THE RATIOS OF AREA OF FOOT PRINT TO AREA OF FOOT OUTLINE AND DIABETIC SOLE ULCER FORMATION

C K Low, P W Shew, B Y Low

ABSTRACT

The ratio of area of foot print to area of foot outline for each foot was studied in 50 normal and 70 diabetic subjects. The diabetic group was divided into 2 groups: 44 patients without and 26 patients with sole ulcers. The chief aim was to find a ratio that could predict ulcer formation.

One hundred feet in the normal subjects had a mean ratio of 0.621 with a range of 0.51 - 0.72. The 88 non-ulcerated feet in the diabetic patients had a mean ratio of 0.611 with a range of 0.49-0.70. The difference was statistically not significant ($p > 0.05$).

Thirty-two ulcerated feet in the 26 diabetic patients had a mean ratio of 0.580 with a range of 0.47 - 0.68. The difference between the ulcer and the non-ulcer group was statistically significant ($p < 0.01$). Twenty non-ulcerated feet in 20 diabetic patients with unilateral involvement had a mean ratio of 0.60 with a range of 0.50 - 0.69. The difference between the ulcerated and non ulcerated feet in these 20 unilateral involved patients was also statistically significant ($p < 0.01$).

The sole ulcers in our study were distributed mainly beneath the metatarsal heads and calcaneum. Analysis of the foot prints revealed multiple dark print areas. They were at the locations corresponding to the above bony prominences. As these bony prominences were high pressure points, the dark print areas could serve as crude indicators of excessive pressure.

The diabetic ulcer group had smaller mean ratio and the reduction of the contact area could contribute to the formation of sole ulcers. The ratio of 0.66 could be a theoretical index of ulcer formation.

Keywords : *Ratios of area of foot print to area of foot outline, Diabetic sole ulcer formation*

SINGAPORE MED J 1993; Vol 34: 49-52

INTRODUCTION

The foot in contact with the ground during the stance phase of walking is bearing the weight of the subject. If the whole sole (A) is bearing the weight of the subject, the weight per unit cm^2 (W/A) will be minimum. However, in actual fact, the area in contact with the ground during walking (B) is smaller than the whole sole (A) and the weight per cm^2 (W/B) will be greater.

The area of the whole sole (A) can be obtained by measuring the area of foot outline. The area of the sole in actual contact with the ground during walking (B) can be obtained by measuring the area of the dynamic foot print. If the weight of the subject is eliminated by dividing W/A by W/B, a ratio of area of foot print (B) to area of foot outline (A) will be obtained. It gives the proportion of the sole in actual contact with the ground during walking. As both area A and area B vary with the size of the foot, the sex and weight of the subject to similar extent, the ratio is less likely affected. These properties greatly simplify the process of analysis as the above 3 factors will not come into consideration.

Department of Orthopaedic Surgery
Toa Payoh Hospital
Toa Payoh Rise
Singapore 1129

C K Low, MBBS, M Med(Surg), FRCS(Edin), FRCS(Glas)
Registrar

B Y Low, MBBS, FAMS, FRCS(Edin), FRCS(Glas)
Consultant

P W Shew, BEng(S'pore)
Engineer, NUS Postgraduate Student

Correspondence to : Dr C K Low

Foot deformities and sole ulcerations are common diabetic complications. Deformity of a diabetic foot can result in abnormal distribution of pressure in the sole during weight bearing and ulcers may form under areas of high pressure. The area of the sole in contact with the ground during weight bearing (B), area of the whole sole (A) and the ratio (B/A) may also be altered.

Our aims in this study were firstly to determine the relationship between the ratios and the sole ulcers in the diabetic feet. Secondly, to look for a ratio that could predict ulcers formation and to evaluate the possible clinical uses of such an index in terms of prevention and management of diabetic ulcers. Finally, to evaluate the use of dark print areas as the crude indicators of high pressure.

MATERIALS AND METHODS

One hundred and twenty subjects with 240 feet were selected. They were divided into Group A : 50 normal subjects, Group B : 44 diabetic patients without sole ulcer, and Group c: 26 diabetic patients with sole ulcers.

The criteria for selection of these subjects were:

1. Since the dynamic foot print method was used, the subjects selected were able to walk normally.
2. In order to eliminate ischaemia as the cause of ulcer formation, the subjects selected had ankle pressure index of more than one, good capillary return over the toes and palpable dorsalis pedis and posterior tibial pulses.
3. Similarly, to eliminate infection or trauma as the cause of ulcer formation, the subjects selected had no history of infection or injury preceding formation of the ulcers.
4. As intact feet were studied, subjects selected had no history of mutilating foot operation.

Every subject was reviewed by clinical examination. The vascular and nervous systems of lower limbs were examined.

The weight of the subject and the ankle pressure index of each lower limb were measured.

For each diabetic patient, the duration of diabetic illness, treatment regime and diabetic complications including any foot deformity were evaluated. The distribution of the ulcers was studied in the diabetic ulcer group.

The subject was instructed to stand on both bare feet with the right foot on a piece of white paper. The outline of the foot was traced with a pen on the paper. The same procedure was repeated for the left foot.

The dynamic foot print method was used in our study because the static method was inaccurate. The static foot print could vary with the posture of the foot and the pressure exerted on the sole while the subject was standing on a piece of paper laying on the ink pad.

The dynamic foot print was obtained by laying a piece of paper on a 40 by 30 cm ink pad. The ink pad was placed 1m away from the subject. In order to avoid inaccurate measurement, the subject was instructed to walk normally, step the right foot on the paper without exerting any extra pressure or changing the foot posture and continue to walk subsequently. The dynamic foot print was obtained on the reverse page of the paper. The advantage was the foot and ulcers would not be stained. Infection of the ulcer could be presented. The same procedure was repeated for the left foot.

The outline and foot print of each foot were scanned separately in the computer using a digital scanning machine. The shape of the foot outline was displaced on the computer screen. The computer programme was designed by using the principle of counting the number of 1 mm^2 that were occupied by the shape of the outline. The number of squares gave the area of the foot outline. The area of the foot print was subsequently measured by the same procedure. The ratio of the area of foot print to area of foot outline was calculated. The longitudinal span of the foot outline was measured. All the 4 items were measured once.

The foot prints of the ulcerated feet was examined. The dark print areas were recorded and compared with the ulcer distribution. The foot print configurations were co-related with the foot deformities.

Group A consisted of 50 normal subjects. They had no medical illness and their feet were normal. Their mean age was 52.4 years with a range of 30-71 years. There were 26 males and 24 females. The mean weight of the subjects was 60.5 kg with a range of 49-75 kg.

Group B had 44 diabetic patients without sole ulcer. Four feet (4.5%) in 3 patients had clawed toes and 3 feet (3.4%) in 2 patients had pes cavus. The remaining 81 feet (92.1%) had no deformity. Their mean age was 57.6 years with a range of 35-76 years. There were 24 males and 20 females. The mean duration of diabetic mellitus was 7.6 years with a range of 1-15 years. Three patients(6.8%) were on dietary control, 25 patients (56.8%) required oral medications and 16 patients (36.4%) needed insulin injections. Two patients (4.5%) had angina pectoris, 3 (6.8%) had hypertension, 2 (4.5%) had renal impairment and 3 (6.8%) had peripheral sensory neuropathy. The mean weight of the patients was 59.6 kg with a range of 49-75 kg.

Group C had 26 diabetic patients with sole ulcers. There were 12 right, 8 left and 6 bilateral ulcerated soles. Two ulcerated feet (6.2%) in 2 patients had no deformity. Nineteen ulcerated feet (59.4%) in 14 patients had pes cavus and 11 ulcerated feet (34.4%) in 10 patients had clawed toes. The mean age of the patients was 61.8 years with a range of 41-89 years. There were 18 males and 8 females. The mean duration of the diabetic mellitus was 10.2 years with a range of 6-20 years. Fifteen patients (57.7%) were on oral medications and 11 (42.3%) required insulin injections. Three patients (11.5%) had angina pectoris, 4 (15.4%) had hypertension, 2 (7.7%) had renal impairment and 6 (23.1%) had peripheral sensory neuropathy. The mean weight of the patients was 58.2 kg with a range of 48-68 kg. Of the 20 non ulcerated feet in 20 patients with unilateral foot involvement, 15 feet (75%) had no deformity, 3 feet (15%) had clawed toes and 2 feet (10%) had pes cavus.

RESULTS

The results of Group A, Group B, ulcerated and non ulcerated feet in Group C were summarized in tables I, II, III and IV respectively.

For each mean, Group A and B were compared by using unpaired t-test. The results were $t=0.82$ for foot print, $t=0.40$ for foot outline, $t=1.52$ for ratio and $t=1.12$ for longitudinal span. As the differences between Groups A and B were statistically not significant ($p>0.05$), Group B was chosen and used to compare with Group C.

Ulcerated feet in Group C and non ulcerated feet in Group B were compared by using unpaired t-test. The results were $t=4.56$, $p<0.01$ for foot print, $t=2.17$, $p<0.05$ for foot outline, $t=2.68$, $p<0.01$ for ratio and $t=5.72$, $p<0.01$ for longitudinal span. These differences were statistically significant.

Non ulcerated feet in Group C and Group B were compared by using unpaired t-test. The results were $t=1.3$ for foot print, $t=1.58$ for foot outline, $t=0.84$ for ratio and $t=0.22$ for longitudinal span. These differences were statistically not significant ($p>0.05$).

Table I – The results of 100 feet in 50 normal subjects (Group A).

	Mean	Range	S.D.
Area of foot print (cm^2)	109.1	76 – 150	15.7
Area of foot outline (cm^2)	157.7	124 – 241	24.5
Ratio	0.621	0.51 – 0.72	0.047
Longitudinal span of foot outline (cm)	23.7	19.9 – 28.2	1.80

Table II – The results of 88 non ulcerated feet in 44 diabetic patients (Group B).

	Mean	Range	S.D.
Area of foot print (cm^2)	107.3	76 – 150	14.4
Area of foot outline (cm^2)	174.3	122 – 245	23.8
Ratio	0.611	0.49 – 0.70	0.043
Longitudinal span of foot outline (cm)	23.4	19.5 – 29.1	1.85

Table III – The results of 32 ulcerated soles in 26 diabetic patients (Group C).

	Mean	Range	S.D.
Area of foot print (cm^2)	95.3	70 – 136	12.1
Area of foot outline (cm^2)	164.1	115 – 232	22.4
Ratio	0.580	0.47 – 0.68	0.06
Longitudinal span of foot outline (cm)	21.3	17.6 – 25.4	1.75

Table IV – The results of 20 non ulcerated feet in 20 patients with unilateral involvement. (Group C).

	Mean	Range	S.D.
Area of foot print (cm^2)	102.6	72 – 152	14.5
Area of foot outline (cm^2)	165.0	115 – 245	15.8
Ratio	0.60	0.50 – 0.69	0.055
Longitudinal span of foot outline (cm)	23.5	19.0 – 28.4	1.86

The ulcerated and non ulcerated soles in 20 patients with unilateral involvement were compared by using paired t-test. The results were $t=3.81$ for foot print, $p<0.01$, $t=2.21$ $p<0.05$ for foot outline, $t=5.75$, $p<0.01$ for ratio and $t=2.95$, $p<0.01$ for longitudinal span. These differences were statistically significant.

The ulcers were distributed beneath the first metatarsal head in 11 (34.3%), second metatarsal head in 3 (9.3%), fourth metatarsal head in 2 (6.3%), fifth metatarsal head in 2 (6.3%), calcaneum in 12 (37.5%) and multiple in 2 feet (6.3%). Examination of their foot prints revealed multiple dark print areas. The ulcers had corresponding dark areas. The other dark prints were at the sites corresponding to the above bony prominences.

DISCUSSION

The differences between Groups A and B were statistically not significant ($p>0.05$) because 100% of the feet in Group A and 92.1% of the feet in Group B had no deformity.

Similarly, the differences between non-ulcerated feet in Groups B and C were also statistically not significant because both groups had greater proportion of normal feet (92.1% and 75.0% respectively).

Four items were analysed in Group B and ulcerated feet of Group C. For each item, the mean of the latter was smaller than the former. Foot print was smaller by 11.2%, foot outline by 5.9%, ratio by 5.1% and longitudinal span by 9.0%. The discrepancies between these 2 groups were statistically significant because the majority (93.8%) of the ulcerated feet were deformed. Pes cavus deformity was noted in 59.4% and clawed toes deformity in 34.4% of the ulcerated feet.

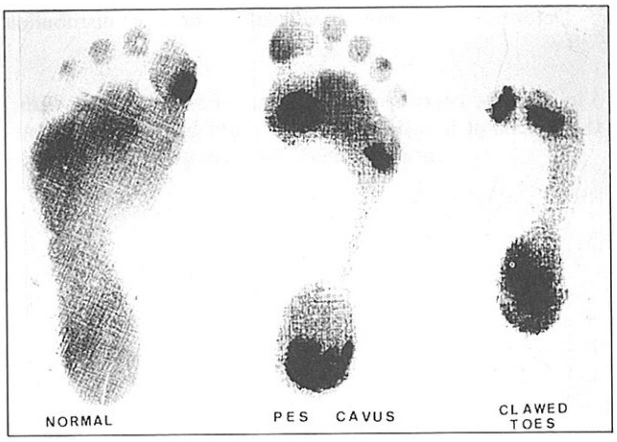
In pes cavus deformity, there was plantaris deformity at the mid tarsal joint causing elevation of the medial arch. The area of foot print was smaller because the area in contact with the mid sole was decreased as a result of high medial arch (Fig 1). In severe pes cavus, the area of foot print was markedly diminished as the lateral weight bearing border was absent. The area of the foot outline was smaller because the longitudinal span was shorter in the presence of high medial arch.

In clawed toes deformity, the interphalangeal joints were flexed and the metatarsophalangeal joints were hyperextended. The area of the foot print was smaller because one or more toe prints were incomplete or missing. In severe deformity, the area of the foot print was more diminished because the area in contact with the anterior portion of the fore sole was decreased and all the toe prints were missing (Fig 1). As the toes were clawed, the longitudinal span of the foot outline was shorter and consequently the area was also diminished.

The ratio of a deformed foot was smaller because the area of foot print was reduced to a greater extent than the foot outline.

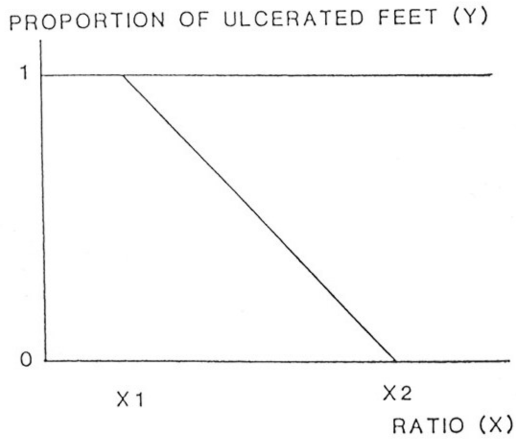
In the ulcerated feet, the ulcers gave dark print spots on the foot print. These spots were within the shape of the foot print. As the area of the foot print was given by measuring the number of 1 mm^2 within the shape of the foot print, the presence of the ulcers would not affect the measurement.

Fig 1 – The foot prints of normal, pes cavus and clawed toes were displayed for comparison. The area in contact with the mid sole was decreased in pes cavus as a result of high medial arch. In severe clawed toes, the area in contact with the anterior portion of the fore sole was also decreased and of all the toe prints were missing.



By considering 32 ulcerated and 108 non ulcerated soles in these 70 diabetic patients together, the proportion of ulcerated feet (Y) in those feet with a ratio (X) was obtained by dividing the number of ulcerated feet with X (N) by the sum of ulcerated and non ulcerated feet with X (S). As ulcerated feet had smaller ratios, Y would be greater if X was smaller. Based on the above observation, a theoretical straight line with a negative slope could be obtained by plotting Y against X (Fig 2) and the following assumptions could be made. The line would intercept with the X axis at a point (X2,0) and another line Y=1 at a point (X1,1). Feet with ratios equal to or smaller than X1 would be all ulcerated. Feet with ratios equal to or greater than X2 would all be non ulcerated. As ulcers would appear in feet with ratios smaller than X2, X2 could be a theoretical index for predicting ulcer formation. Since the ratio of a foot could be altered by orthotic foot wear or corrective surgery, ulcer formation in a foot with ratio less than X2 could be prevented by enlarging it to a point greater than X2. Ulcer healing in a foot with ratio less than X2 could also be facilitated by increasing it to a point larger than X2. Between X1 and X2, the proportion of ulcerated feet increased as the ratio decreased.

Fig 2 – The theoretical regression line would intercept with the X axis at a point of X2. As ulcer would appear in feet with ratios smaller than X2, X2 could be a theoretical index for predicting ulcer formation.

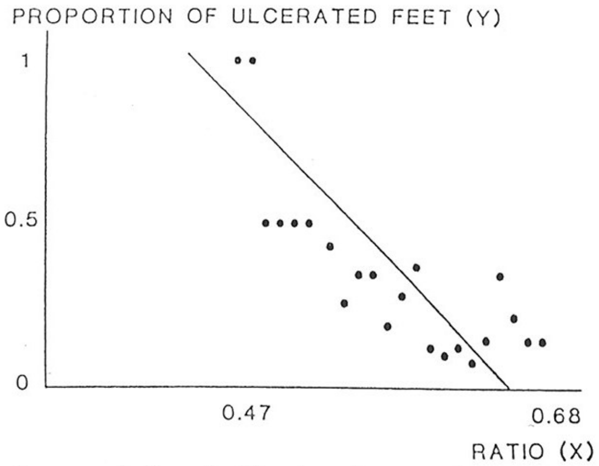


Theoretically, the possibility of ulcer formation in a foot with ratio between X1 and X2 could be predicted from the graph.

In our study, the equation of the regression line obtained by plotting the scatter diagram was given by Y=3 - 4.55X (Fig 3). X1 and X2 were 0.44 and 0.66 respectively. 0.66 could be a theoretical ulcer formation index.

Deformity of the foot could result in abnormal distribution

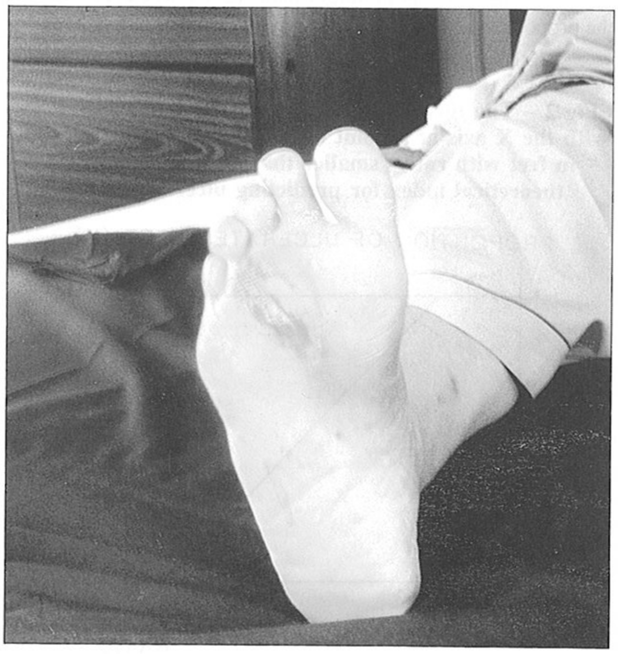
Fig 3 – The regression line in our study intercept with the X axis at a ratio of 0.66. It could be the theoretical index of ulcer formation.



of pressure in the sole. The ulcers in our study were mainly distributed beneath the metatarsal heads and calcaneum (Fig 4). Ulcerations with bony prominences were clinical indications of high pressure area[1]. The abnormal high pressure points in a sole could be identified by a pedobarographic study[2,3]. These findings could help in the prevention and management of sole ulcers by designing a orthotic footwear or planning a corrective surgery which could correct the abnormal distribution of pressure. Subsequently, pedobarographic study could also test the efficiency of orthotic footwear or surgery in reducing the pressure over these dangerous points.

In our study, each ulcerated foot had multiple dark print

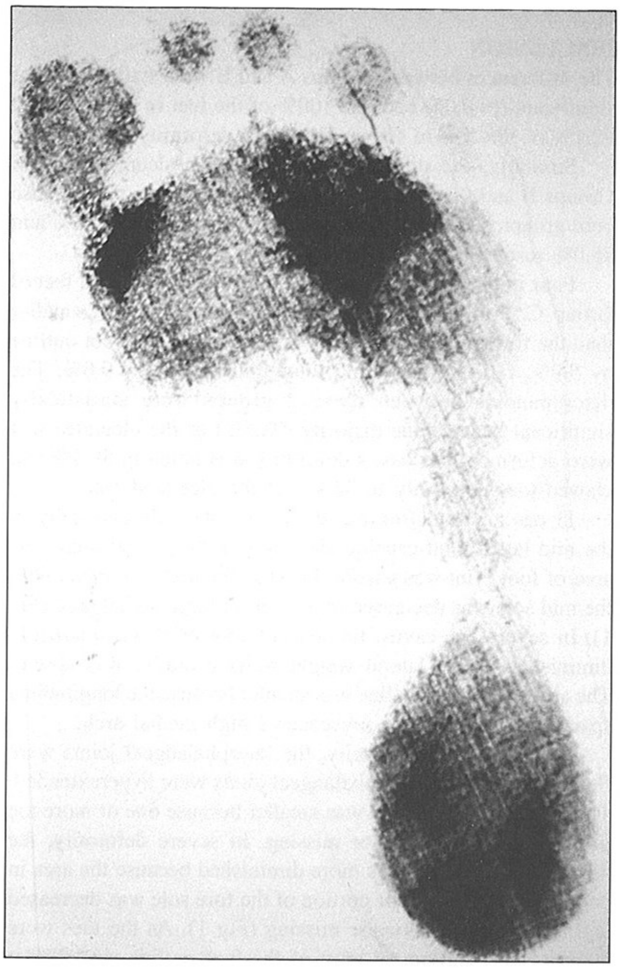
Fig 4 – The ulcer in this foot was situated beneath the fourth metatarsal head. It had a corresponding dark print area as shown in Fig 5.



areas (Fig 5). They were at the locations corresponding to the bony prominences. As these bony prominences were high pressure points, the dark print areas could serve as the crude indicators of high pressure. The dark areas other than those corresponding to the ulcers could also indicate the potential sites of ulcer formation. In area where pedobarographic study was not available, these indicators could help in the design of orthotic footwear. The excessive pressure could be reduced by putting enough padding over the sole at the sites corresponding to the dark print areas. The efficiency of corrective operation could also be evaluated by the disappearance of the dark print areas after operation.

In summary, reduction of the contact area in a deformed diabetic foot could potentiate the effect of abnormal distribution of pressure and contribute to formation of ulcers. The ratio of 0.66 could be a theoretical index of ulcer formation. The dark print areas could serve as crude indicators of high pressure in area where pedobarographic study was not available.

Fig 5 – The foot print of the foot shown in Fig 4 had multiple dark print areas. The one situated opposite the fourth toe print was consistent with the ulcer location. The other dark areas were situated at the locations corresponding to the calcaneum and other metatarsal heads. These areas could indicate the potential sites of ulcer formation.



References

1. Meggitt BF. Diabetes. In: Helal B, Wilson D. eds. The foot. Vol 2, 1st ed. UK: Churchill Livingstone; 1988:710-39.
2. Stokes IAF, Faris IB, Hutton WC. The neuropathic ulcer and loads on the foot in diabetic patients. Acta Orthop Scand 1975;46:839-47.
3. Betts RP, Franks CI, Duckworth T, Burke J. Static & dynamic foot pressure measurement in clinical orthopaedics. Med Biol Eng Comput 1980;18(5):674-84.