ORIGINAL INVESTIGATION

Comparisons of Venous and Diabetic Plantar Ulcer Shape and Area

Harvey N. Mayrovitz, PhD; Joshua Smith, MS; and Connie Ingram, RN

Abstract

That diabetic plantar ulcers are "round-like" and venous ulcers are "irregularly" shaped is well known. However, these notions have not been quantified or substantiated systematically. In this retrospective analysis, geometric parameters—including area (A), perimeter (p), and shape factor (SF)—of 255 venous and 305 plantar ulcers have been determined using length (L) and width (W) in specific calculation models; these calculations then were compared with computer planimetry. Length was the maximum dimension and width was the maximum dimension perpendicular to length. Results show that venous ulcers, when compared with plantar ulcers, have significantly smaller shape factors and smaller W/L ratios. An optimized calculation model ($A=K_0LW$) then was used, in which K_0 was adjusted to minimize root-mean-square (rms) error among venous and plantar ulcers. Values of K_0 differed for venous (K_0=0.67) and plantar (K_0=0.73) ulcers, with no significant overall paired-differences in actual vs. calculated area. Overall, these models correctly identified 91.8% of venous and 95.1% of plantar ulcer areas within 20% of actual areas. If venous ulcer SF was > 0.35, 3% of the ulcers exceeded the 20% error limit; if SF was ≤ 0.35, then 56% exceeded the 20% error. If plantar ulcer SF was > 0.65, no ulcers exceeded the 20% error limit; if SF was ≤ 0.65, 15% did. These findings provide quantitative data of absolute and comparative ulcer shapes and clarify the impact of shape on area assessment accuracy when estimated by simple length by width measures.

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As recently emphasized,[1] wound treatment is a complex process that requires an understanding of multiple interactive factors. These include physiological mechanisms, assessment procedures, debridement and cleansing techniques, bacterial colonization and infection management and prevention, selection of appropriate therapies, and adequate tracking of the wound's progress over time. An important aspect of determining wound progression is the use of an efficient and standardized method to assess wound shape and size. Although it is well known that diabetic plantar ulcers typically are "round-like" and venous ulcers are "irregularly" shaped, there is surprisingly little information in the literature that serves as reference for characterizing these or other ulcer shapes.

It has been demonstrated that initial wound area is a determinant of healing progression.[2-4] Measuring and recording initial wound area and shape helps clinicians develop a treatment plan; tracking changes over time provides important information about the ulcer healing rate and effectiveness of treatment. Because there is little information available regarding the systematic description of venous ulcer shapes or the differences between venous and diabetic plantar ulcers, the present study was undertaken. The primary goals were: (1) to present a reliable method for consistently measuring ulcer dimensions; (2) to develop models that minimize errors in area calculations; (3) to offer reference information that quantitatively describes and compares plantar and venous ulcer areas and shapes; and (4) to determine the ability of the calculation models to accurately predict ulcer areas for ulcers of varying shapes and sizes.

Methods

Area and shape considerations

Despite a variety of available techniques for determining ulcer areas, the "old" method of ascertaining areas from simple

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length and width measurements is widely used.[5-7] Traditionally, length has been described as the longest area of the ulcer measured from head to toe, with width measured as the maximum dimension from side to side.[8] Estimates of ulcer area based on length and width can be done in several ways, and Figure 1 illustrates two possible approaches for a venous ulcer. Similar models have been used to estimate ulcer area,[7,9] although other more complex models are possible.[10]

When assessments are based on length and width, certain choices need to be made. Consider, for example, a perfectly rectangular wound; one likely would measure the length (L) and width (W) and calculate the area (A) as A = L × W. However, practical problems exist, even in this simple example. Few ulcers are truly rectangular. In fact, ulcer shape varies widely, and the problem of determining where to measure the length and width to yield consistent measurements over time becomes unclear. It then is necessary to define a consistent way of measuring these dimensions to minimize the associated subjectivity.

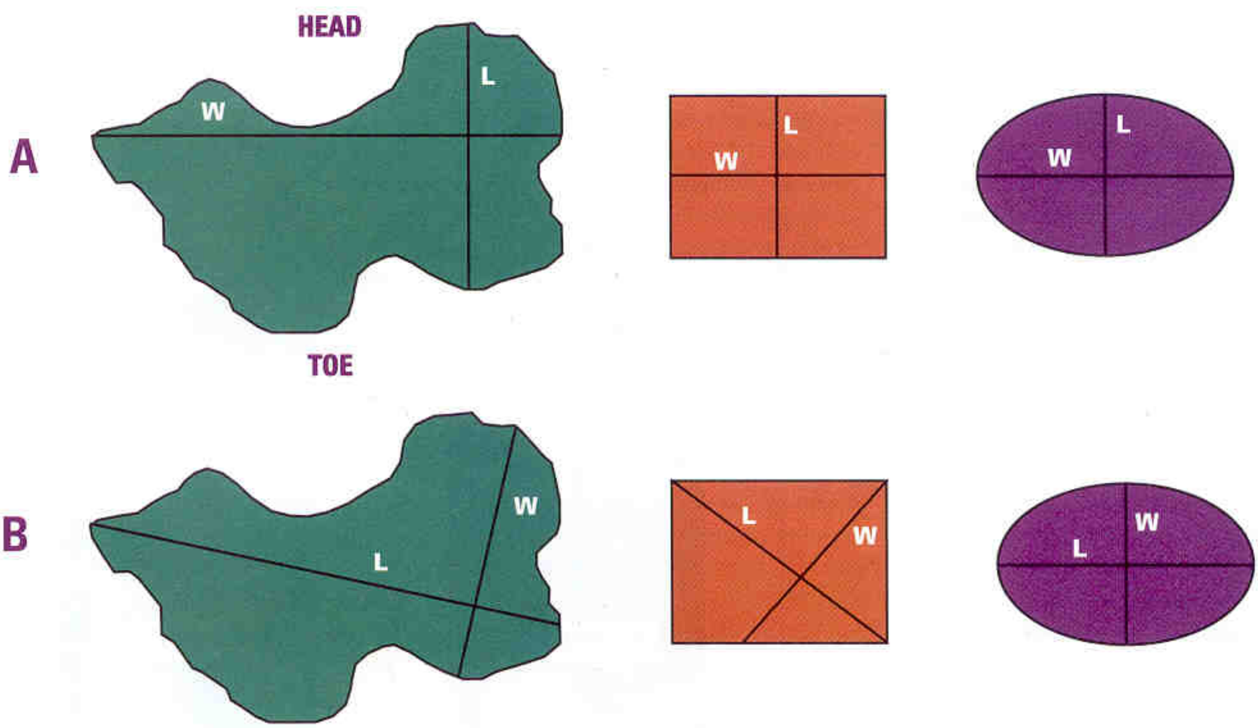
In this retrospective study, consistency was achieved by defining length as the maximum linear dimension of the wound independent of direction (i.e., length is the longest line that may be drawn between any two wound edges) and width as the maximum linear dimension of the wound that is perpendicular to length. Note that in Figure 1, application of this definition to the rectangular model requires that length becomes the diagonal of the rectangle and width is the longest line perpendicular to length. When these definitions of length and width are applied to actual wounds, the choices for length and width are more consistent, especially when combined with a reasonably accurate method of determining ulcer areas.

Ulcer geometry

It also is necessary to offer a quantitative measure that describes an ulcer's shape. Shape can be characterized in terms of a parameter known as shape factor (SF), regardless of whether the shape is "regular" or "irregular."[11] The shape factor of an object provides a measure of its "circularity," with a perfect circle defined as having a shape factor of unity. Shape factor can be determined from an object's area (A) and perimeter (p), and it is calculated by the formula $SF=4\pi(A/p^2)$.

Figure 1

TWO MODELS FOR CALCULATING AREA



In the top illustration (A), the maximum ulcer dimension measured from head to toe is the length (L); the corresponding maximum dimension from side to side is the width (W). In the bottom illustration (B), the maximum ulcer dimension, independent of its orientation, is the length, and the maximum dimension perpendicular to length is the width. A calculation model, described in the text, is needed to estimate the ulcer area. Rectangular and elliptical models in both illustrations show how length and width values are assigned for calculating the area.

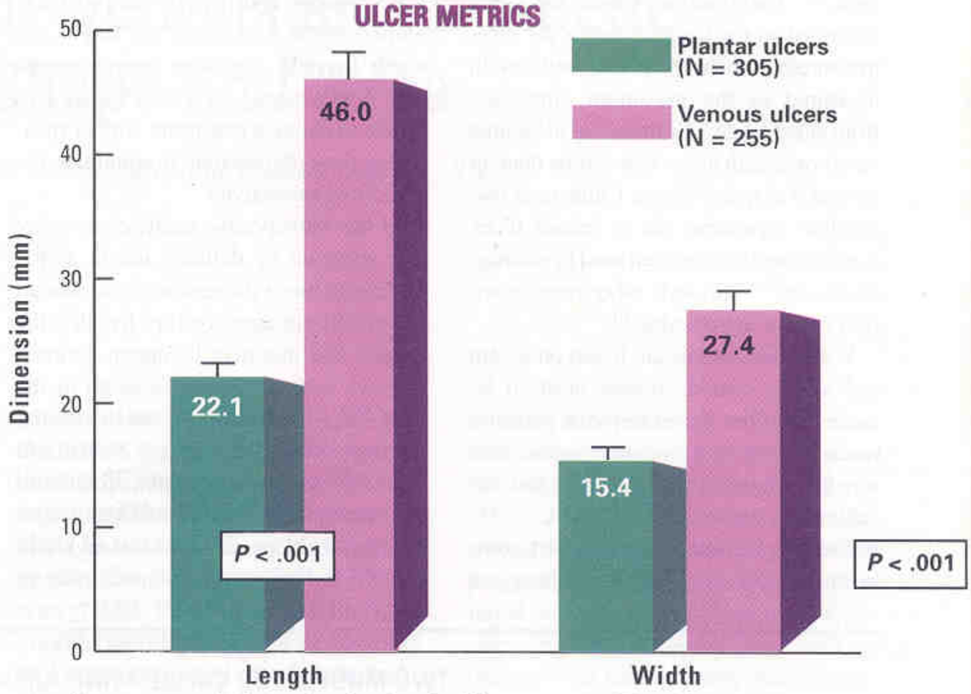
Using a circular shape as an example, the shape factor would be determined as follows: the area of a circle (A) with radius r is equal to πr^2, and its perimeter (p, total length of its boundary) is equal to $2\pi pr$. Applying the definition of $SF=4\pi(A/p^2)$ and substituting the specific values of A and p gives $SF=4\pi(r^2)/(4\pi^2r^2)$. Canceling terms in this ratio yields a SF of unity. For other regular geometric shapes such as rectangles and ellipses, different generalized formulas may be derived to determine shape factor as a function of length (L) and width (W) using the aspect ratio or form factor, which is simply R=W/L. Thus, for a rectangle, $SF=\pi R/(R+1)^2$, and for an ellipse, $SF=2R/(R^2+1)$. The ulcer shape factors subsequently will serve not only to make distinctions between plantar and venous ulcer characteristics, but also to test the accuracy of the calculation models over a wide range of shapes.

Procedures

A retrospective evaluation of 305 diabetic plantar ulcers and 255 venous ulcers was done to obtain actual wound shapes and area assessment errors. The raw source materials were supplied by the ProCyte Corporation (Kirkland, WA) and Organogenesis (Canton, MA). The data consisted of digitized images of actual wound tracings obtained as part of two separate studies, both involving multiple acquisition centers. Each ulcer tracing then was analyzed by computer planimetry using image processing software (SigmaScan, Jandel Scientific, San Rafael, CA).

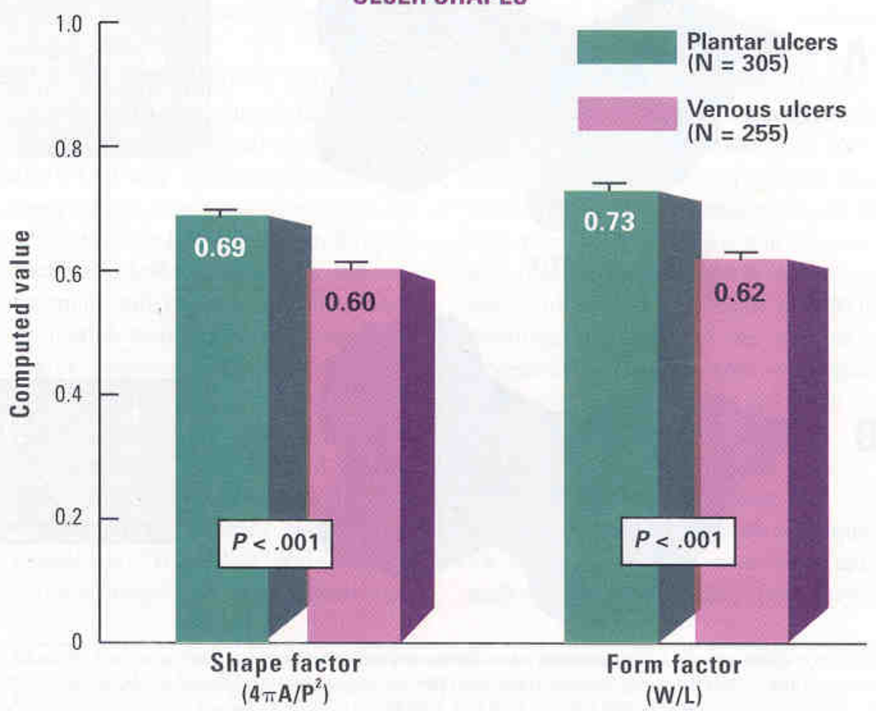
Images of known length, width, and area had been digitized first and used as calibration images for each subsequent measurement. Five parameters were determined for each tracing image: area (A); perimeter (p); length (L), defined as the maximum linear dimension of the wound; width (W), taken as the maximum linear dimension of the wound perpendicular to L; and shape

Figure 2
ULCER METRICS



Mean venous and plantar ulcer length and width are compared. Error bars are +/– SD.

Figure 3
ULCER SHAPES



Mean shape factor and form factor values for venous and plantar ulcers are compared.

factor (SF). SF was determined from the measured A and p according to the formula, $SF=4\pi A/p^2$. The measured L and W then were used to determine areas according to the elliptical calculation model shown in Figure 1. For the elliptical model, an area (A_e) was determined according to the formula, $A_e=KLW$, in which K is a constant that would equal $\pi/4$, or 0.785 in a pure ellipse. The tracing of each ulcer length and width were substituted into the above formula, with K equal to 0.785, and an area A_e was determined for each ulcer.

The calculated area, A_e, then was compared with the area, A, derived by computer planimetry. This comparison was done by computing the percentage error between the two area calculations as follows: $A_{err} = 100(A-A_e)/A$. Negative values of A_{err} errors represent an overestimation, and positive values represent an underestimation of actual area by the elliptical model. Because these positive and negative errors mathematically cancel upon averaging, the square root of the square of each A_{err} (root-mean-square, rms error) was used to characterize errors.

Areas calculated by the "standard" elliptical model subsequently were compared with an "optimized" model. The optimized calculation model was developed using a new constant K_o, which, when applied to the formula $A = K_oLW$, would minimize the rms error. K_o was determined separately for venous and for diabetic plantar ulcers. Thus, L and W measurements for venous ulcers were substituted into the optimized formula specific to venous ulcers; L and W measurements for diabetic plantar ulcers were substituted into the optimized formula specific to diabetic plantar ulcers. Area errors were calculated for each optimized model. Finally, a statistical analysis was done to analyze differences between venous and diabetic plantar ulcer shape and area characteristics. A value of $p < 0.01$ was considered significant.

Results

As shown in Figures 2 and 3, there are several significant quantitative differences between venous and diabetic plantar ulcers. The length (46.0 ± 1.98 mm) and width (27.4 ± 1.23 mm) of venous ulcers were significantly greater than the length and width of diabetic ulcers ($p < 0.001$), whose corresponding dimensions were 22.1 ± 0.76 mm (length) and 15.4 ± 0.47 mm (width). In addition, venous ulcers have significantly smaller shape factors (0.60 ± 0.01 vs. 0.69 ± 0.01, $p < 0.001$) and smaller W/L ratios (0.62 ± 0.01 vs. 0.73 ± 0.01, $p < 0.001$) when compared with diabetic plantar ulcers. These quantitative parameters thus demonstrate significantly less circularity and smaller aspect ratios among venous ulcers.

Accuracy of ulcer area estimation from length and width measurements is dependent on ulcer type, ulcer shape factor, and the calculation model used. The value of K_o, which minimized rms error, was 0.67 for venous ulcers and 0.73 for diabetic plantar ulcers, based on the optimization analysis approach. Ulcer areas calculated with these optimized models resulted in no significant paired-differences between actual areas (computer-derived) vs calculated areas ($p > 0.10$). However, as seen in Figures 4 and 5, the optimized models are slightly more accurate when applied to plantar ulcers. This is manifested as a small difference in the percentage of correctly identified areas that have an rms error < 20%. For plantar ulcers, this is 95.1%; for venous ulcers, 91.8%. It should be noted that only about 50% of venous and 70% of diabetic ulcers have rms errors within 10% of the actual area even when using the optimized model.

Figures 6 and 7 illustrate some important limitations of using only length and width measurements even with an optimized model. For venous ulcers, 56% (14/25) of the calculated areas exceeded a 20% rms error, even when the optimized model was used, if the shape factor was ≤ 0.35; when the shape factor was > 0.35, only 3% (7/230) exceeded this limit. For plantar ulcers, 15% (15/98) of the calculated areas had > 20% rms error with a shape factor ≤ 0.65; no (0/207) calculated areas exceeded this level of error for a shape factor > 0.65.

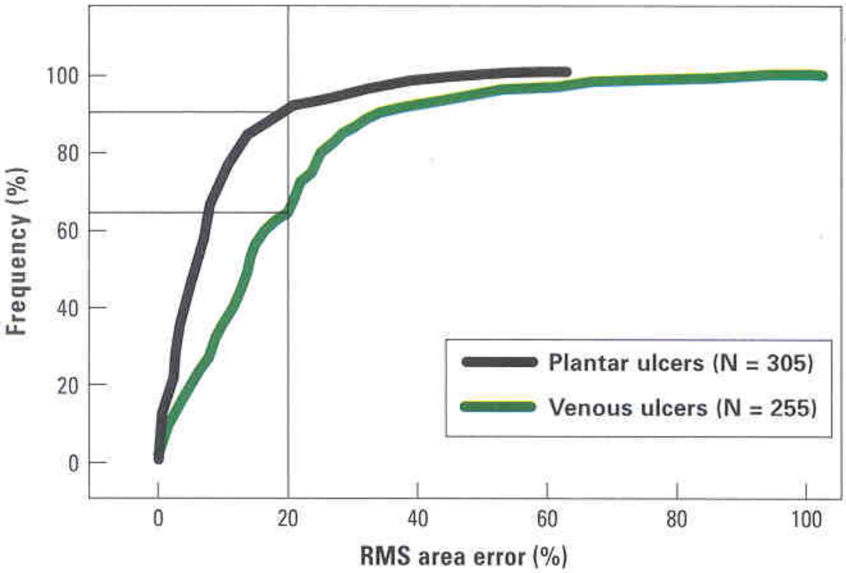
Discussion

Wound shape is an interesting yet little-studied feature of skin ulcers. Early work involving wound shapes has focused on understanding wound contraction and cicatrization (formation of scar tissue as a wound heals).[2,4,9,12-14] These studies focused on a range of factors that affect wound area and shape during the healing process and offered mathematical descriptions of wound closure. More recent studies[7,14,15] have used wound areas to characterize ulcer healing rate, a parameter that may be useful to compare efficacy of treatments. Although healing rate may or may not be useful for a given ulcer type, there remain questions about the validity of the results due to a possible amplification of errors. Thus, whether one decides to report healing rate by any of several methods,[3,7] all of these methods still are dependent on the area measurement method.

Despite a variety of sophisticated methods for measuring wound size,[5,15,16] the "old" method of measuring length and width can be effective and is widely used.[5-7] Length and width are determined by tape measure or ruler either directly over the wound or after tracing the wound on a disposable acetate sheet. Length often is taken as the longest dimension of the skin ulcer from head to toe, and width as the maximum dimension from side to side.[11] This method is

Figure 4

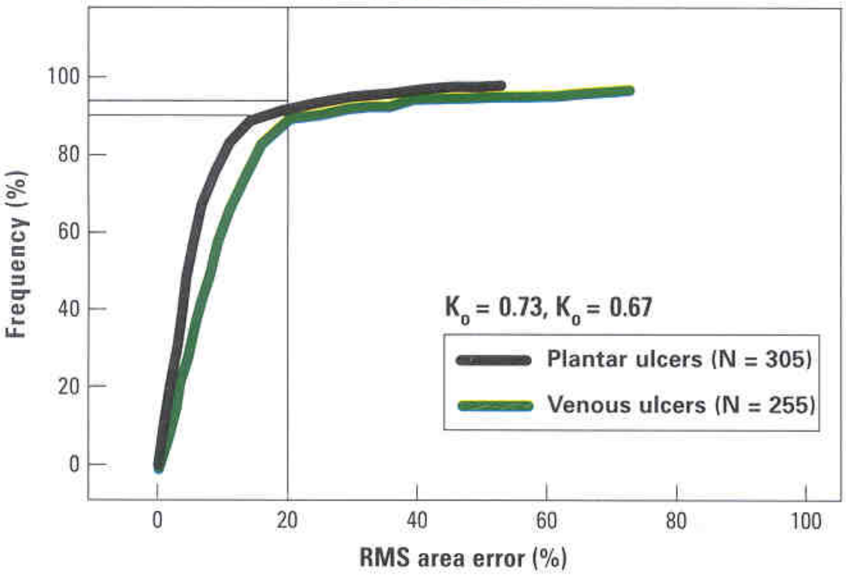
DISTRIBUTION OF RMS AREA ERRORS
PURE ELLIPTICAL MODEL



In the pure elliptical model, root-mean-square area errors for both venous and plantar ulcers are distributed according to the formula $A = 0.785LW$.

Figure 5

DISTRIBUTION OF RMS AREA ERRORS
OPTIMIZED MODEL



The optimized calculation model shows distribution of venous and plantar root-mean-square area errors according to the formula $A = K_oLW$, in which K_o for venous ulcers = 0.73 and K_o for plantar ulcers = 0.67.

a quick assessment tool that provides good interrater and intrarater reliability,[17] yet it may be deceptively simple. The decision as to which dimension to measure can be difficult to make, depending on the "regularity" of the wound's shape and the position of the patient. In fact, further subjectivity is introduced with this method because different clinicians may choose widely different measurements of length and width. This may be a problem in a clinical setting as different people evaluate a wound at various time intervals, leading to wide variances and inaccurate records of ulcer progression.

Although ulcer tracing is a valuable part of a patient's record and serves to alleviate some of the subjectivity, it too has some associated problems, especially in defining area in quantitative terms. First, tracing requires extra equipment and time. Second, it may expose the health care professional to a contaminated surface. In addition, tracing requires definition of wound edges for the entire wound, which may be difficult to determine and adds subjectivity to the measurement. Tracing may become increasingly difficult because the transparency is no longer flat against the wound, depending on the anatomical location of the wound. Further, if the transparency does not contain a grid, the tracing must be copied to grid paper in order to calculate the area. Once the tracing is on a grid, there is still a question of which grid squares to count and which to exclude in determining the area.

Computer planimetry is currently one of the most accurate ways to measure ulcer area from tracings.[3] Unfortunately, it is not always practical in all settings. Computer planimetry requires expensive equipment that may not be readily available, and it is time consuming. Often, a quick, easy way to determine ulcer area is adequate, with a quantitative accuracy that is within 10% to 20% of the actual area.

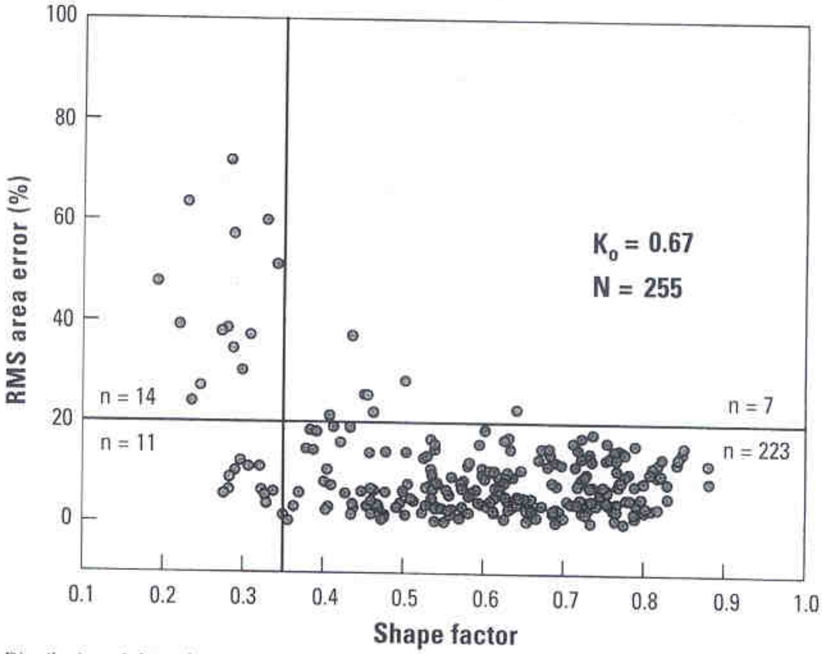
Length and width are not the only parameters of interest for assessing and following wound progression. Instead, the focus is on the entire ulcer area (and volume for deeper wounds), as the healing wound often changes shape through its progression. However, length and width are acquired easily, and a method of deriving area from simple length and width measurements with known ranges of accuracy would appear to be of practical use. This paper does not address errors that exist in actually performing these length or width measurements. Even if linear measurements are assumed accurate, two related questions that impact accuracy remain: How does one choose which measurements to make? How well can these measurements be used to estimate ulcer area?

Thus, the primary aim of the present study was to determine the likely errors in wound area assessment when applying a particular measurement method and calculation model to two different but common ulcers. Important definitions have been offered for ulcer length and width, and they serve to eliminate some subjectivity in these measurements. The advocated measurement method determines length as the longest linear dimension of the wound. Width is then the longest dimension perpendicular to the length. This method is applicable to any wound and eliminates much uncertainty in making these measurements. It should be noted that the errors in area estimation reported in this study do not include errors in the actual measurements of length and width in wounds or errors associated with the initial tracings, nor have the issues of depth and volume been addressed.

Additionally, reference information quantitatively describing both venous and plantar ulcers has been offered. The "irregularity" of venous ulcer shape is well known by wound care professionals, as is the "round-like" appearance of plantar ulcers. Beyond these qualitative

Figure 6

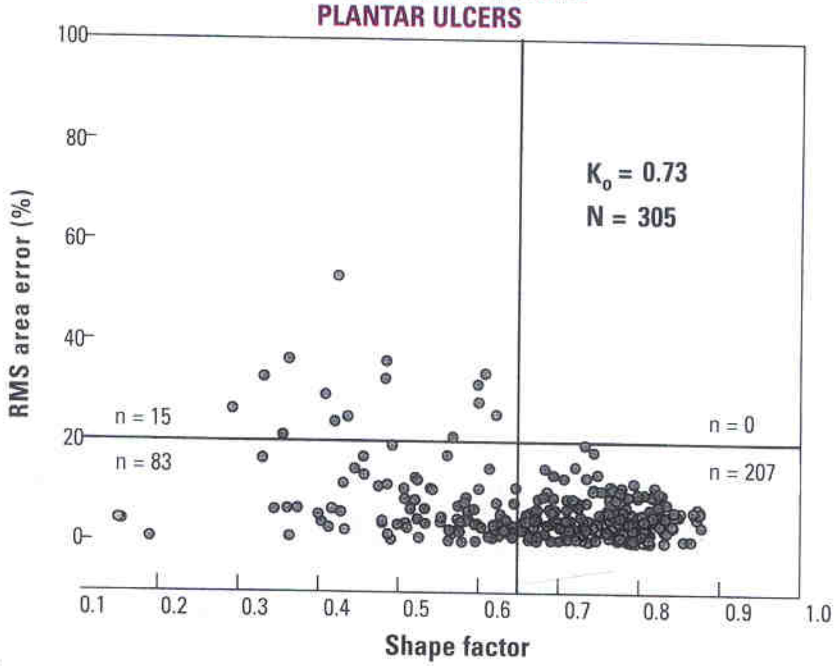
SHAPE FACTOR LIMITATIONS VENOUS ULCERS



Distribution of shape factors with corresponding root-mean-square area error for venous ulcers. Ulcers with an SF < 0.35 have significant area error estimation using the optimized calculation model.

Figure 7

SHAPE FACTOR LIMITATIONS PLANTAR ULCERS



The optimized calculation model is applicable over a wider range of plantar ulcer shape factors.

whose shape and orientation change over time. The demonstration that wounds with low shape factor values are subject to considerable changes in area errors, when estimated with length by width methods, alerts the clinician to the need to consider these issues when wound shape factors change over time (high-to-low or low-to-high). Finally, the included tables and procedure provide the clinician with a practical way of estimating shape factors based on length and width measurements. AWC

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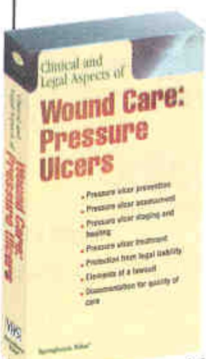

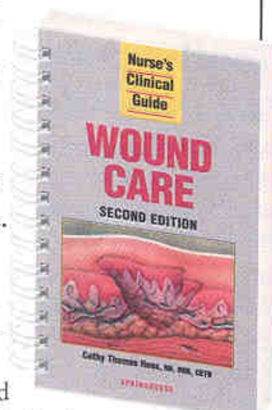

Table 1
SHAPE FACTORS

W/L	GEOMETRIC SHAPES		ULCERS	
	Ellipse	Rectangle	Venous	Plantar
1.00	1.00	0.79	0.80	0.79
0.90	0.99	0.78	0.75	0.75
0.80	0.98	0.78	0.69	0.71
0.70	0.94	0.76	0.64	0.67
0.65	0.91	0.75	0.61	0.65
0.60	0.88	0.74	0.58	0.63
0.55	0.84	0.72	0.56	0.61
0.50	0.80	0.70	0.53	0.59
0.45	0.75	0.67	0.50	0.57
0.40	0.69	0.64	0.48	0.55
0.35	0.62	0.60	0.45	0.53
0.30	0.55	0.56	0.42	0.51
0.25	0.47	0.50	0.40	0.49
0.20	0.38	0.44	0.37	0.47

descriptions, little information exists that is reproducible and therefore useful in determining the "regularity" of a venous or plantar ulcer. Case reports typically document an ulcer's status by noting its area and describing its shape as "irregular." These descriptions fail to relate the complex structures of the ulcers and, unfortunately, usually are not adequate for the purposes of comparison in a clinical setting.

Careful thought is required to balance the ease, simplicity, and relative accuracy of area determination based on length and width measurements. The goal of accurate area estimation is achieved with the calculation models presented, but only on a case-by-case basis. It is clear that certain ulcers do not conform well to these calculation models, specifically those venous ulcers with small (≤ 0.35) shape factors. The area models also are better applied to plantar ulcers versus venous ulcers due to the variety of shape features, specifically the smaller aspect ratios, associated with venous ulcers. However, if the shape factor of the plantar ulcers is ≤ 0.65, a small percentage of area estimates will have large associated errors (> 20% rms). These results imply that the measurement of length and width are not necessarily the method of choice for all wound documentation and tracking. The optimized model, when applied to the appropriate ulcers, is a simple way to estimate ulcer area within 20% of the actual area, within the limitations of the shape factors described. The calculation models conserve time, energy, and resources and are attractive alternatives when more complex methods are not needed, possible, or cost-effective.

The application of these models in a clinical setting will require clinicians to identify certain ulcers for which the models lose their value and realize the associated error in the area estimation. One possible clinically useful approach is to measure the ulcer's length and width, then calculate its aspect ratio, R=W/L. The R value then may be used in the appropriate formula (previously given) to approximate the ulcer's shape factor. However, this is only an approximation because the formulas are based on regular geometric shapes, and calculation of the actual shape factor would require measurements of its area and perimeter, which is not possible with only length and width measures.

Table 2
PERCENT OF ULCERS WITH AREA ERRORS < 20%

SF	VENOUS	PLANTAR
>0.65	100.0	100.0
>0.60	99.4	98.7
>0.55	99.3	98.0
>0.50	98.9	98.1
>0.45	97.6	97.5
>0.40	96.8	96.2
>0.35	97.0	95.6
≤0.35	44.0	71.4

An alternative approach would be to use Table 1 to approximate the SF value corresponding to the measured W/L value for the ulcer being documented. This table incorporates the best estimate of the shape factors for venous and plantar ulcers measured in this study corresponding to their measured W/L value. Once the approximate SF value is obtained, Table 2 would be used to estimate the probable rms error to be expected when area is estimated based on the L and W measurements.

As an example of this procedure, assume that the venous ulcer shown in Figure 1 is measured to have a maximum length of 11.9 cm and a maximum perpendicular width of 7.1 cm (these are its actual measured values); the W/L is thus 0.60. Table 1 shows that for this W/L value, the estimated SF is about 0.58. Table 2 then shows that for this SF value, there is a high likelihood (99.4% of ulcers) that the estimated area obtained from length and width measurements will be within 20% of the actual ulcer area.

Conclusion

The present findings provide quantitative data of absolute and comparative ulcer shapes and also clarify the impact of ulcer shape on area assessment accuracy when estimated by simple length by width measures. The formulas presented for area estimation, which are used when ulcer area is based on only length and width, have defined probable errors and are useful when more sophisticated methods are not available or indicated. Knowledge of the likely errors provides the clinician with an informed judgment as to the validity of the measurements and, thereby, an informed and appropriate level of confidence in their measurements.

The recommended procedure of using a consistent length by width measurement procedure, in which length always is taken as the maximum dimension, contains an intrinsic safeguard to deal with wounds