DOES PLANTER PRESSURE DISTRIBUTION ALTER WITH WEIGHT REDUCTION IN OBESE CHILDREN?

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ABSTRACT

Background: High plantar pressure values in obese children are of great concern due to the risk of inducing pain, discomfort, and foot pathologies, mainly for children’s growing feet. Obese children have been observed to have flat feet compared to those of their non-obese correspondents.

Objective: The purpose of this study was to detect whether there were differences in the static and dynamic plantar pressure distribution variables after weight reduction in obese children.

Methods: Thirty obese prepubescent girls aged from 8 to 11 years were included in the study. The Tekscan foot pressure system was used to measure the static and dynamic plantar pressures before and after nine months of weight reduction program. The peak pressures beneath the forefoot, midfoot and rearfoot were measured for each foot. The weight reduction program consists of a combined dietary and exercise program.

Results: The study revealed high significant differences in the peak force, contact area and in plantar pressure in standing. Significant differences were also found in dynamic pressure variables particularly under the mid foot region which was highly significant.

Conclusion: It was concluded that decreasing the weight of obese children is an important issue because it will decrease both static and dynamic pressure variables, and in consequence decreasing the risk of obtaining foot problems, stress fractures, or ulcerations caused by effect of their increased weights on their growing feet.

INTRODUCTION:

Obesity in children is a major problem and is an aspect of interest requiring more research. Obesity is usually accompanied with multiple health hazards as high blood pressure and diabetes (Songhua et al.2013). Moreover, it is correlated with orthopedic complication due to the increased load on the musculoskeletal system. Obesity will adversely influence the normal development of bones, muscles and joints especially for the rapidly growing children (Morrison et al.2009). Feet is often subjected to high ground reaction forces developed throughout daily living activities (Eils et al., 2002). The medial longitudinal arch is the important structure in the feet for absorbing and distributing these forces. This arch involves joints, muscles, and ligaments, but it is mainly supported
by ligaments (Dowling et al.2001). However, frequent extra loading may elongate ligaments over their elastic end and increasing the possibility of foot soreness and consequently foot pathology (Burnfield et al.2004).

In order to find out some of the musculoskeletal problems relevant to childhood obesity, numerous researches have examined the influence of obesity on foot function. In spite of these studies have frequently reported that obese prepubescent children commonly exhibit flat feet compared to those of their non-obese correspondent, the reason for this high contact area between obese children feet and the ground is unknown (Mickle et al. 2006).

It has been hypothesized that the flat feet of obese children may be produced by the presence of a plantar fat pad below the midfoot area. During infant development, there is a fat pad that still presents under the medial longitudinal arch, despite this fat pad is thought to disappear between two and five years as the foot arch is constructed (Mickle et al. 2006). Riddiford-Harland et al. 2000 reported that the fat pad found in the mid-foot region might persist in the feet of obese children as a protective adjustment to distribute the loads related to their increased body weight.

Alternatively, the flat feet noticed in obese children may result from the disintegration of the medial longitudinal arch as a result of continuously bearing excess body weight which caused by the excessive loading of the feet (Song-hua et al 2013). On the long run, this structural collapse can result in foot pain, as appropriate mechanics of the longitudinal arch are essential for normal foot function (Mickle et al. 2006).

Also, it was reported that foot pain caused by these structural changes in the obese children may restrict obese children from performing their normal physical activity (Mueller et al.2016). Therefore, restriction in the physical activity as a result of foot discomfort may increase the obese child's body weight due to inactivity, and increase loads on the feet which further aggravate foot problems (Mickle et al. 2006& Filippin et al.2007).

These findings support that obese children could be at danger of developing foot problems as a result of the increased stress and forces acting upon the premature musculoskeletal structure of the child feet (Mueller et al.2016). In their study, Hills et al.2001 recommend the evaluation of the changes in pressure distribution under the feet of obese children who are treated to decrease their body fat. It was reported that early treatment of foot conditions at an early stage in life could prevent or delay long-term foot problems and improve the quality of life (Cousins et al.2013). So, the purpose of this study was to evaluate whether there were and differences in the static and dynamic plantar pressure distribution after weight reduction in obese children.

**METHODS**

**Participants**

Thirty obese prepubescent girls were participated in the study. All participants were called up from a local primary school at Al Kharj city, Riyadh, Saudi Arabia. The study was applied after signing a consent form by parents of the participants, which is permitted by the ethical guidelines of the University of Prince Sattam Bin Abdulaziz and in accordance with that established in the Declaration of Helsinki.

**Inclusion criteria**

Participants with those criteria were included:

1. Gender: girls.
2. Age: eight to eleven years
3. Body mass index (BMI) was more than the 95th percentile for age and gender.
4. All participants have pronated foot posture evaluated by the inked footprint.
5. All participants attend three exercise sessions per week for a duration of nine months.

**Exclusion criteria:**

Participants were excluded if they:

1. Had musculoskeletal, neuromuscular, or cardiopulmonary problems.
Had diabetes or any other disease associated with their obesity.  
3. Take any drugs that might affect their growth or body mass (eg, corticosteroids or thyroid hormone).

METHODS

A. For assessment

1. Body mass index:

Each participant height was calculated to the nearby millimeter while she stood in the anatomical position barefoot using a calibrated stadiometer. Body mass was calculated to the nearest 0.05 kg while the participants were wearing light clothing using calibrated Medical Scale (Song-hua et al 2013). These data were used to determine each child’s BMI. A universally accepted measure for determining obesity in children, using the Standard Quetelet Index protocol: body mass divided by height squared (kg/m2) (Mickle et al. 2006). Then the obesity classification system of BMI depending on age and sex, proposed by Cole et al.2000, was applied to each child to determine the degree of obesity.

2. Foot assessment:

The Tekscan HR Mat (Boston, USA) plantar pressure assessment system was used to measure both static and dynamic plantar pressure variables for each participant. This system is a platform-based, low profile, high-resolution foot pressure mapping system. The mat is made up of 8352 individual pressure sensors, which are distributed evenly in rows and columns across the sensor surface. This makes the HR Mat a proper pressure system for children’s feet. Data were collected at 60Hz using the recommended calibration method of the manufacturer. The peak pressure variable will be evaluated as it takes into account both the force developed and the contact area of each foot part (Mickle et al.2011).

During data collection, all participants were allowed to familiarize themselves with the way of walking over the platform to assure that they were comfortable with the method (Cousins et al.2013), all participants were encouraged to use a normal gait pattern and to walk without any shoes at a comfortable speed. To assure a constant speed had been reached before the contact with the platform, participants were requested to contact the platform with their fourth step (Cousins et al.2013). After contacting the mat, three to four additional steps were taken.

Five trials at the participants’ own speed were collected, which has been recorded to provide reliable results (Gatt et al.2014). Participants were advised to walk along the platform in a natural way. Trials in which the participants did not strike the platform with the whole foot, targeted for the platform, or considerably changed gait or speed were not considered for further analysis (Hills et al.2001&Busa et al.2005). Mean values of five valid trials from each foot were collected and further analyzed. Two minutes rest were allowed if the participants feel tired between trials.

The variables were peak force measured in newton (n), contact area measured in centimeter square (Cm²), and peak plantar pressure measured in kilopascals (KPa). Pressure is detected by dividing the force measured by the known area of the sensor. These were measured across three-foot regions; forefoot, midfoot and rear foot. The forefoot was considered the metatarsal heads and toes, the rear was defined as the rear one-third of the foot, and the midfoot refers to the area in between (Caselli et al.2002).

B. For treatment

A combined program of diet and exercise program was applied for managing the participant’s obesity, as the previous studies suggested that combination of diet, exercises, and eating behavioral modification are effective in childhood obesity treatment (Nemet et al.2005&Sun et al.2015). Moreover, a previous study have reported that the short and long-term combined treatment program for obese children is of great value (Sun et al.2015).

1. Diet intervention

The participants and their parents meet a diet specialist nine times during the treatment
period to inform the participants and their parents about healthy food. This meeting includes the reasons and risks of childhood obesity, healthy habits in food selection and food cooking, the benefits of losing weight, food pyramid, food labels, and recommended food amounts (Oude Luttikhuis et al. 2009& Ford et al .2010). The leaflet of important nutritional facts was also given to the participants and their parents during these meetings.

2. Exercise intervention

The participants were instructed to perform a thirty minutes aerobic exercise on a treadmill during each exercise session. Every exercise session was preceded by ten minutes of warming up, ended by ten minutes of cooling down. The exercise intensity was determined as a percentage of heart rate. The participants were instructed to accomplish three exercise sessions per week. Reevaluation for the planter pressure distribution variables were done after accomplishing treatment period of nine months.

Statistical analysis:

Statistical analysis was conducted using Minitab version 16.0 for Windows. Means and standard deviations (SD) were calculated for each variable. The paired sample t- test was used to test significant differences in static and dynamic plantar loading variables before and after the weight reduction program. The level of significance was set at p<0.05. Correlation assessment between the BMI of all the study participants and the static–dynamic pressure variables was applied by Pearson correlation analysis.

RESULTS:

Sixty feet belonged to the 30 children were investigated before and after the weight reduction program. The anthropometric characteristics of the children were presented in table 1. The BMI mean value calculated for these obese children before the program (33.16kg/m²) was significantly different from that obtained after the program (24.17kg/m²) (p= 0.0001). Comparing the group results before and after weight reduction, high significant differences were found in the mean values of the static parameters related to peak force, peak contact area, and peak pressure which are all remarkably decreased as shown in table 2.

Table (1) Anthropometric data (mean ± SD) For the study group before and after:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Before</th>
<th>After</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>10.3 ± 1.4</td>
<td>10.5±1.7</td>
<td></td>
</tr>
<tr>
<td>Body mass(Kg)</td>
<td>56.6±11.5</td>
<td>43.91±7.23</td>
<td></td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.50±0.14</td>
<td>1.52±0.12</td>
<td></td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>33.16±3.14</td>
<td>24.17± 1.28 *</td>
<td></td>
</tr>
</tbody>
</table>

* indicates significant (P≤ 0.05)

Table (2) Static peak force, peak contact area and peak pressure mean values before and after the weight reduction program.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Before</th>
<th>After</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak force (N)</td>
<td>498.6± 215.8</td>
<td>365.3± 117.7</td>
<td>0.004 *</td>
</tr>
<tr>
<td>Peak contact area (cm²)</td>
<td>89.1± 22.5</td>
<td>71.8± 11.9</td>
<td>0.0004*</td>
</tr>
<tr>
<td>Peak pressure (N/ cm²)</td>
<td>36.8± 7.8</td>
<td>26.5± 8.3</td>
<td>0.0001*</td>
</tr>
</tbody>
</table>

* indicates extremely significant (P< 0.05)

During gait, the children after the weight reduction program revealed a significant decrease in the peak force and pressure on the total foot, the rear foot, the midfoot, and forefoot regions compared to the results of children before applying the program with the largest significant difference under the mid foot region. Also they displayed after weight reduction a less contact area for the total foot area and for all regions of the foot, compared to their results before weight reduction (table 3).

Table (3) Dynamic total foot peak, forefoot, midfoot, and rearfoot force, contact area and pressure mean values before and after the weight reduction program.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Before</th>
<th>After</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total foot Peak force (N)</td>
<td>598.6± 215.8</td>
<td>511.3± 117.7</td>
<td>0.0566</td>
</tr>
<tr>
<td>Total foot Peak contact area (cm²)</td>
<td>87.1± 12.5</td>
<td>76.3± 12.9</td>
<td>0.0165</td>
</tr>
<tr>
<td>Total foot Peak pressure (N/ cm²)</td>
<td>44.3± 15.8</td>
<td>37.4± 8.7</td>
<td>0.0405</td>
</tr>
</tbody>
</table>
Nadia L. Radwan / Does Planter Pressure Distribution alter with weight reduction in obese Children?

<table>
<thead>
<tr>
<th>Forefoot force (N)</th>
<th>505.6± 83.9</th>
<th>468.3± 56.5</th>
<th>0.0480</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forefoot area (cm²)</td>
<td>49.8± 5.7</td>
<td>46.6± 5.2</td>
<td>0.0268</td>
</tr>
<tr>
<td>Forefoot pressure (N/cm²)</td>
<td>42.8± 7.8</td>
<td>38.35± 8.3</td>
<td>0.0366</td>
</tr>
<tr>
<td>Midfoot force (N)</td>
<td>367.16± 121.76</td>
<td>273.59± 85.1</td>
<td>0.0011*</td>
</tr>
<tr>
<td>Midfoot area (cm²)</td>
<td>67.13± 12.45</td>
<td>61.13± 11.13</td>
<td>0.0539</td>
</tr>
<tr>
<td>Midfoot pressure (N/cm²)</td>
<td>39.88± 4.92</td>
<td>36.33± 3.97</td>
<td>0.0032*</td>
</tr>
<tr>
<td>Rearfoot force (N)</td>
<td>399.2± 91.9</td>
<td>355.5± 55.9</td>
<td>0.0300</td>
</tr>
<tr>
<td>Rearfoot area (cm²)</td>
<td>38.3± 6.4</td>
<td>34.9± 4.9</td>
<td>0.0244</td>
</tr>
<tr>
<td>Rearfoot pressure (N/cm²)</td>
<td>33.9± 7.1</td>
<td>29.3± 8.3</td>
<td>0.0247</td>
</tr>
</tbody>
</table>

* indicates extremely significant (P< 0.05)

BMI appeared to have a positive correlation with a significant difference in all the static and dynamic pressure variables. Concerning the static variables, the total foot peak force was positive and strong (r = 0.5 , P = 0.01) , while both the total foot peak contact area (r = 0.3, P = 0.01) and the total foot peak pressure (r = 0.4 , P = 0.04) were weakly, but positively correlated to BMI. On the other hand, among the dynamic pressure variables, only the midfoot peak pressure (r = 0.5, P = 0.000) was having a strong positive correlation with BMI, showing a high significant difference, while the other variables were having only weak positive correlation.

**DISCUSSION:**

By reviewing the previous literature, it has been found that studies concerning the difference in plantar pressure distribution variables in obese children compared with their non-obese peers or even comparing these pressure variables before and after weight reduction in obese children are scanty or null. Only little research works have been applied on obese adults or children and they revealed that there are some changes might occur in the rear foot, the midfoot, and the forefoot both in static and dynamic parameters when compared to the non-obese subjects (Hills et al., 2001; Gravante et al., 2003)

For the static plantar pressure variables, the results revealed high significant decreases in the mean values when comparing the peak force, the peak contact area, and the peak pressure before and after decreasing the weight. This is consistent with the rule that the force is the equal to multiplication of mass and acceleration. So, the obtained decrease in static peak forces, pressures after weight reduction was logical. The results come in agreement with the studies of Hills et al. (2001) and Murat and Hakan (2004) who found significant increase in the total peak force and the total contact area in the obese adults group caused by their higher weights when compared to the non-obese persons.

The dynamic variables mean values were also significantly different and decreased in all the foot regions, except in the mid foot region as they were highly significantly decreased in force and pressure variables. Again, our results come in consistent with that of Hills et al. (2001) and Riddiford-Harland et al. (2000) who also found significant difference in all dynamic plantar pressure variables in all foot parts. Moreover, they come in an agreement with Murat and Hakan (2004) who found the significant difference only in the mid foot region. These could be referred also to the decrease in the body masses, and in response to it, the foot contact areas and foot flattening decreased, as happened with the static variables. The matter that is considered as an index to the decreased load on the collapsed medial longitudinal arch in the mid foot region.

The statistical analysis of the correlation co-efficiency appeared to be positive in direction between the BMI and all the static and the dynamic foot plantar pressure variables. It was especially strong in power in both static peak force and dynamic mid foot pressure when correlated to BMI. This come compatible with Hennig and Milani (1993), Nyska et al. (1997) , Hills (2001) and Gravante et al. (2003) and Murat and Hakan (2004) who all reported a correlation between the mid foot plantar pressure and the body weight. They declared
that the increase in body mass has an influence on the increased plantar pressures which in turn can cause structural damages to the feet and to the lower limbs as a whole. The correlation obtained may be attributed to the concept that foot structures adapt itself to the changes in the body weight which is mostly clear at the level of mid foot region due to the structural adaptation happened in the medial longitudinal arch of foot (Nyska et al. ,1997; Riddiford-Harland et al., 2000).

On the other hand, some literatures pointed out that there is low or even no correlation between the increase in body mass and its effect on the increased plantar pressure both in stance and gait (Hennig et al. 1991; Cavanagh et al. 1987). They refer this to the increase in the contact area of the foot due to adaptation of the foot through flattening of the medial longitudinal arch, which might cause a redistribution of plantar loading forces. However, the power of the effect of decreasing the weight on the foot plantar pressures need more investigation.

CONCLUSION:

Regarding the results of this present study, it could be concluded that decreasing the weight of obese children will decrease both static and dynamic pressure variables, the matter that will decrease the risk of having foot disorders, stress fractures in the metatarsal bones, or ulcerations resulting from the increased pressures being applied to their small immature feet bones and structures caused by their obesity.

According to the conclusion, it could be recommended that precautions in choosing these children's shoes and footwear or the use of foot insoles is an issue of consideration. Also, we recommend to give an attention to the necessity of applying some different physical therapy exercises to improve the strength of the foot muscles and the lower limbs as a whole, and to correct the posture or to reduce the pain in order to improve their self-esteem and their quality of life.

Declaration of interest:

The author reports no conflict of interest. The author alone is responsible for the content and writing of this paper.

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