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Static analysis of plantar pressures and kinetic parameters in pes cavus versus normal feet: a case–control study

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Background: At least 10% of the population has cavus feet. This type of foot, characterized by a high medial arch, is usually accompanied by muscle imbalances, calluses, and pain in the hindfoot, lateral column, and forefoot. Early treatments are crucial for these patients, given that they could benefit from the modification of their static plantar pressure distribution to prevent osteoarthritis or pressure ulcers. Baropodometry has been shown to serve as an efficient and cost-effective instrument for evaluating foot features related to ground loads and reactive forces. The primary aim of the current investigation was to assess and analyze subjects with pes cavus and compare the results with patients with normal feet using a pressure platform.

Methods: A total of 82 participants were involved in the research, split into 41 individuals with cavus feet and 41 with normal-arch feet. The descriptive observational case–control study took place from October to December 2024 at the A Coruña University, located in Spain. The Neo-Plate ® baropodometric platform was used to observe static plantar pressures. Three 30-s recordings were needed per individual. The results were analyzed using the IBM SPSS Statistics Software v.19.0 and compared using Student's *t*-test and Mann–Whitney *U* test.

Results: The outcomes indicated that the pes cavus group had less total contact surface area while the weight was focused on the forefoot and hindfoot, the left foot surface area was 150.31 cm^2 ± 22.95 (145.36–155.27) in the case group and 161.71 cm^2 ± 14.88 (156.96–166.45) in the control group, with a $P = < 0.001$, and the case group had higher mean maximum pressure of the right foot (141.25 ± 17.65 kPa) than the control group (135.08 ± 8.67 kPa, $P = 0.001$).

Conclusion: Baropodometric platforms are a reliable tool for studying and interpreting static plantar pressures in subjects with pes cavus. Subjects with cavus feet have a different load distribution than subjects with normal feet, with greater weight-bearing areas in the hindfoot and forefoot, along with less total contact support. Limitations include sex imbalance and type of footwear used in sports practice.

KEYWORDS

biomechanics, cavus foot, pes cavus, plantar pressure, static baropodometry

1 Introduction

Pes cavus is a foot type with an alteration of the medial longitudinal arch, which is higher than in a normal foot. It can also be referred to as a cavovarus foot if a varus deviation is also present in the forefoot. Moreover, a plantarflexion of the first ray, valgus forefoot with pronation and adduction, as well as a varus hindfoot, are seen [1]. This abnormality is accompanied by other musculoskeletal disorders and also by inefficient pressure load distribution while remaining standing. Different studies note that near 10% of the population possesses this kind of foot structure [2,3].

Pes cavus is frequently associated with neurological conditions that cause muscle imbalances during growth. Specifically, the deformity often results from the overpowering force of the posterior tibialis and peroneus longus muscles against the weaker anterior tibialis and peroneus brevis muscles [1]. If the disorder is unilateral, it is more likely to be as a result of a tethered spinal cord or a spinal cord tumor, whereas bilaterality happens most commonly due to a hereditary or congenital source, such as Charcot–Marie–Tooth [1,4] To determine the stage of the pathology, in addition to the use of complementary tests, the Coleman test is usually carried out to distinguish between a rigid and a flexible foot, a crucial classification in this type of patient [5,6]. The importance relies on the early treatment that could be given if a correct diagnosis and maneuvers are performed, preventing people with pes cavus from developing osteoarthritis, overload pressure ulcers (if diabetes mellitus), ankle impingement, etc., using interventions ranging from tape and mobilizations to foot orthotics and surgery [7–11].

It is crucial to understand how the ground reaction forces come into play when maintaining a static position. For this purpose, podobarometric measurements have proven to be useful [12]. Due to this valid and effective platform, alterations in the distribution of plantar pressures can be evaluated, with pes cavus being characterized by a center of pressure that is displaced toward the heel, lateral column, metatarsal region, and toes [13,14].

There is currently no comprehensive database from which to obtain information on plantar pressures in patients with pes cavus using the pressure platform, even though we know how important this would be [3,14,15]. Therefore, the primary objective of this study will be to measure and analyze people with pes cavus and compare the results with patients with normal feet.

The main hypothesis is that patients with pes cavus will have a smaller bearing surface, but the pressure will be increased compared to normal feet.

2 Materials and methods

2.1 Study design and participants

The research, with ID: 2024-033, was approved by the Bioethics Committee of the University of A Coruña (Spain) in October 2024. A descriptive observational case–control study was conducted between October and December 2024, with a total sample of 82 participants. Specifically, a consecutive non-random technique was used to recruit 11 men and 71 women aged 18–65 years old.

To evaluate the static plantar pressures in adults with pes cavus and normal-arch feet, this research adhered to the *Strengthening the Reporting of Observational Studies in Epidemiology* (STROBE) guidelines [16]. To ensure the protection of the patient's personal information and the safeguarding of their digital rights, and to comply with prevailing regulations on human experimentation, the study also followed the *Declaration of Helsinki* and the Spanish Organic Law 3/2018, of December 5th [17,18].

The inclusion criteria were as follows: 1) age between 18 and 65 years; 2) clinical diagnosis of bilateral pes cavus, characterized by a high medial longitudinal arch, confirmed by an experienced podiatrist for the case group, or bilateral neutral feet for the control group; 3) general healthy status with no history of lower limb trauma or surgery; and 4) provision of signed informed consent, with the cognitive ability to understand instructions and communicate with the researchers.

The exclusion criteria were as follows: 1) age outside the range of 18–65 years; 2) presence of lower limb axial deviations, such as genu varum, genu valgum, pelvic obliquity, or spinal deformities capable of altering the center of pressure; 3) limb length discrepancy > 5 mm; 4) history of lower limb surgery or significant trauma; 5) current pharmacological treatment affecting the central nervous system or balance; 6) pregnancy or systemic pathologies, and 7) inability to finish or refuse the informed consent.

Of the 82 participants, 41 were assigned to the pes cavus group (mean age of 26.07 ± 7.16 years) and 41 to the normal foot group (mean age of 25.51 ± 5.99 years). The statistical power analysis conducted had an 80% power (β error = 0.20), a significance level of α-error = 0.05, and was established using a two-tailed test. Epidat Software v.4.2. (created by the Consellería de Sanidade, Xunta de Galicia in Spain, the Pan American Health Organization (PAHO-WHO), and the CES University of Colombia) was used to calculate confidence levels, statistical power, number of subjects needed, and the number for each group to ensure equal group sizes.

2.2 Experimental procedure

Data collection was performed by a podiatrist with more than 10 years of clinical experience. Baseline data collection commenced with a structured interview covering demographic details and health history. Participants were screened for previous musculoskeletal injuries and risk factors associated with systemic conditions, including diabetes mellitus and vascular abnormalities. Subsequently, anthropometric measurements were recorded, and the investigator used *Quetelet´s equation*: body mass index (BMI) = weight/height^2 [19]. In order to complete it, each participant was instructed to remove their footwear and socks and then wait for the clinician to assess the weight (kg) and height (m) so that the BMI could be determined [20,21].

Following the anthropometric assessment, a full physical evaluation of the lower limbs was carried out. The aim was to observe and evaluate their musculoskeletal mobility, muscle strength, and structural integrity. To achieve this, the podiatrist relied on the Kendall test [22]. Because intrinsic and extrinsic foot muscles maintain the medial longitudinal arch, improve footcore, play important roles in the gait, and lead to conditions such as flatfoot or high-arched feet, they were evaluated [6]. To do so, subjects performed active and passive movements of foot plantarflexion, dorsiflexion, inversion, and eversion. Manual resistance to each action was also applied and then compared with its contralateral limb. The scale employed six grades, ranging from 0, or no palpable or visible muscle contraction, to 5, or a complete range of motion against gravity with maximal resistance [23,24].

To conclude the physical examination, the hindfoot flexibility was assessed and categorized using the Coleman test, a validated and established tool in clinical practice and research settings to assess the flexibility, stiffness, and possible correction of a cavus hindfoot. This test is based on the concept of how the first ray contributes to the rearfoot deformity of the patient, allowing the clinician to better understand their biomechanics while standing and, therefore, the best available treatment options [5,7,25].

To perform the Coleman test, subjects were asked to sit with both feet resting relaxed at a 90° angle on the floor. Then, a 2.5 cm block was positioned under the outer column (lateral side) of the foot, ensuring that the first two rays remained unsupported. A foot was considered a flexible cavus foot if the rearfoot adopted a corrected position followed by a neutralization of the heel, indicating that the rearfoot's cavus deformity is a consequence of the first metatarsal plantarflexion. In contrast, a rigid cavus foot was diagnosed if the hindfoot varus did not change.

Upon completion of the physical examination, participants were instructed to stand on the pressure platform to assess static foot loading. The protocol followed was the one detailed by Becerro de Bengoa-Vallejo et al. [12]. It described four focuses for studying the static stance on patients: 1) the mean peak pressure, 2) the surface area, 3) the body weight on the legs, and 4) the type of foot arches [12]. The portable baropodometry platform used in the present investigation was the Neo-Plate® , Herbitas SL (Valencia, Spain) version for Windows because it is a non-invasive and, more importantly, validated method [14].

Specifically, an experienced podiatrist collected the data using the baropodometric platform (40 cm × 40 cm × 0.08 m, 4,096 sensors, 100–150 Hz, 0.01 kPa in each sensor). First, a clinical interview collected demographic data and medical history to screen for exclusion criteria. Anthropometric measurements (height and weight) were taken to calculate BMI. Subsequently, Figure 1 shows the physical examination evaluating musculoskeletal mobility and foot integrity using the Kendall test and the Coleman block test to classify the cavus foot flexibility. Figure 2 following the clinical assessment, static plantar pressure was measured using the Neo-Plate® baropodometric platform. Participants were instructed to stand barefoot in a relaxed position, with arms at their sides and looking at a fixed point at eye level to ensure natural weight distribution. Feet were positioned at shoulder-width apart. Three 30-s recordings were obtained per participant, and the average was used for analysis.

FIGURE 1
Assessment of a participant with pes cavus using the Coleman block test.

Figure 3 shows the baropodometric variables analyzed in the research: 1) forefoot maximum peak pressure (kPpa); 2) heel maximum peak pressure (kPa); 3) total surface area (cm^2); 4) forefoot surface area (cm^2); 5) heel surface area (cm^2); 6) total body weight (%); 7) forefoot body weight (%); 8) heel body weight (%); and 9) type of foot arch, divided into flatfoot, pes cavus, and normal or healthy foot [12,26,27].

Due to the platform dimensions, both feet could be screened. A total of three recordings per participant were taken, and the results were averaged as this provides greater objectivity and validity. A total of 1 min and 30 s (30 s per shot) was needed per individual.

Discarded data included those cases in which subjects moved or where the results were highly altered; at these times, they were asked to repeat the test. The Neo-Plate® , using the Herbitas SL (Valencia, Spain) version for Windows software, was applied to every foot so that a plantar pressure map could be interpreted.

2.3 Data processing and statistical analysis

A descriptive evaluation was conducted for quantitative variables. A p-value of < 0.05 and 95% confidence intervals were deemed statistically significant, employing means and standard deviations (SD). For the group differences, Student's t-test was used when parametric assumptions were met for independent samples, and the Mann–Whitney U test was used for all the non-parametric data. Finally, categorical variables were analyzed using Fisher's exact test. All information was managed and visualized using the IBM SPSS Statistics v.19.0 package [28].

FIGURE 2
Patient positioned on the Neo-Plate baropodometric platform during static data collection, standing with a 30° Fick angle and looking straight ahead.

3 Results

3.1 Sociodemographic and descriptive data

As indicated previously, the study involved 82 participants, split evenly into a control group and a case group, with a mean age ± standard deviation (SD) of 25.51 ± 5.99 years (Table 1) presents the data obtained on the first day of intervention in relation to the age (years) of the subjects, in addition to their weight (kg), height (cm), BMI (kg/m^2), gender (male/female (%), and foot size (cm). There were statistically significant differences in weight (63.12 ± 11.69 kg) and BMI (22.82 ± 3.43 kg/m^2) between groups ($p < 0.001$). The remaining characteristics showed no significant differences between the two groups.

3.2 Primary outcome measures

To compare the static plantar pressures between subjects with cavus feet and subjects with normal feet, contact surface areas, bodyweight distribution, and, most importantly, static plantar pressures were analyzed. In Table 2, the measured variables are listed with their descriptive statistics, p-values (from independent samples of the t-tests), T-student's results, and Cohen's d effect sizes.

The subsequent results indicate statistically noteworthy variations ($p < 0.05$) between both cohorts: The left foot surface area was 150.31 cm^2 ± 22.95 (145.36–155.27) in the case group and 161.71 cm^2 ± 14.88 (156.96–166.45) in the control group, with a p = < 0.001, t-value = −5.46, and Cohen's d = −1.28. The left forefoot surface area was 57.45 cm^2 ± 12.06 (53.60–61.30) in the case group and 72.63 cm^2 ± 10.37 (69.34–75.92) in the control group, with a $p \leq 0.001$, t-value = −5.71, and Cohen's d = −1.39. The left heel surface area was 23.96 cm^2 ± 4.54 (23.52–25.40) in the case group and 29.74 cm^2 ± 4.29 (28.38–31.10) in the control group, with a $p \leq 0.001$, t-value = −5.69, and Cohen's d = −1.32. The right foot medium peak pressure was 141.25 kPa ± 17.65 (135.59–146.91) in the case group and 135.08 kPa ± 8.67 (132.34–137.82) in the control group, with a $p = 0.001$, t-value = 3.56, and Cohen's d = 0.42. The right foot surface area was 138.91 cm^2 ± 20.65 (132.35–145.47) in the case group and 162.77 cm^2 ± 14.28 (158.26–167.28) in the control group, with a $p \leq 0.001$, t-value = −5.62, and Cohen's d = −1.42. The right forefoot surface area was 57.46 cm^2 ± 11.58 (53.78–61.14) in the case group and 73.16 cm^2 ± 9.47 (70.18–76.14) in the control group, with a $p = 0.002$, t-value = −3.23, and Cohen's d = −1.50. Finally, the right heel surface area was 24.08 cm^2 ± 4.54 (22.64–25.53) in the case group and 28.89 cm^2 ± 4.24 (28.54–31.24) in the control group, with a p = < 0.001, t-value = −5.32, and Cohen's d = −1.37.

The remaining variables did not show statistically significant differences when comparing the case group to the control group.

4 Discussion

The central aim of this current investigation was to examine and contrast the static plantar pressures among subjects with high-arched feet *versus* subjects with normal-arched feet. Our hypothesis is confirmed: the morphology of the cavus foot directly affects the distribution of static pressures, especially compared to feet with a normal arch.

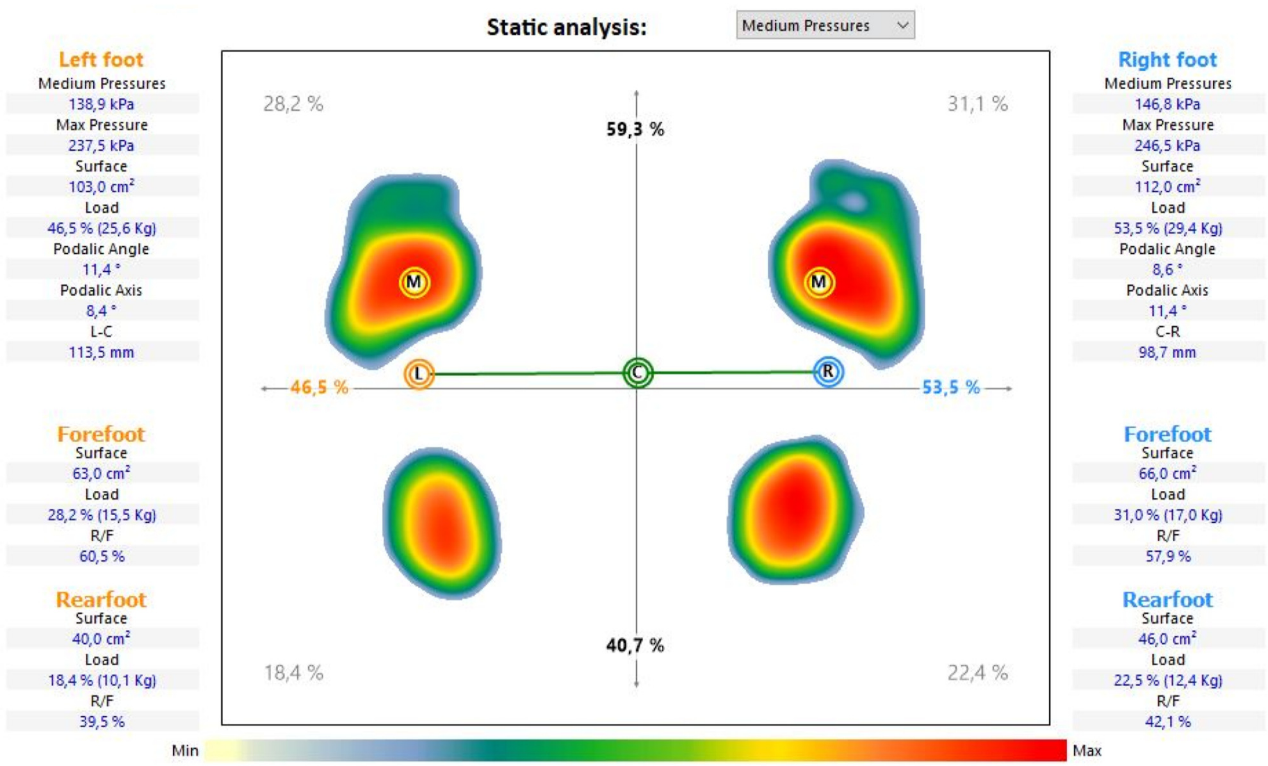

FIGURE 3
Neo-Plate baropodometric variables in the static analysis of right and left pes cavus.

TABLE 1 **Main outcome measurements of the total sample with or without bilateral cavus foot.**

Characteristics	Total sample (n = 82) Mean ± SD (range)	Case group (n = 41) Mean ± SD (range)	Control group (n = 41) Mean ± SD (range)	*p*-value
Age (years)	25.51 ± 5.99 (20–46)	26.07 ± 7.16 (20–46)	24.95 ± 4.55 (21–39)	0.940[a]
Weight (kg)	63.12 ± 11.69 (45–92)	59.76 ± 12.25 (45–92)	66.49 ± 10.18 (53–89)	**<0.001**[a]
Height (cm)	166.50 ± 0.87 (150–192)	166.93 ± 0.93 (150–192)	166.07 ± 0.83 (150–185)	0.780[a]
BMI (kg/m^2)	22.82 ± 3.43 (16.65–32.44)	21.56 ± 3.36 (16.65–30.74)	24.08 ± 3.04 (19.00–32.44)	**<0.001**[a]
Gender, male/female (%)	11/71 (13.4/86.6)	7/34 (17.1/82.9)	4/37 (9.8/90.2)	0.519[b]
Foot size (cm)	38.97 ± 2.50 (35–47.5)	38.82 ± 2.50 (35–47.5)	39.12 ± 2.52 (36–46)	0.414[a]

Bold values correspond to statistically significant data (p < .05, 95% confidence interval).
Abbreviations: kg, kilogram; cm, centimeter; %, percentage; SD, standard deviation; N, number.
[a]Mann–Whitney *U* test was used.
[b]Fisher exact test was used. In all the analyses, *p* < .05 (with a 95% confidence interval) was considered statistically significant.

Due to the pressure platform, we observed that the peak and average pressure readings are elevated in the forefoot and rearfoot of the case group. The cavus deformity, characterized by a high internal arch, limits the contact area in the midfoot, causing greater ground reaction forces to be in the distal and proximal portions. This finding aligns with current data, which describe the general pressure that the calcaneal bone and metatarsal heads experience due to the reduced support provided by pes cavus [9,11,29].

Moreover, the left foot surface area of the case group was 138.90 ± 21.05 cm^2, while in the control group, it was 161.71 ± 14.88 cm^2 ($p < 0.001$), reinforcing the connection between pes cavus biomechanics and the distribution of standing plantar pressures. Reduced contact area is a direct consequence of the elevation of the internal longitudinal arch and varus rearfoot that leads to more pressure [5,16].

An in-depth examination of the foot areas indicates that the variations in contact zones extend not only to the total surface but also to the forefoot and heel. For instance, the left forefoot surface area proved to be smaller than the area of the control feet group (57.45 ± 12.06 cm^2 versus 72.63 ± 10.37 cm^2 in the control group, $p < 0.001$). The same was true for the left heel surface area (23.96 ± 4.54 cm^2 in the case group versus 29.74 ± 4.29 cm^2 in the control

TABLE 2 Primary outcome measurements of the static evaluation of the total sample with or without bilateral cavus foot.

Characteristics	Total sample (n = 82) Mean ± SD (95% CI)	Case group (n = 41) Mean ± SD (95% CI)	Control group (n = 41) Mean ± SD (95% CI)	*p*-value	*T*-value	Cohen's *d*
Left foot medium peak pressure (kPa)	137.91 ± 14.73 (134.70–141.13)	140.85 ± 18.25 (135.08–146.62)	134.97 ± 8.45 (132.30–137.64)	0.242[a]	1.18	0.39
Left foot maximum peak pressure (kPa)	216.71 ± 40.54 (207.91–225.50)	220.70 ± 46.40 (20.08–235.31)	212.72 ± 33.39 (202.13–223.31)	0.826[a]	−0.22	0.19
Left foot surface area (cm^2)	150.31 ± 22.95 (145.36–155.27)	138.90 ± 21.05 (132.22–145.57)	161.71 ± 14.88 (156.96–166.45)	**<0.001**[a]	−5.46	−1.28
Bodyweight on the lower left limb (%)	50.00 ± 3.49 (49.26–50.74)	49.93 ± 3.48 (48.81–51.04)	50.07 ± 3.49 (48.96–51.18)	0.411[a]	−0.82	−0.04
Left forefoot surface area (cm^2)	65.04 ± 14.18 (62.00–68.08)	57.45 ± 12.06 (53.60–61.30)	72.63 ± 10.37 (69.34–75.92)	**<0.001**[a]	−5.71	−1.39
Bodyweight on the left forefoot (%)	32.06 ± 4.88 (31.01–33.10)	30.79 ± 5.06 (29.17–32.40)	33.33 ± 4.41 (31.94–34.71)	0.099[a]	−1.68	−0.53
Left heel surface area (cm^2)	26.85 ± 5.61 (25.64–28.06)	23.96 ± 4.54 (23.52–25.40)	29.74 ± 4.29 (28.38–31.10)	**<0.001**[a]	−5.69	−1.32
Bodyweight on the left heel (%)	17.94 ± 2.80 (17.34–18.54)	19.13 ± 2.88 (18.21–20.05)	16.74 ± 2.45 (15.96–17.51)	0.127[a]	1.55	0.86
Right foot medium peak pressure (kPa)	138.16 ± 14.65 (135.37–141.65)	141.25 ± 17.65 (135.59–146.91)	135.08 ± 8.67 (132.34–137.82)	**0.001**[a]	3.56	0.42
Right foot maximum peak pressure (kPa)	218.06 ± 40.06 (209.38–226.74)	220.76 ± 45.45 (206.18–235.33)	215.35 ± 33.15 (204.83–225.87)	0.469[a]	0.73	0.13
Right foot surface area (cm^2)	150.84 ± 22.84 (145.92–155.77)	138.91 ± 20.65 (132.35–145.47)	162.77 ± 14.28 (158.26–167.28)	**<0.001**[a]	−5.62	−1.42
Bodyweight on the lower right limb (%)	50.00 ± 3.49 (49.26–50.74)	50.07 ± 3.48 (48.96–51.18)	49.93 ± 3.49 (48.82–51.04)	0.411[a]	0.82	0.04
Right forefoot surface area (cm^2)	65.31 ± 13.91 (61.33–68.29)	57.46 ± 11.58 (53.78–61.14)	73.16 ± 9.47 (70.18–76.14)	**0.002**[a]	−3.23	−1.50
Bodyweight on the right forefoot (%)	31.95 ± 4.90 (30.89–33.00)	30.76 ± 5.07 (29.14–32.38)	33.14 ± 4.24 (31.79–34.49)	0.361[a]	−0.92	−0.49
Right heel surface area (cm^2)	26.98 ± 5.76 (25.74–28.21)	24.08 ± 4.54 (22.64–25.53)	28.89 ± 4.24 (28.54–31.24)	**<0.001**[a]	−5.32	−1.37
Bodyweight on the right heel (%)	18.05 ± 2.80 (17.44–18.65)	19.24 ± 2.91 (18.31–20.18)	16.79 ± 2.50 (15.99–17.58)	0.207[a]	1.27	0.90

Bold values correspond to statistically significant data ($p < .05$, 95% confidence interval).
Abbreviations: kPa, kilopascals; kg, kilograms; cm, centimeters; %, percentage; SD, standard deviation; N, number.
[a]Mann–Whitney *U* test was used. In all the analyses, $p < .05$ (with a 95% confidence interval) was considered statistically significant.

group, $p < 0.001$). In the case group, the forefoot and heel zones of the right foot also had smaller surface areas [13,15].

Despite the absence of notable differences in the maximum pressure across the entire foot in the case group, a significantly higher mean maximum pressure of the right foot was found (141.25 ± 17.65 kPa) than in the control group (135.08 ± 8.67 kPa, $p = 0.001$) [9].

Finally, the weight and BMI differences observed between the two groups are also relevant to understanding the results. The control group's mean weight (66.49 ± 10.18 kg) was significantly higher than that of the case group (59.76 ± 12.25 kg), with a BMI of 24.08 ± 3.04 kg/m^2. Even though there is mixed literature on the correlation between BMI and plantar pressures in cavus feet, it is crucial to consider body weight as an element that could amplify pressure in overload areas [30–32].

These results are extremely helpful given that it has been noted that patients with calluses, metatarsalgia, plantar heel pains, or ulcers tend to have higher concentrations of pressure on those pain areas [33]. Therefore, prompt diagnosis is crucial, and due to baropodometry, we have been able to assure its cost-effective use.

This information seeks to increase existing knowledge about hollow feet and plantar pressures analyzed by baropodometry [34].

Nevertheless, some limitations resulted from the study design. As it is a cross-sectional investigation, it was not possible to analyze the plantar distribution of pes cavus throughout time. A notable limitation of this study is the gender imbalance, with a predominance of female participants (86.6%). Consequently, the findings may be more representative of the female population, and caution should be applied when generalizing these results to male individuals. Future research should aim for a more balanced sex ratio to assess potential gender-specific variations in plantar pressure distribution. We recommend that future research study the influence of sports, the relationship between the BMI and plantar pressure, and the type of footwear used when investigating static plantar pressure of cavus feet.

5 Conclusion

This study confirms that subjects with pes cavus exhibit significantly reduced contact surface area and altered pressure distribution compared to the control group. Specifically, pressure loads are excessively concentrated in the hindfoot and forefoot. These findings underscore the clinical necessity of baropodometric analysis to identify overload risks and prevent associated complications.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans, with ID: 2024-033, were approved by the Bioethics Committee of the University of A Coruña (Spain) in October 2024. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

LM-S: Writing – review and editing, Writing – original draft, Visualization, Methodology, Validation, Conceptualization, Supervision, Investigation. HS-M: Visualization, Investigation, Validation, Methodology, Supervision, Writing – review and editing. RB-d-B-V: Methodology, Supervision, Writing – review and editing, Data curation, Investigation, Visualization, Validation, Conceptualization. ML-I: Methodology, Visualization, Investigation, Validation, Conceptualization, Writing – review and editing, Supervision. JB-L: Visualization, Investigation, Project administration, Validation, Writing – review and editing, Supervision, Funding acquisition. IC-H: Writing – original draft, Visualization, Writing – review and editing, Methodology, Validation, Supervision. JG-S: Supervision, Conceptualization, Methodology, Validation, Visualization, Writing – review and editing. DL-L: Supervision, Conceptualization, Methodology, Visualization, Investigation, Resources, Validation, Writing – review and editing.

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Conflict of interest

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