Relationship between the changes of diabetic plantar size and diabetic plantar pressure

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Abstract: The Diabetic plantar size and plantar pressure distribution were deeply influenced by diabetic foot syndrome. In order to recognize the relationship between diabetic plantar size and diabetic pressure distribution, 1471 foot samples were collected, including 951 diabetic feet and 520 normal ones. Firstly, the foot information such as plantar length, width, and pressure value, was gathered; then the data was analyzed by software of CorelDraw 12.0 and Foot Analyzer, the result showed that in the static standing position, the dimension of diabetic plantar length was longer than the health's by about 0.5% and the diabetic plantar width was wider by 1.6-3.5%, however, the diabetics plantar pressure value in our aimed places was lower than the health's by 9.0-22.6%. Finally, based on these results, a linear regression model about the relationship between the changes of diabetic plantar size and diabetic plantar pressure was build: (the margin of pressure value) = -1.965-0.512*(the margin of width). These conclusions were used in diabetic shoe design.

Key words: plantar pressure; plantar dimension; diabetic foot; diabetic shoe

1 Introduction

It is widely believed that the feet are considered as an important part of our body. The feet support not only the whole body's weight, but also bear several times of body weights when we are running or splitting. The diabetic peripheral nerve disease (PND) and peripheral vascular disease (PVD) may affect the nerve of lower limb and make foot become dull to the outside stimulating [1], therefore the foot is easy to get hurt. The loose of sensation under foot may also lead to changes of foot structure such as bone, ligament, and muscle. These changes influence the plantar dimension and the plantar pressure distribution. What's more, when diabetic patient walk with their foot deformities or with wrong size shoe, the plantar pressure would become concentrate in some small regions for the irregular structure change, and lead to callus, blister and trauma of skin, even to the ulcerations and amputations. The high plantar pressure is considered as one of the essential risk factors for plantar ulceration. So, it is important to understand the relationship between the plantar dimensional changes and its plantar pressure distributions and it would be helpful for the suitable diabetic shoes' designing.

Although the dimension change in diabetic patient is a dangerous factor, there has been few reports in literature related this area. Researchers' reports just focused in either foot size or plantar pressure distribution, such as Sicco A. Bus et al. [2]. They reported a kind of forefoot offloading shoe to relief plantar pressure in the diabetic foot and their shoe design was based on plantar pressure distribution [2], thus they only modified the patient shoe, or changed its former structure. However, their research didn't make the foot measurement at the beginning. The majority researches which have been made were about

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the pressure distribution between diabetic and control subject, such as the report of A. Bryant et al. [3]. They investigated plantar distribution in hallux valgus foot; however, they also didn't mention how the foot size for this deformity changed.

In this paper, static foot dimension and static plantar pressure value of 951 diabetes mellitus patients and 520 healthy control subjects' were collected, and the analysis including the length and width of foot in hallux, fifth toe, first metatarsal head, fifth metatarsal head, waist and heel, and static plantar pressure of first to fifth metatarsal heads, waist and medial and lateral heel were collected. Finally, the custom diabetic shoe was worked out.

2 Experimental

2.1 Samples

From Sichuan region, the feet information of 951 diabetes mellitus patients (sexy ratio: male to female=45 to 55, age:60.72±11.04, BMI:24.34±3.47) and 520 control subjects(sexy ratio: male to female=47 to 52, age:61.47±10.39, BMI:23.2±2.79) were measured.

2.2 Instrument

The foot dimension was measured by plantar optical scanners FOS-001 (self-designed, error of ± 0.5mm) and static plantar pressure of was gathered by Instruments of the Plantar Pressure Scanner (JP-1600, Jun Cheng Sports Equipment Co., Ltd. Anhui, China. error of ± 0.05%). The concrete parameters of these instruments refer to their manual. The foot dimensional data was calculated by software of CorelDraw 12.0and the value of plantar pressure was worked out by Foot Analyzer; at last, SPSS 16.0 was applied for statistics analysis.

2.3 Methods

Plantar optical scanner FOS-001 (Fig.1) was used to measure the foot plantar dimension. Firstly, the patient was asked to stand on the surface of scanner, and the bodyweight was divided equally to the two feet; Then foot information was collected by LED signal collector, and the signal was transferred to the signal processor, according to the disposal, the data was transferred to the image in computer. Finally, in order to measure the length and the breadth of each foot, the analysis position (Fig.2) was marked and Software of CorelDraw12.0 was as a tool to analyze the length, as well as the width.

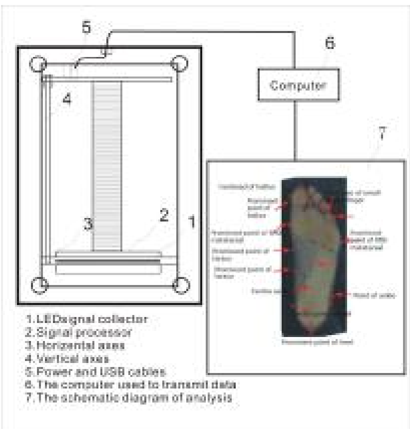

Fig.1The construction of plantar scanner

Fig.2Places of analyzing

Static plantar pressure was collected by JP-1600 Plantar Pressure Scanner and Software of Foot

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Analyzer was applied for collecting the pressure value of 7 places (Fig.3). M1 was symbolized for the first metatarsal head, M2 for the second metatarsal head, M3 for the third metatarsal head, M45 for the fourth and fifth metatarsal head, W for the waist and H1, H2 for the lateral and medial of heel, separately.

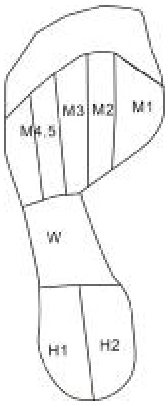

Fig.3 Analysis areas

Statistical comparisons were made between patients and control subjects. A t test was applied to evaluate their differences and leaner regression model was built to assess the relationship between changes of foot breadth and plantar pressure.

3 Results and Discussion

BMI of diabetic was divided into five groups (Fig.4), a total percentage of obese in diabetic patients accounted for 42.2%. Diabetic patient are often characterized as moderately obese [5,6], and there is a relationship between the body weight and plantar pressure as Stokes [12] reported. The obese also is considered as a risk for foot ulceration and other relative disease. So it is important that the diabetic patients need a healthy body weight.

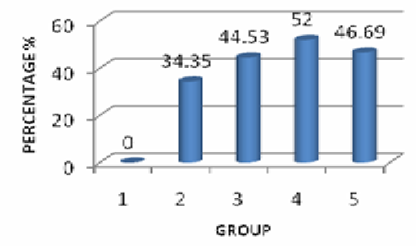

Fig.4 BMI distribution

Note:1 Undernourished [4],2 Ideal weight,3 Overweight,4 Slightly obese,5 Medium obesity,6 Morbid obesity.

In order to assess the differences in foot, a criteria was promoted. Because when concrete foot size was applied to distinguish the differences, compare between the two groups became meaningless for the difference basic foot length. So the ratio between the parts of foot length/width to the total foot length/width was taken to measure the differences. The equation was shown below:

$$\text{percentage of the position} = \frac{\text{the length/ width of position}}{\text{the total foot length/ width}}$$

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Tab.1 Compare of Diabetic foot and the normal's in width (Mean ±Std. Deviation %)

	Hallux (%)	small digital figure (%)	the first metatarsal head (%)	fifth metatarsal head (%)	the waist (%)	the heel (%)
Diabetic foot	40.19±6.043	53.29±7.435	46.23±6.257	57.86±7.560	48.08±6.911	68.64±10.233
Control foot	39.21±3.327	51.60±3.937	44.31±4.021	55.54±3.580	46.51±4.796	65.29±5.980
Reference	39	54.1	43	57	46.7	67.7
Significant value	0.000	0.000	0.000	0.000	0.000	0.000

Note: The basic breadth is the widest of the foot, and is a horizontal distance between the first metatarsal head to the fifth metatarsal head (Fig.2).

Tab.2 Compare of Diabetic foot and the normal's in length(Mean ±Std. Deviation)

Name	Hallux (%)	small digital figure (%)	The first metatarsal head (%)	The fifth metatarsal head (%)	the waist (%)	the heel (%)
Diabetic foot	90.27±1.333	77.25±1.969	72.59±6.322	62.79±3.977	44.22±3.199	16.99±2.071
Control foot	90.31±33.126	77.35±3.197	72.58±3.137	62.12±3.185	44.90±4.475	15.26±3.453
Reference	90	78	72.5	63.5	41	18
Significant value	0.721	0.500	0.967	0.001	0.002	0.000

Note: The foot length is the longest of foot, and is the distance of the horizontal line which drawn in the top and drawn in bottom of the foot (Fig.2).

From Tab.1 and Tab.2, in width the two groups demonstrated significantly higher in all foot positions, however, measurement for length was significantly lower in all foot positions. The reason why in width direction, the foot changed greatly was mainly for the PND and PVD which made the foot lose sensation or decrease the blood supplement then leaded the changes of the organism such as muscles, ligaments. These changes also inactivated the foot functions and finally leaded to deformities of foot, for example: the hallux valgus [7], in which the foot size especially the width changed so large.

In the measurement of static plantar pressure, the differences from the first to the fifth were not obvious (Fig.5). The static plantar pressure value of diabetic in all of reference places was lower than the control subject. The distinction was by about 5 N/cm^2 in the M1, 3 N/cm^2 in the M2, 7 N/cm^2 in M3, 6 N/cm^2 in M4-5, 5 N/cm^2 in waist, 4 N/cm^2 in the LM and HM each.

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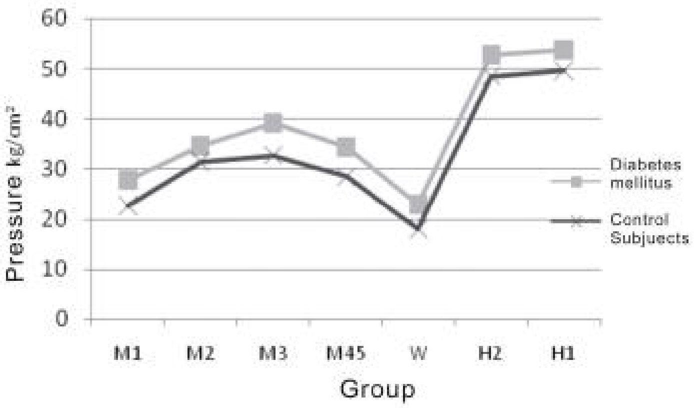

Fig.5 Pressure value distribution between diabetic and health people of both feet

At a certain weight, it was that the greater the contact area, the smaller the pressure value. Thus, in normal clinical observation, diabetic foot with the collapsed transverse arch caused an increasing of the breadth, and decreased the plantar pressure value. The reason of this phenomenon was for diabetic complications. Such complications included the peripheral nerve disease and the peripheral vascular disease. One leaded the patient to lose the sense of pain, and another caused the insufficient blood supply in the foot [8]. The effects of these two complications made properties of tendon and ligament weak, and made functions of these two parts unable to support the arch of foot, so the arch collapsed. Also for this result, the outcome of changes was presented in the size of length and breadth.

From the Fig.6, a clearly image of how foot changed was shown. The two foot had a same foot length, and had a similar BMI. The purpose of this contrasting was to prove the trend of change in plantar size and static plantar pressure. “A” was a foot with hallux valgus, the clay area (area of ellipse was centre of pressure (COP)) was smaller than that of “B”. It meant that thanks to the hallux valgus and the collapse of arch, the basic breadth (the widest of the foot) and the heel, both of them considered to be places cushioning the force under the feet, were expanded. That’s maybe the reason why in the static standing measurement, the plantar pressure of diabetic was lower than the control subject.

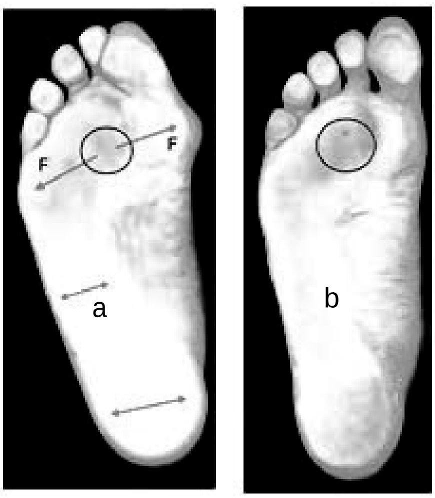

Fig.6 Diabetic plantar size changed trend between the normal foot and deformity’s foot

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Tab.3 Linear relationship between the changes of diabetic plantar size and diabetic plantar pressure

	M1	M2	M3	M45	W	H2	H1
width	1.92%	0		2.32%	1.56%	3.35%	
pressure	-7.07	-5.39	-9.49	-9.23	-7.31	-9.59	-6.27

A leaner regression model was built (Tab.3): (the margin of pressure value) = -1.965-0.512*(the margin of width). It meant that when the breadth added 1mm, the pressure increased 24.77N/cm^2 (1kg=10N). This result of pressure value was depended on the static measurement, so there was some difference with other researches. The report in literature was that the dynamic pressure values under foot of diabetes mellitus who suffered PND and PVD were significantly larger than the control subject and diabetes mellitus without PND and PVD [8]. Different method used in research maybe the reasons for this variety [9, 10, 11]. They focused on the dynamic foot pressure scanning, but we only applied static foot pressure scanning; another reason maybe that the data was used by other expert to design the way to avoid the foot injuries, whereas we used the outcome of research to design the customary last and to design the therapeutic shoe to avoid the ulceration of the diabetic foot, so as the purpose was different, the way to think about was different as well.

The designing of functional shoe was a systematical project. It was not only needed the technicians who knew the biomechanical of the foot, but also needed the designer who understand how to apply the data to the last and shoe. So in college, the feasibility of this method to design the shoe and how the effects of the shoe which designed by this method needed further discussing and proving [5].

4 Conclusions

According to this paper, there were several important conclusions.

1) The breadth of six key positions in DM was larger than the CS by 1.6-3.5%. So when to design the diabetic shoe, It is very important to leave reasonable places to keep the hullux, first and the fifth metatarsal head safe;

2) The plantar pressure value of DM was larger than the CS in most of key position of foot by 9-15% in LH and MH, 22.6% in waist, 12-20% in metatarsal head;

3) A linear regression model of relationship between the width and the plantar pressure was built : “the distinction of pressure value = -1.965 – 0.512 * the breadth”. This model was very essential to design the last and insole, for if a exactly size of breadth was get, the approximate pressure value could be calculated, then it could be used in insole design as soon as quickly. It also shorted the times using in making customary shoe;

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