



Research Paper

Studies on foot morphological characters – A basis for the development of footwear with fit and comfort for obese individuals

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ABSTRACT

Overweight and obesity are increasing health problems that cause excess body weight to chronic heel-pain, plantar-fasciitis, ankle, knee-pain and other ill-foot problems. There is a need for designing suitable footwear for these people based on their foot-morphologies and body mass index (BMI). In the present study, the foot morphological parameters such as height, weight, length of foot, ball girth, instep girth, heel girth and ankle girth were measured. Data were analysed descriptively and were statistically correlated with the foot characteristics according to BMI categorisation of obese individuals. The results showed significant linear relationship on ball girth and ankle girth with response to BMI. The instep girth and heel girth showed positive correlation with BMI. No significant difference in length of foot with body mass index of obese individuals was observed. The results are useful for the design of shoe lasts for obese individuals and for the development of comfort footwear.

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INTRODUCTION

Overweight and obesity are major health problems in many parts of the world and the incidence of these conditions is on the increase. The prevalence of obesity is increasing in both developed and developing countries (Dennis, 1992). Among numerous other medical conditions, a high incidence of osteoarthritis, painful feet and symptomatic complaints in the joints of the lower extremities are frequently reported for obese persons. Obesity is a medical condition in which excess body fat accumulates to the extent that it may have a negative effect on health. Obesity has reached epidemic proportions globally, with more than 1 billion people in the world being overweight adults, and there are around 300 million people who are obese (Garrow, 1988). The population under higher BMI categories is constantly on rising trend all over the world and has become primarily a threatening factor for the people not along overseas but also for countries such as India. According to the survey conducted by All India Institute of Medical Science, it was observed that 34% of men and 40.3% women were overweight and obese. In the

twenty-first century, obesity has reached epidemic proportions in India, with morbid obesity affecting 5% of the country's population (Jung et al., 2001). India is following a trend of other developing countries that are steadily becoming more obese. According to National Family Health Survey (NFHS-3), the overall prevalence of overweight/obesity in India was 12.1% in men and 16% in women. In India, a study conducted by Swami et al. (2015) estimated that prevalence of overweight and obesity among elderly in urban area was 33% (Krauss et al., 2008).

Obesity is defined as a condition of abnormal or excessive fat accumulation in adipose tissue, to the extent that health is impaired (Manna e al., 2001). Obesity is most commonly caused by a combination of excessive food intake, lack of physical activity and genetic susceptibility (Mauch et al., 2009). It is mostly preventable through a combination of social changes and personal choices, changes to diet and exercising are the main treatments (WHO, 2000). Obesity is a leading preventable cause of death worldwide with increasing rates in adults and children. Body mass index

(BMI) is a simple and widely used method for estimating body fat mass (Mei et al., 2002). BMI was defined in the 19th century by the Belgian statistician (Nigg et al., 1999). People are generally considered obese when their body mass index (BMI), a measurement obtained by dividing a person's weight by the square of the person's height, is over 30 kg/m² with the range 25-30 kg/m² defined as overweight (Prentice and Jebb, 1995). BMI is calculated by dividing the subject's mass by the square of his or her height, typically expressed either in metric or US. $BMI = \text{Weight (in kg)} / \text{Height}^2 \text{ (in m)}$. The Morphology changes with BMI Individuals are classified into different categories as per their BMI as shown in Table 1 (Nuttall, 2015). Body Mass Index (BMI) was derived from booking weight (kilograms) and height (metres). Using this, the patients were categorized as underweight (<18.5 kg/m²), normal or lean BMI (18.5–22.9 kg/m²), overweight (23.0 –24.9 kg/m²) and obese (≥ 25 kg/m²) based on the revised consensus guidelines for India.

The foot dimensional characters are significantly different from normal subjects to obese subject. The foot morphological features are affected due to heaviness of weight of obese individuals and the girth measures of feet that are wider than the normal subjects. The feet of obese are predominantly found with lower foot arches due to excessive pounding and loading over the plantar surface of feet. Hence, the wide feet character along with lower foot arch is the primary factors affected by higher level of body mass index.

The studies on foot morphology especially for obese individuals assume importance and it further necessitates modelling of Shoe-Lasts to exactly meet the terms of foot morphological parameters. The knowledge of foot morphology is important for the design and development of footwear. The anthropometrics emphasizes that any aspect of pathological function is depending on the morphology, and the objective way of evaluating and comparing the aspects of morphology in the human is highly significant in footwear applications. Anthropometry is very important field of application in footwear and orthotics industry (Priyadharshini et al., 2017; Suresh et al., 2015). Anthropometry refers to the measurement of the human individual, which involves the systematic measurement of the physical properties of the human body, primarily dimensional descriptors of body size and shape. At present, anthropometry plays an important role in industrial design, clothing design, ergonomics where statistical data about the distribution of body dimensions in the population are used to optimize products. Changes in lifestyles, nutrition, and ethnic composition of populations lead to changes in the distribution of body dimensions (e.g. the obesity epidemic) and require regular updating of anthropometric data collections. A study by Defour et al. (2009) examined the factors associated with foot pain, including current and past shoe wear. Footwear should be based on foot shape. Hence, knowledge of foot anthropometrics is an important

prerequisite to optimize last design (Swami et al., 2005). It is well known that foot shape is manifold and could differ from one individual to another (Sweeting, 2007). Fit has been identified as a primary component of footwear comfort and discomfort (The Hindu, 2007). Various types of foot should be considered in manufacturing shoes (Waterson and Sell, 2006).

From the above survey and discussion, it can be observed that obesity leads to varied foot deformation. Although, many research findings have been carried out on foot characteristics, the relationship between foot dimensional characteristics of obese and footwear conforming the morphological features of obese foot has not been much explored from literature findings. Hence, the obese individuals pose hardship in choosing ideal footwear to meet their foot dimensional and functional requirements. Finally, it has warranted the necessity of studying the foot anthropometric characteristics of obese individuals in this research. The data on varied foot parameters would form the basis for the design and development of shoe-last especially for obese individuals.

The main purpose of the present foot morphological research is to develop footwear with the proper fit and comfort for improving the well-being of obese individuals during locomotion. There seems considerable scope and potential of research for obese possessing with varied foot deformities and foot related problems, it was revealed from literature research. There is a need and necessity to explore technical interventions on design and development of shoe-last for obese individuals from the data of foot characteristics. The foot anthropometric characteristics play a key role for the design and development of shoe-last and appropriate footwear respectively. Footwear and last designers primarily rely on length, widths and girths of foot to design the lasts for shoes. Footwear should be made according to the foot dimensions of the user population. Fundamentally, the foot anthropometric survey has been prioritised as an important component of research. To achieve the above-said objectives, the rest of the study is organized as follows: materials and methods, description of the experiments, results and discussion and thereafter, the conclusion is drawn.

MATERIALS AND METHODS

Foot anthropometric studies for obese

This survey was aimed at to study the distinctive characteristics of foot morphology in high body mass index (BMI) population. To commence the studies on foot anthropometric characteristics, the prime importance of conductance of foot survey was informed to the targeted individuals. To measure the dimensions of foot, sliding and spreading callipers, measuring tapes, Stature meters etc were procured from local market and standard methods

Table 1: Description of BMI classification.

Underweight	< 18.5
Normal range	18.5 – 24.9
Overweight	≥ 25.0
Preobese	25.0 – 29.9
Obese	≥ 30.0
Obese Class I	30.0 – 34.9
Obese Class II	35.0 – 39.9
Obese Class III	≥ 40.0

Table 2: Mean and SD measures of Foot characteristics of obese.

S/N	Description	Mean ± SD
1	Height	1.70 ± 0.08
2	Weight	97.27 ± 15.24
3	Body Mass Index	33.77 ± 4.98
4	Ball Girth	268.69 ± 12.10
5	Instep Girth	286.33 ± 23.64
6	Heel Girth	350.80 ± 30.17
7	Ankle Girth	265.56 ± 21.26
8	Length of foot	283.22 ± 28.88

were followed as described study by Singh and Bhasin (1989). Emphasis was placed on identifying appropriate human subjects who fall under the obese categorisation prior to the foot survey activities. The participants' consent was sought and their willingness to take part with this activity was obtained. The participants exclusively males with a total strength of 55 were enrolled for the study on foot morphological characters. Calliper and tape measures are used as instruments for classic approaches to quantify foot-anthropometrics. Tapes were used to measure the circumference of foot, whereas calliper rules measure height, width and length dimension of foot. The anthropometric measurements such as height, weight, length of foot, ball girth of foot, instep girth, heel girth and ankle girth for the obese participants were taken and the mean and standard deviation on these parameters were estimated and are shown in the **Table 2**.

The somatometric measurement of length of foot was taken between foot end and foot tip (anterior point of the most protruding toe) along the medial tangent of the foot (foot measuring line: y-axis). A sliding calliper was set over which foot was placed axially. The foot outline was measured for the length of foot (Singh and Bhasin, 1989).

The ball girth of foot was measured using the tape covering the maximum circumference over the first metatarsophalangeal protrusion and fifth metatarsophalangeal joint protrusion. The instep girth was measured using the tape covering the circumference of the foot passing through the instep point. Subsequently, the heel girth was measured covering the dimension around a foot passing through the instep and heel feather point. The ankle girth was measured covering the circumference of the

ankle region of foot of the obese participants (Montagu and Brozek, 1960).

Total body-mass with minimum possible clothing was observed in standard weighing machines for the subjects. It can be clearly understood that the foot parameters identified for foot anthropometric survey are significantly distinct from the normal foot subjects. The characteristics such as girth dimensions of foot are wider and larger for obese participants. The foot survey research reveals the findings that the foot parameters of obese are not as similar as normal foot and there is a significant difference between them.

RESULTS

To achieve the objectives of the present study, morphological characteristics of sample feet were garnered. The primary anthropometric characteristics: Height, Weight, BMI, Ball girth, Instepgirth, Heelgirth, Ankle girth and Length of foot were measured from the participation of 55 male obese categorised people. It was observed that the age group ranges between 22 and 57 of the participants classified as obese were enrolled in the foot anthropometric studies. The heights of the participants ranging from 1.35 to 1.89 m were measured. The weight of the participants from 72 kg to the maximum weight of 120 kg was measured and subsequently the BMI values were measured under the ranges between 25.51 and 42.82. The fitting girth measurements were obtained from 240 to 295 mm. The instep girth values ranging between 250 and 355 mm were observed and followed with the heel girth

measurements from 240 to 390 mm. Finally, the ankle girth values ranging between 214 and 328 mm and length of foot from 215 to 395 mm were obtained from the participants.

The mean and standard deviation on the foot characteristics of obese were calculated and are shown in [Table 2](#).

The mean and standard deviation for height was 1.70 ± 0.08 , followed by weight and body mass index with 97.27 ± 15.24 and 33.77 ± 4.98 , respectively. The girth measures on the different regions of foot are shown in the [Table 2](#). The mean and standard deviation for the ball girth was 268.69 ± 12.10 , Instep girth 286.33 ± 23.64 , Heel girth 350.80 ± 30.17 , Ankle girth 265.56 ± 21.26 and length of foot 283.22 ± 28.88 .

Statistical analysis

The data collected on the foot characteristics were analysed using statistical methodologies. The following statistical parameters were observed: Mean, minimum, maximum, variation, range, standard deviation, degree of freedom, coefficient of variation and correlation coefficient. The statistical method "Bivariate Pearson analysis" was carried out initially. The bivariate Pearson Correlation produces a sample correlation coefficient, r , which measures the strength and direction of linear relationships between pairs of continuous variables. The Pearson Correlation evaluates whether there is statistical evidence for a linear relationship among the same pairs of variables in the population, represented by a population correlation coefficient, ρ ("rho").

The Pearson Correlation is a parametric measure. The correlation can take on any value in the range $[-1, 1]$. The sign of the correlation coefficient indicates the direction of the relationship, while the magnitude of the correlation (how close it is to -1 or $+1$) indicates the strength of the relationship:

- -1 : perfectly negative linear relationship
- 0 : no relationship
- $+1$: perfectly positive linear relationship.

The strength has been assessed by the following general guidelines:

- $0.1 < |r| < 0.3$ small / weak correlation
- $0.3 < |r| < 0.5$ medium / moderate correlation
- $0.5 < |r| < 1$ large / strong correlation.

The Body Mass Index and fitting girth, ankle girth had a statistically significant linear relationship ($p < .01$) and can be observed in [Table 3](#). The direction of the relationship was positive (that is, Body Mass Index and fitting girth, ankle girth were positively correlated), meaning that these variables tend to increase together. For instance: the

greater Body Mass Index is associated with larger fitting girth and ankle girth. The magnitude or strength of the association was approximately moderate ($0.3 < |r| < 0.5$).

The Body Mass Index and Instep girth and heel girth had a statistically significant linear relationship ($p < 0.05$). The direction of the relationship was positive, that is, Body Mass Index and instep girth and heel girth were positively correlated, meaning that these variables tend to increase together. For instance; the greater Body Mass Index is associated with greater instep girth and heel girth. The magnitude, or strength, of the association is approximately moderate ($0.3 < |r| < 0.5$).

The Body Mass Index and length of foot did not have a statistically significant linear relationship (that is, $p > 0.005$). The direction of the relationship was negative, that is, Body Mass Index and length of foot were negatively correlated and were inclined to decrease together. Hence, the magnitude or strength of the association is approximately weak ($0.1 < |r| < 0.3$).

The Scatter Plot is presented to graphically illustrate the relationship of BMI with foot parameters: Ball girth and Instep girth are shown in [Figures 1 and 2](#).

It can be observed from the tabulated data that most of the obese samples were within the range 30 to 35. From [Figure 1](#), it can be seen that the subjects of more than 80% are plotted within the body mass index ranges of 30 to 35. The fitting girth or ball girth parameter determines that the circumference measure of widest fore- part region of foot is concentrated in the ranges between 260 and 280 mm, respectively. It clearly implies that the subjects with the body mass index values of 30 to 35 possess wider ball girth dimensions and are categorised under wider fit measures.

From [Figure 2](#), it can be observed that the subjects of more than 70% are plotted within the body mass index ranges of 30 to 35. The instep girth parameter determines that the circumference measure of highest region of foot is concentrated in the ranges between 260 mm and 300 mm respectively. It describes that the subjects with the body mass index values ranging between 30 and 35 represent higher girth dimensions and are significantly distinctive as compared with normal foot characteristics.

From [Figure 3](#), it can be observed that the subjects of more than 80 % are plotted within a body mass index range of 30 to 35. The heel girth parameter determines that the circumference measure of heel region of foot is concentrated in the ranges between 300 and 380 mm respectively. It suggests that the subjects with the body mass index values between 30 and 35 represent higher heel circumference dimensions and are significantly possessing higher proportion as compared with normal foot characteristics.

From [Figure 4](#), it can be observed that the subjects of more than 60% are plotted within the body mass index ranges of 30 to 35. The ankle girth parameter determines that the circumference measure of ankle region of foot is concentrated in the ranges between 260 and 280 mm

Table 3: Statistical parameters for foot dimensions.

Item	Fitting girth mm	Instep girth	Heel girth	Ankle girth	Length of foot
Pearson Correlation	0.396**	0.301*	0.329*	0.369**	-0.09
Significance(2-tailed)	0.003	0.026	0.014	0.006	0.503

** . Correlation at 0.01(2-tailed).

*. Correlation at 0.05(2-tailed).

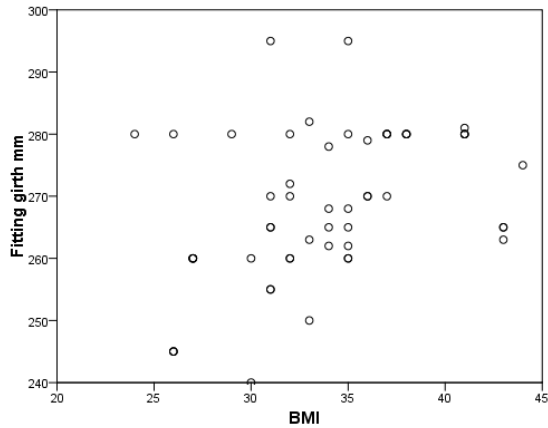


Figure 1: Scatter plot for BMI vs. Fitting Girth.

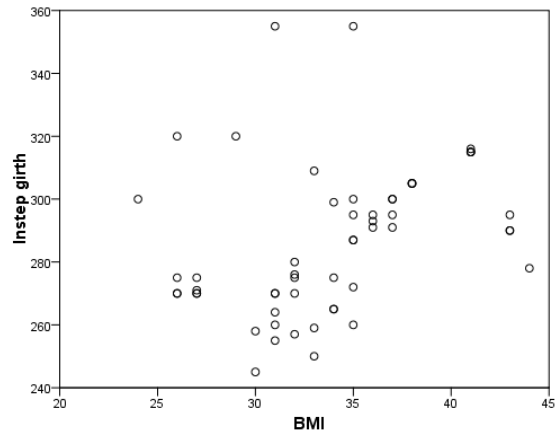


Figure 2: Scatter plot for BMI vs. Instep Girth.

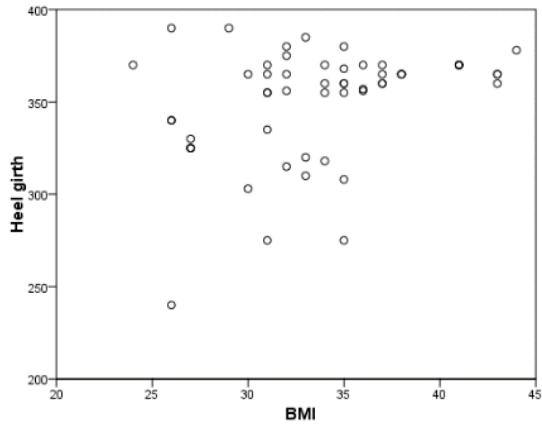


Figure 3: Scatter plot for BMI vs. Heel Girth .

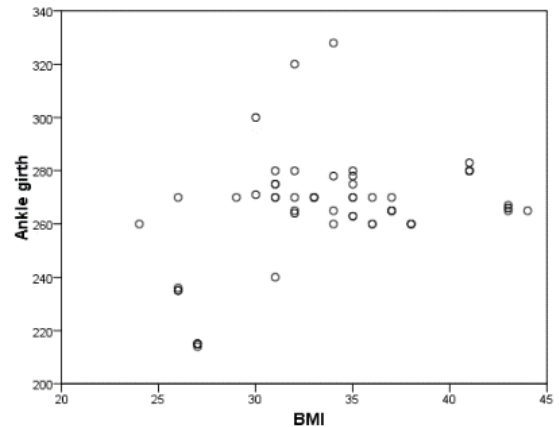


Figure 4: Scatter plot for BMI vs. Ankle Girth .

respectively. This implies that the subjects with body mass index values ranging between 30 and 35 represent higher ankle circumference values and are significantly different from normal foot characteristics.

In Figure 5, it can be observed that the subjects of more than 60% are plotted against the body mass index ranges of 30 to 35. The length of foot examined is around 275 mm and is concentrated densely in this region. This indicates that there is no significant difference in response of higher body mass index proportion falling under the obese category.

In summary, it is clearly understood that the obese feet possess higher range of foot dimensional characters and are evidenced from the scatter plot diagrams. These data indicate that the development of shoe-last is necessary exclusively for obese individuals. Since all the foot anthropometric parameters pertaining to obese are significantly different from the foot characteristics of normal subjects, the development of shoe-last and the construction of footwear assumes greater importance and is an immediate need for the well-being of obese individuals.

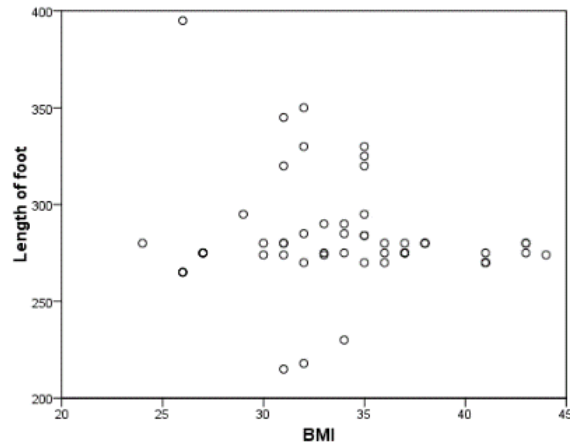


Figure 5: Scatter plot for BMI vs. Length of foot.

CONCLUSION

The foot morphological characteristics of obese individuals were evaluated and the data obtained were analysed statistically in this study. The Pearson Correlation analysis showed that the Body Mass Index, ball girth and ankle girth had statistically significant linear relationship and were found to be positively correlated. This indicates that with increase in Body Mass Index, the dimensions of ball girth and ankle girth also increase in proportion. Similarly, the Body Mass Index and Instep girth and heel girth showed statistically significant linear relationship, indicating increase in instep girth and heel girth with increase in body mass index. In the case of the relationship of Body Mass Index with the length of the foot, there was no much significant statistical linearity. Hence, this study concludes based on the findings that there is a significant difference in footwear between normal and obese individuals on the foot morphological features. These research findings will be helpful and supportive for the modelling of their shoe-last, as a result, the design and development of appropriate footwear exclusively for the obese individuals with fit and comfort, need to be considered.

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