10 points or lower)[1], the prevalence of floating toes was high (98.0%). There were no significant sex differences in the floating toe score (Table 2).

Table 3 shows the correlation between the floating toe score and each parameter. The floating toe score showed a significant moderate correlation with age, height, weight, and AP-COP position. However, no correlation was found between the floating toe score and the Rohrer index.

The results of the univariate analysis showed that the correlation coefficient was 0.87 for height and weight. Therefore, considering the influence of multicollinearity, we did not include the two independent variables of height and weight in the same model. Instead, we analyzed the dependent variables using two different models (Tables 4 and 5). The coefficients of determination, R^2, for each set of data were 0.170 and 0.173, respectively, suggesting a poor fit.

DISCUSSION

In this study, we found a significant relationship between the AP-COP position and the floating toe score in children's upright posture. This is the first study to show the relationship between the AP-COP position and floating toe score in Japanese elementary school students.

Regarding the significant association between the position of AP-COP and floating toe score in the upright posture, as mentioned above, the position of AP-COP (% foot length) in the upright posture is almost the same as the position of COG. This suggests that the COG in the upright posture of the participants in this study is located posteriorly (on the heel side). The body weight should ideally be supported by three points, namely the toes, thenar, and heel[8]. However, it can be deduced that in children with floating toes, the body weight is probably only supported by the thenar and heel.

Multivariate analysis revealed a correlation between floating toes and somatometric factors, specifically height and weight. In our review of previous studies, we found no reports linking children's height or weight to floating toes. Wako et al. reported no correlation between body composition (specifically lower limb muscle mass) and the floating toe score in

Table 2. Physical characteristics, AP-COP position, and floating toe score (male vs. female)

Variable Median (25–75% tile)	Children		
	Total (n=403)	Male (n=208)	Female (n=195)
Age (years)	9 (8–11)	9 (8–11)	9 (8–11)
Height (cm)	135 (126–145)	135 (126–145)	135 (126–145)
Weight (kg)	32 (26–37)	32 (26–38)	31 (25–37)
Rohrer Index	125 (116–138)	126 (117–140)	124 (115–135)
AP-COP position (%)	31 (26–37)	32 (27–39)	30 (26–37)
Floating toe score	3 (2–5)	3 (2–5)	3 (2–5)

AP: anterior-posterior; COP: center of pressure.

Table 3. The correlation between floating toe score and each parameter

	Correlation coefficient
Age (years)	0.327***
Height (cm)	0.359***
Weight (kg)	0.364***
Rohrer index	−0.026
AP-COP position	0.419***

***p<0.001.
AP: anterior-posterior; COP: center of pressure.

Table 4. Multiple linear regression analysis (Model 1)

Model 1	Unstandardized coefficients		Standardized coefficients	
Variable	B	Standard error	Beta	95% confidence interval
(Constant)	−6.49	1.653		
Age	−0.097	0.119	−0.074	−0.331 to 0.136
Height	0.06	0.018	0.293***	0.024 to 0.096
AP-COP position	0.086	0.014	0.287***	0.057 to 0.114

***p<0.001.
AP: anterior-posterior; COP: center of pressure.

Table 5. Multiple linear regression analysis (Model 2)

Model 2	Unstandardized coefficients		Standardized coefficients	
Variable	B	Standard error	Beta	95% confidence interval
(Constant)	−1.499	0.625		
Age	0.029	0.086	0.022	−0.139 to 0.198
Weight	0.065	0.019	0.227***	0.028 to 0.102
AP-COP position	0.082	0.015	0.272***	0.053 to 0.110

***p<0.001.
AP: anterior-posterior; COP: center of pressure.

8-year-old children[9]. The present study encompassed a broader age range of participants, spanning from 6–12 years old. Given the variation in participant age distribution and the different body compositions examined, the results from the two studies are not directly comparable. Further research is required to understand how height and weight influence the floating toe score in children.

The mean position of AP-COP in children in our study was 32.3 ± 8.2%. In a study on Japanese children aged 3–10 years, the position of AP-COP was reported to range from 31% to 37%, a finding that aligns with previous research[6]. Since reports from other countries are not available for a direct comparison, we posit that the issue at hand could be attributed to Japanese children's AP-COP position, which is closer to the heel and may explain the occurrence of floating toes. Recently, Baranda et al. reported a high prevalence of excessive thoracic kyphosis in a study involving 731 children aged 8–12 years from a Spanish elementary school[10, 11]. Czaprowski et al. classified children's postures and identified various types of postures with excessive thoracic kyphosis, including the swayback posture[11]. This posture is characterized by a posterior (closer to the heel) AP-COP position with excessive thoracic kyphosis and a posterior pelvic tilt. Our study did not evaluate posture; therefore, it is impossible to determine whether many children had swayback posture or not.

This study has a few limitations. First, this cross-sectional study precluded us from determining if factors such as AP-COP position, height, and weight that were found to be associated with floating toes are indeed risk factors for floating toes. Additionally, the goodness-of-fit of multiple regression analysis performed in this study was low. Therefore, further studies are needed in the future. A second drawback of the present study is that the evaluation of floating toes was conducted only in a static standing posture. We intend to conduct additional research in the future, including dynamic evaluation. Lastly, we could not assess inter- and intra-examiner agreements for the AP-COP position. We believe that both inter- and intra-examiner agreements are essential for ensuring the accuracy of measurements.

In conclusion, the results of this study suggest that a significant relationship exists between the AP-COP position and floating toe score in an upright posture in Japanese elementary school children.

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Conflict of interest

The authors declare no conflicts of interest in this work.

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