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Impact of body weight on shifting of foot pressure among adult subjects

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Purpose: The aim of the study was to compare the distribution of foot plantar pressure between normal and obese adult subjects during walking. *Methods*: Sixty male and female adult volunteers (aged 20–40) were recruited into the study. They were equally divided into 30 normal subjects (BMI = 18.5–22.9 kg/cm^2) into group I and 30 obese subjects (BMI ≥ 25.0 kg/cm^2) into group II, according to their BMI. *Results*: There were statistically significant differences between normal and obese subjects in foot length, width, and pressure distribution in the hindfoot, midfoot, forefoot, and toes. There was a statistically significant increase in the plantar pressure of all measured areas in obese persons in comparison with the normal subjects. In addition, all measures of foot pressure showed statistically significant differences between the same sex of both groups, while the obese subjects of both genders have higher foot pressure in all measured areas. High positive correlations were detected between BMI, peak pressure, foot contact, and foot width in both groups, but there was a weak positive correlation between normal BMI and foot contact area. *Conclusion*: The distribution of plantar foot pressure is different in adult obese subjects than in normal adult subjects during walking activity. The obese persons have larger foot length, width, higher peak pressure, and contact area. This study can help physical therapists to understand the differences of foot pressure between normal and obese subjects, and consequently, to detect any expected foot abnormalities accompanied by obesity.

Key words: *foot pressure, obese, normal adults*

1. Introduction

The foot is a main functional unit of human body that has main role in balance and locomotion during activity of daily living [4], [7], [17], [30]. Most humans devote a large part of their time either during walking or in the standing, however, little information is available about the foot functions during standing. The major part of musculoskeletal system that withstands significant loads during standing and walking is the foot [15], [17].

The World Health Organization (WHO) reported that obesity is considered a main world health issue. It has an alarming growing rate and is an important risk factor for different musculoskeletal pathologies [1]. Persistent loading on musculoskeletal system of the obese subjects has been concerned in predisposition to pathology of gait patterns, loss of flexibility and subsequent progressive functional disability [16].

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It was reported that plantar feet pressure distribution is affected by several factors, such as foot structure, body weight, gender and mobility of the joint [21]. The pressure distribution on the sole of the feet depends on the magnitude of body weight of subjects [18]. Analysis of the distribution of plantar pressure is expected to provide valuable information in clinical practice [18]. This analysis may deliver additional feedback about the etiology of discomfort and symptomatic complaints in the joints of the lower extremities that can be associated with overweight [29].

The assessment of either static or dynamic loads may provide feedback about structural and functional traits of the feet. In addition, the assessment of plantar pressure shows a significant role in managing patients who are at hazard of developing different foot problems, such as foot ulcer, flat foot, Charcot foot etc. [20]. At the same time, the effects of BMI on foot plantar pressure have not been studied adequately [29]. Limited studies evaluated influence of body weight, body pressure distribution mass index on plantar pressures in children [20], [10]. Higher foot plantar pressure distribution and lower feet sensitivity were reported in obese children than in non-obese [10]. There is more feeble walking stability with flatter pattern of foot in obese child [28]. This may affect performance of weight bearing activities and lead to higher risk of foot injuries in obese children [28], [10]. Up to knowledge of investigators, there is still shortage in the previous studies that investigated the foot pressure distribution among adults with obesity in both genders, therefore, the objectives of this study were to: (1) evaluate impact of body weight in obese subjects on foot pressure distribution and detect how much different from distribution in normal weight subjects during walking; (2) evaluate foot pressure distribution differences among male and female subjects either normal or obese during walking; (3) establish correlation between BMI, foot pressure distribution, and foot configuration during walking. The study's null hypothesis stated that there should be no impact of BMI on the foot pressure distribution and there might be no statistical significant differences in foot plantar pressure distribution between obese and normal subjects and between both genders. In addition, there may be no correlation between BMI, foot plantar pressure and foot configuration.

The studies that examined plantar forces and plantar pressure distribution beneath the foot in obese and normal adult subjects are limited [6]. The previous studies on potential differences in peak plantar pressure over the sole of the foot (heel, middle foot and metatarsal regions) between normal and obese adult subjects are few [16], [12]. To the authors knowledge, there are no previous studies measuring the shifting of the plantar pressure on different foot regions in normal or obese subjects during dynamic activity such as walking, or comparing the plantar pressure distribution between both genders (male and female) in order to know which sex is more vulnerable to the expected foot abnormalities caused by the obesity.

2. Materials and methods

2.1. Design of the study

The present research was on experimental cross-sectional study.

2.2. Subjects

Seventy-eight male and female volunteers (aged from 20 to 40) were recruited into this study. Only sixty volunteers were included in statistical analysis as eighteen volunteers did not meet the design criteria. Demographic data of all participated volunteers were age, weight, height, body mass index (BMI), foot length, and foot width (Table 1). Thirty normal body weight subjects (15 males and 15 females) were assigned to group I (BMI = 18.5–24.9 kg/cm^2). Thirty obese subjects (15 males and 15 females) were assigned to group II (BMI ≥ 30.0 kg/cm^2) [16]. All participants preferred to kick the ball with right leg, except for 5 participants, who preferred to kick the ball with the left leg. All pressure variables were collected from the dominant foot. The purpose and procedure of this study were explained in detail for all participants. An informed consent form was signed by each participant. Human research was approved by Institutional review Board of Imam Abdulrahman Bin Faisal University (Non-grant IRB-2017-03-065).

All participants were free from any musculoskeletal abnormalities or locomotor limitations, which was confirmed by investigating the participants' medical history and by observation. All participants with foot deformity, lower extremity trauma, joint disorders, surgery of the hip, knee, ankle or foot, leg length discrepancies, disorders, diabetes or related peripheral neuropathy, vascular insufficiency, problems of cooperation including eye, ear or cognitive using walking aids were excluded from the study [21].

2.3. Instrumentation

Dynamic foot pressure image data collection involvess the use of Embed-x Platform system (Novel-gmbh © 1992–2008, Germany) [26]. The platform system is designed from flat rigid plate of pressure sensors which are embedded in artificial foam floor to allow normal walking. The platform dimension is about 700 × 403 × 15.5 (18) mm, while the platform-based foot plantar pressure sensor is 475 × 320 mm [2]. The reliability of the plantar pressure platform of Novel emed-x® was proved in literature [14]. The number of the sensors that arranged in the matrix configuration of the plate is 6080 with a resolution of 4 sensor/cm^2 and frame rate of 400 Hz. The pressure threshold of the platform is 10 kPa with accuracy of ±5% [14]. This platform with calibrated capacity sensors connected to notebook by software (Novel database and Emed®-R recorder software). The Emed-x system could be ongoing from Novel database software and it includes wide-ranging software for foot checking and analysis. While, the Emed®-R recorder software processes dynamic foot pressure distribution and provides multi-video synchronously. The system begins recording when the subject's foot comes in contact with the platform, and the data is stored [14].

2.4. Procedure

This study was performed in physical therapy lab., College of Applied Medical Sciences, Imam Abdulrahman Bin Faisal University. Body height and weight were measured by weight and height scale adjusted to zero level at the beginning of measurement. The length of both lower limbs was measured from supine lying position to detect leg discrepancy using measurement tape, and the distance between the anterior superior iliac spine to the medial malleolus was detected. The foot dimensions were measured for each subject by using a caliper [16]. The foot length was measured from the heel to the tip of the second toes and the foot width was determined across the metatarsal break. The foot pressure data was collected from both feet by walking barefoot across the platform (the order of the feet that strikes the platform was randomized). Familiarization trials were conducted to enable each participant to strike the center of the platform during the normal walking. Three repetition trials were done barefoot and the average of these trials was recorded [24]. Each participant walked across the pressure platform with self-preferred walk speed and started with two footsteps before contact the center of the platform. In the current study, the foot pressure during walking was detected for four anatomical foot areas (hind-foot, mid-foot, forefoot and toes) of the dominant foot [24], [9]. Also, the total area and average pressure for the whole dominant foot were detected [10].

2.5. Statistical analysis

The mean and standard deviation (mean ± SD) values of the all measured variables were calculated. SPSS version 22.0 statistical package for the Social Sciences was used for the statistical analyses. The distributions normality was confirmed by the Shapiro–Wilk test ($p > 0.05$). The independent *t*-test and paired sample *t*-test were used to identify the differences in anthropometric data, foot width, and length within group and between groups. The significance level was set at $p < 0.05$. Correlation analysis was applied to examine the relationships among the BMI, peak pressure distribution, foot contact area, and foot width in normal and obese subjects. Pearson correlation test (r) was significant at $p < 0.01$ and $p < 0.05$. The sample size of 87 participants produced the analysis power of 91% with the alpha level of 0.05. G*Power 3.1.9.4 software was used for calculation.

3. Results

There were statistically significant differences in the demographic data between normal and obese groups. These differences were in height, weight, BMI, foot length and width ($p = 0.012$, $p = 0.000$, $p = 0.000$, $p = 0.000$, $p = 0.000$ respectively), as shown in Table 1.

Table 1. Demographic data of all participants in the study

Variables	Normal group (30)	Obese group (30)	*t*-value	*p*-value
Age [years]	33.1 ± 2.1	33.4 ± 2.3	–0.554	0.584
Height [cm]	175 ± 6	171.8 ± 2.6	2.7	0.012*
Weight [kg]	69.9 ± 6.4	110.7 ± 6.5	–22.4	0.001*
BMI [kg/cm^2]	22.7 ± 0.84	37.4 ± 2.5	–28	0.001*
Foot Length [cm] Lt.	24.9 ± 1.2	26 ± 0.65	–4.9	0.001*
Foot Length [cm] Rt.	25 ± 1.1	26 ± 0.66	–4.8	0.001*
Foot width [cm] Lt.	8.7 ± 0.47	9.5 ± 0.41	–7	0.001*
Foot width [cm] Rt.	8.7 ± 0.51	9.5 ± 0.41	–6.3	0.001*

* Significant level at *p*-value < 0.05.

Table 2. The foot pressure distribution in normal and obese subjects (dominant foot)

Variables	Normal group (30)	Obese group (30)	*t*-value	*p*-value
Peak pressure [kPa]	406.9 ± 63.02	576.3 ± 13.30	–14.4	0.001*
Hindfoot P [kPa]	245.53 ± 17.68	361.74 ± 16.10	–26.6	0.001*
Midfoot P [kPa]	116.74 ± 9.80	215.57 ± 9.17	–40.3	0.001*
Forefoot P [kPa]	268.15 ± 11.82	388.75 ± 7.90	–46.5	0.001*
Toes P [kPa]	407.96 ± 62.31	576.45 ± 10.42	–14.6	0.001*
Contact area [cm^2]	125.68 ± 11.67	146.44 ± 3.28	–9.38	0.001*

*Significant level at *p*-value < 0.05.

Table 3. The foot pressure distribution in male and female normal and obese subjects (dominant foot)

Variables	Male (n = 30)			Female (n = 30)		
	Normal (n = 15)	Obese (n = 15)	*p*-value	Normal (n = 15)	Obese (n = 15)	*p*-value
Peak pressure [kPa]	417.45 ± 63.9	579.80 ± 10.2	0.001*	369.29 ± 62.5	572.78 ± 15.4	0.001*
Hindfoot P [kPa]	253.93 ± 17	356.33 ± 17.5	0.001*	237.13 ± 14.4	367.15 ± 12.9	0.001*
Midfoot P [kPa]	120.20 ± 10.6	214.53 ± 8.7	0.001*	113.20 ± 7.8	216.60 ± 9.8	0.001*
Forefoot P [kPa]	278.33 ± 6.1	387.70 ± 8.5	0.001*	257.97 ± 5.5	389.80 ± 7.3	0.001*
Toes P [kPa]	417.3.9 ± 63.8	575.84 ± 11.5	0.001*	398.53 ± 61.5	577.07 ± 9.6	0.001*
Contact area [cm^2]	136.71 ± 4.2	146.14 ± 3.8	0.001*	114.65 ± 2.1	146.75 ± 2.8	0.001*

*Significant level at *p*-value < 0.05.

Furthermore, there were statistically significant differences in the peak pressure, hindfoot pressure, midfoot, forefoot, and toe pressure between normal and obese groups, in favor of obese subjects that have higher pressure in all measured areas ($p < 0.05$) as shown in Table 2.

In addition, all foot pressure variables measured showed statistical significant differences between the same sex of both groups (male in normal and obese groups & female in normal and obese groups) in favor of obese subjects of both sex, which have higher foot pressure in all measured areas ($p < 0.05$) (Table 3).

The Pearson's correlation coefficient (r) presented a high positive correlation between BMI and peak pressure distribution in normal group (r = 0.621) and a high positive correlation between BMI and foot width in normal group (r = 0. 629). Moreover, a weak positive correlation was found between BMI and the contact area in normal group (r = 0.054). On the other hand, a moderate positive correlation was detected between peak pressure distribution and BMI of obese groups and female obese group (r = 0.412), while a high positive correlation was detected between foot contact area and BMI of obese group (r = 0.625). Finally, there was a moderate positive correlation between foot width and BMI of obese group (r = 0.518), as shown in Table 4.

Table 4. Person product moment correlation coefficient of BMI for normal and obese subjects (dominant foot)

Variables	Normal-BMI (n = 30)	Obese-BMI (n = 30)
Peak pressure [kPa]	p = 0.000**	p = 0.024*
Contact area [cm^2]	p = 0.777	p = 0.000**
Foot width [cm]	p = 0.000**	p = 0.003**

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

4. Discussion

The main objective of this study was to investigate the impact of high body weight on foot pressure distribution among obese subjects and to detect the significant differences foot pressure distribution between normal and obese subjects during walking activity, and also to detect the effect of gender on foot pressure distribution. The selected subjects in the current study were either normal – with BMI 18.5–22.9 kg/m^2 or obese – with BMI from 30 kg/m^2 or higher as obesity, according to WHO Regional Committee of the Western Pacific [27]. In the current study, the pressure distribution was measured in all foot regions of adults and this came in agreement with the literature.

The results of the current study showed statisticall significant alterations between normal and obese subjects in foot length and width. Correlation analysis showed positive correlations between foot width and BMI in normal and obese groups. These are supported by previous studies, in which a high BMI was related to wide and flat feet [11], [25]. As reported in previous study, increase in bodyweight may alter anthropometric measures of the foot by mechanical loading [3]. Thus, obese individuals exhibited flatter feet, which can be explained by the fact that increase in bodyweight make alterations to foot structure [8]. In addition, it was found that foot anthropometrics showed significant decreases in arch elevation and arch firmness, with concurrent increases in foot length and arch fall among pregnant women as a result of temporary weight gain [23]. This difference can be explained by the hypothesis of increase in the total square area of foot as a result of contractions and extension of the plantar muscles due to load of the body weight on the foot [3]. Also, it can be explained by significant modifications to the feet as a result of accompanied excessive and repetitive loads on the feet with overweight body [13]. Contrary to changes in foot anthropometrics with weight gain, the weight loss appeared to have non-significant effects on foot structure. The current results came in contradict with Hills et al. [16] that found non-significant differences between obese and non-obese groups in foot length whereas the foot width was significantly greater only for obese subjects. This difference may be attributed to many differences, such as mean age, BMI and measured tools between both studies.

The results of contact area and foot peak pressure in the current study proved significant differences between the normal and obese adult subjects, which were higher in obese subjects in comparison with normal-weight subjects. This came in agreement with previous results of significant changes in contact area between pre-obese and non-obese adult's subjects during standing in mid foot regions [21]. The results were matched also to obese children [13], [19]. It was found that obese children showed greater area of contact and peak pressure in comparison with the non-obese children [13] and this occur not only to obese but also to overweight children [19]. Then, another investigation found significantly higher relative area impulses of contact with the plate at the midfoot among obese children during walking [24].

Regarding pressure distribution, it was found that the obese subjects have significantly higher pressure in the hindfoot, midfoot, forefoot and toe than normal subjects. This is supported by many studies [8], [5]. The highest pressure in obese adults was observed in our study on toes and it was reported in the previous study [5], in which the author found that the peak pressures under metatarsal heads (from II to V) and heel were statistically significantly higher with increasing the body mass.

Butterworth et al. [8] found that obese individuals exhibited higher peak plantar pressures when walking. The authors found bodyweight was significantly related to rising load on the foot, mainly the forefoot and midfoot, which suggests that obesity increases the stresses applied to the foot through increased bodyweight.

This study showed positive correlations between peak pressure distribution and BMI in normal and obese subjects, which was supported by previous studies [21]. It was found that in the foot of obese, the pressure distribution was consistently distributed and there was an increase in the distribution of pressure under midfoot with increased BMI values [21].

Second finding of the current study was that all measured variables reported statistically significantly higher values of foot pressure in male and female obese subjects than in normal subject. The differences between male and female subjects in length, width and height due to genetic, natural and environmental factors were confirmed by the literature. The difference in plantar pressure distribution between male and female was proved among normal weight subjects. This can be explained by larger contact area of the men foot than that of women foot [22]. Unfortunately, only one study compared plantar pressure distribution between normal and obese female college students [29]. The authors investigated effect of body mass index on plantar pressure distribution. The study found non-significant changes in the forefoot and hind-foot peak pressure [29]. The difference in results may be caused by the difference in measurement technique, as in current study the foot pressure was measured during walking motion, while Yoon et al. [29] measured peak plantar pressure in a static position. In addition, in this study, the measured variables include all four anatomical foot areas (hindfoot, midfoot, forefoot, toes) and peak foot pressure, while in the other study the pressure was measured only in the forefoot and hind-foot areas [29]. There are some limitations that need to be considered in the current study. The small sample size in the studied groups (only 30 for each group). The groups are only normal and obese, with no intermediate or overweight subjects. Further studies on larger sample size in the normal, overweight and obese subjects are recommended. Foot pressure distribution difference between normal and obese subjects should be considered during physical therapy programs.

5. Conclusions

The foot pressure distribution in obese is different than in normal subjects during walking activity. In addition, the obese persons have larger foot length, width, higher peak pressure and contact area. This study can help physical therapists to understand the foot pressure distribution differences between normal and obese subjects to detect effects of weight gain on foot pressure and, consequently, to detect any accompanied expected foot abnormalities that can be associated with obesity.

Conflict of interest

There is no any conflict of interest that may have affected either the conduct or the presentation of this research.

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