The relationship between body mass index and lower extremity biomechanics in children aged 10-12 years: a comprehensive analysis

Carlos Lahoz[1], Jorge Pérez-Rey[2], David González[3], José Gallart[3], Mercedes Ruidíaz[4], Mª José Luesma[2]

[1] Department of Education of the Government of Navarra, Santos Justo y Pastor Public School, Fustiñana, Navarra, Spain
[2] Department of Human Anatomy and Histology, University of Zaragoza, 50009 Zaragoza, Spain
[3] Private Practice, Gallart & González Podiatric Clinic, 50004, Zaragoza, Spain
[4] Department of Physiatry and Nursing, University of Zaragoza, 50009 Zaragoza, Spain

SUMMARY

Childhood obesity has emerged as a global health concern leading to complications, such as bones and muscles misalignment of knees, flat feet and changes in walking patterns. Although some studies have individually linked these conditions to body mass index (BMI), the relationship between these variables needs to be explored. This study aimed to investigate the associations between BMI and knee position, foot position and plantar footprint in children aged 10 to 12 years. Data were collected from 59 children by measuring their BMI, knee alignment, foot position and plantar footprint. Spearman's correlation coefficient was used to examine the relationship between BMI and inter-malleolar distance (DIM), foot position and plantar footprint. The Mann-Whitney U test was used to compare these variables between boys and girls (p-value < 0.05).

Higher BMI values were associated with higher DIM in both boys and girls. Furthermore, we observed that genu valgum was positively correlated with foot pronation and a flattened plantar footprint. No significant differences were found in relation to BMI, variations in foot position or footprint types. Our research provides evidence that there is a connection, between BMI and genu valgum in children between the ages of 10 and 12. We have also found a correlation between genu valgum and foot pronation among children in this age group. These findings highlight the significance of addressing childhood obesity to prevent any health issues.

Keywords: Body mass index – Paediatric obesity – Genu valgum – Flatfoot – Biomechanics

Corresponding author:
M.J. Luesma, PhD. Department of Human Anatomy and Histology, University of Zaragoza, Calle Domingo Miral s/n, 50009 Zaragoza, Spain. Phone: +34 656230642. E-mail: mjluesma@unizar.es

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INTRODUCTION

The human body is a system with interconnected parts that influence each other, providing functionality and overall well-being. One area of interest in biomechanics is the study of the impact of body mass index (BMI) on knee alignment, foot position and plantar footprint type (Domjanic et al., 2015). Investigating the interaction between these variables is crucial for understanding the underlying mechanisms influencing gait and foot function, as well as identifying risk factors associated with foot-related dysfunctions and injuries (Hoang et al., 2023).

Childhood obesity has become a major global health problem (Liebert, 2010). In recent years, its prevalence has raised concern worldwide. According to a report by the World Health Organization, the number of obese or overweight children and adolescents aged 5-19 years exceeded 340 million in 2021 (Jankowicz-Szymanska and Mikolajczyk, 2016).

Children who are overweight or obese have an increased risk of developing type 2 diabetes and cardiovascular disease in adulthood. In addition, excess weight in children is associated with musculoskeletal problems, as well as valgus misalignment of the knees or flat feet (Ratu Alicia, 2023; Ryzhov et al., 2020). It can also affect balance, posture, and the ability to move efficiently, and may even increase the risk of osteoarthritis at an early age (Calcaterra et al., 2022).

Genu valgum is a pathological condition characterised by a misalignment in the frontal plane of the knee joint, which can affect stability, biomechanics and energy efficiency during gait (Shapouri et al., 2019). The occurrence of this phenomenon can be attributed to genetic factors, trauma or specific medical conditions, with its prevalence in obese children aged 10-12 years being 53.3% (Putri et al., 2020).

Moreover, current evidence suggests that there is a correlation between foot position and BMI, revealing a higher prevalence of pronated feet among individuals with higher BMI values (Carvalho et al., 2017) and in turn, pronated feet are often associated with flat feet (Sadeghi-Demneh et al., 2015). Flat feet are a condition in which the medial longitudinal arch of the foot is decreased or absent. This condition is seen in up to 10% of the childhood population (Boryczka-Trefler et al., 2021) and can lead to a different gait patterns, which can make walking or running biomechanically less efficient leading to premature fatigue, or to foot, ankle and leg pain (Kayll et al., 2022).

Although there is strong evidence suggesting individual associations between each of these conditions with BMI, there is a lack of research that comprehensively addresses the intricate relationships between each of the lower limb joints with each other and with BMI (Jankowicz-Szymanska and Mikolajczyk, 2016).

Gaining a comprehensive understanding of the complex relationship between these variables is of utmost importance in implementing a holistic preventive strategy to address childhood obesity and its associated musculoskeletal complications. To achieve this goal and complement the current scientific literature, the present study aims to analyse the relationship between BMI and knee position in the transverse plane, foot position and plantar footprint together in children aged 10-12 years.

MATERIALS AND METHODS

Participants

The sample was taken from the Primary Education classes of the San Bartolomé Public School in Ribaforada (Navarra), with the prior acceptance of the school. The study included students in 5th and 6th grade of primary school enrolled in the 2021-22 academic year, who provided consent to participate in the research signed by their parents and/or guardians. Pupils who were not between 10 and 12 years of age were excluded. Finally, 59 pupils were included in the study. The principles of the Declaration of Helsinki were followed. The protocol was verified and approved by the Research Ethics Committee of the

Community of Aragon (CEICA) (Registration nº: PI20/263), and the legal guardians of the children signed the informed consent.

Protocol

To calculate body mass index, participants were weighed barefoot using a portable electronic scale. The child stood in the centre of the scale platform distributing his/her weight between both feet, facing forward, with arms alongside the body, and without any movement. Light clothing was allowed, excluding long trousers, shoes and sweatshirt.

Height was measured with a standard tape measure at the highest point of the head, the hair being compressed. Body mass index (BMI, weight in kg divided by height in metres squared) was calculated, determining the weight status of the participants (normal weight, overweight and obese) using BMI cut-off points according to the tables established by the World Health Organisation according to age and sex.

Knee alignment was assessed with the limbs in extension, in neutral rotation and trying to bring the two legs together, so that either the femoral condyles or the tibial malleoli touched (Gupta et al., 2021). It was measured with a tape measure expressed in centimetres (cm). If the participant, when bringing the legs together, joined the knees before the malleoli, the inter-malleolar distance (IMD) was measured and its value was expressed in positive values.

If, on the other hand, the malleolus was touched first, the inter-condylar distance (ICD) was measured, representing this measurement in negative values. The result of this measurement gives a variable called inter-malleolar-intercondylar distance (IMD-IC) which allows us to work as a quantitative variable. Given that the result of this variable is affected by the height of the child (length of the lower limbs), the relative intermaleolar-intercondylar distance (relative IMD-IC) is taken into account using the following equation: Relative DIM-IC= DIM-IC (cm)/ Height (cm) x 100.

Foot position was assessed statically using the Foot Posture Index (FPI-6) through 6 visual criteria about the rearfoot, midfoot and forefoot (Redmond et al., 2006). This clinical instrument is used to score values from -2 to +2 for each of the 6 criteria that the FPI-6 gives according to the degree of pronation or supination. The result of this method gives an FPI value ranging from -12 to +12. This result allows the foot to be classified into different positions, as shown in Table 1. Negative FPI values represent a supination position (the lower the value, the greater the supination), and the higher the FPI value the greater the degree of pronation, which allows us to work quantitatively with the numerical value of the FPI

Table 1. Typification of foot position with FPI values according to Redmond et al. (2006).

FPI values	Position of the foot	Position of the foot (simplified)
-5 a -12	Foot in extreme supination	Foot in supination position
-1 a -4	Foot in supination	
0 a +5	Foot in normal position	Foot in normal position
+6 a +9	Pronating foot	
+10 a+12	Foot in extreme pronation	Foot in a pronated position

and as a nominal qualitative variable according to the classification of the authors by the score obtained (Table 1).

The acquisition of the plantar footprint was performed with an ink pedigraph with which each subject in an orthostatic position left their footprints printed on a piece of paper as described by Gonzalez-Martin et al. (2021) in their study. Measurements to determine the type of footprint were performed according to the method described by Hernández Corvo (1989) and Lara Diéguez et al. (2011). This is a quantitative method by which a numerical value is obtained, the Hernández Corvo Index (IHC), which represents the percentage of the width of the midfoot area concerning the forefoot. Its value ranges from 0 to 100 and allows the classification of the plantar footprint into different types according to this value, ranging from flat feet (IHC values close to 0) to extreme cavus (IHC values close to 100) (Table 2). This method allows working quantitatively with the value of the Hernández Corvo Index and presents good precision, with high inter-observer reproducibility, obtaining a high Lin's concordance correlation coefficient (>0.98) (Buendía- Lozada, 2011).

Data analysis

Data were collected in an Excel spreadsheet (Microsoft Office Professional Plus 2016, Microsoft Inc., USA). IBM SPSS software version 24 (SPSS®IBM® Corporation, New York, USA) was used for data analysis. A descriptive analysis of the variables disaggregated by gender was performed. It was checked whether the analysed variables followed normality criteria for the choice of statistical tests. Spearman's correlation coefficient was used to analyse the correlation between BMI and relative DIM-IC, FPI and IHC, given the absence of normality, and the Mann-Whitney U-test was used to compare the variables between boys and girls.

Statistical significance was assumed for a p-value < 0.05.

RESULTS

Of the 59 students, 33 (55.9%) were girls and 26 (44.1%) were boys with a mean age of 11.49 (±0.66). The mean BMI was 20.44 (±4.27) with no significant differences in BMI between boys and girls in the study (p-value =0.29). According to this parameter, 30 students (50.8%) had a nor-

Table 2. Typification of plantar footprint according to Hernandez Corvo Index value.

IHC (%)	Type of foot	Type of foot (simplified)
0-34	Flat feet	Flat feet
35-39	Flat/normal feet	
40-54	Normal foot	Normal foot
55-59	Normal/cavity foot	
60 74	Pes cavus	Pes cavus
75-84	Strong pes cavus	
85 100	Extreme pes cavus	

Table 3. BMI and body status.

Descriptive characteristics of BMI and body status according to WHO tables.							
	n	Age (years)	BMI	Body status n (% within gender)			
				Underweight	Normoweight	Overweight	Obesity
Children	26	11.50(±0.66)	20.84(±3.78)	0 (0%)	12 (46.2%)	6 (23.1%)	8 (30.8%)
Girls	33	11.48(±0.66)	20.13(± .65)	2 (6.1%)	18 (54.5%)	8 (24.2%)	5 (15.2%)
Total	59	11.49(±0.66)	20.44(± .27)	2 (3.4%)	30 (50.8%)	14 (23.7%)	13 (22%)

Mean (standard deviation)
n= number of cases; BMI (body mass index)

mal body weight status, 14 (23.7%) were overweight, 13 (22%) obese and 2 cases (3.4%) were underweight. The body status of the students according to gender is described in Table 3.

The mean relative DIM-IC obtained in the total sample was 1, 67 (±1.76). In the boys' group, it was 1.59 (±2.08) and 1.74 (±1.5) in the girls, with no significant differences between the two groups (p-value =0.89).

The mean FPI value for the feet of the total sample (n= 118) was 3 (±4.29); for boys' feet (n=52) the mean value was 2.56 (±4.41) and for girls' feet (n=66) it was 3.35 (±4.29). The Mann-Whitney U test, with a p-value of 0.61 showed no difference between genders. The classification of foot position according to the value of this parameter is described in Table 4.

The mean value of the IHC of the 118 footprints analysed was 54.06 ± 12.81; the difference between the mean value of the IHC according to gender was significant with a p-value = 0.014 in the Mann-Whitney U-test. The mean value of the footprints for boys was 50.76 ± 14.51 vs. 54.06 ± 12.81 for girls. The distribution by gender of the footprint typology obtained after the IHC analysis is shown in Table 4.

Correlation analysis between BMI and the variables analysed found a direct and moderate association between BMI and relative DIM-DIC both in the total sample (rho=0.47; p-value = 0.00) and separated by gender (Boys: rho=0.63; p-value = 0.00 / Girls: rho= 0.4; p-value = 0.02).

In contrast, there was no evidence of an association between BMI and total and gender- disaggregated values of FPI and IHC (p-value < 0.05) (Table 5).

A direct and weak association (rho < 0.3) was found between the values of relative DIM-DIC and FPI when analysing the data of the sample as a whole (rho= 0.27; p-value =0.00) and in the group of girls (rho=0.29; p-value =0.01), so that the higher the DIM, the greater the pronation of the foot, but no such correlation was found in the group of boys (Table 5).

A weak and indirect association was found between the relative DIM-DIC and IHC values for the total sample (rho= -0.185; p-value =0.04), so that the greater the inter-malleolar distance the greater the flattening of the plantar footprint. This relationship was not found when analysing these variables disaggregated by gender (Table 5).

Correlation analysis between FPI and IHC values determined that there is an indirect and moderate association between these two variables, both in the total sample (rho=- 0.39; p-value = 0.00), and separated by gender (Boys: rho=-0.49; p-value = 0.00 / Girls: rho= -0.34; p-value = 0.00), that is, the greater the degree of pronation the greater the degree of flattening.

DISCUSSION

The present study aimed to investigate the effect of body weight on frontal plane knee posi-

Table 4. Description of the variables foot position and footprint type; comparison between boys and girls and statistical significance.

		Total n (%)		Children n (%)		Girls n (%)		Sig*
Foot position (FPI-6)	**Neutral foot**	59	50%	28	53.8%	31	47%	0.67[a]
	Pronated foot	39	33.1%	15	28.8%	24	36.4%	
	Supinated foot	20	16.9%	9	17.3%	11	16.7%	
Plantar footprint type (IHC)	**Flat feet**	8	6.8%	5	9.6%	3	4.5%	0.051[b]
	Flat/normal feet	3	2.5%	0	0%	3	4.5%	
	Normal foot	42	35.6%	24	46.2%	18	27.3%	
	Pes cavus	24	20.3%	9	17.3%	15	22.7%	
	Strong pes cavus	41	34.7%	14	26.9%	27	40.9%	

Table 5. Correlation between BMI and relative DIM-DIC. FPI and IHC values by gender and statistical significance for Spearman correlation coefficient test.

	Children		Girls		Total	
	Correlation Coefficient	**Sig**	**Correlation Coefficient**	**Sig**	**Correlation Coefficient**	**Sig**
BMI and relative DIM-DIC	0.630	**0.001**	0.403	**0.02**	0.474 0.**00**	
BMI and IPF	-0.004	0.97	0.109	0.38	0.043 0.64	
BMI and IHC	-0.039	0.78	-0.21	0.08	-0.171 0.06	
Relative DIM-DIC and FPI	0.239	0.08	0.296	**0.01**	0.277 0.**00**	
Relative DIM-DIC and IHC	-0.257	0.06	-0.094	0.45	-0.185 0.**04**	
IPF and HCI	-0.491	**0.00**	-0.342	**0.00**	-0.394 0.**00**	

tion, foot position and plantar footprint type, and whether there is an interrelationship between all these variables. It is important to note that the present study focused specifically on the relationship between BMI and variables measuring lower limb joint alignment without considering other potential factors that may influence these variables.

Genu valgum is a dysfunction of the knee joint characterised by inward angulation of the knees, causing a misalignment of the lower limbs, so that when the knees are together the inner malleoli of the ankle do not touch. This condition is often seen in people with excess body weight, as this causes an increased load on the lower limb joints and can lead to misalignment of the knee joint (Khandha et al., 2016), indeed our results show that children with a higher BMI were more likely to have a valgus deviation of the knee.

On the other hand, our results showed no statistically significant relationship between BMI and foot position or plantar footprint type, suggesting that pronated foot or plantar footprint flattening is not dependent on the weight of the subject and that there are therefore other factors that cause these mismatches. These findings contrast with the results of previous studies that have found associations between BMI and foot position (Molina-García et al., 2023; Escalona-Marfil et al., 2022; Bann et al., 2022). Other study showed that subjects with higher BMI were at higher risk of ossification of the posterior longitudinal ligament and the yellow ligament of the spine, which may affect foot position (Zhao et al., 2022). In our study, we did not record variables relating to these spinal ligaments.

When we studied the relationship between knee alignment with foot position and plantar footprint type, we found that an increase in the relative inter-malleolar distance (genu valgum) was associated with an increase in foot pronation, both in the overall analysis of the population and in the group of girls, and that this alteration of the knee was also related to a flattening of the plantar footprint.

With the above mentioned, it seems plausible to hypothesise that in these interrelationships, valgus knee position is more of a risk factor for pronated foot position and flat footprint than BMI, and although genu valgus does have a direct relationship with weight, the fact that overweight or obesity has no impact on foot position or footprint raises the question of what other factors influence foot position and footprint type. Bourgleh et al. (2019) state in their study that genu valgum can lead to altered biomechanics of the lower limb and is also related to increased pronation of the foot, which in turn can contribute to the development of flat feet which supports the results found in our research.

When we independently analysed the relationship between foot position and footprint type, we found that the greater the degree of foot pronation, the greater the flattening of the footprint. This finding reinforces current evidence showing a relationship between the two variables (Latey et al., 2018).

Although clinical measurement by goniometer and radiographic measurement of the femorotibial angle provides a more accurate way of quantifying genu valgum (Liou et al., 2022; Colazo et al., 2020), at the clinical level it has been shown that the measurement of the intermalleolar distance is a valid system for the diagnosis of genu valgum (Ciaccia et al., 2017; Witvrouw et al., 2009).

However, to estimate the degree of genu valgum realistically we opted to utilize the DIM method as explained in our methodology. While this decision does not impact our obtained results, it does pose a limitation when comparing our findings to studies that directly measure the angle, between the thigh and leg for quantifying knee deviation. It is worth noting that our research specifically focuses on a population and caution should be exercised when attempting to draw associations within adult populations.

To address this limitation and enhance the body of evidence on this subject future research should explore these relationships across age groups. Moreover, future studies need to consider factors that may influence limb alignment to establish a direct relationship between weight and such alterations.

In conclusion, our study provides insights into the connection between BMI, genu valgum, foot position and footprint type. The findings support research indicating a correlation between BMI and genu valgum as well as between genu valgum and foot pronation. However, no significant differences were observed in terms of BMI, foot position or footprint type.

These findings show that the relationship, between these variables is intricate and indicate that there could be factors influencing foot position and type of footprint. It is important to research to better understand how these mechanisms interact and explore interventions, for addressing these lower limb conditions.

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