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RESEARCH ARTICLE

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Immediate Effects of the Metatarsal Dome Element on the Overload of the Central Metatarsals in Young Subjects

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ABSTRACT

This study examines the immediate effects of using a dome-shaped metatarsal pad on reducing central metatarsal loading and attempts to correlate central metatarsal overload with metatarsal morphology, laterality (identifying which foot more frequently experiences forefoot overload), gender, and BMI. The sample consisted of 50 participants aged between 18 and 49, all students from the Vale do Ave School of Health, without exclusion criteria, and showing at least one peak point of overload in one of the central metatarsals. This overload was measured using the isobaric variant of colometry on a pressure platform, in a standardized position as defined in the methodology. The study concludes that applying a metatarsal dome element significantly reduces peak pressure in the forefoot, confirming a statistically significant effect on reducing middle metatarsal region overload. No significant relationships were found between middle metatarsal overload and factors such as digital or metatarsal morphology, gender, or BMI, although a statistically significant relationship was noted with foot laterality, with the left foot showing greater overload. The study suggests that future research could refine these findings by categorising foot types (normal, cavus, or flat) to explore potential correlations with metatarsal overload and increasing the sample size for improved statistical reliability.

ARTICLE HISTORY

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Introduction

Metatarsalgia is a common overuse injury characterized by pain in the forefoot, typically in the region of the metatarsal heads. This condition primarily affects individuals who engage in high-impact activities, such as running or jumping, but it can also result from improper footwear or foot deformities [1]. Some studies, showed that the pain experienced in metatarsalgia can significantly impact daily activities, leading to reduced mobility and quality of life [2].

There are several potential causes of metatarsalgia, including, foot structure and deformities, such as a high arch (pes cavus), long second toe, or a short first metatarsal bone, can predispose individuals to metatarsalgia. Foot deformities, like bunions or hammertoes can also increase the pressure on the metatarsal heads, contributing to forefoot pain [3].

High-impact sports, especially running and jumping, place significant stress on the metatarsal heads. Repetitive activities that involve pushing off the foot can exacerbate the condition [4].

Wearing ill-fitting or unsupportive shoes is another common cause of metatarsalgia. Shoes with narrow toe boxes or high heels increase pressure on the forefoot, exacerbating the problem [5].

Some authors also mentioned that conditions such as rheumatoid arthritis, diabetes, and gout can lead to inflammation and structural changes in the foot, increasing the likelihood of developing metatarsalgia [6].

Despite the multiple aetiologies for metatarsalgia, the aspect of middle metatarsal region overload is often the common denominator, this condition typically results from repetitive overloading of the metatarsal head(s) due to anatomic or biomechanical abnormalities such as first ray hypermobility, hallux abduct valgus (HAV), ankle equinus, claw or hammer toe deformities, lesser MTP joint instability and/or atrophy of the plantar fat pad. A movement system diagnosis of abnormal pronation or supination may also contribute to overload the

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development of metatarsalgia because of altered loading of the metatarsal head although, the most related conditions of middle metatarsal regiongia are related to pronation and its resulting insufficiency of the 1st ray [7].

Although, clinically, inversion of the transverse anterior arch (TAA) is spoken of as a pathological condition of the forefoot that predisposes to metatarsalgia, in reality the literature does not agree on the presence of a transverse anterior arch and according to mentions that although the metatarsal diaphysis are longitudinally curved with the middle metatarsal region heads being longer, this demonstrates a false presence of but they noted that at the level of the heads the metatarsals all rest at the same transverse level. According to Cavanagh, Rodgers & Iiboshi, 1987 cited by demonstrated that there is no such thing as TAA in the metatarsal heads, demonstrating this by measuring peak plantar pressures in asymptomatic individuals, noting that the pressure points were greater in the metatarsal diaphysis and that TAA exists only because of the increased concavity of the middle metatarsal regions forming an anterior arch [8]. This theory was corroborated years later by Kanatli et al. [9].

In reality, the existence of a TAA is more a condition resulting from the effective plantar flexion of the 1st metatarsal than an intrinsic anatomical condition of the middle metatarsal regions. In fact, from our bibliographical research, it can be seen that the existence of a transverse anterior arch is possibly more a result of the effective plantar flexion of the 1st metatarsal than an intrinsic anatomical condition of the middle metatarsal regions. For this reason, when the 1st metatarsal has a condition of insufficiency (and doesn't flex effectively), the middle metatarsal regions become overloaded.

In fact, many studies on metatarsalgia address the issue of middle metatarsal region overload, which is associated with many structural and biomechanical pathologies of the foot, emphasizing the importance of overload in the tissue stress that causes pain and often lesions such as Morton's neuroma, plantar plate lesions, etc. [10, 11].

Given the importance of forefoot overload in metatarsalgia, podobarometry is often used to assess and measure metatarsal overload and is considered by some authors to be a valid instrument for this purpose [12].

The metatarsal dome element, also known as a “metatarsal pad”, serves to redistribute peak plantar pressure across the forefoot, thereby reducing pressure on the metatarsal heads [8]. By transferring the load over a larger surface area, it elevates the TAA of the forefoot, increasing the spacing between the metatarsal heads. This adjustment can effectively alleviate pain, particularly in cases of Morton’s neuroma, where excessive forefoot pressure leads to compression and irritation of the intermetatarsal nerve [13,14].

As metatarsalgia is a highly prevalent problem, the solution of orthopaedical treatment based on customized insoles is well documented in the literature.

The “metatarsal pad” is commonly used as a conservative treatment for metatarsalgia, with studies supporting its role in pressure redistribution and pain relief [14]. The most frequently employed design is teardrop-shaped, and it should be positioned just proximal to the metatarsal heads for optimal biomechanical effect [15]. This placement helps to decrease plantar overload and mitigate symptoms associated with increased forefoot pressure.

As metatarsalgia is a highly prevalent problem, the solution of orthopaedical treatment based on customized insoles is well documented in the literature, however, in reality, studies are sometimes not entirely consensual as to the benefit of adding a “metatarsal pad”, even though this element is the most widely referenced in the literature as beneficial in metatarsalgia [16].

Therefore, in view of this finding, we conducted this study with the aim of ‘Evaluating the immediate effects of the metatarsal dome element on middle metatarsal region overload’ and “evaluate the immediate effects of the metatarsal dome element on middle metatarsal region overload’, as well as to relate middle metatarsal region overload to metatarsal morphology”.

Methodology

This study involved 50 participants, aged 18 to 49, from both genders, who were recruited from the community of the Escola Superior de Saúde do Vale do Ave – Portugal. The research was conducted in a natural setting, specifically in the practical classroom. To be included, participants had to show at least one red-colored pressure point in the middle metatarsal region (second, third, and fourth metatarsals) on a static isopressure analysis.

Inclusion Criteria - Participants had to meet the following criteria: Signed informed consent.

Aged 18 years or older, with no upper age limit specified due to the absence of scientific

justification for such a restriction and the unlikelihood of including elderly individuals based on the study setting.

Presence of at least one red-colored point on the middle metatarsal region area during static isopressure analysis.

Exclusion Criteria

Diagnosed rheumatic diseases

History of forefoot surgery, including hallux valgus (HAV), claw toes, or Morton’s neuroma.

History of traumatic injuries to the forefoot.

Materials

A questionnaire and data collection form.

Namrol® Podoprint aluminium pressure platform to measure middle metatarsal region overload with and without the “retro metatarsal pad”.

Asus® computer with the pressure platform software.

Two metatarsals’ domes (element 1 and element 2) made from 5mm thick Z- polyurethane foam, commercial brand Zahonero . One for the right foot and one for the left foot Examination table for foot assessment and marking.

Digital caliper for measuring the metatarsals cushions.

Adhesive tape for securing the metatarsals cushions.

Black marker for identifying the navicular bone and metatarsal heads on the foot.

The size and shape of the metatarsals dome were based on a prefabricated model used as a shape (Figure 1).

Figure 1: Dome metatarsal element that served as a template (Own source, 2022).

Both Elements were Measured using a Caliper and the Following Measurements were Obtained:

Centre height: 5mm (figure 2)

Side height (buffed): 0.1 mm (figure 3)

Proximal face height (buffed): 0.1 mm (figure 4)

Distal face height (buffed): 0.1mm (figure 5)

Pressure platform

Figure 2: Central height of element 1 and 2 (Own source, 2022)

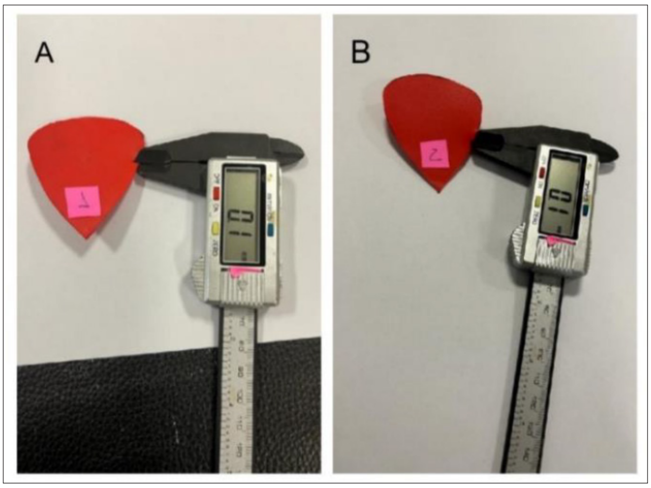

Figure 3: Side height (buffed): (A) element 1 and (B) element 2 (Own source, 2022)

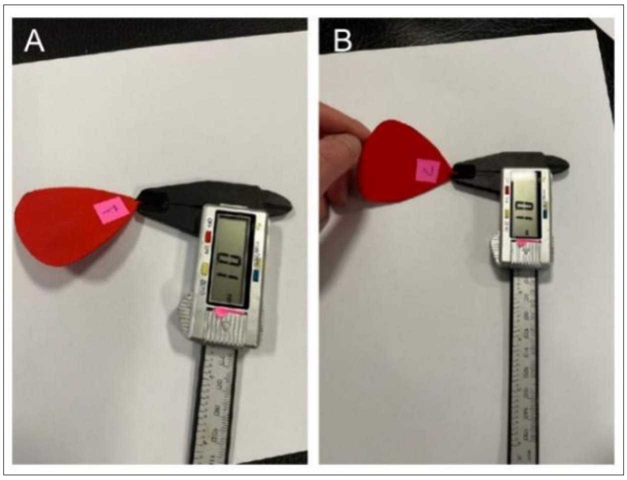

Figure 4: Proximal face height (buffed): (A) element 1 and (B) element 2 (Own source, 2022)

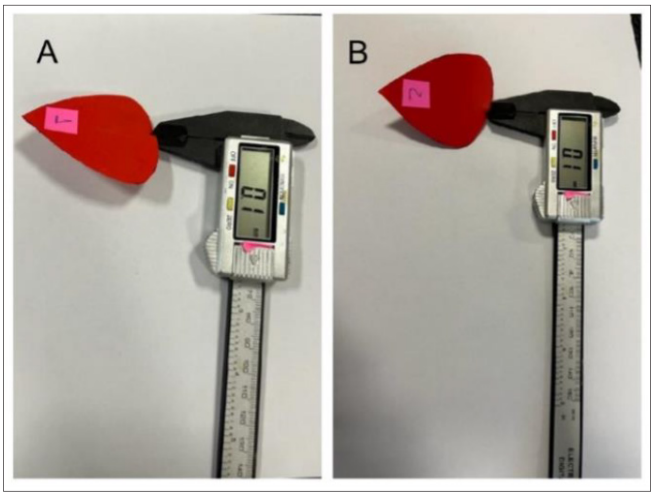

Figure 5: Distal face height (buffed): (A) element 1 and (B) element 2 (Own source, 2022)

In this research, we used the Namrol® Podoprint Aluminium pressure platform (figure 6).

Figure 6: Pressure platform Namrol® Podoprint Aluminium pressure platform (Own source, 2022)

Procedures

The platform was directly connected to a computer, which contained its software, via a USB cable and the individuals in the sample were assessed in the fundamental position.

Initially, once the request had been drawn up and accepted by the supervisor, the coordinating committee of the Podiatry degree course (was informed that this study would be carried out, and the ESSVA ethics committee was sent the documents requested to carry out the data collection.

Afterwards, the individuals attending the ESSVA facilities were invited verbally to take part in the study and went to the practical classroom. Once they had given their informed consent, the participants answered a questionnaire indirectly, the final part of which consisted of a data collection grid. All the individuals in the population who did not fulfil the exclusion criteria were admitted to the study.

Data Collection

The subject lay down on the couch in the supine position and the navicular was marked on both feet using a black pen (figure 7).

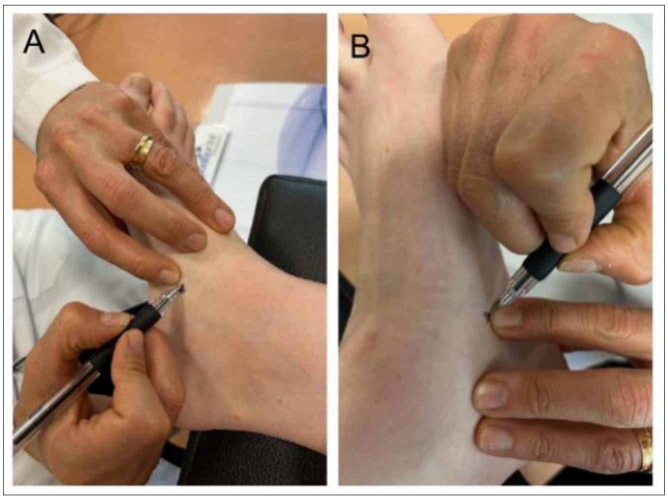

Figure 7: Marking the navicular bone: (A) on the right foot and (B) on the left foot (Own source, 2022)

Next, the individual stood on the pressure platform where the point of the navicular was aligned with the first line of the platform, then the feet were adjusted so that the alignment reference line was aligned, and the individual was asked to look straight ahead in the fundamental position and eyes towards the horizon (Figure 8). If there was an overload in the middle metatarsal region area (red color in the isopression version) in one or both feet, the individual was part of the sample, and the overload values were noted on the data collection sheet (Figure 8).

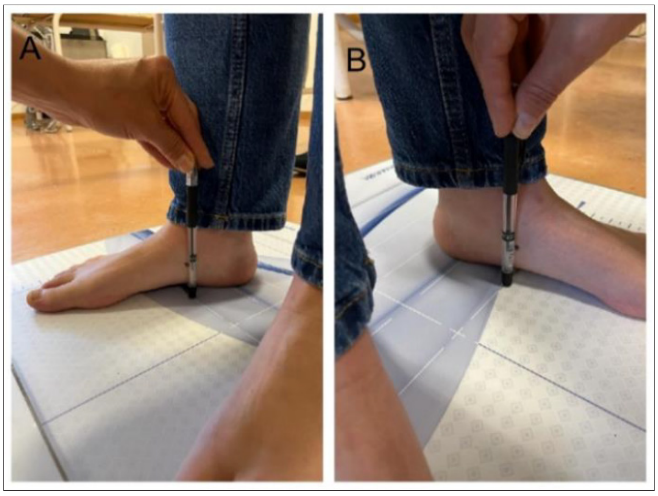

Figure 8: Alignment of the navicular with the first line of the pressure platform: (A) on the right foot and (B) on the left foot (Own source, 2022)

To determine the pressure of the central point in grams per square centimeter (g/cm2), a line was drawn from the most lateral point to the most medial point where the overload existed, and then half of this value was marked with another line, thus determining the pressure of the central point (Figure 9).

Figure 9 : Example of an individual with central overload on both feet on the isopressure version of the pressure platform (Own source, 2022)

Next, the individual lay back on the couch where the digital morphology was assessed by comparing the length of the first and second toes (figure 10), the metatarsal morphology through palpation by marking the first and second metatarsal heads on the dorsal surface of the foot with the aid of a black pen. We checked for keratopathies in the central plantar metatarsal area (Figure 11) and marked the metatarsal heads on the plantar surface by palpation using a black pen. Then, the metatarsals dome was applied to the corresponding foot with the aid of adhesive tape, behind the marking of the second, third and fourth metatarsal heads (Figure 12). Finally, the individual stood on the platform and was aligned on the platform, as described above, and the data relating to peak point pressure after the application of the metatarsal dome element was recorded as before.

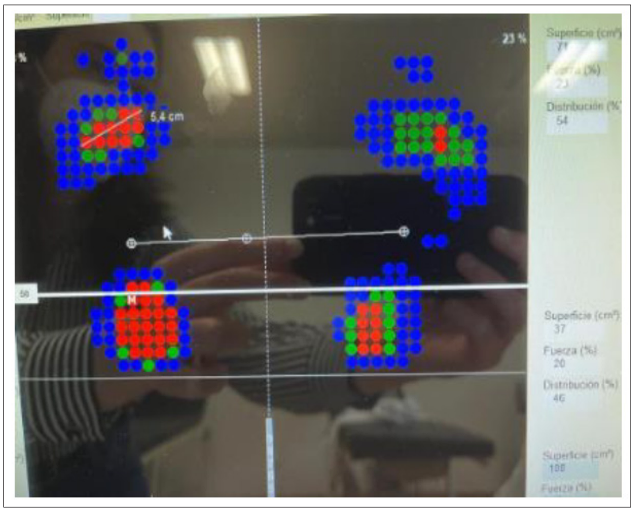

Figure 10 : Example of marking the pressure of the central point by braiding a line from the most medial side to the most lateral side of the central overload zone (Own source, 2022)

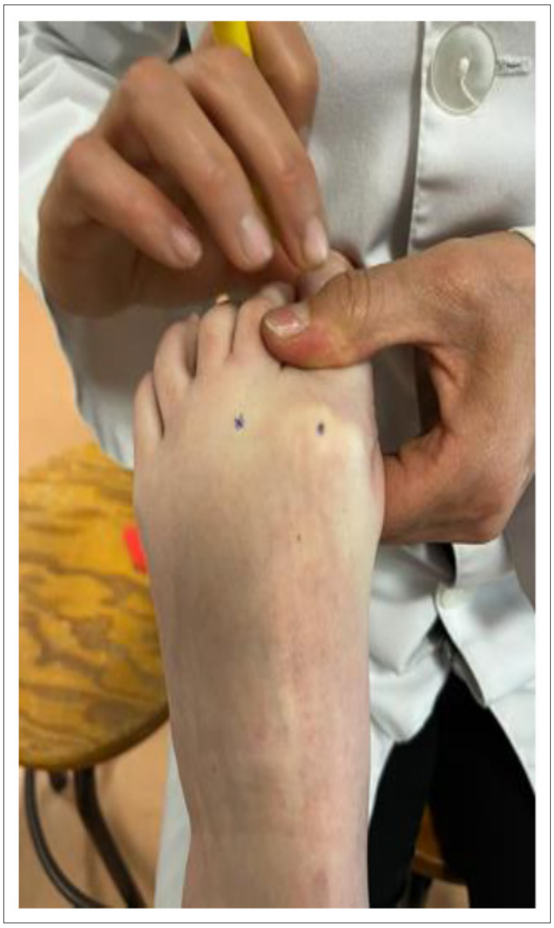

Figure 11: Marking of the 1st and 2nd metatarsal heads on the dorsal surface of the foot (Own source, 2022)

Figure 12: Marking of the metatarsal heads on the plantar surface of the foot (Own source, 2022)

Statistical procedures

For the statistical analysis of our results, we used Microsoft Office 365 Excel to organize the database and obtain some graphical figures, and SPSS® (Statistical Package of the Social Science) version 28.0 for statistical analysis.

Results

The sample consisted of 50 individuals who met the inclusion and exclusion criteria defined above. For this study, data was collected on 05, 06 and 16 May 2022. The defined sample has a median age of 22, with the youngest and oldest being 18 and 49 years old respectively. Of the 50 individuals in the sample, 25% are female and the BMI category with the highest prevalence is normal weight (60%) and with the lowest prevalence the obesity category (2%). Regarding the morphological characteristics of the sample (Table 1), the most common digital morphology in the left foot (44.4%) and right foot (42.9%) was the greek foot and the most prevalent metatarsal morphology in the left foot was the index plus minus (51.1%) and in the right foot it was the index minus (51.4%).

Table 1 - General features of the sample

	Features
Age (years), median (minimum - maximum)	 22 (18-49)
Gender, n (%) Female Male	25 (50) 25 (50)
BMI (kg/m²), n (%) Low weight Normal Excess weight Obesity	 6 (12) 30 (60) 13 (26) 1 (2)
Digital morphology, n (%) Left foot: Egyptian Greek Square Right foot: Egyptian Greek Square	 19 (42,2) 20 (44,4) 6 (13,3) 14 (40) 15 (42,9) 6 (17,1)
Metatarsal morphology, n (%) Left foot: Index plus Index minus Index plus minus Right foot: Index plus Index minus Index plus minus	 2 (4,4) 20 (44,4) 23 (51,1) 2 (5,7) 18 (51,4) 15 (42,9)

The analysis of the immediate effect of the ""retro mematarsal pad"" on central pressure showed statistically significant changes (p<0.001) in both feet, with a significant decrease of pressures.

Table 2: Immediate effect of the metatarsal dome element on central pressure

	Without element -peak point pressure (g/cm²)	**With element - peak point pressure (g/cm²)**	**p**
Left foot, median (minimum-maximum)	622,50 (516-799)	563,50 (0-748)	**< 0,001**
Right foot, median (minimum-maximum)	588,50 (505-850)	525,50 (0-748)	**< 0,001**

Bold: p<0.05

Demographic and morphological characteristics and their relationship with peak point pressure are showed on table 3, as shown below, there´s no statistically significant changes (p<0.05) in the morphological variables.

Citation: Avidos Liliana, Portela Manuel, Oliveira Fernando Miguel, Taveira Nazaré (2024) Immediate Effects of the Metatarsal Dome Element on the Overload of the Central Metatarsals in Young Subjects. Progress in Orthopedic Science. POS-158.

Table 3: Demographic and morphological characteristics and their relationship with peak point pressure

	Peak point pressure (g/cm^2) - Left foot	p	Peak point pressure (g/cm^2) - Right foot	p
Digital morphology, median (minimum-maximum) Egyptian Greek Square	629 (516-770) 610 (517-799) 604 (543-653)	0,569	519 (510-850) 581 (505-735) 619 (513-735)	0,314
Metatarsal morphology, median (minimum-maximum) Index plus Index minus Index plus minus	- 663,50 (517-799) 606 (516-764)	0,062	- 582 (510-850) 589,50 (505-753)	0,152
Gender, median (minimum-maximum) Female Male	613 (517-770) 645,50 (516-799)	0,524	588,50 (505-850) 586,50 (513-750)	0,138

Concerning to the variation in pressure between left and right feet (Table 4), there was a higher prevalence of overload in left feet (median=634) and statistically significant changes were found (p=0.033).

Table 4: Relationship between pressure variation in left and right foot

	Peak point pressure (g/cm^2) - Left foot	Peak point pressure (g/cm^2) - Right foot	p
Pressure variation, median (minimum- maximum)	634 (468-799)	589 (505-850)	0,033

The following diagrams shows the relationship between BMI and peak point overload in the left and right foot. The correlation coefficient for the left foot is higher (r=-0.001) than for the right foot, although there were no statistically significant differences in both feet.

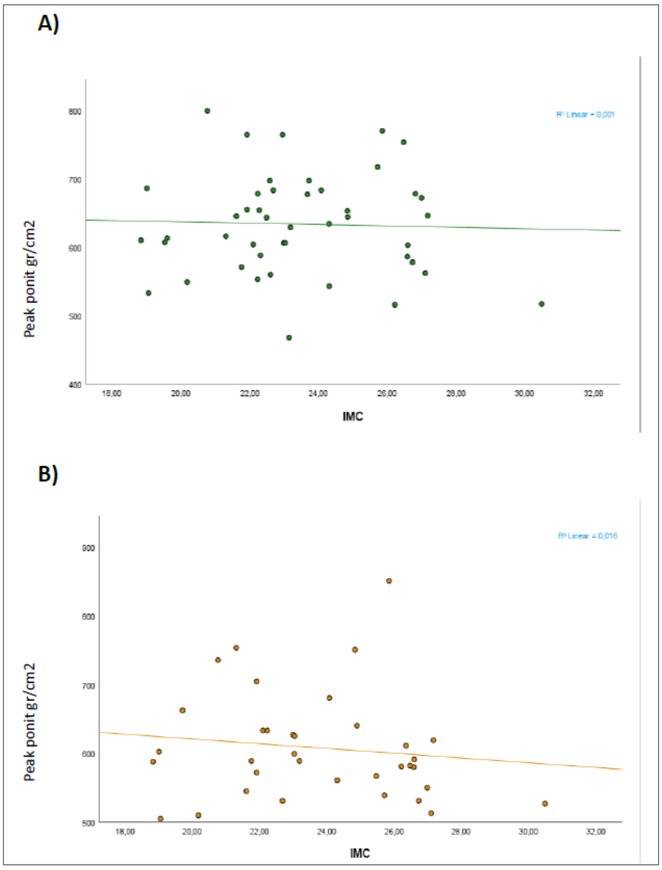

Diagram - A) Relationship between left foot peak point pressure and BMI and B) Relationship between right foot peak point pressure and BMI.

Discussion

This chapter provides a careful discussion of the main findings of this study.

Regarding the BMI of the sample, there was a higher prevalence of normal BMI, and it should be emphasized that obesity is only represented in one individual. This may be due to two factors, the first being age, as mentioned by Yahia et al. in the study, and the second factor may be due to the fact that the vast majority of the sample were health students, which may show that students in this area may be aware of a healthy lifestyle [17].

Concerning to the digital morphology, there was a slight prevalence of the Greek foot type. This finding does not corroborate the data in most of the literature, Pita-Fernandez et al., found a digital dominance of the Egyptian but they showed that the square foot type is the lowest prevalent, not the Greek foot type, corroborating our findings. when we analyze the data for the metatarsal morphology, this study revealed an equal number of index minus and index plus minus morphologies, which is similar to the study of Pita-Fernandez et al., that found a slight prevalence of index minus, relative to index plus minus, and a much lower incidence of index plus. In this context, a study by States the opposite, as it finds a higher prevalence of index plus, however showed that the most dominant metatarsal morphology was index plus [18].

These variations may be related to age, as in the study by the ages were higher, which may indicate that the younger generations may have different anthropometry in relation to the shape of the foot, since they have larger foot dimensions, the methodology was also very different, since it was done by radiographic measurement, which could also be a factor in the disparity between the findings This highlights the disparity between these data on digital morphology and metatarsal morphology, and so further studies in these areas are suggested.

With regard to the main objective, "To assess the immediate effects of retro metatarsal cushion on middle metatarsal region overload", this study revealed that there is statistical significance in this objective, i.e. when the element is applied, the pressure at the peak point, decreases in both feet, in, about, 60gr per cm2, which proved to be statistically significant. Thus, there is a relationship between the immediate effects of applying the metatarsal dome and a reduction in middle metatarsal region overload. This result corroborates some of the literature found, such as the study by Landorf et al., which showed metatarsal dome elements reduce plantar pressure in the forefoot in older people with a history of forefoot pain, especially when the element is positioned just proximal to the metatarsal heads, as in our study. It's worth pointing out that the study was carried out on elderly people, so we can say that this effectiveness of metatarsal dome elements in reducing focal load also occurs in young feet like those in our sample [19]. Thus demonstrating that this element is useful in circumstances of metatarsal overload, namely in the symptomatology of metatarsal pain, as some authors.

state that one of the causes of metatarsalgia is excessive overload in the forefoot and in Morton's Neuroma, many authors refer to it as being associated with repetitive pressure on the forefoot [13,20]

In this line of reasoning, the present study validates the effectiveness of the metatarsal dome element in Morton's neuroma pathology.

The relationship between middle metatarsal region overload and digital morphology was not statistically significant. It was not possible to compare this finding with the literature, as no studies were found in which the same relationship was established. Even so, we understand that digital morphology may be an influencing factor. However, as our sample had variability in the three types of morphology, even if there was some relationship, it was dispersed in the sample number (n) and, perhaps for this reason, no relationship was found in these variables.

Regarding middle metatarsal region overload with metatarsal morphology in this study, there was also no statistical significance. However, as mentioned above with regard to digital morphology, we believe that metatarsal morphology may be an influencing factor, since according to Michaud, the length of the metatarsals can influence the transfer of forces between them. Therefore, as our sample had an equal prevalence of index minus and index plus minus, this does not highlight any possible differences or relationships between these variables [8].

More recently, Suh et al., also found more prevalence of index minus metatarsal formula was in the patients with primary metatarsalgia [21]. Also, Kaipel et al., stated in his studies, that the Relative metatarsal length had no influence on plantar-loading parameters. Shortening of a symptomatic ray to decrease plantar-loading parameters cannot be supported from a biomechanical rationale [22].

In our study, however, we believe that the dispersion of our sample, with a very similar number of individuals with index minus and index plus minus, may have contributed to the loss of significance of this relationship.

With regard to the relationship between middle metatarsal region overload and gender was also not statistically significant. This result corroborates a study by states that although men had a larger contact area on the plantar surface of the foot compared to women, there were no differences in the pressure point between the genders. Another study compared forefoot contact area and peak plantar pressure between both genders and found no significant differences between forefoot peak plantar pressure and gender [23].

Regarding the relationship between middle metatarsal region overload and foot laterality, in our study there was statistical significance between these variables, with the sample showing more overload in the left foot. This finding corroborates the study of Jorgetto et al., when he analyzed plantar pressure in 200 individuals with diabetic neuropathy, also found higher pressure peaks in the left foot [24]. The reason for this result is not entirely clear, but it may be due to the fact that most of the individuals are right-handed and, therefore, most of them have a left foot. Tuna et al., also found an increase in metatarsal overload in the left foot compared to the right, especially in the middle region [25]. Both, our sample and the sample from the aforementioned study show this result, however, it’s worth noting that both of these studies were carried out on patients with diabetes mellitus, i.e. they were different samples to ours.

We found no statistically significant difference between middle metatarsal overload and BMI. This is contrary to what is stated by that obesity is a significant factor that can influence peak plantar pressure values in the foot. that obesity is a significant factor that can influence peak plantar pressure values in the foot and that the sample did not have a prevalence of obese individuals. However, the study of Arnold et al., showed that the relationship between increasing body mass and peak and mean plantar pressure was dependent upon the plantar region [26]. Even so, they found that the second to fifth metatarsal region displayed statistically significant increases in mean pressure in the 5, 10 and 15 kg groups compared to the control (normal weight). Other authors have reported the similar results, Rojas-Torres et al., also related the highest pressure levels recorded were consistently present in the central forefoot (3rd metatarsal head) [27]. We believe that this difference between our results and previous studies is due, on the one hand, to the fact that our sample is very young and therefore still has good plantar adiposity, which effectively dissipates the forces that may be more intense in the forefoot, even though there is an increase in body weight; on the other hand, as our rate of overweight and obesity was very low, any statistical relationship loses significance with this BMI variable.

Conclusions

After analysing the results and discussing them, we can draw some conclusions about this research project.

With regard to the main objective, "To assess the immediate effects of the metatarsal dome element on middle metatarsal region overload", it was found that the metatarsal dome element significantly reduces the peak pressure point in the forefoot, Thus, there is a statistically significant relationship between the immediate effect of applying the metatarsal dome element and the reduction in middle metatarsal region overload.

As for the relationship between middle metatarsal region overload and digital morphology and metatarsal morphology, it was concluded that there was no statistically significant relationship.

With regard to the relationship between middle metatarsal region overload and gender, the results were not statistically significant, even showing a great similarity between the peak plantar pressures of the forefoot in men and women.

The relationship between middle metatarsal region overload and foot laterality was statistically significant, with the left foot showing the greatest overload.

Finally, the relationship between middle metatarsal region overload and BMI was not statistically significant, highlighting only that our sample had a very low prevalence of obese people.

Future Proposals

Although this study has answered the main objective, it has left room to refine the questions raised and add new data.

That said, in addition to evaluating and relating what was done in this study, it might make sense to evaluate the type of foot, differentiating it into normal, cavus or flat feet to see if there is any relationship between middle metatarsal region overload and the type of foot. Another proposal would be to increase the study sample to try to obtain more statistical significance.

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