

Foot anthropometrics in individuals with diabetes compared with the general Swedish population: Implications for shoe design

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Background: The literature offers sparse information about foot anthropometrics in patients with diabetes related to foot length, foot width and toe height, although these measurements are important in shoe fitting. A poorly fitted shoe is one of many contributory factors in the development of diabetic foot ulcers. The purpose of this study was to describe the foot anthropometrics in groups of patients with diabetes, in groups representing the general population and to explore whether foot anthropometrics differ between patients with diabetes and the general population.

Method: Foot anthropometrics (foot length, foot width and maximum toe height) was measured in 164 patients with diabetes, with and without neuropathy (n = 102 and n = 62 respectively). The general population was represented by 855 participants from two sources.

Results: Foot length, foot width and toe height varied (220-305 mm; 82-132 mm and 15-45 mm respectively) in the diabetic group and in the group representing the general population (194-306 mm; 74-121 mm and 17-31 mm respectively). Age, gender and BMI influence the foot anthropometrics, however, when adjusting for these variables the index foot length/width was lower (2.58) in patients with diabetes without neuropathy vs. controls (2.63), p = 0.018. Moreover, patients with diabetes with neuropathy had wider feet (98.6 mm) compared with the controls (97.0 mm), p = 0.047.

Conclusions: The individual variations of foot length, foot width and maximum toe height were large. The impact of gender on foot anthropometrics was confirmed and the impact of age and BMI were shown. Patients with diabetes seemed to have a wider forefoot width and a lower foot length to foot width ratio compared to the controls.

Keywords: foot deformities, foot ulcers, footwear, prevention, shoe design, shoe lasts, diabetes, diabetic foot, anthropometrics

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The biomechanical interaction between the foot and the shoe, three-dimensional appearance of the foot and the relationship between foot anthropometrics and the shoe have been shown to be important in the prevention of diabetic foot ulcers

(DFU) [1-3]. In Sweden at the present time, foot measurements are not mandatory when patients are provided with therapeutic footwear at a department of prosthetics and orthotics (DPO). However, foot measurements are essential for the construction of the

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last upon which the shoe is created. In the 1950s, the Swedish Shoe Industry's Research Institute (SFI) stated that the length and width of the foot should be measured before recommending any shoe to a customer [4]. Based on 8,000 foot measurements of Swedish men, the SFI constructed a standardised system, "the SFI last system", which aimed to provide the majority of Swedish men with well-fitting shoes. This system included six different types of lasts, specified in three dimensions.

In patients with diabetes, the loss of protective sensation (peripheral neuropathy), together with poorly fitting shoes, increases the risk of developing DFU [3, 5, 6]. The risk is further increased by the presence of other risk factors, such as peripheral angiopathy, peripheral neuropathy, foot deformities, skin pathologies, previous ulcers or amputation or osteoarthropathy, Figure 1 [7, 8]. Based on the recommendations of the International Working Group on the Diabetic Foot (IWGDF), patients with diabetes, should have access to well-fitting shoes if they are at risk of developing DFU [5, 9]. Early prevention, together with well-fitting shoes, podiatry and access to specialists, has been shown to be successful. Bus and van Netten recently suggested that the target should be to reduce the incidence of DFU by 75% [10]. Their suggestion is based on a review of the scientific literature regarding the prevention of DFU recurrence. These authors found that interventions that included pressure-relieving therapeutic footwear, surgical interventions, home monitoring of foot temperature and, most importantly, adherence to treatment could produce a 75-80% decrease in DFU risk. The provision of adequate footwear is considered successful when it corresponds in every aspect to guidelines and recommendations relating to DFU prevention and care; i.e. a) when the patient finds the shoe acceptable, b) when the shoe has a design that accommodates all three dimensions of the foot and c) when the function of the shoe is satisfactory [9, 11-15]. A shoe that does not accommodate the length, width and height of the foot will be a potential risk factor for the onset of DFU. It has also been suggested that other factors, such as the patient's age, gender and body dimensions expressed as body mass index (BMI), play an important role in shoe fitting [16-23].

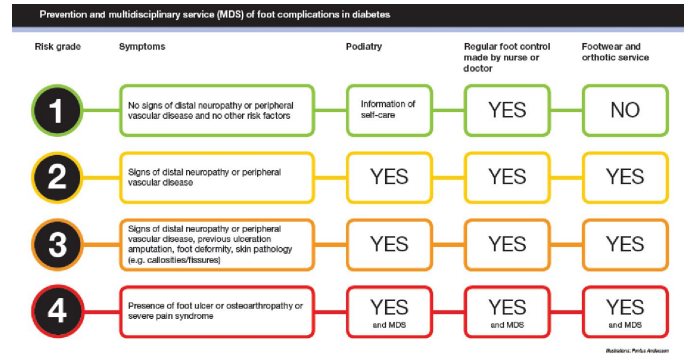


Figure 1 The Swedish foot ulcer risk classification system. The one-page guide line illustrates the risk classes, the symptoms and the regional recommendations regarding interventions with podiatry, regular controls and footwear/orthotics [7].

In Sweden, the prescription of footwear for patients with diabetes at risk of developing DFU follows national and regional guidelines and patients are frequently referred to a certified prosthetist and orthotist (CPO) or an orthopaedic shoemaker for the prescription of adequate footwear [7]. The aims of the study were to describe the foot anthropometrics in groups of patients with diabetes and in groups representing the general population and to explore whether foot anthropometrics differ between patients with diabetes and the general population.

Method

Study design

This retrospective cohort study examined and compared foot anthropometrics (foot length, foot width and maximum toe height) in a group of patients with diabetes, Group D (n=164), with those of a control group of participants without known diabetes, Group C (n=855), representing the general population (Figure 2).

Participants

A total of 1,019 participants were included in the present study. All patients in Group D were referred to a DPO by a medical doctor. Their feet were recognised as being at risk of DFU and the patients were provided with therapeutic footwear or insoles at the DPO. The participants have previously been described [24, 25].

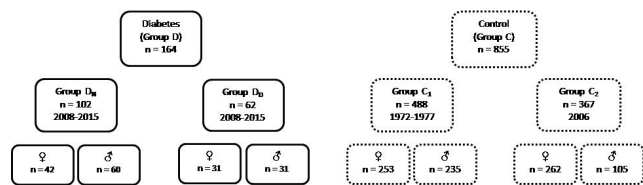


Figure 2. Study population. Presentation of the number of patients included in the two study groups derived from studies of patients with diabetes and studies of foot anthropometrics (the control group). The year when the measurements were obtained are shown in the figure.

Group D was split into two sub-groups, one comprising patients with peripheral neuropathy (D_N) and one comprising patients without neuropathy (D_D), Figure 2.

Group C comprised participants from two sources. One group consisted of participants from unpublished research from the SFI, Group C_1 . These data are stored at ArkivCentrum in Örebro, Sweden. The other group consisted of participants that have previously been presented by Hansson et al., Group C_2 [26].

Group D

Foot anthropometrics, age and gender in Group D were registered by nine experienced CPOs. All patients were at risk of developing DFU according to the Swedish DFU risk classification system (Figure 1) [7, 8]. The patient's body height and weight were self-reported. Neuropathy was diagnosed following international recommendations using a set of measurements [27, 28]. In detail, neuropathy was considered present if at least one of the following tests demonstrated a positive finding a) the 10 g monofilament test, vibration test using a tuning fork C128 Hz, the slight touch of a pencil, or awareness of different positioning of the hallux or b) a tingling or numb feeling in the feet, a positive Ipswich Touch Test or self-reported answers from the patients that their feet were currently less sweaty compared with recent years [27-29]. Forty-two (58%) of the women and 60 (66%) of the men had neuropathy. A total of 51 of the 164 (31%) patients were diagnosed with diabetes type 1.

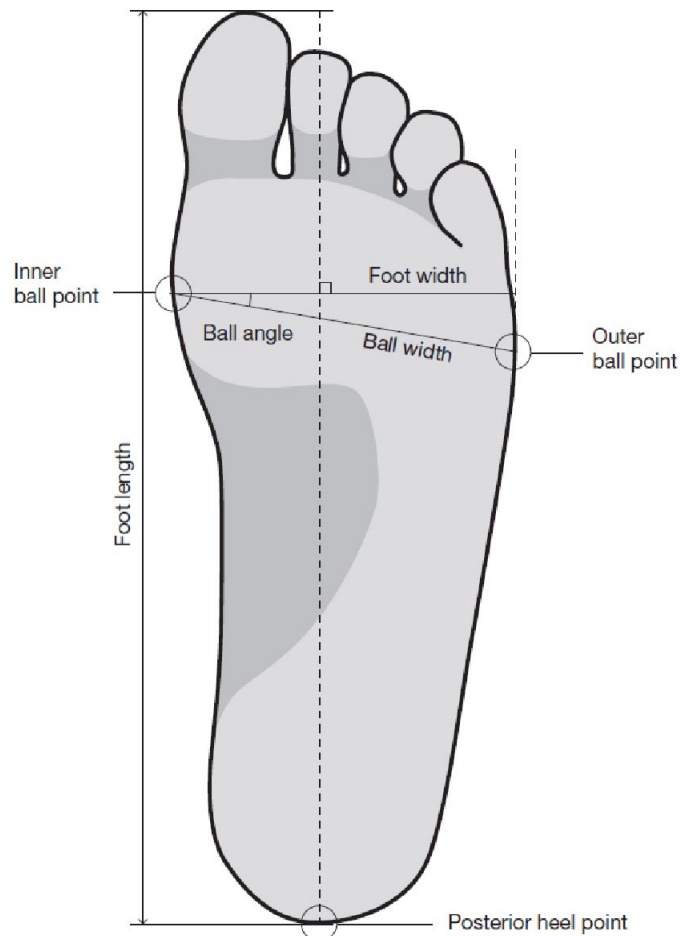


Figure 3 Definition of foot measurements. Foot length: the line, parallel to the foot axis, from the posterior heel point to the most distal toe point. The line passes through the centre of metatarso-phalangeal joint 2. Foot width: measured to the foot axis perpendicularly as the projected length of the distance in the forefoot through the centre of the first metatarsal head to the lateral side. Ball width: the line from the inner to the outer ball point. Ball angle: the space between the two intersecting lines “foot width” and “ball width”.

Control Group C_1

Foot anthropometrics, age and gender were registered in Group C_1 ($n=488$). A randomly selected cohort, 200 women and 200 men respectively, from a total of 2,382 (546 women and 1,836 men) individuals were analysed. The measurements were collected in Sweden 1972-1977 by the SFI [30, 31]. The women included in the cohort worked at shoe factories or offices and the men in the cohort were in the military service. The measurements of the conscripts were made by three different investigators in a project managed in collaboration with the Swedish Defence Materiel Administration [30]. The foot measurements of the retired persons and the 200 women were

registered and examined by one investigator employed at the SFI. A further set of 88 measurements, registered by SFI, from retired persons was included.

Control group C₂

Foot length, foot width, age, gender, height and weight were registered in Group C₂ [26]. The foot anthropometrics in Group C₂, 262 women and 105 men, were measured by trained personnel in 2006. Body height was measured using a rigid measuring tape attached to the wall. Body weight was measured with a digital measurement device with an accuracy of 0.1 kg. The raw data were obtained from Skövde University and Chalmers University of Technology, Gothenburg, Sweden [26].

Foot anthropometrics

The definition of foot length and width used in present study is described in Table 1 (all tables are included in attached Supplement PDF) and illustrated in Figure 3. The equipment, measurement and methods used in the sub-groups are reported in Table 1, together with information on the accuracy of the measurements. In Group D, foot length and foot width were measured with a standardised calliper (Fotmått, model Hyssna, Jerndahls Skinn & Läder; Kumla, Sweden, and Footy, article number 500210, Brunngård, Borås). In Group C₁, a special foot measurement apparatus (Figures 4 and 5) was used to measure foot length and ball width. The foot of the participants in Group C₁ were fixed in the foot measurement device and aligned in a local coordinate system with the foot length axis (line) projected from the posterior part of the middle of the heel through an interdigital point between digit 1 and digit 2. It is noteworthy that the measurements of foot length using this technique placed the heel in an 18 mm heel height position and the length measured was the projected foot length, Figure 3. The projected foot length is approximately 0.6 mm shorter than a measurement obtained with zero heel height. The only exception from this routine was the measurement of foot length and ball width in 97 conscripts, year 1975, and in the group of retired persons. These measurements were obtained using a special body calliper device, an anthropometer [32].

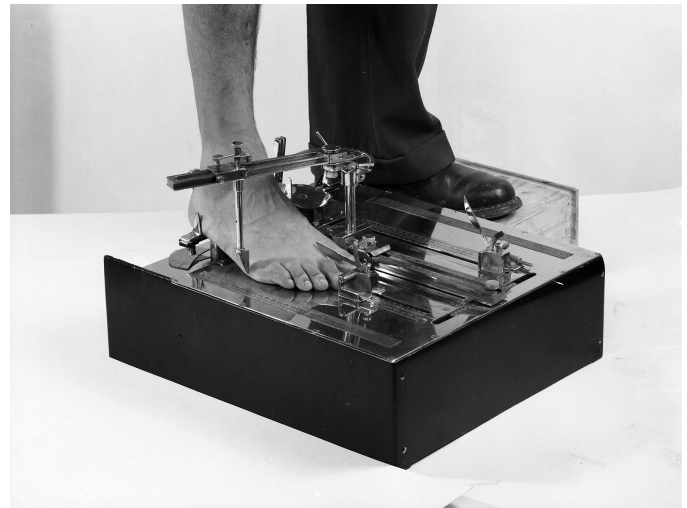


Figure 4 Foot measuring apparatus. The foot measurement apparatus was constructed to measure 21 foot anthropometrics (length, width, heights and angles). It was developed by Nils Haraldsson and used by the Swedish Shoe Industry's Research Institute. Between 1940-1990, the feet of 16,000 people in Sweden were measured. The right foot was placed naked and with the planta horizontally on the measurement device and fixed with a metal plate between the hallux and the 2nd toe. The posterior part of the heel rested against a bar. Subjects stood with their weight equally distributed between both feet. The heel height was fixed at 18 mm. Foot length was measured with a bar mounted perpendicular to a longitudinal scale. A turnable scale mounted on the longitudinal scale was used for measurements of ball width. All measurements at the SFI were performed with the same measurement device. Photographer Curt Götlén 1951/Örebro stadsarkiv.

In Group C₂, a rigid measuring tape was used to measure foot length and foot width with an accuracy of ± 2 mm. In Group C₁, the measurements of the width of the forefoot, made by the SFI, are by definition the ball width, a line from the inner ball point to the outer ball point, Figure 3. To calculate a comparable measurement of foot width, perpendicular to foot length, the following equation was used: $f(fw) = \cos \alpha * bw$ where fw is the foot width, α is the ball angle and bw is the ball width. The maximum toe height, a measurement for identifying the foot deformity "hammertoes" (Figure 6), was introduced and measured using a ruler. The SFI reported a standard error of the mean of 0.18 mm [4] for the toe height measurement and Hellstrand et al. found a mean difference of 0.5 mm [25]. In Group D, digits 1-5 were measured and, in Group C₁, toe height (digits 2-4) was measured in 200 women.

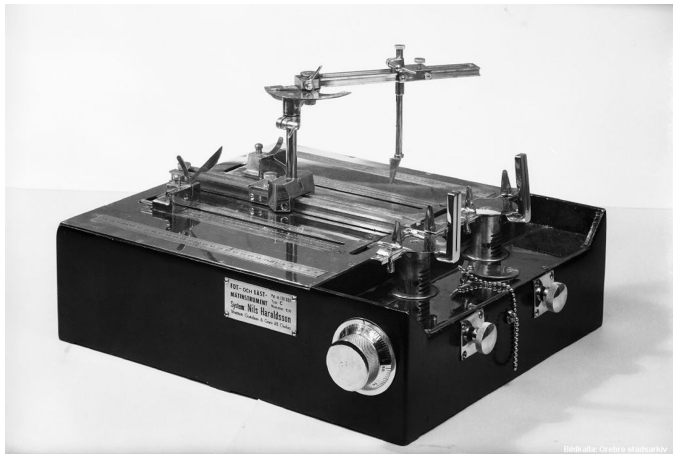


Figure 5 Foot measuring apparatus in detail. Foot measurement apparatus developed by Nils Haraldsson and used by the Swedish Shoe Industry's Research Institute. Between 1940-1990, the feet of 16,000 people in Sweden were measured. Photographer Curt Götlin 1951/Örebro stadsarkiv. Homepage available 2016-04-22 The apparatus can be seen at the Kumla Skoindustri Museum.

Patients reported experience measure

A subgroup ($n = 97$) of the patients with diabetes was interviewed by a research assistant, following a structured protocol, regarding how much they had used the footwear and how they experienced wearing the footwear

Statistical analysis

General demographics and the foot anthropometrics (length, width and maximum toe height) in the four groups are reported using the mean and standard deviation (SD). Due to dependency between the right and the left foot, only the right foot was analysed. Measurements with invalid data were excluded. Differences between groups regarding foot anthropometrics were examined in the following three comparisons.

Comparison 1 examined whether there were differences between groups (D_N , D_D , C_1 and C_2) in the dependent variables (foot length, foot width, $\text{index}_{FL/FW}$ and maximum toe height respectively). One-way analysis of variance (ANOVA) was used, followed by multiple comparisons. By using residual plots and Q-Q plots, the assumptions of the analyses were analysed.



Figure 6 Hammertoe deformity. A hammer toe deformity with areas of of high pressure indicated by the red areas. The structural changes is a combination of the flexion of the the interphalangeal joints and the extension of the metatarsal phalangeal joints.

The variable maximum toe height had minor deviations from the assumptions, with a skewed distribution of the residuals and the logarithmic value was therefore used for all further analysis.

Comparison 2 examined whether there were differences between groups regarding the dependent foot variables, considering the covariates of age and gender.

Comparison 3 examined whether there were differences between groups regarding the dependent foot variables, considering the covariates of age, gender and BMI.

In comparisons 2 and 3, the covariates were added in a linear mixed model with fixed effects with factors (study groups and gender) and quantitative variables (age and BMI). The above-mentioned foot anthropometrics were dependent variables. Differences between groups were corrected for differences regarding the covariates of age, gender and BMI. Group C_2 was excluded in comparison 2 in terms of the maximum toe height analysis (toe height had not been measured) and Group C_1 was excluded in comparison 3 (height and weight had not been measured).

Excel 2010, SPSS 22 and SAS version 9.3 (SAS Institute Inc. Cary, N.C., USA) software were used. The SAS procedure, MIXED with LSMEANS and ESTIMATE statements, statistical tests and comparisons of population marginal means were used

in the comparative analyses. In the following text, the term “analysis of covariance” is used to describe the method.

Results

The demographics showed that participants with diabetes were older and had a higher BMI (women: 61 ± 14.4 years BMI 26.7 ± 4.9 ; men: 63 ± 13.7 years BMI 28.7 ± 5.2) compared with the participants representing the general population (women: 41 ± 16.5 years BMI 23.1 ± 3.4 ; men: 34 ± 17.9 years BMI 24.1 ± 3.5). A full presentation of the participants is given in Table 2. In Table 3, the details (HbA1c and duration) of patients with diabetes are presented.

The analysis of foot anthropometrics was based on 164 measurements in Group D and 855 measurements in Group C, Figure 2. The exploration of foot anthropometrics revealed that, among women, the foot length varied from 245.4 ± 10.9 mm (Group D_D) to 242.3 ± 12.3 mm (Group C₂) and the width varied from 96.8 ± 4.9 mm (Group D_D) to 90.9 ± 7.7 mm (Group C₁), Table 4. Women with diabetes with neuropathy had the largest toe height (25.8 ± 4.6 mm).

The foot length among men varied from 271.4 ± 15.2 mm (Group D_N) to 262.7 ± 13.7 mm (Group D_D). Moreover, the width varied from 105.8 ± 7.9 mm (Group D_N) to 98.8 ± 5.7 mm (Group C₁). Men in Group D_N had the largest toe height (28.3 ± 5.7 mm).

The individual variation in foot anthropometrics in patients with diabetes was: foot length (220-305 mm), foot width (82-132 mm) and toe height (15-45 mm) and the variation in the control group was foot length (194-306 mm), foot width (74-121 mm) and toe height (17-31 mm).

The first comparison of differences between groups revealed that patients in Group D_N had 11.0 mm longer feet compared the controls in Group C₂ ($p \leq 0.001$). The controls in Group C₁ had 5.5 mm longer feet than the controls in Group C₂ ($p \leq 0.001$). Foot width in patients with and without neuropathy was wider (101.5 mm and 99.6 mm respectively) compared to the controls ((94.7 mm and 94.4 mm respectively, ($p \leq 0.001$)). Maximum toe height was higher in patients with diabetes and neuropathy (26.9 mm) compared with the controls in Group C₁ (25.2

mm) ($p \leq 0.001$).

In the second comparison, considering the effect of age and gender on foot anthropometrics, only the index_{FL/FW} was unaffected by age and gender and the covariate of age did not affect foot length. However, regarding foot width, both men and women had an estimated annual increase in width of 0.085 mm/year and men generally had 9.0 mm wider feet than women. Maximum toe height was affected in a similar way. Men had a 0.09 mm higher maximum toe height compared with women. With age, the increase in toe height was 0.03 mm annually. Group D_N had a larger toe height (25.5 mm) than Group D_D (24.4 mm), $p = 0.049$. Furthermore, Group D_D had a lower toe height than Group C₁ (27.1 mm), $p \leq 0.001$. Foot width, adjusted for age and gender was wider in patients with diabetes compared to the controls and accordingly the index_{FL/FW} was higher in the groups representing the general population compared to the diabetics.

The third comparison revealed that gender and BMI affected foot length and foot width. With every unit increase in BMI, foot length and foot width increased by 0.6 mm. Adjusting for these covariates, foot width still differed comparing Group D_N with Group C₂ (98.6 mm vs. 97.0 mm), $p = 0.047$. The index_{FL/FW} differed when comparing Group D_D (2.58) with Group C₂ (2.63) $p = 0.018$.

Patients reported experience measure

Eighty-six out of a total of 97 patients (response rate 89%) participated in the interview at three months after the visit to the DPO (Table 6). Thirty patients had been provided with footwear and among those 70% had used their therapeutic footwear often or all the time and 76 % stated they were content or very content with the footwear. Twenty-nine patients made comments, Table 7. Seven of the comments were categorised as complaints related to the footwear, such as “The shoe appears to be too large”. Ten patients reported that the use of footwear and/or foot orthoses was dependent on the season and location (indoors or outdoors).

Discussion

To our knowledge, this is the first study presenting foot anthropometrics in patients with diabetes and the general population in terms of foot length, foot width, index_{FL/FW} and maximum toe height. Foot

length, foot width and toe height varied in the diabetic group (220-305 mm; 82-132 mm and 15-45 mm) and in the group representing the general population (194-306 mm; 74-121 mm and 17-31 mm). Patients with diabetes had wider feet compared to the participants representing the general population. The main finding is that several factors affect foot anthropometrics and include the presence of diabetes, neuropathy, gender, age and BMI.

The maximum toe height measurement is of special interest when it comes to preventing foot ulcers in patients with diabetes (Figure 6). Large toe height is typical of a hammer-toe deformity. This deformity with dorsal flexion of the metatarsal phalangeal joint and plantar flexion of the interphalangeal joints, causes high peak pressure to certain areas of the toe [33]. Measurements of maximum toe height provide important information and guidance in the selection of a shoe with an appropriate toe box height relative to the maximum individual toe height. A threshold value of 25 mm is suggested, based on toe box heights common in off-the-shelf shoes, ranging from 22-26 mm [34]. The range for toe box height and the suggested threshold value correspond well to the toe box heights (24.5-28.5 mm) standardised in the SFI lasts for men with a foot length of 260 mm [4]. Patients with a toe height of greater than 25 mm should be identified and provided with shoes with a toe box height that allows the toes to move without limitation [35].

Foot anthropometrics appeared to be affected by age. Based on the presented data, the toe height age coefficient of 1.003 indicates an annual increase in maximum toe height of 0.3% (Table 5). A simulation of an increment in toe height implies that a person who, at the age of 20, has a maximum toe height of 25 mm would, at the age of 40 years, have a toe height of 27.8 mm (a total increase of 10.4%). At the age of 80 years, the maximum toe height would be 29.2 mm (a total increase of 15.5%).

The effect of age on foot width was not statistically significant when all three covariates (age, gender and BMI) were included in the model. However, Tommassoni et al. measured ball forefoot circumference as a combined width and height measurement and found an increase with age [22]. In their study, older women (65-75 years) had a larger forefoot circumference, 235.4 ± 8.3 mm, compared

with younger women (25-35 years) 217.2 ± 11.5 mm. Tommassoni found similar results for older men (256.4 ± 7.8 mm) vs. younger men (242.1 ± 17.4) [22]. A well-fitting shoe, with good function, should correspond to the forefoot width and the forefoot circumference to avoid pressure-induced DFU in the forefoot. Previous findings shows that unfortunately, wearing ill-fitting shoes that are too narrow, are common [36].

The CPOs and orthopaedic shoemakers play an important role in guiding patients towards choosing an appropriate shoe. In this context, foot measures obtained on regular basis, are a good starting point for a discussion between the CPO and the patient regarding shoe lasts that fit the foot according to foot length, foot width and toe height.

Not surprisingly, gender was a covariate of importance to explaining the variation in foot anthropometrics in terms of foot length and foot width. Both measurements, length and width, were larger in men than in women (comparison 2, Table 5) and the results confirm previous findings of gender differences, showing that men in general have longer and wider body segments than women [22, 37-39]. Several shoes are designed for unisex purposes and it is reasonable to consider whether shoes manufactured on such lasts actually fit both men and women [40]. The findings in the present study show gender differences for all three dimensions of the foot.

Possible systematic errors in measurement technique (tools and personnel) and/or sample bias might affect the validity of the data. The foot measurement apparatus developed and used by the SFI was designed to obtain robust measurements on thousands of people in Sweden half a century ago. These measurements had high precision (Table 1). The measurement error reported in Group C₁ was small (± 0.14 mm) in terms of the foot length. Measurements and the accuracy of foot length and foot width, measured with a rigid measuring tape in Group C₂ was acceptable ± 2 mm [26]. The mean difference regarding foot length and foot width measurements in Group D was (0.2 and 0.7 mm respectively), which indicates that the method used was reliable [25]. The method for measuring foot width was similar in Group D and Group C₂. The foot width in Group C₁ was derived from the ball

width measurements, Table 1 and Figure 3 [30]. Due to the high accuracy of the ball width measurements (± 0.06 mm) the calculated foot width measurement is considered to be high [4]. The measurement error in toe height measurement was acceptable in Group C₁ (± 0.18 mm) and in Group D (a mean difference of ± 0.5 mm).

The lack of anthropometric foot data of greater sample sizes was the reason for the use of several data sources, some of older date. The data from SFI was considered to be of high quality as the foot anthropometrics in Group C₁ was obtained by the use of a well-established technique with high accuracy [30-32, 37, 41].

A certain question of interest is whether the participants born at later date, in general, had longer body segments and longer feet. This might be an expression of the secular trends [4, 42-44]. In that case, a consequence should be that the general population born in the 1960s (Group C₂) would have longer feet than the older population born in the 1930s (Group C₁). However, no such difference was supported in the present data.

Patients with diabetes and neuropathy appeared to have longer feet (comparison 1) and higher toe height (comparison 2). However, due to multiple comparisons the p-value is not convincing and this finding need to be confirmed in larger studies. Moreover, the test of assessing neuropathy in current study did not discriminate between slight and severe expressions of neuropathy. It is reasonable to expect that imbalance of muscle forces leading to foot deformities is related to the severity of neuropathy.

Patients reported experience measure

The majority of the patients who received therapeutic footwear used the footwear frequently and were satisfied with the footwear. However, the standardized routine used in the interview has not been validated. It is suggested that a combination of interviews and validated surveys should be used in coming studies [45]. Bus and van Netten showed that adherence to the prescribed intervention is a primary factor for successful treatment of DFU, i.e. the provision of adequate footwear is only successful if the patient uses the shoes [10]. Consequently, the patient must find the shoe suitable according to

his/her preferences, and the shoe must have a shape and function suitable for the foot, considering the general recommendations in terms of DFU prevention and care [9, 11]. This is a challenge as, besides being an assistive devices [46], footwear is part of the patient's personal attributes and identity.

Statistical considerations

The results of the three comparisons (ANOVA analysis and the following two analyses of covariance) were not adjusted for multiple comparisons, i.e. some of the differences may have appeared by chance. Therefore, the p-value increased when the covariates of age, gender and BMI were included in the model. Prospective longitudinal studies, including larger cohorts, are suggested to confirm the findings of the present study. All four study groups were included in the first comparison of differences in foot anthropometrics between groups. However, due to lack of data of height and weight, C₁ was excluded in comparison 3, the analysis in which BMI was considered. In the comparison of maximum toe height, Group C₁ was represented by a cohort of 200 women and Group C₂ was not included due to lack of relevant data.

Shoe design

Large individual diversity, in terms of foot length, width and maximum toe height, was present in patients with diabetes with and without neuropathy. Moreover, age, gender and BMI influence the foot shape of individuals. All these aspects need to be considered in shoe design. The shoe last must correspond to the three-dimensional appearance of the foot, allowing the forefoot and the toes to move [36, 47]. Appropriate fit at the hindfoot and midfoot is also essential to ensure that the shoe stays on the foot [4].

One basic prerequisite for functional shoe design is an appropriate knowledge of foot biomechanics [5, 36, 48]. This is of utmost importance when manufacturing shoes for patients at risk of developing DFU. In order to enhance the shoe-fitting procedure, standardised routines including regular measurements of foot anthropometrics are suggested. This should preferably be supplemented by a shoe measurement specification from the manufacturer. Moreover, a thorough documentation of foot anthropometrics in

patient's medical record would facilitate a long-term provision and follow-up.

To highlight the need for standardisation, the following example of shoe length in relation to foot length is presented. The recommendation for how much longer a shoe should be in relation to the longest toe, found in the literature, varies and ranges from 10 to 20 mm [35, 49]. In clinical practice in Sweden, an extra length of 10 mm is recommended in relation to the foot length of adults, measured in a weight-bearing position [50].

The index_{FL/FW} needs to be rediscovered and used in shoe fitting. This measurement was recommended by the SFI and was used in shoe shops in the 1950s to 1970s, before an appropriate shoe last was chosen for the customer. The index_{FL/FW} gives a two-dimensional ratio, which is of great interest and assistance before a suitable last type is selected for patients [4, 47, 49]. When custom-made orthopaedic shoes are required a further set of measurements are needed [4].

In the development of good practice to prevent DFU, some attempts have been made to structure the provision of footwear and therapeutic footwear [35, 51]. Dahmen et al. developed a matrix of the features to be included in a therapeutic shoe, e.g. rocker bar, outsole, shaft flexibility, shaft height, insole and heel counter, corresponding to the identified risk factors for the onset of DFU. These risk factors were loss of protective sensation, autonomic dysfunction, limited joint motion, hollow-claw foot, Charcot deformity and hallux amputation [11, 52]. A limitation in the matrix was the lack of foot anthropometrics, such as length, width, the index_{FL/FW} or maximum toe height. However, length measurement was included in the footwear assessment tool presented by Barton et al., but this tool did not include the width or maximum toe height [51].

Conclusion

The individual variations of foot length, foot width and maximum toe height were large. The impact of gender on foot anthropometrics was confirmed and impact of age and BMI was found. Patients with diabetes seemed to have wider forefoot width and a lower foot length/foot width ratio compared to the controls. Standards for measurements of foot length, foot width and toe height should be developed and

used at the DPOs. Accordingly, shoes designed for patients with diabetes should include the same standardised information as the foot measurements.

Declarations

Abbreviations

BMI; body mass index, DFU; diabetic foot ulcers, CPO; certified prosthetist and orthotist, C; control, DPO; department of prosthetics and orthotics, D; diabetes, IWGDF; International Working Group on the Diabetic Foot, SD; standard deviation, SFI; the Swedish Shoe Industry's Research Institute

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Availability of data and material

The data sets supporting the conclusion of this article are included in the article.

Authors' contribution

UT designed the study, researched the data, contributed to discussions, and wrote the manuscript. JS and RT designed the study, researched the data, contributed to discussions, reviewed and edited the manuscript. KH and JK contributed to discussions, reviewed and edited the manuscript.

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Competing interest

The authors declare that they have no competing interests.

Consent for publication

Not applicable.

Ethics approval consent and permission to participate

The study was approved by the Gothenburg Regional Ethical Review Board (299-07, 461-12 and 1041-13). Patients were informed of the study design before they provided written consent.

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