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Association between pediatric obesity and foot morphology: insights from a large-scale cross-sectional study using photogrammetry

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Abstract

Background Childhood obesity is a critical public health concern with implications for musculoskeletal development. Foot posture abnormalities—particularly pes planus—may be associated with obesity and could serve as early diagnostic indicators.

Aim This study investigated the relationship between foot posture and obesity in children aged 4–14 years using non-invasive assessment methods.

Materials and methods A total of 7,908 children (mean age: 8.7 ± 2.9 years; 51.2% male) were assessed using photogrammetry and the Staheli Arch Index, along with the Jack Test to classify foot posture. BMI categories and foot posture types were statistically compared.

Results Rigid pes planus was found in 9.6% of children, flexible pes planus in 7.8%, and high arch in 3.8%. Among overweight and obese children, the prevalence of rigid pes planus was significantly higher ($p < 0.001$). Logistic regression revealed that rigid pes planus increased the risk of obesity by 7.2 times (OR = 7.156; 95% CI: 5.179–9.887).

Conclusion Rigid pes planus is strongly associated with obesity in children. Foot posture screening, especially in early childhood, may serve as a valuable tool for identifying children at risk for obesity-related complications and guiding early preventive interventions.

Keywords Pediatric obesity, Foot posture, Pes planus, Photogrammetry, Childhood health

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Introduction

Childhood obesity has emerged as a critical global health concern, with its prevalence rising alarmingly over the past four decades [1–3]. According to the World Obesity Federation, it is projected that by 2025, over 206 million children and adolescents aged 5–19 will be classified as obese—a figure expected to exceed 250 million by 2030 [4]. This trend is particularly pronounced in high-income nations, where severe obesity among youth is becoming increasingly common [5–8]. A study conducted across European countries found that approximately one-quarter of children with obesity are classified as severely obese [6].

The health consequences of pediatric obesity are well-documented, encompassing a wide range of acute and chronic comorbidities, including neurological [9], dental [10], cardiovascular [11–14], psychosocial [11, 15–17], respiratory [18–22], endocrine [12, 23, 24], musculoskeletal [19, 25–27], renal [28, 29], gastrointestinal [29, 30], dermatological [31] issues impacting functional mobility and participation [19, 32]. Obesity not only increases susceptibility to these conditions but also subjects children to peer-related stigma and bullying [33].

Physical inactivity and obesity are now among the leading global risk factors for mortality, ranked fourth and fifth, respectively, by the World Health Organization [34]. Childhood obesity often leads to adult obesity, with the prevalence of excess weight and obesity rising significantly between the ages of 5 and 19 [35–37]. In response to this growing concern, countries worldwide have implemented national action plans promoting physical activity and obesity prevention. Research highlights the importance of addressing these issues during childhood, including interventions focused on nutrition and physical activity [38, 39].

The foot is a dynamic structure essential for balance, posture, walking, running and jumping [40, 41]. Abnormalities in foot morphology and posture can lead to postural instability, balance issues, movement restrictions, musculoskeletal problems and reduced mobility [42]. Foot posture disorders, notably pes planus, are among the primary factors limiting mobility. Pes planus is defined by the collapse of the medial longitudinal arch (MLA) and a heel position characterized by valgus [43]. Prevalence rates for pes planus vary significantly (5–48%), likely due to differences in measurement methods. Contributing factors include measurement variations, age, gender, early shoe use, inadequate exercise, excess weight and genetic predisposition [44, 45].

Despite the high prevalence of pes planus in the general population, limited awareness and inadequate screenings have hindered accurate incidence determination [46]. Clinical diagnoses and index assessments after imaging have shown that individuals with pes planus are often overweight or obese, indicating a relationship between pes planus and obesity [43, 46–52]. Pes planus leads to productivity losses, healthcare expenses and numerous related diseases, imposing a substantial financial burden on national economies. In Germany, for instance, obesity-related direct costs amount to apes planusroximately €29 billion annually, with indirect costs reaching €33 billion [53]. Economic impact studies estimate that healthcare costs and productivity losses associated with overweight and obesity in France, Australia, Germany, Canada and Saudi Arabia range from 0.5 to 1.6% of GDP [53–57]. In Turkey, obesity-related healthcare expenses rose from $5 billion in 2004 to $14 billion in 2012 and the economic burden of obesity reached $28 billion in 2022, amounting to 3.06% of Turkey's GDP. According to the OECD, Turkey will allocate 12% of its healthcare spending to this issue between 2020 and 2050.

Functional and structural impairments in the MLA exacerbate balance problems, gait disturbances and muscle fatigue [58–65]. They are also associated with risks for hip pain [66] and low back pain [67]. These factors contribute to sedentary behavior, which in turn promotes weight gain and obesity. Exercise, physical development, weight management and a healthy lifestyle are closely linked [68]. Physical inactivity influences the prevalence of pes planus in children [69–71]. Technology-driven gaming addiction today exacerbates joint laxity, which is also related to insufficient exercise in children.

Studies indicate that the prevalence of pes planus among children with obesity ranges from 14 to 67%. Research demonstrates that pes planus is more common in overweight or obese children [72–75]. This study highlights the need for evidence-based research on obesity associated with pes planus and calls for interventions focused on addressing obesity through pes planus treatment. Given the limited research on obesity driven by pes planus, this study aims to quantify the number of children affected by this condition, to underscore the role of pes planus as a contributing factor to obesity and to raise public awareness. This study hypothesized that children with abnormal foot posture, particularly rigid pes planus, have a significantly higher risk of overweight and obesity compared to those with normal foot posture, independent of age and sex.

Materials and methods

Study design and participants

The study was conducted between May 2023 and April 2024, with ethical approval obtained from the Scientific Research Ethics Committee of Çanakkale Onsekiz Mart University under project number 2023-YÖNP-0396. In the study, OpenEpi, Version 3 program was used for power analysis in calculating the sample size. In the sample calculation, the research universe was accepted as 573,391 people according to the 2025 Çanakkale province population data. Using the known sample size calculation formula, we determined that the target population should consist of at least 1511 participants with a 99% confidence interval and 80% power. The 99% confidence level was selected to enhance statistical robustness, given the large target population and the potential for small effect sizes. Although not mandated by an institutional protocol, this conservative threshold was chosen to maximize representativeness and minimize sampling error. Participants were selected using simple random sampling and included 7,908 children aged 4 to 14, drawn from various private nurseries, daycare centers, kindergartens, primary schools and middle schools. For participants to take part in the study, a parental consent form was completed by the children's families. Additionally, an informational consent form was also filled out by the children's families. Exclusion criteria included the presence of clinical conditions that could interfere with foot assessment, such as pain, edema, or ulcers; a history of fractures resulting in foot deformities; major foot deformities or amputations; and neurological disorders such as Cerebral Palsy or Spina Bifida. Additionally, children who did not voluntarily agree to participate in the study were excluded from the research.

Procedures

Body mass index

Both weight and height were measured following standard procedures, with children removing their shoes and socks. Each child's height was measured to the nearest millimeter using a portable calibrated stadiometer, while weight was measured to the nearest 0.05 kg using a calibrated electronic scale. The Body Mass Index (BMI) was then calculated by dividing body weight by the square of height (kg/m^2).

Footprint collection and evaluation

All measurements were conducted in nurseries, daycare centers and school settings, where children removed their shoes and socks. After explaining the procedure, footprints were collected using a podoscope (Chinesport S.p.A., Udine, Italy), which is reliable, easy to use and enhances foot visibility. Podoscopic footprint measurement is commonly used clinically to assess pes planus symptoms due to its simplicity and speed [44, 76, 77]. Footprint collection was feasible even with limited participant compliance, as it required minimal researcher intervention. The reliability of footprint analysis has been confirmed in several studies, showing it as an effective, low-cost method without the risks associated with radiological imaging [69].

During measurements, a screen ensured privacy. Only class teachers and researchers were present and results were shared exclusively with the class teachers. Parents received a brochure explaining pes planus and parents of affected children were informed about their child's pes planus status via the brochure. Footprints were taken with each child's feet cleaned with alcohol and dried. The podoscope device used in the study (Chinesport S.p.A., Udine, Italy) was factory-calibrated and maintained according to the manufacturer's specifications. In addition, the PODATA software employed for image analysis includes an internal calibration routine that verifies measurement accuracy prior to each use. Participants were instructed to stand evenly on both feet, looking straight ahead and to hold this position on the glass surface for at least five seconds. Images were saved to a computer and analyzed using the Global Postural System/PODATA software for high-precision evaluation [78]. Pes planus evaluation was done using the Staheli Index [79] and a checklist was created for flexible/rigid pes planus assessments (Jack Test). This evaluation categorized participants as normal, flexible/rigid, or pes cavus. Reliability and observer consistency were calculated by two specialists using the Inter Observer Agreement (IOA) formula, yielding an agreement rate of at least 90%.

Staheli's Arch Index (SAI)

Staheli's Arch Index (SAI), defined by Staheli, Chew and Corbett (1987), is a widely used footprint assessment parameter. It is calculated as the ratio of the narrowest arch area to the widest heel area. Reference values used in this study were: <0.29 for pes cavus, 0.3–0.70 for normal, 0.71–1.0 for flexible pes planus and ≥1.01 for rigid pes planus [79].

Jack test

The Jack Test, or first toe dorsiflexion test, indicates flexible pes planus if medial longitudinal arch formation occurs when the first toe is dorsiflexed in a neutral position. This test is a primary indicator that exercise can correct foot shape in cases of flexible pes planus [80, 81].

Reliability and validity of the footprint measures

The Staheli Arch Index (SAI) and Jack Test were selected due to their common use in pediatric pes planus assessment. The SAI has demonstrated both high reliability and acceptable validity in previous studies as a diagnostic tool for pes planus when compared with radiographic measures [79]. Likewise, the Jack Test has shown clinical validity as a simple and reliable indicator to distinguish between flexible and rigid pes planus in children. In our study, inter-observer agreement was calculated for both the SAI and Jack Test using the Inter Observer Agreement (IOA) formula, yielding a minimum agreement rate of 90%, which supports the reliability of these assessments. However, we acknowledge that more advanced validation against gold standard methods such as radiographic imaging could further strengthen the interpretation of results.

Statistical analysis

Normality of quantitative data was assessed with the Kolmogorov-Smirnov test. For non-normally distributed variables, group comparisons were conducted using the Kruskal-Wallis H test, with post-hoc analysis via the Dunn-Sidak test. Frequency differences for categorical variables were examined with the Chi-square and Exact tests. The effects of independent variables on dependent variables were analyzed through multivariate logistic regression. Statistical significance was set at $p<0.05$, with parameters reported as Mean, Standard Deviation, Median (1st Quartile–3rd Quartile), n (count) and percentage (%). Data analysis was performed using IBM SPSS Version 22 (IBM SPSS for Windows Version 22, IBM Corporation, Armonk, New York, USA).

Results

In Table 1, the BMI values of participants by gender and age distribution were examined. Among males, those classified as underweight had BMI averages ranging from 12.5 to 15.6 kg/m², those with a normal BMI ranged from 15.1 to 19.4 kg/m², overweight participants ranged from 17.6 to 25.4 kg/m² and obese individuals ranged from 19.6 to 29.0 kg/m².

For females, the underweight group had BMI averages between 12.4 and 16.2 kg/m², those with a normal BMI ranged from 14.8 to 20.3 kg/m², overweight individuals had averages from 17.6 to 26.2 kg/m² and obese participants had BMI averages between 19.0 and 29.7 kg/m².

Table 2 illustrates the percentage and frequency distribution of participants by various demographic factors. The proportion of male participants within each age group ranged from 39.4 to 55.6%, while female participants ranged from 44.6 to 60.6%.

The average height across age groups ranged between 108 cm and 168 cm. When considering percentiles by age group, the percentage distribution of those classified as normal ranged between 39.8% and 72.7%, underweight between 6.3% and 54.5%, overweight between 2.6% and 16.2% and obese between 3.0% and 18.6%.

The distribution of foot types by age group showed that the percentage of individuals with normal feet ranged from 68.4 to 85.0%. The prevalence of rigid pes planus ranged from 6.0 to 22.9%, flexible pes planus from 4.6 to 10.6% and high-arched feet from 0.0 to 6.7%.

Table 3 presents the distributional differences in foot type by age group, which were found statistically significant among males ($p<0.001$). The proportion of participants with normal feet increased with age, while the percentage of those with high arches was generally lower. As age increased, the proportion of participants with rigid and flexible feet decreased.

A similar trend was observed among females, where age group and foot type differences were also statistically significant ($p<0.001$). The percentage of females with normal foot type increased with age, whereas high-arched feet were less common. With increasing age, the percentage of participants with rigid and flexible feet decreased (Fig. 1.).

Table 4 shows the significant statistical differences in foot posture by obesity type ($p<0.001$). Those with normal or high-arched feet showed higher percentages of underweight and normal weight individuals, while those with rigid or flexible feet showed higher rates of overweight and obesity (Fig. 1).

Table 1 Obesity status by gender among participants

Age	Gender							
	Male				Female			
	Obesity type				Obesity type			
	Underweight	Normal weight	Overweight	Obese	Underweight	Normal weight	Overweight	Obese
	Median(Q1-Q3)	Median(Q1-Q3)	Median(Q1-Q3)	Median(Q1-Q3)	Median(Q1-Q3)	Median(Q1-Q3)	Median(Q1-Q3)	Median(Q1-Q3)
4	13.6(13.3–14.3)	15.1(14.9–15.7)	17.6(17.5–17.8)	19.6(18.3–20.8)	14.0(13.1–14.3)	15.2(15.0-15.7)	18.1(17.8–18.2)	19.0(19.0-19.8)
5	12.5(11.9–12.9)	15.1(14.3–15.7)	18.1(17.4–18.3)	21.1(20.8–21.1)	12.4(11.5–12.9)	15.1(14.1–15.8)	17.8(17.6–17.9)	20.0(18.9–20.2)
6	12.9(12.4–13.2)	14.8(14.1–15.5)	17.8(17.4–17.9)	20.8(19.4–22.0)	12.6(12.4–13.1)	14.8(14.1–15.5)	17.6(17.4–18.0)	19.5(19.4–21.7)
7	13.2(12.8–13.4)	15.4(14.6–16.0)	18.4(18.1–18.7)	21.3(19.8–24.0)	13.0(12.5–13.1)	15.4(14.5–16.3)	18.0(17.7–18.3)	20.0(19.5–21.3)
8	13.0(12.8–13.2)	15.6(14.6–16.6)	19.2(18.6–19.8)	21.7(20.8–23.9)	13.2(12.4–13.4)	15.3(14.5–16.1)	18.9(18.7–19.7)	21.6(20.5–23.7)
9	13.2(13.0-13.7)	16.2(15.3–17.1)	19.8(19.2–20.7)	23.6(21.8–25.4)	13.2(12.8–13.8)	16.5(15.4–17.5)	20.0(19.6–20.2)	22.5(21.5–23.6)
10	13.6(13.2–13.8)	16.4(15.4–18.1)	21.1(20.5–21.8)	24.8(23.9–25.5)	13.4(12.8–13.7)	17.0(15.8–18.3)	20.9(20.4–21.8)	24.5(23.7–26.1)
11	14.0(12.9–14.3)	17.4(16.0-18.9)	22.8(22.1–23.6)	26.5(25.3–28.2)	14.0(13.4–14.4)	17.9(16.1–19.7)	22.5(22.0-23.4)	26.7(25.1–29.1)
12	14.3(13.8–14.7)	18.2(16.9–19.6)	24.0(23.6–24.6)	29.0(27.0-30.8)	14.5(13.7–14.9)	18.9(17.4–20.1)	24.5(23.7–25.1)	27.5(26.3–30.9)
13	14.5(14.1–15.2)	19.2(17.6–21.1)	24.3(24.0-25.3)	27.8(27.1–29.8)	14.2(13.3–15.4)	18.6(17.4–20.7)	24.5(24.2–25.7)	29.7(27.8–30.9)
14	15.6(15.2–16.2)	19.4(18.1–21.1)	25.4(24.7–26.6)	28.9(27.6–31.5)	16.2(16.2–16.3)	20.3(18.4–21.6)	26.2(25.8–26.3)	29.7(28.3–31.2)

Median(1.Quartile-3.quartile)

Table 2 Percentage and frequency distribution of participants by various variables

		Age										
		4	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Gender	Male *n* (%)	212 (45.9)	185 (39.4)	381 (52.9)	409 (46.6)	285 (48.4)	356 (51.6)	676 (47.8)	590 (50.9)	293 (48.7)	336 (55.6)	173 (53.9)
	Female *n* (%)	250 (54.1)	284 (60.6)	339 (47.1)	469 (53.4)	304 (51.6)	334 (48.4)	739 (52.2)	568 (49.1)	309 (51.3)	268 (44.4)	148 (46.1)
Height (cm)	Median (Q1-Q3)	108 (104–113)	114 (110–117)	119 (116–124)	126 (122–130)	131 (127–134)	137 (132–142)	143 (138–147)	147 (142–153)	155 (149–161)	160.5 (155–166)	164 (158–168)
Weight (kg)	Median (Q1-Q3)	17 (15–19)	18 (16–21)	21 (19–24)	24 (22–27)	26 (23–32)	32 (27–38)	36 (31–42)	41 (34–51)	46 (39–55)	52 (45–63)	56 (48–66)
BMI	Median (Q1-Q3)	14.6 (13.7–15.2)	14.6 (13.2–15.7)	14.7 (13.8–15.6)	15.4 (14.3–16.6)	15.6 (14.4–17.6)	16.8 (15.3–19.5)	17.5 (15.6–20.2)	18.6 (16.1–22.2)	19.1 (16.9–22.4)	20.3 (17.6–23.9)	20.8 (18.3–24.5)
Obesity type	Underweight *n* (%)	252 (54.5)	134 (28.6)	124 (17.2)	118 (13.4)	72 (12.2)	72 (10.4)	120 (8.5)	102 (8,8)	61 (10.1)	38 (6.3)	26 (8.1)
	Normal weight *n* (%)	184 (39.8)	299 (63.8)	510 (70.8)	638 (72.7)	397 (67.4)	420 (60.9)	920 (65)	720 (62.2)	410 (68.1)	407 (67.4)	213 (66.4)
	Overweight *n* (%)	12 (2.6)	14 (3)	34 (4.7)	57 (6.5)	50 (8.5)	70 (10.1)	229 (16.2)	161 (13.9)	68 (11.3)	75 (12.4)	39 (12.1)
	Obese *n* (%)	14 (3)	22 (4.7)	52 (7.2)	65 (7.4)	70 (11.9)	128 (18.6)	146 (10.3)	175 (15.1)	63 (10.5)	84 (13.9)	43 (13.4)
Foot posture	Normal *n* (%)	316 (68.4)	341 (72.7)	605 (84)	689 (78.5)	491 (83.4)	551 (79.9)	1099 (77.7)	890 (76.9)	481 (79.9)	497 (82.3)	273 (85)
	Rigid *n* (%)	106 (22.9)	82 (17.5)	64 (8.9)	80 (9.1)	42 (7.1)	72 (10.4)	104 (7.3)	100 (8.6)	36 (6)	43 (7.1)	26 (8.1)
	Flexible *n* (%)	34 (7.4)	34 (7.2)	33 (4.6)	93 (10.6)	42 (7.1)	49 (7.1)	128 (9)	90 (7.8)	52 (8.6)	41 (6.8)	22 (6.9)
	High arch (Pes Cavus) *n* (%)	6 (1.3)	12 (2.6)	18 (2.5)	16 (1.8)	14 (2.4)	18 (2.6)	84 (5.9)	78 (6.7)	33 (5.5)	23 (3.8)	0 (0)

Median(1.Quartile-3.quartile)

Table 3 Analysis of foot type by age group among participant

	Age	Foot Posture				
		Normal	Rigid	Flexible	High Arch (Pes Cavus)	*p*
Male	4	134(63.2)	62(29.2)	16(7.5)	0(0.0)	*p* < 0.001*
	5	117(63.2)	44(23.8)	22(11.9)	2(1.1)	
	6	317(83.2)	42(11.0)	16(4.2)	6(1.6)	
	7	303(74.1)	46(11.2)	54(13.2)	6(1.5)	
	8	225(78.9)	29(10.2)	19(6.7)	12(4.2)	
	9	269(75.6)	48(13.5)	29(8.1)	10(2.8)	
	10	524(77.5)	46(6.8)	68(10.1)	38(5.6)	
	11	442(74.9)	60(10.2)	40(6.8)	48(8.1)	
	12	223(76.1)	25(8.5)	31(10.6)	14(4.8)	
	13	274(81.5)	21(6.3)	30(8.9)	11(3.3)	
	14	143(82.7)	20(11.6)	10(5.8)	0(0.0)	
Female	4	182(72.8)	44(17.6)	18(7.2)	6(2.4)	*p* < 0.001*
	5	224(78.9)	38(13.4)	12(4.2)	10(3.5)	
	6	288(85.0)	22(6.5)	17(5.0)	12(3.5)	
	7	386(82.39)	34(7.2)	39(8.3)	10(2.1)	
	8	266(87.5)	13(4.3)	23(7.6)	2(0.7)	
	9	282(84.4)	24(7.2)	20(6.0)	8(2.4)	
	10	575(77.8)	58(7.8)	60(8.1)	46(6.2)	
	11	448(78.9)	40(7.0)	50(8.8)	30(5.3)	
	12	258(83.5)	11(3.6)	21(6.8)	19(6.1)	
	13	223(83.2)	22(8.2)	11(4.1)	12(4.5)	
	14	130(87.8)	6(4.1)	12(8.1)	0(0.0)	

Chi Sqaure test; 0.05

*distributional difference is statistically significant

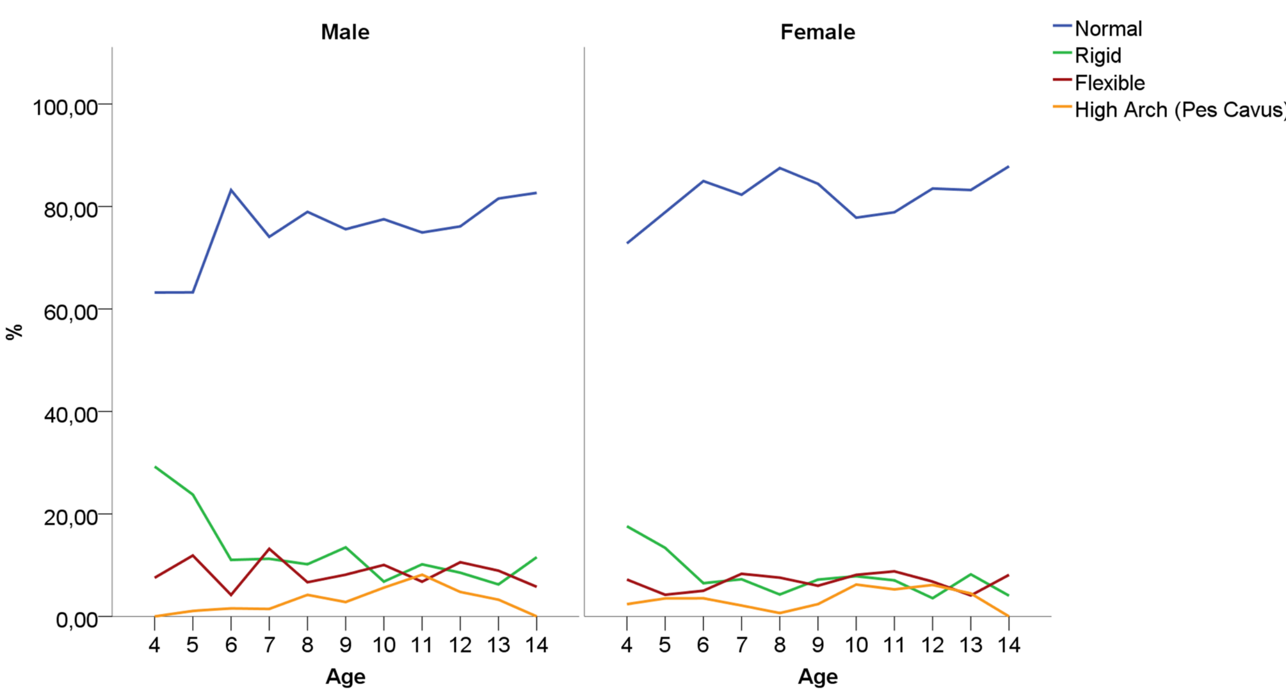

Fig. 1 Percentage distribution of foot type by gender and age group

Table 4 Relationship between foot posture and obesity type

Foot posture	Obesity type				
	Underweight	Normal-weight	Over-weight	Obese	*p*
Normal *n*(%)	928(14.9)	4160(66.7)	585(9.4)	560(9.0)	$p < 0.001$*
Rigid *n*(%)	81(10.7)	401(53.1)	105(13.9)	168(22.3)	
Flexible *n*(%)	54(8.7)	335(54.2)	100(16.2)	129(20.9)	
High arch (Pes cavus) *n*(%)	56(18.5)	222(73.5)	19(6.3)	5(1.7)	

Chi Sqaure test; 0.05

*distributional difference is statistically significant

In Fig. 2, participants with normal foot posture are shown to represent a higher percentage in each group. Those classified as underweight or normal weight had higher rates of normal and high-arched feet compared to rigid and flexible groups. Similarly, overweight and obese individuals had higher rates of rigid and flexible foot postures compared to other groups.

In Table 5, regression analysis identified factors affecting obesity. When the underweight group was used as the reference, being 4, 5, or 6 years old compared to 14 years old had a statistically significant effect on obesity. Having flexible, high-arched, or rigid feet also significantly impacted obesity compared to having normal feet. A person with rigid feet had a 1.969 times (approximately 2-fold) higher likelihood of obesity than someone with normal feet.

For the likelihood of being overweight, male gender showed a statistically significant effect compared to females. Age groups of 4 to 8 years had a significant effect on being overweight compared to 14 years. Flexible, rigid and high-arched feet also significantly impacted the likelihood of being overweight compared to normal feet. The risk of being overweight was approximately 4.4 times higher in individuals with rigid feet compared to those with normal feet.

For the likelihood of being obese, male gender had a statistically significant effect compared to females. Being 4, 5, 6, or 7 years old had a significant impact on obesity likelihood compared to being 14 years old. Rigid, flexible and high-arched feet also had a significant effect on obesity compared to normal feet. The risk of obesity was 7.156 times (approximately 7 times) higher for individuals with rigid feet compared to those with normal feet.

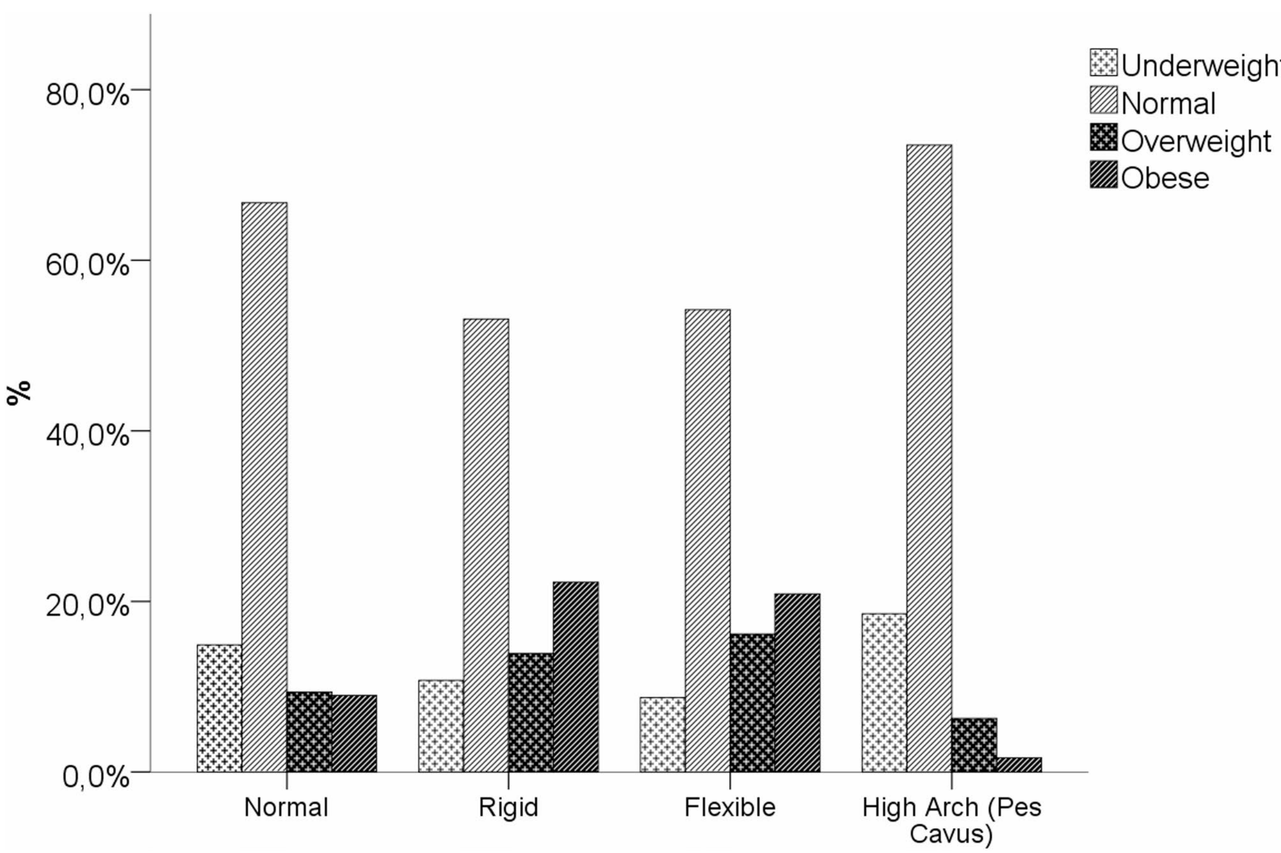

Fig. 2 Distribution of foot type by obesity type among participants

Table 5 Analysis of obesity types and contributing factors

Obesity Type		B	Wald	*p*	OR(95%CI)
Normal	Intercept	2.006	90.382	$p<0.001$*	
	Gender = male	0.093	1.740	0.187	1.097(0.956–1.259)
	Gender=(female)reference	0			
	Age = 4	−2.538	120.176	$p<0.001$*	0.079(0.050–0.124)
	Age = 5	−1.349	33.408	$p<0.001$*	0.259(0.164–0.410)
	Age = 6	−0.683	8.755	0.003*	0.505(0.321–0.794)
	Age = 7	−0.427	3.417	0.065	0.652(0.415–1.026)
	Age = 8	−0.379	2.408	0.121	0.684(0.424–1.105)
	Age = 9	−0.330	1.824	0.177	0.719(0.446–1.160)
	Age = 10	−0.033	0.021	0.885	0.967(0.616–1.519)
	Age = 11	−0.112	0.229	0.632	0.894(0.565–1.414)
	Age = 12	−0.163	0.427	0.513	0.849(0.521–1.386)
	Age = 13	0.292	1.185	0.276	1.340(0.791–2.268)
	Age=(14) reference	0			
	Foot Type = High Arch	−0.370	5.326	0.021*	0.691(0.504–0.946)
	Foot Type = Flexible	0.440	7.546	0.006*	1.552(1.134–2.124)
	Foot Type = Rigit	0.677	23.049	$p<0.001$*	1.969(1.493–2.596)
	Foot Type=(Normal) Reference	0			
Overweight	Intercept	0.118	0.205	0.650	
	Gender = male	0.201	4.235	0.040*	1.223(1.010–1.481)
	Gender=(female)reference	0			
	Age = 4	−3.800	92.519	$p<0.001$*	0.022(0.010–0.049)
	Age = 5	−2.837	55.233	$p<0.001$*	0.059(0.028–0.124)
	Age = 6	−1.693	27.900	$p<0.001$*	0.184(0.098–0.345)
	Age = 7	−1.195	15.637	$p<0.001$*	0.303(0.167–0.547)
	Age = 8	−0.737	5.474	0.019*	0.479(0.258–0.887)
	Age = 9	−0.423	1.917	0.166	0.655(0.360–1.192)
	Age = 10	0.299	1.150	0.284	1.349(0.780–2.332)
	Age = 11	0.122	0.184	0.668	1.130(0.646–1.977)
	Age = 12	−0.231	0.555	0.456	0.793(0.431–1.459)
	Age = 13	0.330	1.036	0.309	1.391(0.737–2.624)
	Age=(14) reference	0			
	Foot Type = High Arch	−1.060	14.614	$p<0.001$*	0.346(0.201–0.597)
	Foot Type = Flexible	1.214	41.233	$p<0.001$*	3.366(2.324–4.874)
	Foot Type = Rigit	1.487	71.843	$p<0.001$*	4.424(3.137–6.240)
	Foot Type=(Normal) Reference	0			

Table 5 (continued)

Obesity Type		B	Wald	*p*	OR(95%CI)
Obese	Intercept	0.094	0.135	0.714	
	Gender = male	0.222	5.226	0.022*	1.248(1.032–1.509)
	Gender=(female)reference	0			
	Age = 4	−3.909	106.080	$p<0.001$*	0.020(0.010–0.042)
	Age = 5	−2.587	56.086	$p<0.001$*	0.075(0.038–0.148)
	Age = 6	−1.373	20.596	$p<0.001$*	0.253(0.140–0.458)
	Age = 7	−1.199	16.303	$p<0.001$*	0.302(0.169–0.540)
	Age = 8	−0.489	2.589	0.108	0.613(0.338–1.113)
	Age = 9	0.076	0.068	0.794	1.079(0.608–1.917)
	Age = 10	−0.234	0.694	0.405	0.791(0.456–1.373)
	Age = 11	0.126	0.200	0.655	1.134(0.652–1.972)
	Age = 12	−0.386	1.539	0.215	0.680(0.370–1.251)
	Age = 13	0.367	1.318	0.251	1.444(0.771–2.704)
	Age=(14) reference	0			
	Foot Type = High Arch	−2.263	22.844	$p<0.001$*	0.104(0.041–0.263)
	Foot Type = Flexible	1.547	71.718	$p<0.001$*	4.697(3.284–6.719)
	Foot Type = Rigit	1.968	142.315	$p<0.001$*	7.156(5.179–9.887)
	Foot Type=(Normal) Reference	0			

Multvariate logistic regression analysis: Reference group: Obesity type (Underweight); OR = ODDS ratio; a:0.05

*Nagelkerke R^2:0.166

* the effect is statistically significant; Dependent variable: Obesity type; Predictor varianle: Foot type, Age, Gender

Discussion

This study investigated the association between overweight/obesity and foot posture in a large pediatric population, drawing on one of the most comprehensive datasets in recent years. Our findings indicate a clear and statistically significant relationship between increased body mass and abnormal foot posture.

As part of the descriptive analysis, we found that among the 7,908 children aged 4 to 14 years, 14.1% were underweight, and 10.9% were obese. Foot posture analysis revealed that 78.8% had normal posture, 9.6% had rigid pes planus, 7.8% had flexible pes planus, and 3.8% had high arches. The data demonstrate that rigid and flexible pes planus were significantly more prevalent among overweight and obese children (Table 5; Figs. 1 and 2).

This association gains further relevance considering that childhood obesity rates in Turkey remain concerning. National data indicate that 17.9% of six-year-olds are overweight or obese, rising to 20–21% by age 18. According to the COSI-TUR 2016 study, 14.6% of 7–8-year-olds were overweight and 9.9% were obese, with higher rates among boys (13.6% vs. 11.3%) than girls (15.7% vs. 8.5%). These trends represent a 19.3% increase from COSI-TUR 2013, with the most significant rise observed among girls. Overall, nearly one in four Turkish children aged 0–18 faces weight-related issues [82]. When interpreting pes planus prevalence across ages, Notably, the medial longitudinal arch typically forms between ages 2 and 6 and is generally fully developed by age 10 [83].

Consistent with previous research, our analysis further revealed that pes planus rates declined markedly between ages 4 and 7, then fluctuated slightly between ages 7 and 14. This age-related trend aligns with previous studies indicating that younger children are more prone to pes planus [44, 72, 73, 84] and that its prevalence decreases and stabilizes with age [45, 73, 84–88]. The overall pes planus rate in our study (36.7%, rigid + flexible) is consistent with prior findings reporting rates between 21% and 42.5% among children under 10 years [87, 89–91]. Biomechanical mechanisms may underlie these associations, as increased body weight leads to greater plantar loading, reducing arch height and increasing foot contact area. These findings suggest that children without pes planus may develop it over time due to excess weight. Furthermore, literature indicates that while flexible pes planus often resolves with age, rigid forms may persist or worsen [45].

Moreover, gender-based differences were also notable. Our findings revealed a higher prevalence and risk of pes planus among boys, corroborating prior studies [44, 69, 72, 92, 93]. Reported prevalence rates vary between 14% and 31%, with some studies indicating that boys are up to twice as likely as girls to have flat feet [72, 73, 94]. This may be attributable to anatomical and developmental differences, as well as biomechanical loading patterns, such as greater heel-loading in boys [86]. Urban residency has also been linked to higher pes planus rates compared to rural environments [90].

In addition to age and gender, BMI emerged as a strong predictor of both rigid and flexible pes planus. Prior research shows pes planus prevalence ranges from 9 to 13% among overweight/obese children and 2–4% among normal-weight peers [69, 71, 72, 92, 93, 95]. The broader literature reports a general prevalence range of 4–28%, supporting a positive correlation between BMI and pes planus risk [96]. Our data showed that rigid foot posture peaked at age 4 and declined thereafter. However, meta-analyses highlight that the age at which the medial longitudinal arch (MLA) stabilizes remains inconclusive [97]. While some studies suggest arch development continues until ages 12–14, others argue that the majority of foot arch formation occurs between ages 4 and 6, with approximately 20% of children never developing full arches [98].

Given these findings, the role of targeted intervention is particularly relevant in this context. Studies suggest that physical exercise is effective in correcting flexible pes planus, especially among children aged 4–6 years [99, 100]. According to Table 4, children with rigid and flexible foot types were significantly more likely to be overweight or obese. Table 5 illustrates that rigid foot posture nearly doubled the likelihood of being overweight and increased the odds of obesity by more than sevenfold.

Despite these robust findings, this study has limitations. First, it includes only children aged 4–14 living in coastal cities in Turkey's Marmara Region, which may limit generalizability. Children under 4 were excluded due to evidence that foot arches typically do not form until after age 3 [101, 102]. Second, physical activity levels and other lifestyle variables—known to influence both foot posture and weight—were not assessed. Additionally, subcutaneous fat distribution, which may interfere with visual foot assessments, was not measured. Some literature suggests this may not significantly affect pes planus classification [103], but this remains debated.

Practical implications include the potential use of non-invasive screening tools like the Staheli Index and Jack Test in school health programs to help identify children at risk of obesity-related complications. Such early detection could facilitate timely intervention through multidisciplinary strategies. Future research should adopt longitudinal and interventional designs to explore causality, incorporate confounding variables such as physical activity, footwear habits, and socioeconomic status, and examine the biomechanical and metabolic consequences of early foot posture abnormalities.

Conclusion

This study highlights a significant association between abnormal foot posture—especially rigid pes planus—and increased risk of overweight and obesity in children aged 4–14 years. Early childhood showed the highest prevalence of rigid pes planus, while excess weight was more common in all abnormal foot types.

The use of simple, non-invasive screening tools like podoscopy and Staheli's Index may support early identification of obesity risk. Integrated school-based interventions targeting both foot health and body weight may enhance early prevention and health outcomes. Future longitudinal studies are needed to clarify causality and optimize prevention strategies.

In this study, variables such as physical activity level, footwear habits, and socioeconomic status were not evaluated as potential confounders. Future studies incorporating these variables are recommended.

Authors' contributions

Conceptualization, H.B., M.A., Ö.E., A.D., G.Ö.; methodology, H.B., M.A., Ö.E., A.D., G.Ö.; formal analysis, A.D.; investigation, H.B., M.A., Ö.E., A.D., G.Ö.; data curation, H.B., M.A., Ö.E., A.D., G.Ö., L.P.A.; writing—original draft preparation, H.E.U., İ.A., R.Ç., Ö.E., M.I.A.; writing—review and editing, H.B., M.A., Ö.E., A.D., G.Ö., L.P.A.; supervision, H.B., M.A., Ö.E., A.D., G.Ö., L.P.A.

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Data availability

All the data obtained and produced in the scope of this study has been not deposited into a publicly available repository and the data will be made available on request.

Declarations

Ethics approval and consent to participate

The study was conducted in accordance with the Declaration of Helsinki and approved by the Scientific Research Ethics Committee of Çanakkale Onsekiz Mart University (Project No: 2023-YÖNP-0396). Informed consent was obtained from all participants. For all children under 18 years of age, written informed consent was obtained from their parents or legal guardians.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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