Geometric, shape and area measurement considerations for diabetic neuropathic plantar ulcers

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Abstract

Though neuropathic plantar ulcers are known to be "round–like," systematic quantitative data on their shape and geometric features are not readily available. A sample of 305 ulcers were retrospectively assessed to provide distribution data on quantitative geometric and shape parameters. After tracing the ulcer during the patient's initial visit, the following parameters were determined: surface area (A), maximum length (L), maximum perpendicular width (W), perimeter (p), shape factor (SF), and an ulcer regularity index (URI). SF assesses ulcer "circularity" and URI measures ulcer perimeter "smoothness" in comparison to a fictitious circle with the same contained area. SF and URI values of 1.0 correspond to 100 percent circularity and regularity. These data and the associated distributions, which are derived from a reasonably large random sample, provide a useful quantitative description of plantar ulcer geometry and shape.

1997;43(9):58–65

Introduction

Though neuropathic plantar ulcers are known to be "round-like," systematic quantitative data on their shape and geometric features are not extensively available. In the planning of research studies and for some clinical purposes it is sometimes useful to have apriori knowledge of likely ranges and distributions of ulcer dimensions, shapes and geometric features. One of the goals of the present study was to provide such reference ranges by evaluating 305 diabetic neuropathic plantar ulcers for which ulcer tracings were obtained at patient initial visits as part of a multicenter study. Additionally, the extent to which the area of various ulcer shapes could be estimated using simple length and width measurements was investigated. This was done by determining areas of ulcer tracings through use of computerized
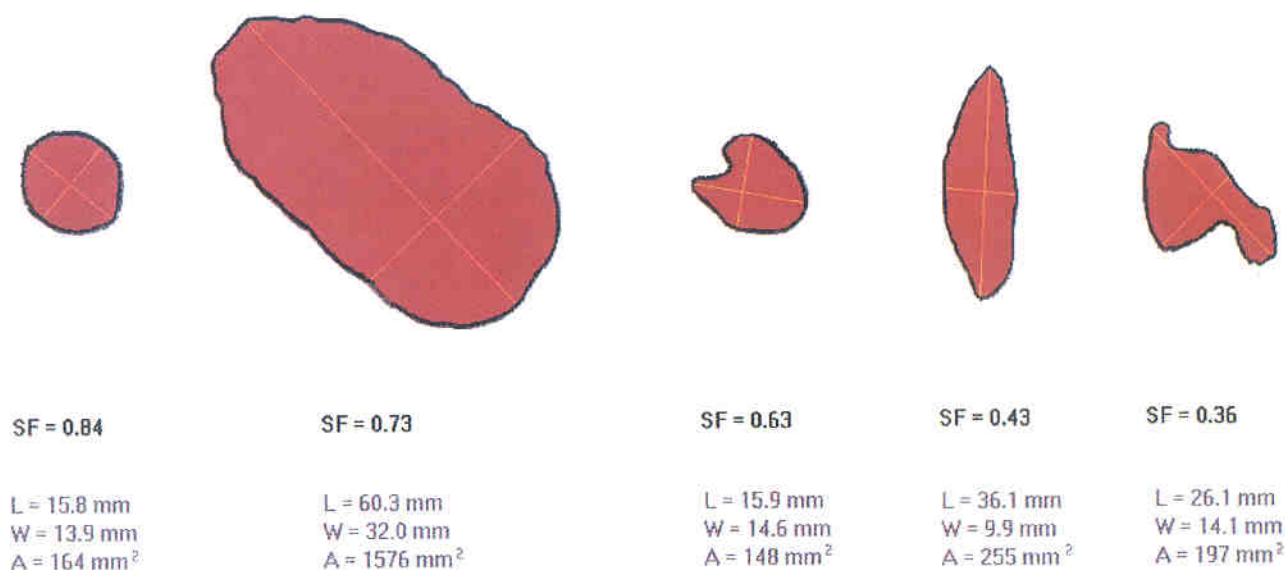
SF = 0.84	SF = 0.73	SF = 0.63	SF = 0.43	SF = 0.36
L = 15.8 mm	L = 60.3 mm	L = 15.9 mm	L = 36.1 mm	L = 26.1 mm
W = 13.9 mm	W = 32.0 mm	W = 14.6 mm	W = 9.9 mm	W = 14.1 mm
A = 164 mm^2	A = 1576 mm^2	A = 148 mm^2	A = 255 mm^2	A = 197 mm^2

Figure 1. *Varying shape factors of diabetic plantar ulcers.* Ulcer tracings illustrating the variety of sizes and shapes of diabetic ulcers. Note that shape factor (SF), a measure of "circularity," is independent of area (A). Lines on ulcers are the ulcer's maximum length (L) and perpendicular width (W). Printed with permission from H.N. Mayrovitz, PhD.

planimetry. Results were compared with areas obtained using the standard elliptical ulcer shape model and with areas obtained using a formula developed to minimize overall root mean square area error.

Methods

A sample of 305 diabetic plantar ulcers was retrospectively evaluated to provide distribution data on quantitative geometric and shape parameters and assessments of ulcer area via several methods. Raw source material used was supplied to our laboratory for analysis and consisted of digitized images of ulcer tracings, which were originally obtained at patient first visits as part of a multi–center study. To obtain the necessary metric, shape and area data for the present study, each image was analyzed as follows. Using imaging processing soft-

ware, four parameters of each ulcer were determined: the perimeter (p), the area contained within the perimeter (A), the maximum ulcer length (L), and the maximum width (W) defined as the maximum dimension perpendicular to the line of maximum length. From the measured A and p, the shape factor (SF) of the ulcer was determined from the formula $SF = 4\pi A / p^2$. SF ranges from 0 to 1 and is an index of ulcer "circularity" with a value of 1.0 representing a perfect circle. The measured L and W values were then used to compute "fictitious" ulcer areas (Ae) based on an often used elliptical shaped ulcer model. According to this model, area is calculated by the formula, $Ae = (\pi/4)LW$ where the constant $\pi/4$ has the numerical value of 0.785. Finally, a formula was developed in the form Area = KLW in which K was determined as the constant value

which minimized the overall root–mean–square error between the actual area determined by computer planimetry and the area derived from the "optimized" area formula. Accuracy of area estimates from L by W measurements to estimate ulcer area progression from the initial assessment was also tested. This was done by sequentially evaluating a randomly selected sample of 81 ulcers (from the initial 305) for up to 16 weeks (1034 individual assessments).

Results

Plantar ulcer geometry and shape

Figure 1 illustrates various shapes of a few selected plantar ulcers and their associated lengths, widths and shape factors. The lines of maximum length (L) and maximum width (W) perpendicular to L are indi-

Table 1. Summary of geometric and shape data for 305 plantar ulcers

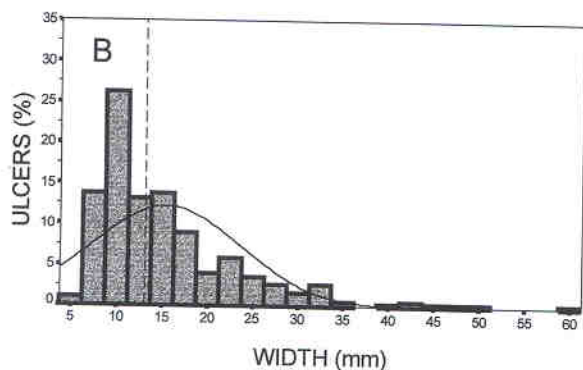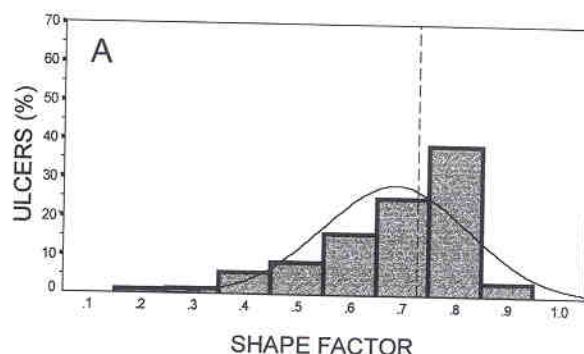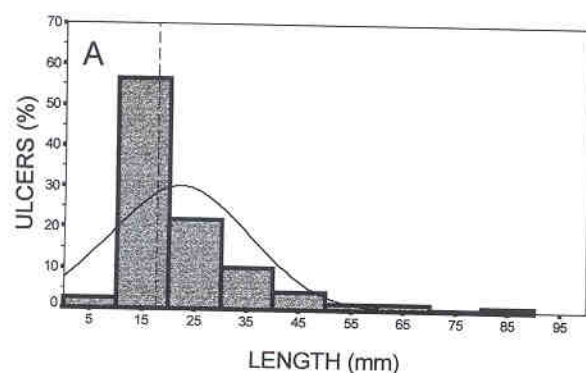|	A (mm²)	L (mm)	W (mm)	W / L	P (mm)	SF
Median	164.1	17.8	13.1	0.750	55.9	0.728
Mean	311.7	22.1	15.4	0.732	68.9	0.685
SD	411.5	13.2	8.1	0.165	40.5	0.139
Max.	3306	85.4	60.6	0.997	269.2	0.878
Min.	25	8.3	5.8	0.207	27.3	0.151
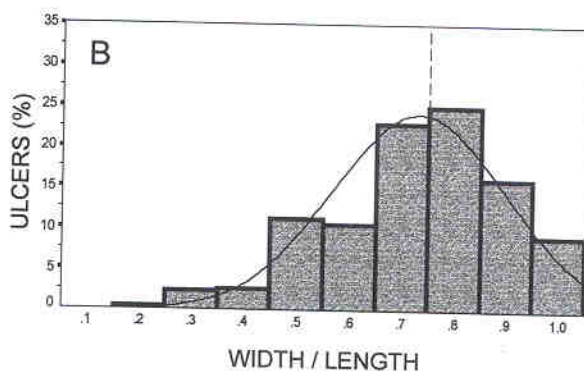
Figure 2. *Diabetic plantar ulcer metrics.* A) Frequency distribution of ulcer lengths. Length is defined as the maximum linear dimension of the 2–D ulcer tracing as shown in Figure 1. The dashed vertical line is the median length showing that 50 percent are less than 17.8 mm in length. B) Frequency distribution of ulcer widths. Width is defined as the maximum linear dimension perpendicular to the length. According to this definition, the width of any particular ulcer is never greater than the length. The median, shown by a dashed vertical line, indicates that 50 percent of ulcer widths are less than 13.1 mm. Printed with permission from H.N. Mayrovitz, PhD.

Figure 3. *Diabetic plantar ulcer shapes.* A) Frequency distribution of ulcer shape factors. Plantar ulcers are generally round–like in appearance and as shown here by the dashed vertical line, 50 percent of the studied ulcers have shape factors greater than 0.728. B) Frequency distributions of W/L. The median ratio (0.75) shown by the dashed vertical line indicates that 50 percent of ulcers have widths that are equal to at least three–fourths of the length. Printed with permission from H.N. Mayrovitz, PhD.
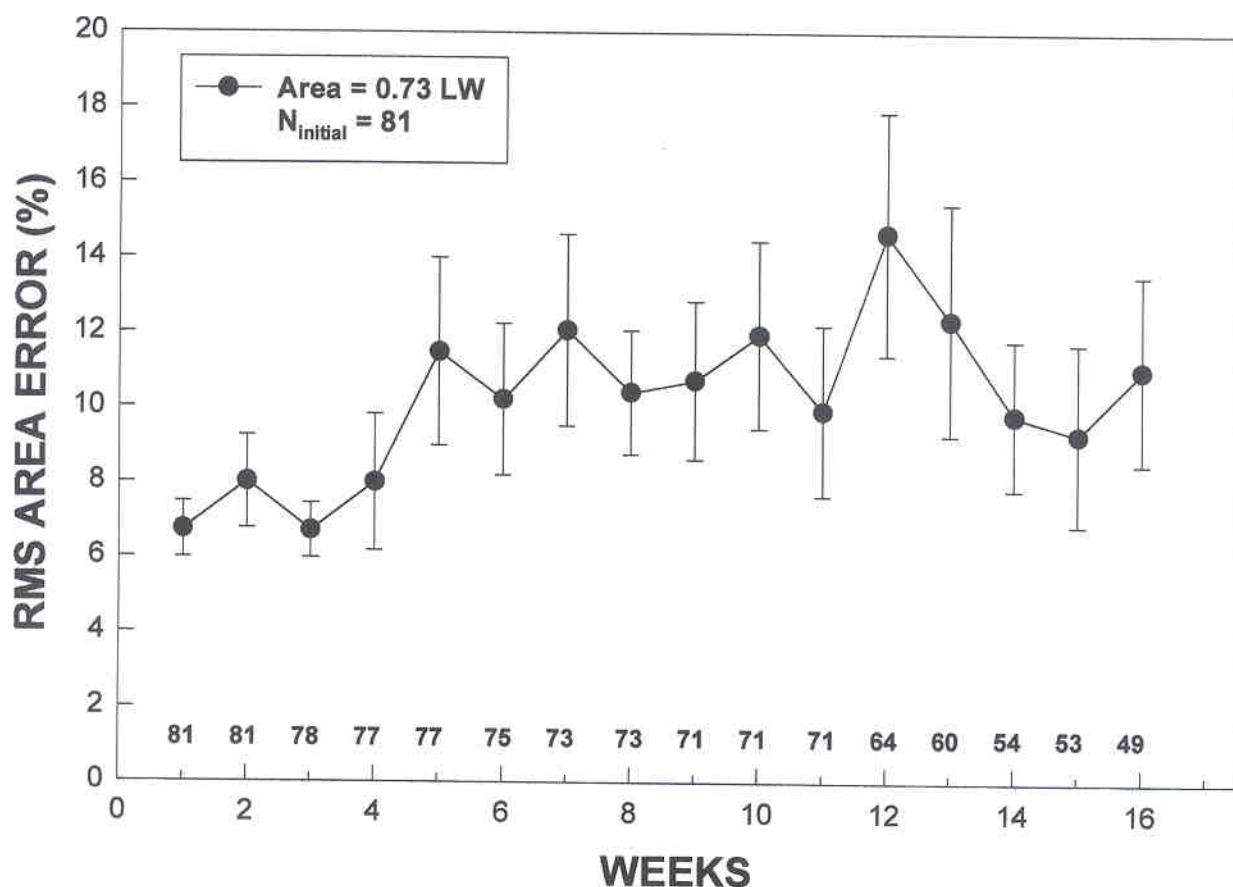
Figure 4. *Week–by–week ulcer area estimation errors.* Eighty–one plantar ulcers were examined for healing progression for a period of up to 16 weeks. The number of subjects (N) assessed at each week is indicated just above the week number. Each data point designates the mean +/– sem. At weekly intervals, root–mean–square (RMS) errors using the optimized formula were calculated. Errors ranged from a low of 6.7 percent at week 1 to a high of 14.6 percent at week 12. The optimized model exhibits sufficient accuracy in area assessment to be applicable during various stages of ulcer progression. Printed with permission from H.N. Mayrovitz, PhD.

cated within the ulcer area. By comparing the two left–most ulcers in the figure it may be noted that area per se is not a good indicator of associated shape factor. Thus the much larger area ulcer in fact has a smaller shape factor. Table 1 summarizes key geometric and shape parameters as obtained for all 305 ulcers. By way of comparison and to place the shape factor value in perspective, the following may be useful. A square ulcer would

have a shape factor equal to 0.785; an exact ellipse shape with a minor to major axis ratio of 0.43 would have a shape factor about equal to the median value determined for all plantar ulcers (0.728) in the present study; the median shape factor previously determined for a sample of 255 venous ulcers was 0.62, which is significantly less than that for the plantar ulcers. The frequency distribution of the plantar ulcer shape factors and of selected geo-

metric parameters are shown in Figures 2 and 3.

Plantar ulcer area estimations at initial visit

When the ellipse model is used to calculate ulcer area, there is an 8.1 percent overestimation of area as compared with planimetry. The value of K determined to minimize overall absolute mean error using the formula, Area = KLW is found to be K = 0.73 with

resultant overall mean error of 0.51 percent. The corresponding root–mean–square errors are 8.7 percent and 6.2 percent for the ellipse and optimized calculation models respectively. Thus use of the new formula tends to slightly improve estimated ulcer area. Stated another way, using the formula, Area = 0.73LW results in 84.5 percent of ulcer area estimates to be within 10 percent of the true area, whereas using the standard formula, Area = 0.785LW results in 72.8 percent of the estimates to be within 10 percent of the actual area.

Ulcer area progression

As shown in Figure 4, week–by–week root–mean square (rms) errors using the optimized formula ranged from a low of 6.7 percent at week 1 to a high of 14.6 percent at week 12. The overall mean error rate (weeks 1 through 16) was 10.0 +/− 0.52 percent. Thus the present results (strictly applicable to plantar ulcers) show good week–by–week and overall accuracy in area assessment.

Discussion

Wound shape is an interesting, important, but infrequently studied feature of human skin ulcers.[1-6] The fact that neuropathic plantar ulcers and malleolar ischemic ulcers tend to be "round–like" and venous ulcers tend to be "irregularly" shaped is common knowledge, but beyond this there are aspects of wound shape which are of both fundamental and clinical interest. The specific aspects of concern here are 1) a description of the geometry and shapes of a large sample of plantar ulcers to serve as a reference base and 2) the determination of the accuracy with which the areas of such ulcers could be estimated by simple length by width measurements. Regarding the second goal, it is noted that although an increasing number of sophisticated methods have been described to measure ulcer area,[7-13] the "old" method of measuring wound length (L) and width (W) is still used, and properly so, by healthcare professionals. In fact, as more ulcers tend to be treated in home healthcare environments, proper application of the length by width method may be more frequently used to help track progression and develop outcome data. It has been noted that this method is easy to use, inexpensive, fast, and has good inter–rater and intra–rater reliability.[14] The present results add to this list by showing that when the optimized formula herein developed (Area = 0.73LW) is applied to plantar ulcers a reasonable accuracy in ulcer area estimation is also obtained. Proper application of this method is based on a consistent choice of L and W even as the ulcer shape changes over time.[15] A consistent measurement rule that is independent of the perceived shape or orientation of the ulcer here put–forward is to define and measure length (L) as the longest line that can be drawn between any two wound edges and width (W) as the maximum dimension perpendicular to the line along which the maximum length was measured.

Acknowledgements

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