Research Article

The Evaluation of Plantar Pressure Distribution in Non-Obese, Pre-Obese, Obese Class I and Obese Class II Adults

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Abstract

Background: Many studies have been carried out on the plantar pressures. But, none of them has compared the plantar pressures of non-obese, pre-obese, class I obese, and class II obese individuals. In this study, we aimed to measure the dynamic and static plantar pressures of pre-obese, class I obese and class II obese individuals, and then to compare those values with those of non-obese controls.

Methods: This study was performed on 240 feet of 30 non-obese, 30 pre-obese, 30 class I obese and 30 class II obese subjects. Static and dynamic pedobarographic evaluations were performed during standing and walking. The findings were compared between the groups.

Findings: Statistically significant differences were found between the groups in terms of rear foot plantar pressures, total plantar force, and total contact surface areas in static pedobarography. In dynamic pedobarography, statistically significant differences were found between the groups in terms of middle foot, lateral forefoot, middle forefoot maximum pressure values and plantar contact areas.

Interpretation: In class I and class II obese individuals, we determined increases in total contact area and pressure in static and dynamic pedobarographic evaluations. Between the BMI values of 18.5-30 kg/m², the foot can adapt itself to this situation biomechanically, and the increase in pressure and contact surface stays limited in parallel with that. But, when the BMI reaches at 30-35 kg/m² range, the contact surface and pressure also increase. At 35 kg/m² and higher BMI levels, the increase reaches a plateau since the contact surface and pressure values peak.

ABBREVIATIONS

BMI: Body Mass Index

INTRODUCTION

In 21st century, the populations' tendency towards overweight and obesity also increases, and World Health Organization considers this situation as epidemic covering both the developed and developing countries [1, 2]. Although the effect of musculoskeletal system diseases on mortality is minimal, they are among the important reasons leading to pain and disability [3]. Many factors play role in etiology of these diseases. The most important modifiable factor among them is the obesity [2, 4]. Obesity leads to many disorders in musculoskeletal system, especially in low back, hip, knee, ankle, and foot [5-7].

The plantar loading increases in obese individuals. Many studies examining this point have been carried out [8-11]. But the number of studies comparing the plantar pressures of obese individuals and non-obese individuals is less [12-14]. On the other hand, we could find no study comparing the plantar pressures of non-obese, pre-obese, class I obese and class II obese individuals as separate groups during literature review. For this reason, we have not sufficient information about if there is a difference between the obesity groups in terms of plantar pressures and if the pressure increases in parallel with the level of obesity.

From this point, in our study, we aimed to measure the dynamic and static plantar pressures of pre-obese, class I obese and class II obese individuals, and then to compare those values with those of non-obese control group.

METHODS

The study protocol was approved by the local Ethical Committee of Trakya University (no.2010/21) and all the study participants gave informed consent.

The subjects

This study was performed on 240 feet of 30 non-obese, 30 pre-obese, 30 class I obese and 30 class II obese subjects who had no foot complaint and invited from our general rehabilitation polyclinic to Trakya University Medical School pedobarographic investigation laboratory. As a general procedure American
Orthopaedic Foot and Ankle Society (AOFAS) scale was evaluated to determine the pain, functional and alignment status of the feet. Each of the study participants had the whole score of 100, indicating that they had normal feet [15]. The study subjects were excluded if they had [1] foot pain and deformities [2], class 3 obesity [3], acute lower extremity trauma [4], lower extremity surgery like prosthesis operations of the hip, knee, ankle or foot [1], leg length discrepancies [6], problems of cooperation, including eye, ear or cognitive disorders [7], diabetes or related peripheral neuropathy [8], vascular insufficiency and [9] walking aids. Demographic properties like age, weight, height and body mass index (BMI) were assessed and noted. The study participants were gathered in four groups according to their BMI values [16].

**Pedobarographic evaluation**

Pedobarographic assessment was performed by a Mini-Emepedopedobarography device (Novel, Munich, Germany) [17]. This system measures plantar pressure in a static and dynamic manner. The device consists of a Canon colour printer, monitor, pressure sensitive platform, remote control, power supply and connections between printer and platform as well as monitor and platform. The dimensions of the pressure measurement platform of the device are 650x290x25mm. This platform consists of three sensors in each cm². The dimensions of each sensor area are 360x180mm. The sampling rate is 16 frames/s, the storage foot peak pressure value (N/cm²) [5], middle forefoot peak pressure (N/cm²) [3], total plantar force, and total contact area (cm²). The pressure sensitive platform, remote control, power supply and connections between printer and platform as well as monitor and platform. The dimensions of the pressure measurement platform of the device are 650x290x25mm. This platform consists of three sensors in each cm². The dimensions of each sensor area are 360x180mm. The sampling rate is 16 frames/s, the storage foot peak pressure value (N/cm²) [5], middle forefoot peak pressure (N/cm²) [3], total plantar force, and total contact area (cm²).

As to dynamic measurement, the subjects were asked to walk continuously along a 30 m long area, for a few minutes before arriving at a wooden walking platform, which was 5 m long. They were instructed to put the foot on the platform during their normal walking rhythm. The normal walking rhythm was taken as the standard for each patient as we knew the walking speed could maximally affect the pressure values as much as 7% [18]. The subjects were asked to retry in case of a fixed stride and wrong foot position on the platform. The walking period was performed separately for each foot. The following seven parameters were evaluated during dynamic measurement: [1] forefoot peak pressure value (N/cm²) [2], rear foot peak pressure value (N/cm²) [3], total plantar force (N) [4], forefoot plantar force percentage (%) [5], rear foot plantar force percentage (%) [6], total contact area (cm²).

**Statistical analysis**

The statistical analyses were carried out by using STATISTICA AXA 7.1 software. The conformity of the measurable data to normal distribution was tested with single sample Kolmogorov Smirnov test, and then the intergroup comparisons between the groups exhibiting normal distribution was performed by using variance analysis and post-hoc Bonferroni test, while the test of those exhibiting non-normal distribution was performed by using Kruskall-Wallis variance analysis and Mann Whitney U test. In intra group comparisons, matched series t-test and Wilcoxon matched dual samples test were used, while Pearson χ² test was used in qualitative data. As definitive statistics, arithmetic mean and standard deviation were used. The level of significance was considered as p<0.05 for all of the statistics.

**RESULTS**

Within the scope of this study, 240 feet of 120 subjects were examined. In accordance with BMI levels of the subjects, 4 groups were established. In each group, there were 30 individuals, 20 female (66.6%) and 10 males (33.3%). The groups were determined as non-obese individuals (control group), pre-obese, class I obese, and class II obese individuals. While there was statistically significant difference between the groups in terms of age, there was no statistically significant difference in terms of height. Demographical information regarding the patients is presented in Table 1.

Static pedobarographic parameters of the patients, which we obtained in standing position, were compared. In terms of rear foot peak pressure, total plantar force, and total contact area levels, there were statistically significant differences between the groups (p=0.001) (Table 2). In terms of the forefoot peak pressure levels, and the forefoot plantar pressure percentage and rear foot plantar pressure percentage of the cases, there was no statistically significant difference between the groups (p>0.05) (Table 2).

Dynamic pedobarographic parameters of the subjects, which were obtained during walking, were also compared. Among these parameters, the significant differences were found between the groups in terms of middle foot, lateral forefoot, middle forefoot maximum pressure levels and plantar contact areas (p<0.001) (Table 3, Figure 1). No statistically significant difference was found between the groups in terms of peak phalanx pressure, medial forefoot peak pressure, and rear foot peak pressure (p>0.005) (Table 3).

**DISCUSSION**

In this study we aimed to analyze plantar loading characteristics of non-obese, pre-obese and obese adults during standing and normal walking. Our findings indicate that obese adults were more likely to have increased plantar pressure values. There are a few studies on the pedobarographic alterations in obese adults and most found increased peak plantar pressure values when compared with non-obese subjects [12-14,19].

When compared the static pedobarographic parameters of the participants, we determined that there was statistically significant difference between the groups in terms of rear foot peak pressure, total plantar force, and total contact area levels.
Table 1: The characteristics of the study population.

<table>
<thead>
<tr>
<th></th>
<th>Non-obese (n=30)</th>
<th>Pre-obese (n=30)</th>
<th>Obese class I (n=30)</th>
<th>Obese class II (n=30)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>30.47 (8.05)**</td>
<td>34.37 (7.89)*</td>
<td>40.53 (8.22)</td>
<td>39.17 (7.2)**</td>
</tr>
<tr>
<td>Mean height (m)</td>
<td>1.66 (0.11)</td>
<td>1.63 (0.11)</td>
<td>1.63 (0.10)</td>
<td>1.61 (2.94)</td>
</tr>
<tr>
<td>Mean weight (kg)</td>
<td>64.13 (10.85)</td>
<td>74.27 (11.90)</td>
<td>86.73 (10.48)</td>
<td>98.04 (11.74)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>23.06 (1.60)</td>
<td>27.48 (1.25)</td>
<td>32.56 (1.34)</td>
<td>37.18 (1.42)</td>
</tr>
<tr>
<td>Gender (n)</td>
<td>Male- Female</td>
<td>10 - 20</td>
<td>10 - 20</td>
<td>10 - 20</td>
</tr>
</tbody>
</table>

**Abbreviations:** BMI: Body Mass Index; SD: Data Presented is Mean Values; ANOVA: One-Way Analysis of Variance
Statistically significant difference was found: ** between non-obese group and obese class I group, *** between non-obese group and obese class II group, # between pre-obese group and obese class II group.

Table 2: Comparison of static pedobarographic values between the groups.

<table>
<thead>
<tr>
<th></th>
<th>Non-obese (n=30)</th>
<th>Pre-obese (n=30)</th>
<th>Obese class I (n=30)</th>
<th>Obese class II (n=30)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forefoot PP (N/cm²)</td>
<td>9.76 (13.85)</td>
<td>7.90 (3.86)</td>
<td>7.17 (2.32)</td>
<td>7.67 (2.72)</td>
</tr>
<tr>
<td>Rear foot PP (N/cm²)</td>
<td>9.27 (2.94)**</td>
<td>9.73 (3.23)**</td>
<td>11.13 (3.65)</td>
<td>11.75 (3.50)</td>
</tr>
<tr>
<td>Total plantar force (N)</td>
<td>324.15 (70.13)**</td>
<td>361.65 (75.55)**</td>
<td>419.28 (105.97)**</td>
<td>484.03 (98.51)**</td>
</tr>
<tr>
<td>Forefoot plantar pressure percentage (%)</td>
<td>49.98 (12.54)</td>
<td>44.18 (13.76)</td>
<td>42.22 (11.95)</td>
<td>41.97 (11.31)</td>
</tr>
<tr>
<td>Rear foot plantar pressure percentage (%)</td>
<td>53.88 (11.19)</td>
<td>55.65 (13.87)</td>
<td>58.78 (11.95)</td>
<td>57.98 (11.41)</td>
</tr>
<tr>
<td>Total contact area(cm²)</td>
<td>86.98 ± 18.51**</td>
<td>89.77 ± 19.14**</td>
<td>100.63 ± 17.96#</td>
<td>105.00 ± 16.04#</td>
</tr>
</tbody>
</table>

**Abbreviations:** SD: Data Presented are Mean Values; PP: Peak Pressure; ANOVA: One-Way Analysis of Variance; Kruskal: Wallis One-Way Analysis of Variance; N: Newton
Statistically significant difference was found: * between non-obese group and pre-obese group, ** between non-obese group and obese class I group, *** between non-obese group and obese class II group, # between pre-obese group and obese class II group, # between obese class I group and obese class II group.

Figure 1 Representing the relationship between middle foot peak pressure and plantar contact area, according to BMI values.
We determined that the maximum rear foot peak pressure statistically significantly increased as the BMI increased. Initially, the maximum rear foot peak pressure increases in parallel with BMI levels. But, this increase follows a more horizontal course in non-obese and pre-obese group, and is statistically insignificant. Then, a sharp and statistically significant increase occurs in pre-obese and class I obese individuals in proportion to non-obese group. In class II obese group, the pressure reaches at its peak value. But, we couldn’t find statistically significant difference between the classes I obese group and class II obese group. Moreover, when the weight exceeds the class II obesity limit (35 kg/m²), the increase in graphic follows a more horizontal course. In short, firstly the weight increases but pressure graph follows a more horizontal course, between 30 and 35 kg/m² levels a peak occurs in pressure graph and, it shows a plateau after 35 kg/m² level.

In a study comparing the non-obese individuals and class I obese individuals, it has been found that foot-forefoot plantar pressure increased in individuals having class I obesity [13]. Fabris et al. [20], have found a similar result with the morbid obese individuals in proportion to non-obese subjects. In study of Hills et al. [14], similar with our results, it has been observed that, in proportion to non-obese individuals, the rear foot peak pressure values increased.

We determined that the total contact area increased as the BMI increased. The increase in contact area showed similar characteristics with the increase in rear foot peak pressure. While BMI varies between 18.5 and 30 kg/m² levels, the foot arches resist to the increase in weight and the enlargement in contact area stays limited. While BMI values vary between 30 kg/m² and 35 kg/m² levels, the foot arches collapse and the contact area rapidly enlarges and, it can be said that, after 35 kg/m², the contact area doesn’t enlarge in parallel with the increase in weight. But, there are also studies attributing the enlargement in contact area to the increase in fatty tissue in medial arch rather than the change in foot structure [21].

Similarly with our study, also the previous studies have found significant increase in foot width and contact area in class II obese individuals in proportion to non-obese individuals, in class I obese individuals in proportion to non-obese individuals, and in pre-obese and morbid obese individuals in proportion to non-obese individuals [13,14,19,20].

In our study, we also compared the dynamic pedobarographic parameters of the participants. The lateral and middle foot peak pressures increase in parallel with the increase in weight, and statistically significant differences occur in all of the groups.

Just like in previous parameters, the middle foot peak pressure increased as the BMI increased. But, this increase doesn’t reach the statistically significant level between class I and class II obese individuals. In study of Hills et al. [14], the increases have been found under the tips of 2nd and 4th metatarsus in male and 3rd and 4th metatarsus in female class II obese individuals. These results indicate that, in parallel with our findings, the plantar pressures increased at middle and lateral sections of the forefoot. But, no difference has been found in peak pressure levels of medial and lateral sections of forefoot between the non-obese individuals and class II obese individuals in a previous study. But, in parallel with our results, it has been observed that the peak pressure of middle forefoot plantar pressure increased. Authors have asserted that, based on this finding, the increase in pressure has started from middle plantar region [13].

Finally, we found no increase in rear foot peak pressure, among the dynamic pedobarographic parameters.

The significant difference of ages between the study groups is a limitation of our study. Non-obese and pre-obese patients were younger than class I and class II obese patients. Due to the advanced age, the biomechanical structure of the foot may have deteriorated and led to the alterations in plantar pressure values. The clearer results can be obtained by increasing the number of patients in groups and ensuring more homogenous distribution in terms of the ages. By involving all of the obesity groups, except for the morbid obese individuals, and non-obese groups, we aimed to generalize the result to entire society. Moreover, by keeping the number of female and male subjects equal, we eliminated the confusing factor of gender.

As a result, we found increases in total contact area and pressure in class I and class II obese individuals in standing position and while walking. Foot can adapt itself to this situation biomechanically between 18.5 and 30 kg/m² BMI values and,

| Table 3: Comparison of dynamic pedobarographic values between the groups. |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
|                             | Non-obese (n=30)            | Pre-obese (n=30)             | Obese class I (n=30)         | Obese class II (n=30)        |
| Phalanx PP (N/cm²)          | 44.63 (22.81)               | 43.00 (20.25)               | 40.02 (19.03)               | 43.80 (19.84)               |
| Medial forefoot PP (N/cm²)  | 30.37 (20.18)               | 28.82 (19.11)               | 26.38 (12.16)               | 35.63 ± 20.48               |
| Middle forefoot PP (N/cm²)  | 29.82 (11.9)                | 33.06 (11.83)               | 33.85 (8.87)                | 40.85 (15.34)               |
| Lateral forefoot PP (N/cm²) | 23.70 (10.53)               | 28.15 (11.35)               | 26.47 (10.24)               | 31.33 (16.68)               |
| Middle foot PP (N/cm²)      | 9.97 (4.34)                 | 11.42±3.98                  | 14.58 (5.08)                | 16.82 (10.58)               |
| Rear foot PP (N/cm²)        | 24.40 (6.08)                | 23.68 (6.17)                | 24.38 (8.90)                | 24.52 (6.41)                |
| Plantar contact area (cm²)  | 132.33 (18.11)              | 134.30 (21.39)              | 147.88 (18.82)              | 149.37 (20.27)              |

Abbreviations: SD: Data presented are mean values; PP: Peak Pressure; ANOVA: One-Way Analysis of Variance; Kruskal: Wallis One-Way Analysis of Variance; N: Newton

Statistically significant difference was found: between non-obese group and pre-obese group, between non-obese group and obese class I group, between non-obese group and obese class II group, between pre-obese group and obese class I group, between pre-obese group and obese class II group.
In parallel with that, the increase in pressure and contact area remains limited. But, when the BMI values reached at 30-35 kg/m² range, the foot cannot resist this weight anymore. Therefore, foot arches collapse and the contact area and the pressure increase. At 35 kg/m² and higher BMI levels, since the contact area and the pressure levels get closer to the maximum levels, the increase follows more horizontal course, so the graph shows a plateau at this level.

In conclusion, we can state that pedobarographic examination has an important role in revealing the biomechanical effects of the obesity on foot. After the studies to be carried out with more subjects, including the morbid obese individuals, the effects of obesity on the foot would be better understood.

CONCLUSION

In conclusion, we can state that pedobarographic examination has an important role in revealing the biomechanical effects of the obesity on foot. After the studies to be carried out with more subjects, including the morbid obese individuals, the effects of obesity on the foot would be better understood.

REFERENCES