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The relationship between body mass index and footprint parameters in older people

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ABSTRACT

Background: The relationship of body mass index (BMI) with footprint parameters has been studied in paediatric populations, but there are limited data regarding the effects of BMI on parameters in the elderly.
Objectives: To establish the relationship between BMI and static footprint parameters in the elderly population.
Methods: 128 subjects aged 65 and above with no history of lower extremity surgical intervention and no significant lower extremity weakness were included in the current study. BMI and footprint parameters of arch angle, Chippaux–Smirak index (CSI), Staheli index (SI), arch index (AI) and footprint index (FI) were measured for each subject, and statistical analysis was done to investigate the correlation between BMI and the parameters.
Results: Weak correlations detected between all calculated indices and angles with BMI, except the left foot arch angle. CSI, SI and AI of the right foot were found to be positively correlated with BMI, while a negative correlation between the arch angle and FI of right foot was shown with BMI.
Conclusions: The results reveal a relationship between BMI and footprint parameters that are indicative of flatfoot in the elderly. This could be due either to confounding of the footprint measure by fat or possibly due to an as yet unknown structural change that requires further evaluation.

1. Introduction

Foot pain in older adults has been associated with a variety of conditions, with the most commonly reported causes being calluses or corns, hallux valgus, hammer toes, pes planus, edema, incorrectly fitting footwear, and generalized osteoarthritis [1–3]. Pes planus (flatfoot) is a condition in which the medial longitudinal arch is abnormally flattened down. Several studies have investigated potential causes of pes planus in adults. Ligament laxity, obesity and dysfunctions of the tibialis posterior muscle are among the possible etiological factors [4–6].

A continually ageing population is a global concern for world health, and an increasing number of older patients requiring physiatrist treatment is financially challenging. Obesity in the elderly, the prevalence of which is rising globally, is a major challenging healthcare problem [7]. Body mass index (BMI), an anthropometric technique widely used to determine whether patients are overweight or obese, is affected by age and is reduced with advancing ages over 60 years [8]. BMI has been found to be related to clinical indices such as mortality rate and some serious medical conditions, and also to the footprint parameters in several studies. Poorer motor development and endurance performance in children, higher mortality rates, more pregnancy complications, and poorer oral health are also among the conditions that have been associated with higher BMI values [9–12]. BMI has also been found to be related with foot problems in several studies. Hill et al. [13] examined 3,206 participants and found that obese cases had an increased prevalence of foot pain. However, higher BMI values have been claimed to be associated with lower prevalence of hallux valgus in older community-dwelling females. Monteiro et al. [14] reported that obese postmenopausal women have higher peak pressure in the metatarsal areas, mid-foot and lateral heel and claimed that these pressure increases could cause foot pain. Steele et al. [15] studied the effects of obesity on foot structure, function and the foot pain in older adults, and described more bulky plantar fat pad, lower hallux and lesser toe force in obese group.

The functional mechanics of the human foot are greatly influenced by the height of the medial longitudinal arch, and different techniques have been used to evaluate these arch types. Direct clinical measurement, X-ray, ultrasonography and footprint parameters

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have all been used to predict arch height [16]. Several footprint parameters have been introduced to determine medial longitudinal arch height and their reliabilities have been studied. Otsuka et al. [17] examined 242 women and 98 men aged 60 years or older to see if flatfoot is associated with foot symptoms and BMI and found higher prevalence of foot pain and fatigue in the identified flatfoot group. The study also revealed a linear correlation between the prevalence of flatfoot with obesity in women, but not in men. To identify flatfoot in participants, a line (H line) was drawn on footprints connecting the second toe and the intersection of the internal and external surface tangents of the foot. Cases were considered as having flatfoot if the concavity of the medial arch was medial to the H line, a technique that is not widely used to define flatfoot. Queen et al. [18] studied the reliability of footprint parameters, comparing them with navicular height and demonstrated that footprint index (FI) is the most reliable index followed by Staheli index (SI), Chippaux–Smirak index (CSI), arch index (AI), truncated arch index and arch length index. Foot structure and footprint parameters are affected by age as older people have flatter and more pronated feet [19]. Villarroya et al. [20] analysed footprint parameters of 245 children aged 9–16.5 years, and compared arch angle and CSI of normal weight, overweight and obese groups. Their results found a decrease in arch angle and an increase in CSI with higher BMI values. Dowling et al. [21] and Riddiford-Harland et al. [22] compared obese and non-obese prepubescent children and found that the obese cases had lower arch angle and higher CSI values.

There are few studies investigating the effects of BMI on footprint parameters in the elderly population. Aurichio et al. [23] evaluated 227 women and 172 men aged 60 years and over to find the relationship of BMI with Foot Posture Index and AI. Foot Posture Index is based on the measurement of positional abnormalities in the foot by palpation and observation. Investigations revealed a positive correlation between BMI and AI and some of the Foot Posture Index criteria and concluded that obese women have flatter feet while obese men's feet are more pronated. The relationship between BMI and other footprint indices were not investigated [23,24].

Establishing the exact effects obesity has on foot structure, and defining simple and safe ways to detect such changes in the medial arch, can help physiatrists to have a better understanding of foot discomfort in the elderly and to be more successful in the management of foot related problems in daily clinical practice. The aim of this current study was to analyse the relationship between BMI and footprint parameters of arch angle, CSI, SI, AI and FI in the older population.

2. Materials and methods

2.1. Participants

One hundred and twenty-eight participants aged 65 years and over were recruited for the current study. Participants were included in the study if they had no history of lower extremity injury, no history of foot or ankle surgery and no major medical condition which may result in lower extremity weakness. The study was approved by the Ethics Committee of the participating university.

2.2. Measures

2.2.1. BMI

BMI of each subject was calculated using the standard Quetelet Index protocol: body weight without shoes divided by height squared (kg/m^2). Weight was measured using a standard set of digital weighing scales.

2.2.2. Footprint parameters

Static weight-bearing footprints were taken using a mirrored foot photo box (a podoscope). The podoscope consists of a box with a glass top which is illuminated by fluorescent lights. It provides the clinician with a view of the plantar surface of the foot and the areas that are in contact with the glass when a patient stands on it. A mirror is positioned below the glass at 45° to reflect the view to the observer. Photographs of the views were taken using a 3.2 megapixel digital camera at a 45° angle to the mirror to obtain a proportional view from a distance of 50 cm.

The measurements of indices and angles were calculated using computer software specifically developed for this study. To test software reliability of the software several manual measurements were performed, compared the results with the software measurements, and obtained excellent results. The software automatically calculates four indices and the arch angle when the user manually draws a line encircling the contact area of the footprint to separate contact and non-contact areas, based on the colour reflected by the fluorescent light on the plantar surface of the foot. The user also determines key points on the image including the most medial and the most lateral points of the metatarsal, mid-foot and rear-foot regions, the base of the second toe, the lowest point on the footprint, and the point where the slope of the inner segment of the longitudinal arch first touches the metatarsal outline of the arch. To calculate the arch angle, the software automatically draws a line from the most medial point of the metatarsal region to the point where the slope of the inner segment of the longitudinal arch first touches the metatarsal outline of the arch. The arch angle is calculated by the software as the angle between this line and the medial borderline of the footprint. The medial borderline is the line connecting the most medial points of the metatarsal and the rear-foot regions. According to the points determined by the user, the software calculates four indices of CSI, SI, AI and FI. The CSI is the minimal distance in the mid-foot region divided by the maximal distance in the forefoot region and the SI is the ratio of the minimal distance in the mid-foot region to the maximal distance in the rear-foot region. To calculate AI and FI, the software draws a longitudinal line from the lowest point of the footprint to the base of the second toe on the footprint, and then divides the toeless footprint to three equal segments, drawing perpendicular lines to the longitudinal line. The AI is then calculated as the ratio of the area of the middle third of the toeless footprint to the entire area of the toeless footprint. FI is calculated as the ratio of the non-contact area to the contact area of the toeless footprint [15]. As the areas are non-standard geometric shapes, the software counts the pixels in the areas to calculate the surface areas. All calculations were separately done for the right and left feet.

The method to measure arch angle and the mentioned indices of footprint is demonstrated in Fig. 1. The podoscope device that was used to take footprints is depicted in Fig. 2. A screenshot of the software used to calculate arch angle and indices is seen in Fig. 3.

2.3. Data analysis

Statistical analysis was performed using SPSS for Windows version 15.0. Differences in the parameters between men and women were tested using independent *T*-test. To determine the correlation between BMI and the parameters, Pearson correlation coefficients were calculated. Correlation coefficients less than 0.3 are considered weak. All significance levels were set at $p < 0.05$.

3. Results

The mean age of participants was 70.6 ± 4.8 years. Women accounted for 77 (60.2%) with 51 (39.8%) being men. The average