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Research on Establishing a Foot Sizing System for Women with Diabetes as a Basis for Shoe Design

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Abstract

Diabetic patients often suffer from foot diseases, in which foot ulcers are a dangerous complication and lead to the risk of amputation. Therapeutic shoes are well-fitting (highly comfortable) shoes that play an important role in reducing the risk of foot ulcers. Therefore, diabetics need to use therapeutic shoes, which are designed based on the patient's foot measurements. This article presents the results of research on establishing a foot size system based on measurements of 221 female diabetic patients at Khoai Chau District Medical Center, Hung Yen Province and at National hospital of Endocrinology. As a result, a foot size system based on the French size system has been built. The size system includes 5 sizes by foot length: 218, 224.5, 231, 237.5 and 244 mm. Each size of foot length has 5 sizes of its width (fullness). This size system accommodates more than 92.6% of the feet of women with diabetes. The research results are the basis for designing shoes to meet the usage requirements for Vietnamese women with diabetes.

Keywords: Diabetes, diabetic patients, shoes for diabetics.

1. Introduction

Diabetes is a dangerous chronic disease and the number of people affected is increasing rapidly, especially in developing countries such as Vietnam [1-3]. According to research results of the National hospital of Endocrinology [4], in 2020, in Vietnam, the rate of diabetes in people between 30 and 69 years old is 7.3%, the rate of pre-diabetes is 17.8%. The rate of undiagnosed diabetes is 62.6%. By 2025, Vietnam will have about 8.7% or about 4.2 million people from 30 to 69 years old with diabetes [4].

The feet of diabetic patients often suffer from different types of damage such as dry skin, peeling or cracking, calluses, deformities, impaired/loss of protective sensation and ulcers [2, 3]. Wounds on the feet, especially ulcers, are very difficult to heal due to lack of oxygen and nutrients, reduced antibodies, etc., and lead to a high risk of amputation. Over 25% of diabetic patients have foot-related problems and the risk of amputation in diabetic patients is 15 - 46 times higher than that of people without the disease [5-7].

Therapeutic shoes have been shown to play an important role in reducing diabetic foot ulcers [8-11]. Using inappropriate (uncomfortable) shoes is also one of the main causes of diabetic foot ulcers. Research results by Shan M Bergin [9] reported that the rate of diabetic foot ulcers due to trauma from footwear was 54.0%. According to research by Viswanathan *et al.* the rate of new lesions on the feet of diabetic patients wearing regular shoes is up to 33%, while in patients wearing therapeutic shoes this rate is only 4% [10]. Luigi U.'s study [11] reported that the number of diabetic patients with foot ulcers due to poorly fitting shoes was 5.1 times higher than that of patients wearing well-fitting shoes.

That is why studying diabetic feet to design therapeutic or well-fitted shoes/highly comfortable shoes is of interest to scientists around the world [12-14]. Research results show that, due to complications, the anthropometric characteristics of diabetic feet are different from those of people without this disease. Normally, the width and circumference measurements of diabetic feet are larger than normal human feet. The degree of difference depends mainly on the level of patient's foot complications [12-14].

In Vietnam, recently there have been studies on anthropometric characteristics of diabetic female feet [15-17]. However, these studies were conducted in one location so representativeness may not be guaranteed. In this study, the feet of women with diabetes were measured at two different medical locations to establish a foot size system for them. This is the basis for designing shoe lasts and "Extra Depth Diabetic Shoes" for mass production [18].

2. Research Objects and Methods

2.1. Research Objects

The research subjects were female diabetic feet,

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mainly type 2. Diabetic feet, depending on the level of complications and risk of ulcers, were divided into 4 groups [9, 11]:

1) Low risk group for foot complications: Normal feet, normal foot protection sensation;
2) Moderate risk group for foot complications: Impaired protective sensation of the foot, no foot deformity, no history of foot ulcers or previous amputation;
3) High risk group for foot complications: Loss of protective foot sensation, foot deformities, no history of foot ulcers or previous amputation;
4) Group at very high risk of foot complications: Loss of protective foot sensation, foot deformities, history of foot ulcers or previous amputation.

The goal of the research is to study the feet to mass-produce "Diabetes Shoes with Deep Depth" for women with diabetes. Therefore, this study focuses on groups at low and moderate risk of foot complications. “Extra Depth Diabetic Shoes” will help prevent foot ulcers in diabetic patients. Patients with a history of foot ulcers or at high risk of foot ulcers should use customized shoes and insoles [18].

2.2. Research Methods

The overall flow chart of the process and method of measuring the feet and establishing the foot size system for women with diabetes is shown in Fig. 1.

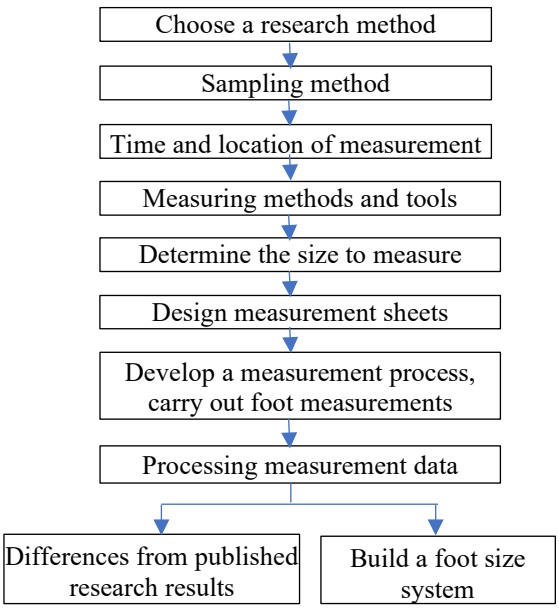


Fig. 1. Flow chart of the process of establishing the foot size system for women with diabetes

2.2.1. Time, location and number of patients need to be measured

In this study, a cross-sectional anthropometric research method was used. This means measuring the feet of different patients at the same time period. Patients were randomly selected according to their list.

In this study, patients at low and moderate risk of foot ulcers were selected for study.

To ensure the representativeness and reliability of the measurement results, the number of feet to be measured is calculated by the formula [19]:

$$m = \frac{t\sigma}{\sqrt{n}} \Rightarrow n = \frac{t^2\sigma^2}{m^2}, \quad (1)$$

where: n - is the number of feet to be measured; t - is the probability: with $p = 0.95$, $t = 1.96$; m - is the error of the set (mm), $m = 1, 2, 3, 4, 5...$; σ- is the standard deviation of foot length (mm).

Measurement results of 30 female patients showed a value of σ equal to 9.3 mm. According to (1), with $p = 0.95$, the minimum number of feet to be measured (n) with $m = 1$ mm is 332, $m = 2$ mm is 83.

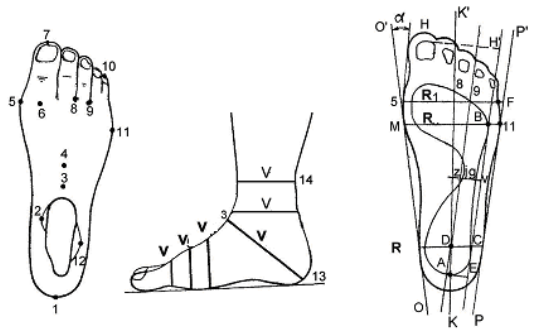
To ensure representativeness of the measurement results, we measured patients' feet at two medical locations.

1) Khoai Chau district Medical center, Hung Yen province. This is a typical province of the Northern Delta region of Vietnam. At this center, diabetic patients periodically come for examination and get medicine. The measurement period is from January 2021 to April 2021. Feet were measured on weekday mornings. Hereafter referred to as HY group.
2) Department of Endocrinology - National Endocrine Hospital. At this hospital, there are not only patients living in Hanoi but also patients living in the Northern provinces of Vietnam coming for examination and treatment. Measurement period is from December 2022 to January 2023. Hereafter referred to as the NT group.

At these 2 locations, the feet of 221 female diabetic patients were studied, specifically: group 1 was 116 patients, group 2 was 105 patients. This number is larger than the minimum number that needs to be measured, which is 83 people.

2.2.2. Methods and tools for measuring feet

The direct measurement method is used to measure the foot. Patients stood upright, their body weight evenly distributed on both feet, the distance between the feet was 20 cm [19]. Both bare feet were measured. Before measuring, anthropometric landmarks on the foot were marked as shown in Fig. 2 a, b [19].



a b c

Fig. 2. Anatomical points on the foot and foot measurements, in which:
1 - Pternion
2 - The most medial point of medial malleolus
3 - Junction point
4 - Top of instep point
5 - Metatarsale tibiale
6 - Top of ball girth point
7 - Tip of 1st toe
8 - Point between 2nd toe and 3th toe
9 - Point between 3th toe and 4th toe
10 - Tip of 5th toe
11 - Metatarsale fibulare
12 - The most lateral point of lateral malleolus
13 - Landing point
14 - Ankle point.

The measurements of the foot are determined as follows (Fig. 2):

Lbc - Foot length: Distance from point 1 to point 7;
Lkt - Length to medial ball: Distance from point 1 to point 5;
Lkn - Length to lateral ball: Distance from point 1 to point 11;
Lngu - Length to the end of 5th toe: Distance from point 1 to point 10;
Rkt - Width of medial ball: Distance from point 5 to point F;
Rkn - Width of lateral ball: Distance from point 11 to point M;
Rkng - Width of ball: Distance from point 11 to point 5;
Rg - Width of heel: Measured at the widest part of the heel;
Vkt - Medial ball girth: Perimeter of cross-section measured through point 5;
Vkn - Lateral ball girth: Perimeter of cross-section measured through point 11;
Vkng - Ball girth: Perimeter of cross-section measured through point 5 and point 11;
Vgi - Waist girth: Perimeter of cross-section measured through point 4;
Vbu - Instep girth: Perimeter of cross-section measured through point 3;
Vgot - Heel (cross) girth: Perimeter of cross-section measured through point 3 and 13;
Cnc - Height at 1st toe: Measured in the middle of 1st toe nail;
Ckt - Medial ball height- Height at point 6;
Cgi - Waist height - Height to point 4;
Cbu - Instep height - Height to point 3;
Cmc - Height at lateral ankle center: Height to point 12.

Feet are measured by a flexible tape measure, a caliper with a minimeter scale, and a foot measuring device.

2.2.3. Method to build a foot size system for diabetic patients

Excel software is used to process measurement data. After eliminating raw errors, the maximum value (*Max*), minimum value (*Min*), average value (*Mean*), and standard deviation (σ) of 23 parameters of the left and right feet were determined. The mean values of the left and right foot measurements of each patient group were compared. Next, we compared the mean foot measurements of the two patient groups. This is the basis for combining measurement data to build a foot size system for diabetic patients. The differences between the mean values of the left and right foot measurements of each patient group, as well as the average values of the two patient groups, were evaluated by ANOVA test.

The foot size system is built as for a normal human foot, as following proceduce [17, 19]:

1) Determine key measurements of the foot. Which are usually the length and ball circumference.
2) Build regression equations between key measurements and the remaining ones.
3) Select increments of key measurements.
4) Suggest the optimal number of sizes according to the foot length and width/fullness.
5) Build a table of foot measurements for each size.

In step 3, we need to select increments of key measurements of the foot. This depends on the sizing system selected. Currently, in the world, the French, English, American, Metric and Mondopoint international size systems are the most commonly used. In this study, the foot size system was built according to the French size system with length increments of 6.67 mm. This increment is most suitable. It is convenient for patients to choose shoes that fit their feet. And the sizing system has a reasonable number of sizes.

3. Results and Discussion

3.1. Foot Measurements of Women with Diabetes

According to the data in Table 1, the average values of the measurements of length, width, height, and circumference of the right and left feet of HY group 1 differ by no more than 0.5 mm. This difference in NT group is no more than 1.3 mm. ANOVA analysis

results showed that there was no real difference in the measurements of the left and right feet of each study patient group ($p > 0.05$). This shows that the patient's choice and use of shoes will be convenient. Shoes are produced in pairs, in which the left shoe and right shoe are symmetrical. Therefore, it is necessary to average the measurements of the right and left feet to build a foot sizing system. This also increases the reliability of the measurement results, as the number of feet measured is doubled (442 feet). The difference in average values of foot measurements of the two patient groups is shown in Table 2.

Table 1. Average values of measurements of the right and left feet according to each patient group

Foot measure-ments	HY group						NT group					
	Mean, mm			*σ*, mm			*Mean*, mm			*σ*, mm		
	Right foot	Left foot	Difference	Right foot	Left foot	Difference	Right foot	Left foot	Difference	Right foot	Left foot	Difference
Lbc	231.9	231.6	0.3	8.2	8.2	0.0	230.2	231.1	-0.9	8.3	8.7	-0.4
Lkt	168.5	168.6	-0.1	7.3	7.6	-0.3	166.1	166.4	-0.3	6.8	7.0	-0.2
Lkn	150.0	149.9	0.1	7.2	7.5	-0.3	147.4	148.7	-1.3	6.3	6.1	0.2
Lngu	193.8	193.5	0.3	7.8	8.0	-0.2	190.3	191.6	-1.3	7.7	7.8	-0.1
Lgot	42.3	42.7	-0.4	5.4	5.3	0.1	41.3	41.1	0.2	5.5	5.7	-0.2
Rkt	93.6	93.3	0.3	4.7	5.0	-0.3	91.6	92.5	-0.8	5.5	5.4	0.1
Rkn	89.1	89.0	0.1	5.5	5.6	-0.1	87.9	89.0	-1.1	5.3	4.9	0.4
Rkng	96.2	96.5	-0.3	5.7	5.5	0.2	95.7	95.2	0.5	5.5	5.2	0.3
Rg	61.0	60.7	0.3	3.1	3.3	-0.2	60.2	60.9	-0.7	3.6	3.6	0.0
Cnc	19.7	20.1	-0.4	1.8	1.7	0.1	18.4	18.9	-0.6	1.6	1.6	0.0
Ckt	31.1	30.8	0.3	3.1	3.2	-0.1	30.0	30.8	-0.8	3.0	3.0	0.0
Cgi	44.1	43.7	0.4	4.6	4.6	0.0	47.5	48.4	-0.9	4.6	4.4	0.2
Cbu	60.0	59.8	0.2	5.2	4.9	0.3	62.1	62.5	-0.4	4.9	4.9	0.0
Cmc	59.4	59.4	0.0	3.3	3.4	-0.1	55.7	56.3	-0.6	3.1	3.4	-0.3
Vkt	210.2	210.1	0.1	11.2	10.9	0.3	209.8	210.2	-0.4	11.0	10.9	0.1
Vkn	212.4	212.3	0.1	10.1	10.4	-0.3	213.0	212.8	0.2	10.0	9.9	0.0
Vkng	223.7	223.7	0.0	12.2	12.6	-0.4	222.7	223.0	-0.3	12.3	12.6	-0.3
Vgi	217.5	217.5	0.0	9.8	10.0	-0.2	214.3	214.6	-0.4	9.6	9.9	-0.3
Vbu	240.0	239.1	0.9	11.5	11.3	0.2	237.3	237.4	-0.1	11.1	11.3	-0.2
Vgot	292.9	292.8	0.1	13.6	13.9	-0.3	294.7	295.1	-0.4	13.1	13.6	-0.5
Vco	190.1	190.2	0.0	15.0	14.6	0.4	194.9	195.2	-0.3	15.1	14.9	0.2
Goc	8.9	9.9	1.0	8.3	8.1	0.2	7.8	9.8	-2.0	8.3	8.2	-0.1
H	0.8	0.8	0.1	0.2	0.1	0.1	0.8	0.7	0.0	0.2	0.1	0.1

Table 2. Average values of foot measurements of each patient group and average of both groups

Foot measure-ments	*Mean*, mm				*σ*, mm			Both groups of patients			
	HY group	NT group	Difference	*p*	HY group	NT group	Difference	*Mean*, mm	*σ*, mm	*Min*, mm	*Max*, mm
Lbc	231.7	230.7	1.0	0.3799	8.2	8.5	-0.3	231.2	8.4	205.0	251.5
Lkt	168.5	166.2	2.3	0.0142	7.5	6.9	0.5	167.4	7.2	149.0	181.5
Lkn	150.1	148.0	2.1	0.0149	7.4	6.2	1.2	149.1	6.8	132.5	164.5
Lngu	193.5	191.0	2.5	0.0158	7.9	7.8	0.2	192.4	7.8	173.5	208.0
Lgot	42.5	41.2	1.3	0.0000	5.4	5.6	-0.3	41.2	5.5	36.5	47.0
Rkt	93.5	92.1	1.4	0.0717	4.9	5.5	-0.6	92.8	5.2	79.0	107.5
Rkn	89.1	88.5	0.6	0.4780	5.6	5.1	0.5	88.8	5.3	73.5	103.5
Rkng	96.3	95.5	0.8	0.5389	5.6	5.4	0.3	95.5	5.5	83.0	108.5
Rg	60.8	60.6	0.2	0.6949	3.2	3.6	-0.4	60.7	3.4	48.0	74.0
Cnc	19.9	18.7	1.2	0.0000	1.8	1.6	0.2	19.3	1.7	15.0	25.0
Ckt	31.0	30.4	0.6	0.0960	3.2	3.0	0.2	30.7	3.1	23.5	39.0
Cgi	43.7	46.9	-3.2	0.0000	4.6	4.5	0.1	45.7	4.6	37.5	57.0
Cbu	59.6	62.3	-2.7	0.0710	5.1	4.9	0.2	60.9	5.0	52.0	73.5
Cmc	59.4	56.0	3.4	0.0000	3.4	3.3	0.1	57.8	3.3	49.0	64.5
Vkt	210.6	210.0	0.6	0.7327	11.1	11.0	0.1	210.3	11.0	180.0	251.0
Vkn	212.3	212.9	-0.6	0.7366	10.3	10.0	0.3	212.6	10.1	180.0	249.0
Vkng	223.7	222.8	0.9	0.6162	12.4	12.5	-0.1	223.3	12.4	195.0	253.5
Vgi	217.5	214.5	3.0	0.0642	9.9	9.8	0.2	216.1	9.8	185.0	250.0
Vgot	294.0	294.9	-0.9	0.6499	13.8	13.4	-0.3	294.4	13.6	250.0	330.0
Vco	191.2	195.1	-3.9	0.0167	14.8	15.0	0.5	192.5	14.9	160.0	230.5

Table 3. Comparison of measurement results with published research results

Foot measurements	Mean, mm				σ, mm		
	Measurement results	Published results	Difference	*p*	Measurement results	Published results	Difference
Lbc	231.2	230.7	0.5	0.2448	8.4	9.4	-1.0
Lkt	167.4	170.0	-2.6	0.6032	7.2	8.0	-0.8
Lkn	149.1	150.2	-1.1	0.9543	6.8	7.7	-0.9
Lngu	192.4	192.1	0.3	0.0966	7.8	8.2	-0.4
Lgot	41.2	40.3	0.9	0.8851	5.5	3.8	1.7
Rkt	92.8	92.8	0.0	0.3786	5.2	5.4	-0.2
Rkn	88.8	89.2	-0.4	0.5540	5.3	5.9	-0.6
Rg	60.7	60.3	0.4	0.5497	3.4	4.6	-1.2
Cnc	19.3	19.1	0.2	0.0001	1.7	2.0	-0.3
Ckt	30.7	31.0	-0.3	0.7605	3.1	2.8	0.3
Cgi	45.7	45.0	0.7	0.0016	4.6	3.9	0.7
Cbu	60.9	60.2	0.7	0.0553	5.0	3.9	1.1
Cmc	57.8	58.6	-0.8	0.0172	3.3	3.5	-0.2
Vkt	210.3	212.7	-2.4	0.0707	11.0	12.9	-1.9
Vkn	212.6	214.8	-2.2	0.0310	10.1	13.0	-2.9
Vkng	223.3	223.1	0.2	0.8339	12.4	11.8	0.6
Vgi	216.1	215.7	0.4	0.2051	9.8	12.3	-2.5
Vgot	294.4	295.3	-0.9	0.2752	13.6	15.9	-2.3
Vco	192.5	191.9	0.6	0.1681	14.9	14.3	0.6

The average values of the main measurements of the feet of both groups were not much different. Foot length *Lbc* difference is 1.1 mm, ball circumference *Vkng* difference is 0.9 mm. The results of ANOVA analysis showed that there was no real difference in the main measurements of the left and right feet of the patients (p>0.05). Thus, it is possible to combine the measurement data of both groups to build a foot size system for women with diabetes. The results of determining the statistical characteristics of diabetic female feet in this study and comparing them with the results of published work [17] are shown in Table 3.

According to the comparison results in Table 3, the mean values and standard deviations of the main measurements of diabetic female feet measured in this study are similar to the results of published research [17]. The length and ball circumference of the foot differ by 0.5 mm and 0.2 mm, respectively. ANOVA analysis results showed that there were no real differences in the main measurements of diabetic female feet in both studies (p>0.05). However, there is still a small difference in the absolute average values of the foot measurements. Some foot measurements such as Vkt and Vkn have differences of up to 2.4 mm. Study [17] was published 7 years ago and was conducted at 1 medical location. The results of this study were only conducted at 2 medical locations so they are more representative. Therefore, this result should be used to rebuild the foot size system for women with diabetes in Vietnam.

3.2. Results of Building a Foot Sizing System for Women with Diabetes

3.2.1. Results of selecting and proving key measurements

Key measurements are often important ones. They have a strong correlation with some measurements of the foot, and follow the law of normal distribution. To establish the foot sizing system, two main measurements are used, which are its length and ball circumference [19].

To prove that the experimental distribution of the foot length and ball circumference is normally distributed, the frequency of the theoretical distribution was calculated [19]. The distribution chart of foot length *Lbc* and ball circumference *Vkng* according to theoretical and experimental frequency distribution is shown in Fig. 3 and Fig. 4.

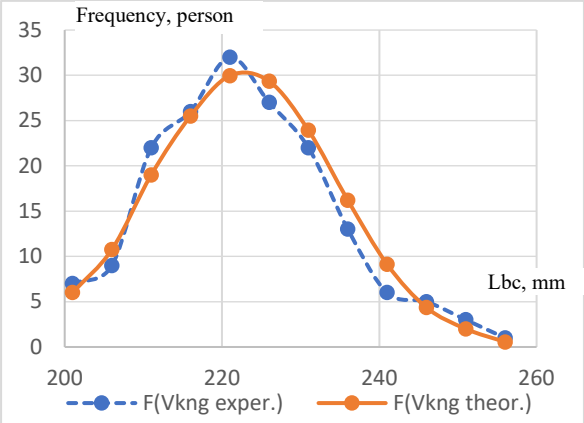


Fig. 3. Theoretical and experimental distribution chart of foot length *Lbc*

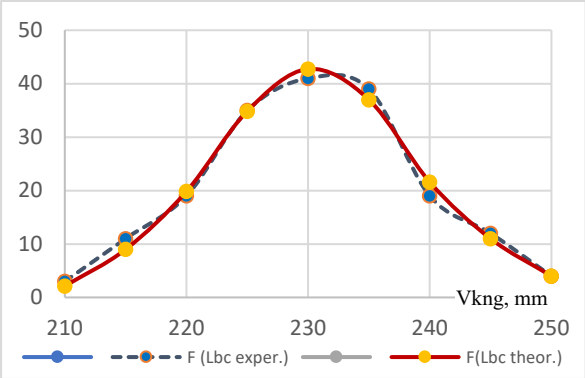


Fig. 4. Theoretical and experimental distribution chart of ball circumference *Vkng*

Observing the above charts, we see that the experimental and theoretical distribution lines of the measurements of foot length and ball circumference are quite close to each other. The χ^2 values calculated according to *Lbc* and *Vkng* are all smaller than the theoretical value with a reliability of 0.95. Therefore, it can be concluded that the distribution of the experimental measurements of patient's foot length and circumference is a normal distribution, and these measurements are the key ones.

3.2.2. The result of determining the relationship between the foot measurements and its key measurements

According to the measurement data, regression equations and correlation coefficients of the patient's female foot measurements with their key ones have been built (Table 4). In general, length measurements correlate well with foot length *Lbc*. Foot circumference and width measurements have a good correlation with ball circumference *Vkng*. This result is similar to that for normal human foot measurements.

Table 4. Regression equations and correlation coefficient *r* of patient foot measurements

Foot measurements	Regression equations	Correlation coefficient *r*
Lkt	*Lkt* =0.724*Lbc*	0.86
Lkn	*Lkn* = 0.6445*Lbc*	0.80
Lngu	*Lngu* = 0.8323*Lbc*	0.85
Lgot	*Lgot* = 0.1783*Lbc*	0.68
Lmc	*Lmc* = 0.303*Lbc*	0.53
Rkt	*Rkt* = 0.4148*Vkng*	0.80
Rkn	*Rkn* = 0.3973*Vkng*	0.70
Rkng	*Rkng* = 0.4281*Vkng*	0.85
Rg	*Rg* = 0.2716*Vkng*	0.49
Cnc	*Cnc* = 0.0862*Vkng*	0.47
Ckt	*Ckt* = 0.1374*Vkng*	0.18
Cgi	*Cgi* = 0.2043*Vkng*	0.48
Cbu	*Cbu* = 0.2719*Vkng*	0.81
Cmc	*Cmc* = 0.2517*Vkng*	0.99
Vkt	*Vkt* = 0.9406*Vkng*	0.85
Vkn	*Vkn* = 0.952*Vkng*	0.88
Vgi	*Vgi* = 0.976*Vkng*	0.81
Vbu	*Vbu* = 1.0632*Vkng*	0.60
Vgot	*Vgot* = 1.3174*Vkng*	0.65
Vco	*Vco* = 0.8613*Vkng*	0.55

3.2.3. Results of building the foot size system

- Building a size structure by foot length

The theoretical value of part α_i of *i* size is equal to the probability (frequency) of the normal distribution of the value *Bз* in the corresponding interval *j* (*Xjн*, *Xjв*), in which *Xjн*, *Xjв* are the lower and upper limits of interval *j*. $\alpha_i = P(Xjн < Bз < Xjв) \approx \Phi(Zjв) - \Phi(Zjн)$, in which: $\Phi(Z)$ - Lampplace function, determined according to the table according to the values of *Zjв* and *Zjн*: $Zjв = (Xjв - X)/\delta$ and $Zjн = (Xjн - X)/\delta$ [19]. The set of α_i values across all foot length classes is the structure for sizing feet by length (Table 5). When building the size system, sizes with a frequency of 3% or more are considered [19]. Therefore, by foot length, a size system should be built with 5 sizes from 218 mm to 244 mm. It covers 94.1% of female diabetics by foot length.

- Building a size structure by foot width

According to the foot length in the size ranges 218÷244 mm, determine the average ball circumference of each foot size, and the number of sizes by foot width needs to be considered (Table 6).

According to the data in Table 6, the difference in ball circumference between the smallest size of the foot and its largest size is 19.7 mm. When increasing foot length by 6.5 mm, its ball circumference increases by an average of 5 mm. On average, 5 width sizes are needed in 10 mm increments. This size number can accommodate 98.6% of patients according to foot width.

Table 5. Results of calculating the size structure by foot length according to the French size system

Foot size by lenght	Boundary values of layer X, mm		Z standard value		Values of the Laplace function $\Phi(Z)$		$P(B_{3j}^{н} < B_3 < B_{3j}^{в})$	α_j
	$B_{3j}^{н}$	$B_{3j}^{в}$	$Z_j^{н}$	$Z_j^{в}$	$\Phi(Z_j^{н})$	$\Phi(Z_j^{в})$		
205.0	202.0	208.0	-3.43	-2.71	0.0011	0.0023	0.001	0.1
211.5	208.5	214.5	-2.65	-1.93	0.0028	0.0202	0.017	1.9
218.0	***215.0***	***221.0***	***-1.87***	***-1.14***	***0.0233***	***0.102***	***0.079***	***8.6***
224.5	***221.5***	***227.5***	***-1.08***	***-0.36***	***0.1151***	***0.3156***	***0.201***	***21.8***
231.0	***228.0***	***234.0***	***-0.30***	***0.42***	***0.3372***	***0.6179***	***0.281***	***30.5***
237.5	***234.5***	***240.5***	***0.48***	***1.20***	***0.6406***	***0.8599***	***0.219***	***23.9***
244.0	***241.0***	***247.0***	***1.27***	***1.99***	***0.8729***	***0.9693***	***0.096***	***10.5***
250.5	247.5	253.5	2.05	2.77	0.9732	0.996	0.023	2.5
257.0	254.0	260.0	2.83	3.55	0.9966	0.9988	0.002	0.2
			Total					**100**

Table 6. Average ball circumference *Vkng* for each foot size and number of sizes by width

Foot size by lenght	*Vkng* *Min*, mm	*Vkng* *Max*, mm	*Vkng* Mean, mm	*Vkng* difference by length sizes, mm	*Vkng* selected value, mm	Difference between *Max* and *Min*, mm	Number of sizes by width in 10 mm increments
218.0	214.3	201.0	241.5	-	213.5	40.5	4.1
224.5	218.4	201.0	246.0	4.1	218.5	45.0	4.5
231.0	223.6	203.5	252.0	5.2	223.5	48.5	4.9
237.5	228.0	208.0	249.0	4.4	228.5	41.0	4.1
244.0	234.0	209.5	265.0	6.0	233.5	55.5	5.6

Table 7. Comparison of the values of foot sizes with published results

Published results		Results of this study	
Foot size by length, mm	*Vkng* value, mm	Foot size by length, mm	*Vkng* value, mm
216	216	218.0	213.5
223	220	224.5	218.5
230	224	231.0	223.5
237	228	237.5	228.5
244	232	244.0	233.5

Thus, the size system for women's feet with diabetes is built according to the French size system including 5 sizes by length (from size 218 mm to size 244 mm). Each size by length is built into 5 sizes by width (Table 7). The size system can accommodate over 92.6% of female diabetic feet. This is a very high response rate, meaning most patients can choose shoes that fit their feet. However, in actual shoe production, it is very difficul t to fully meet the 5 width sizes for each size according to foot length. Normally, shoes for diabetics are produced in 3 width sizes. Thus, the middle 3 sizes in this foot size system will be used, and can accommodate 83.6% of female diabetic feet.

In the published study [17], foot size by length used increments of 6 and 7 mm (rounded to mm). In this study, this value is taken as 6.5 mm, so it is more reasonable and accurate. The average *Vkng* values of the two studies also differed. In the study [17], the variation in *Vkng* measurements between adjacent sizes according to foot length was 4 mm. Meanwhile, this value in the current study is 5 mm and is rounded to 0.5 mm.

To obtain the foot size system, in addition to the main dimensions of length and toe circumference that have been determined, it is necessary to calculate the remaining measurements according to the built regression equations (Table 4). Results of determining foot measurements according to 5 length sizes 218; 224.5; 231, 237.5, 244 mm in 5 width sizes are shown in Table 8.

Table 8. System of foot measurements for women with diabetes

Foot measure-ments	Values of measurements according to length and width (fullness) of the foot, mm														
	218					**224.5**					**231**				
	193.5	**203.5**	**213.5**	**223.5**	**233.5**	**198.5**	**208.5**	**218.5**	**228.5**	**238.5**	**203.5**	**213.5**	**223.5**	**233.5**	**243.5**
Lbc	218.0	218.0	218.0	218.0	218.0	224.5	224.5	224.5	224.5	224.5	231.0	231.0	231.0	231.0	231.0
Lkt	158.0	158.0	158.0	158.0	158.0	162.5	162.5	162.5	162.5	162.5	167.0	167.0	167.0	167.0	167.0
Lkn	140.5	140.5	140.5	140.5	140.5	144.5	144.5	144.5	144.5	144.5	149.0	149.0	149.0	149.0	149.0
Lngu	181.5	181.5	181.5	181.5	181.5	187.0	187.0	187.0	187.0	187.0	192.0	192.0	192.0	192.0	192.0
Lgot	39.0	39.0	39.0	39.0	39.0	40.0	40.0	40.0	40.0	40.0	41.0	41.0	41.0	41.0	41.0
Lmc	49.0	49.0	49.0	49.0	49.0	50.5	50.5	50.5	50.5	50.5	52.0	52.0	52.0	52.0	52.0
Rkt	80.5	84.5	88.5	84.5	97.0	82.5	86.5	90.5	95.0	99.0	84.5	88.5	92.5	97.0	101.0
Rkn	77.0	81.0	85.0	81.0	93.0	79.0	83.0	87.0	91.0	95.0	81.0	85.0	89.0	93.0	96.5
Rkng	83.0	87.0	91.5	87.0	100.0	85.0	89.5	93.5	98.0	102.0	87.0	91.5	95.5	100.0	104.0
Rg	52.5	55.5	58.0	55.5	63.5	54.0	56.5	59.5	62.0	65.0	55.5	58.0	60.5	63.5	66.0
Cnc	16.5	17.5	18.5	17.5	20.0	17.0	18.0	19.0	19.5	20.5	17.5	18.5	19.5	20.0	21.0
Ckt	26.5	28.0	29.5	28.0	32.0	27.5	28.5	30.0	31.5	33.0	28.0	29.5	30.5	32.0	33.5
Cgi	39.5	41.5	43.5	41.5	47.5	40.5	42.5	44.5	46.5	48.5	41.5	43.5	45.5	47.5	49.5
Cbu	52.5	55.5	58.0	55.5	63.5	54.0	56.5	59.5	62.0	65.0	55.5	58.0	61.0	63.5	66.0
Cmc	48.5	51.0	53.5	51.0	59.0	50.0	52.5	55.0	57.5	60.0	51.0	53.5	56.5	59.0	61.5
Vkt	182.0	191.5	201.0	191.5	219.5	186.5	196.0	205.5	215.0	224.5	191.5	201.0	210.0	219.5	229.0
Vkn	184.0	193.5	203.5	193.5	222.5	189.0	198.5	208.0	217.5	227.0	193.5	203.5	213.0	222.5	232.0
Vkng	193.5	203.5	213.5	203.5	233.5	198.5	208.5	218.5	228.5	238.5	203.5	213.5	223.5	233.5	243.5
Vgi	189.0	198.5	208.5	198.5	228.0	193.5	203.5	213.5	223.0	233.0	198.5	208.5	218.0	228.0	237.5
Vbu	205.5	216.5	227.0	216.5	248.5	211.0	221.5	232.5	243.0	253.5	216.5	227.0	237.5	248.5	259.0
Vgot	255.0	268.0	281.5	268.0	307.5	261.5	274.5	288.0	301.0	314.0	268.0	281.5	294.5	307.5	321.0
Vco	166.5	175.5	184.0	175.5	201.0	171.0	179.5	188.0	197.0	205.5	175.5	184.0	192.5	201.0	209.5

Foot measure-ments	Values of measurements according to length and width (fullness) of the foot, mm									
	237.5					**244**				
	208.5	**218.5**	**228.5**	**238.5**	**248.5**	**218.5**	**228.5**	**238.5**	**248.5**	**258.5**
Lbc	237.5	237.5	237.5	237.5	237.5	244.0	244.0	244.0	244.0	244.0
Lkt	172.0	172.0	172.0	172.0	172.0	176.5	176.5	176.5	176.5	176.5
Lkn	153.0	153.0	153.0	153.0	153.0	157.5	157.5	157.5	157.5	157.5
Lngu	197.5	197.5	197.5	197.5	197.5	203.0	203.0	203.0	203.0	203.0
Lgot	42.5	42.5	42.5	42.5	42.5	43.5	43.5	43.5	43.5	43.5
Lmc	53.0	53.0	53.0	53.0	53.0	54.5	54.5	54.5	54.5	54.5
Rkt	86.5	90.5	95.0	99.0	103.0	88.5	92.5	97.0	101.0	105.0
Rkn	83.0	87.0	91.0	95.0	98.5	85.0	89.0	93.0	96.5	100.5
Rkng	89.5	93.5	98.0	102.0	106.5	91.5	95.5	100.0	104.0	108.5
Rg	56.5	59.5	62.0	65.0	67.5	58.0	60.5	63.5	66.0	69.0
Cnc	18.0	19.0	19.5	20.5	21.5	18.5	19.5	20.0	21.0	22.0
Ckt	28.5	30.0	31.5	33.0	34.0	29.5	30.5	32.0	33.5	35.0
Cgi	42.5	44.5	46.5	48.5	51.0	43.5	45.5	47.5	49.5	52.0
Cbu	56.5	59.5	62.0	65.0	67.5	58.0	61.0	63.5	66.0	69.0
Cmc	52.5	55.0	57.5	60.0	62.5	53.5	56.5	59.0	61.5	64.0
Vkt	196.0	205.5	215.0	224.5	233.5	201.0	210.0	219.5	229.0	238.5
Vkn	198.5	208.0	217.5	227.0	236.5	203.5	213.0	222.5	232.0	241.5
Vkng	208.5	218.5	228.5	238.5	248.5	213.5	223.5	233.5	243.5	253.5
Vgi	203.5	213.5	223.0	233.0	242.5	208.5	218.0	228.0	237.5	247.5
Vbu	221.5	232.5	243.0	253.5	264.0	227.0	237.5	248.5	259.0	269.5
Vgot	274.5	288.0	301.0	314.0	327.5	281.5	294.5	307.5	321.0	334.0
Vco	179.5	188.0	197.0	205.5	214.0	184.0	192.5	201.0	209.5	218.5

Compared to the published research results [17], the foot measurement values in the size system in Table 9 are different. This is due to: 1) the difference in the mean values of the foot measurements in the two studies; 2) the difference in the values of foot length and *Vkng* in the sizing systems (Table 9); and 3) the difference in coefficients in the regression equations showing the correlation between the foot measurements with it length and ball circumference. For example, comparing the measurements of the 231 mm foot length of this study with the 230 mm foot length size of the previous study [17] is shown Table 9.

Table 9. Comparison of measurements of the 231 mm foot length of this study with the 230 mm foot length size of the previous study

Foot measure-ments	Published results, mm	Results of this study, mm	Difference, mm
Lbc	**230.0**	**231.0**	-1.0
Lkt	168.5	167.0	1.5
Lkn	149.5	149.0	0.5
Lngu	191.0	192.0	-1.0
Lgot	41.2	41.0	0.2
Rkt	93.0	92.5	0.5
Rkn	89.5	89.0	0.5
Rg	60.5	60.5	0.0
Cnc	19.0	19.5	-0.5
Ckt	30.9	30.5	0.4
Cgi	45.0	45.5	-0.5
Cbu	60.3	61.0	-0.7
Cmc	58.4	56.5	1.9
Vkt	213.6	210.0	3.6
Vkn	215.9	213.0	2.9
Vkng	**224.0**	**223.5**	0.5
Vgi	216.3	218.0	-1.7
Vgot	296.2	294.5	1.7
Vco	192.4	192.5	-0.1

4. Conclusion

Results of measuring and processing measurement data of 442 feet of female diabetic patients at Khoai Chau district Medical center, Hung Yen province and at the Department of Endocrinology, National hospital of Endocrinology show that: 1) there is no real difference in the average measurements of the left and right feet of each patient group; 2) there is no difference in the average values of the foot main measurements of the two patient groups; 3) The results obtained in this study are similar to published research results [17].

A foot size system of women with diabetes has been built according to the French size system. The size system includes 5 sizes by length (218 mm, 224.5 mm, 231 mm, 237.5 mm and 244 mm). Each size by length has 5 sizes by width. This foot size system can satisfy over 92.6% of female diabetic feet. This result is a very important basis for designing and manufacturing shoe lasts, designing and mass producing "Extra Depth Diabetic Shoes". Shoes will ensure proper fit and prevent foot ulcers in diabetic women in Vietnam.

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