This manuscript was accepted for publication in Advances in Skin and Wound Care on 6/21/2008

Wound Areas by Computerized Planimetry of Digital Images: Accuracy and Reliability

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ABSTRACT

Background: Tracking wound 'size' is an essential part of treatment. Because a wound's initial size may affect apparent healing rates, its surface area (S) and its area to perimeter ratio (S/P) are useful to document healing. Assessments of these parameters can be done by computerized planimetry of digital images using suitable software.

Objective: Because wounds are often evaluated by different caregivers and because measurement-time is important, our objective was to determine accuracy, repeatability and measurement-time of S and S/P from measurements of images recorded by digital photography.

Methods: Six wound images of various complexities with known areas were measured in triplicate by 20 senior nursing students during two sessions one week apart. Images included; an ellipse, two traced venous ulcers, and photos of a pressure, diabetic plantar and venous ulcer. Area error was determined as the percentage difference between known and planimetry measured areas. Reliability was assessed from test-retest coefficient of variations (CV%) from which the smallest meaningful percentage change (SMPC) was determined.

Results: Area errors (mean±SD) ranged from -2.95±7.01% to +2.32±6.04%. For well defined image margins (images 1-4), area and S/P SMPC values were all less than 3.2%. For less well defined borders (images 5-6), SMPC were larger ranging between 6.2%-10.8%. Wound measurement-time decreased from 93.4±35.1 seconds at session one to 67.7±24.4 at session two ($p<0.001$).

Conclusions: Results based on the specific software used and on the outcomes of the study group, indicate that simple computer-based planimetry of digital images can provide rapid, accurate and reliable estimates of wound area and S/P ratios.

INTRODUCTION

Tracking and documenting changes in wound area is an important part of the overall treatment and assessment process.[1-9] A variety of methods to estimate a wound's area have been used and some have been assessed with respect to their utility and reliability.[10-16] Some researchers have combined standard photography with transparency tracings[15] and others have compared the use of video camera recordings with tracing methods.[17] Perhaps the simplest method is to measure wound length (L) and width (W) and multiply these together to get an estimate of area. Results obtained with this approach, when applied to diabetic wounds and venous ulcers in comparison to areas obtained using planimetry of wound tracings, showed overall good agreement if a suitable multiplying constant was used in the area calculations.[18-20] However, significant individual differences between these L x W area determinations could occur principally related to wound shape and its change with treatment and time. This fact suggests that simple L x W measurements may be useful indicators under certain conditions[21, 22] but they are not suitable for situations in which more accurate assessments of area change are needed such as to estimate healing rates.

When attempting to determine the rate with which a wound is healing, the manner by which such a rate is calculated, and the initial area of the wound, may influence the calculated healing rate. For example, it has been reported that healing rates, calculated as change in wound area per day, were significantly and independently affected by the wound's initial area and other wound geometric factors.[5] In contrast, when the ratio of the wound's surface area (S) to its perimeter (P) was used as an index of healing, there was no dependence on initial wound area.[5] Several investigators have suggested that use of the S/P ratio is a useful method to characterize wound healing rates.[5, 23-26]. Changes in this parameter are a measure of the change in a wound's effective radius, which is an index of movement of a wound's margin toward the center for healing or away from the center in the case of wound enlargement. Thus, if a wound's shape is a circle, then twice the S/P ratio would be exactly equal to its radius. For other shaped wounds the S/P value can be viewed as an effective radius. The S/P ratio has been used to assess healing rates in venous ulcers and has been reported to be a suitable indicator of linear healing per day.[5, 27] The S/P ratio has also been used to predict time to wound closure based on a nonlinear delayed exponential model of healing[23, 24] which seems to offer some predictive features.[25] Whether wound healing progression is judged on the basis of changes in absolute area, changes in area relative to initial area, or changes in the S/P ratio all depend on a suitably accurate and reliable method to determine the wound's area. The use of digital photography, which is now widely available for wound documentation, offers several benefits to other more complex methods. It can be done cheaply and quickly and perhaps more importantly, it requires no contact with the wound bed in contrast to various wound tracing methods. Once the digital image is obtained, if it is to be used for other than simple visual documentation, there remains the need to determine wound area from the digitized image. Technologically, this task can be done using computerized planimetry in which the margins of a wound, as depicted on the digitized image, are outlined on a computer screen and the enclosed area is automatically determined by a suitable software algorithm. Such software is now quite affordable and readily available commercially (**www.limbvolmes.org**).

Because individual wounds are often treated and evaluated by different nurses, therapists and other care givers, it is important to have an estimate of the accuracy and reliability with which this process can be carried out. Although certain aspects of this question have been studied by determining intra and inter-rater reliability of various methods[1, 10, 12, 14, 16, 17, 28], most studies have used only a few raters thereby limiting the generalizability of the results. Further, few studies have addressed the issue of absolute accuracy. A notable exception is a study in which a group of nurses and student nurses evaluated three differently shaped plaster of Paris wound models of known area.[14] Models were measured by several methods including; directly measured L x W of the model, planimetry of tracings of the model, and computerized stereophotogrammetry using a commercial system. It was reported that that the smallest measurement error resulted with the computerized area determination and that only this method had a sufficiently high single tester reliability to justify its use for clinical measurements. However, the reported percentage errors, even with the clearly defined margins of the models used, was 14.9% in the best case using the stereophotogrammetry system for area determinations.

The goal of the present study was to focus on both accuracy and reliability issues associated with using simple digital photography combined with computerized planimetry. The study employed a group of 20 nursing students as testers, who performed computerized area determination tasks on six differently shaped images that had known areas. The goal of this research was to determine the accuracy and repeatability of area measurements achieved by this representative group of student nurses who were at the time six months from graduation.

METHODS

Participants

The group consisted of 20 4th year nursing students who were in their senior year of a four year a Bachelor's of Science in Nursing (BSN) at Nova Southeastern University.

Images

Six test images of various complexities having areas known to within ±0.15cm^2 , as determined by methods described in the next section, were subsequently measured in triplicate by planimetric methods by the 20 student nurses during two sessions, one week apart. Images (**figure 1**) included; an ellipse (image 1), two traced venous ulcers (images 2-3), and photos of a sacral pressure ulcer (image 4), a diabetic plantar ulcer (image 5) and a venous leg ulcer (image 6). To obtain test images 1-3, the shapes and the horizontal calibration bars were drawn with a computer and then printed on heavy photographic paper. To obtain test image 4-6, a calibration bar was placed on a photograph of the ulcers and then printed. All six printed images with their imbedded calibration bars were then photographed with a digital camera (Sony Cybershot) at a resolution of 1024 x 768 pixels. The calibration bars would subsequently be used by the raters to calibrate the linear dimensions of the images for area determinations using the area software. Lengths of the calibration bars were verified with a micrometer accurate to ±0.1 mm. Photographs were taken with a 90^o angle between the camera's line of sight and the plane of the image being photographed. The physical distance of the camera image sensor to the target was about 30 cm and the camera's zoom was used if necessary to render the captured image, including the imbedded calibration marker, to occupy at least 75% of the available viewing area.

Figure 1

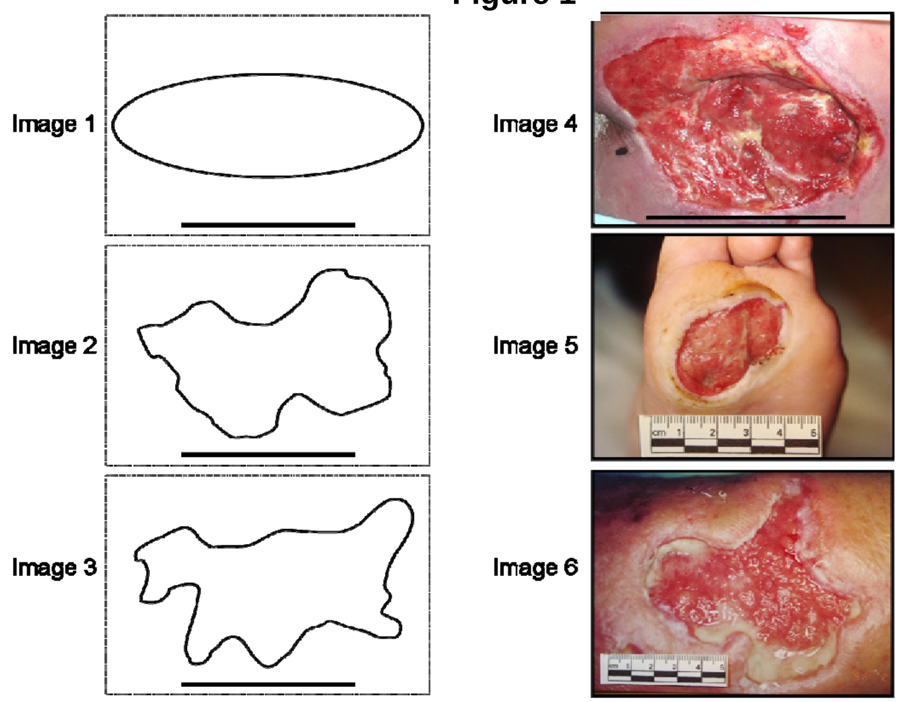


Image Areas

Using a scalpel, the entire perimeter margin of each shape was carefully scored to produce a cutout of the target shape inside area. The shapes were then weighed on a scale accurate to 0.0001 grams. To determine actual areas, weight (Wi) of each target shape was compared to a computer generated and drawn square of known area (A_K) that was printed on the same paper as the target shape. The square was cut out from the paper and its weight (W_K) determined in the same way as the target shape. Areas (Ai) were determined as Ai = (Wi/W_K) x A_K. Weight measurements were done in triplicate and the average value used for the calculation. To test the accuracy of the weight method for determining areas, a series of circular shapes with areas spanning the range of the target images were computer drawn, printed and then cut out exactly as was done for the target images. The weight-determined areas were then compared to calculated areas for each circular shape (calculated-measured) as shown in table 1. Absolute error ranged from -0.017 cm^2 for the smallest area to 0.351 cm^2 for the largest area; calculated percentage errors ranged from -0.66% to +0.32%. Based on the data of **table 1**, we conclude that weight-determined areas estimate image areas of 10 cm^2 or larger with percentage errors not greater than 0.32% and by percentage errors not greater than 0.66% for image areas less than 10 cm^2.

Table 1. Weight-determined areas for circular calibration shapes.

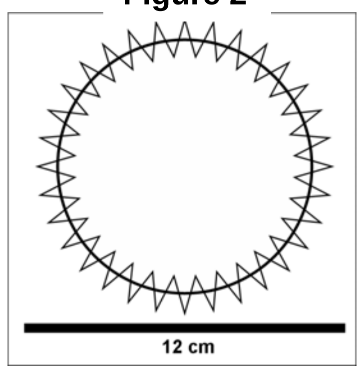
		Area by Weight		
Area Calculated (cm^2)	Weight (g)	Area (cm^2)	Error (cm^2)	Error (%)
119.97	2.7855	119.62	0.351	0.29
79.95	1.8557	79.69	0.259	0.32
40.04	0.9316	40.01	0.028	0.07
10.20	0.2367	10.17	0.031	0.30
5.06	0.1183	5.08	-0.025	-0.50
2.54	0.0596	2.56	-0.017	-0.66

Weight-determined areas for target images 1 through 6 were respectively 84.0 cm^2, 87.0 cm^2, 86.7 cm^2, 81.4 cm^2, 6.47 cm^2 and 41.0 cm^2. Weight-determined areas for all images are taken as actual areas for analytical comparisons of student measurement accuracy that will follow.

Shape Factors

One reason for using shapes of similar absolute area for images 1-3 was that it would then be possible to determine the extent to which the shape factor affected the accuracy and reliability of the area determinations. The shape factor (SF) is a parameter defined by the relationship $SF = 4\pi S/P^2$ in which S and P are surface area and perimeter respectively[16]. If two shapes have equal areas then the SF is an index of the amount of smoothness of the shape's perimeter. This concept may be visualized with the aid of **figure 2** that shows two shapes, one a pure circle with a smooth margin and the other a circular-like shape but with a saw-tooth like margin. Both margins enclose exactly the same area (70.8 cm^2). The SF of the pure circle is 1.0. Any other shape with the same enclosed area will have a SF less than 1.0. If instead of having a smooth perimeter, the circle's perimeter was wiggly as shown in the figure, its SF would be much less than 1.0. In the extreme example shown the SF of the wiggly area is 0.118. An ellipse's SF depends on the ratio of its major axis dimension (L) to its minor axis dimension (W); $SF = 2 (W/L) / ((W/L)^2 + 1)$.[16] For test image 1, which has a W/L = 1/3, this corresponds to a SF = 0.600. For images 2-3 the corresponding SF are 0.571 and 0.395 respectively. Shape factors for ulcer images 4, 5 and 6 were approximately 0.792, 0.773 and 0.442 respectively. The approximate shape factors for images 2 through 6 were determined by dividing the areas as determined by weight by the square of the perimeter as determined by planimetry.

Figure 2



Procedures

Prior to beginning the measuring protocol the entire class of 20 students received a 15 minute introduction by the first author to the tasks they would need to perform and were shown each image once on a computer screen. They were instructed to trace the shapes as if they were actually documenting a patient's wound. To familiarize them with the operation of the software they would subsequently be using, the first author demonstrated a planimetry tracing procedure on image 1. The software used was a modified version of an inexpensive commercially available wound area determination program (WoundAreas Professional, www.bimeco.org). The modification was that the normally visible values that would be shown for wound areas and perimeters were electronically masked. Thus the student had no knowledge of the values that were obtained. During the measurement procedure the student would display the first image (image 1) on the computer screen and then calibrate the horizontal dimension using the imbedded calibration bar or scale. The calibration procedure was quite simple. It only required a rater place the mouse cross-hair over two separated points on the calibration bar and click the mouse. The points for each image were standardized, being at the beginning and end of the bars for images 1 through 4 and at the zero and five cm marks for images 5 and 6. After this they would trace the image three times in succession using a mouse. After three tracings the software instructed the student to load the next image (image 2) and so on until all six images had been traced three times. Each time a new image was loaded the student needed to calibrate using the imbedded calibration bar which was 10 cm in length for images 1-4 and 5 cm for images 5 and 6. For each tracing, each value obtained for area, perimeter, calibration factor, and the time to complete was captured and stored for later analysis by the principal investigator. The order of analyzing the images was 1 through 6 for all raters. The above procedures were repeated by each student one week later as a re-test factor.

Analysis

Accuracy: The error attributable to the full planimetry procedure is defined as the difference between each image's area as determined by its weight and the image's area as determined by the planimetry method; Error = (weight-determined area - area determined by planimetry). The planimetry-determined area was the average of the three tracings for each image. Sources of potential error in the full planimetry procedure include the calibration, the selection of the margin to be traced, and the actual tracing procedure. For images 1-3 the margin was well defined so that it was anticipated that margin identification would not be a major factor. In contrast, for images 4-6, a judgment was needed as to what constituted the margin to be traced. This decision was left to the student evaluator. Percentage errors along with associated standard deviations (SD) were determined for the entire group for each image.

Reliability: Interrater reliability or precision is simply the extent to which the different students, who have used the same measurement tool and process, get equal measurement values. Precision of measurements among students was determined and is reported based on the coefficient of variation (CV%) of S values obtained for each image. CV% was calculated as the standard deviation (SD) of values obtained among students divided by the mean; CV% = 100 x (SD/mean). First and second week values of CV% were calculated separately.

Intrarater reliability or repeatability in the present context is the extent to which students replicated the measured values on the two separate occasions. The lower the repeatability, the greater is the amount of change that must occur to confidently accept a change as real. This minimum amount of change is calculable from the method error (ME)[29] which can be expressed as ME = $SD_{diff}/\sqrt{2}$, in which SD_{diff} is the standard deviation of differences between the two separate measurement sessions[30]. A group test-retest coefficient of variation (CV_{12}%), that includes both session 1 and session 2 measurements, can then be determined as CV_{12}%=.100 x (ME/M_{12}) in which M_{12} is the overall mean value of session 1 and 2 measurements. The utility of CV_{12}% is that in 95% of paired repeated measurements, the percentage difference between the values obtained is expected to be less than $1.96\sqrt{2}$ CV_{12}%.[31] From a practical point of view, this implies that if measurements are made by any evaluator on the first session and made by any different evaluator on second session, then the smallest meaningful percentage change (SMPC) needs to be greater than 2.77 CV_{12}%. SMPC is determined for both S and S/P.

An alternative, but less robust approach, is to consider differences in values obtained by the same evaluator at the two different measurement sessions. To provide such a comparative estimate, the percentage difference between area values obtained on the 1st and 2nd sessions for each image and rater were determined and the average among raters calculated.

Shape Factor Dependence was analyzed by determining if there was a significant correlation between the SMPC and the shape factor. This was done by linear regression analysis of SMPC on SF with a significance level of <0.05 taken as significant.

Time factors were analyzed based on the time to complete each image measurement procedure during session 1 (T1) and during session 2 (T2). T1 and T2 were determined as the average of the three measurements done for each image at each session. Questions of whether there was a change in measurement time with session and whether measurement time depended on image were analyzed using a general linear model for repeated measures with time as the repeated measure.

RESULTS

Accuracy results using the digital planimetry method are summarized in **table 2**.

Table 2. Area parameters and measurement accuracy estimates.

Image	SF	Area (S) by weight (cm^2)	Area (S) by planimetry (cm^2)		Area Error (%)		
			Test 1	Test 2	Test 1	Test 2	Combined
1-Ellipse	0.600	84.0±1.0%	83.5±2.1	83.4±1.9	0.31±2.50	0.75±2.30	0.53±2.38
2-Venous Ulcer	0.571	87.0±0.15	85.4±1.2	84.9±1.9	1.87±1.41	2.44±2.24	2.16±1.87
3-Venous Ulcer	0.395	86.7±0.15	86.4±1.7	86.0±1.1	0.33±1.96	0.75±1.27	0.54±1.64
4-Sacral Ulcer	0.792	81.4±0.15	81.4±1.3	81.9±1.8	0.01±1.55	-0.53±2.21	-0.28±1.90
5-Plantar Ulcer	0.773	6.47±0.15	6.38±0.29	6.26±0.47	1.40±4.43	3.25±7.31	2.32±6.04
6-Venous Ulcer	0.442	41.0±0.15	42.5±2.9	41.9±2.9	-3.80±6.98	-2.11±7.12	-2.95±7.01

Planimetry values are mean ± SD. SF is the Shape factor of the measured area. Test 1 and Test 2 data are for values obtained one week apart. Neither planimetry areas nor errors differed significantly between test 1 and test 2. Data in the column labeled Combined includes test 1 and test 2 errors.

The main result shows that the mean area error is less than 3% for all images of both test sessions. The larger errors, and those having the larger standard deviations, are those associated with measurements of the plantar and venous ulcer photo images. For the venous ulcer, the mean area determined by planimetry is slightly greater than the weight-determined area whereas for the plantar ulcer the mean planimetry area is slightly less than the weight determined area. Paired t-tests for possible differences between sessions in planimetry determined areas and for area errors show these to be not significant for any image ($p>0.2$). Combining 1st and 2nd session errors yields the overall combined percent area errors listed in the last column of the table. This area error shows no defined relationship to either shape factor ($p>0.5$) or absolute value of the various areas ($p>0.5$). Repeatability results for area, perimeter and calibration factor are summarized in **table 3**.

Table 3. Repeatability estimates.

Image	Area CV%		Perimeter CV%		Calibration Factor CV%		SMPC=2.77 CV_{12}%		%Diff
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Area (S)	S/P	
1-Ellipse	1.50	1.81	1.33	1.48	0.30	0.65	2.51	2.45	0.02±3.38
2-Venous Ulcer	1.44	2.30	2.01	2.07	0.57	0.79	2.52	2.51	0.42±1.78
3-Venous Ulcer	1.96	1.28	1.72	2.14	0.64	0.67	2.42	2.35	0.26±1.94
4-Sacral Ulcer	1.55	2.20	2.47	2.41	0.31	0.42	2.62	3.17	0.24±1.63
5-Plantar Ulcer	7.49	7.56	4.26	3.90	0.56	0.60	10.79	10.05	0.15±3.48
6-Venous Ulcer	6.72	6.98	2.43	2.64	0.82	0.80	7.14	6.25	1.31±4.82

Area, Perimeter and Calibration Factor coefficients of variation (CV%) show variability of measurements among students for each test session. SMPC is the smallest meaningful percentage change based on the test-retest variability (CV_{12}%). %Diff is the mean ± SD of individual rater percentage differences in area measurements between Test 1 and Test 2

For areas and perimeters the coefficients of variation among students (CV%) were similar for both test sessions and were less than 2.5% for images 1 through 4. Measurements of the plantar and venous ulcer photo image yielded the largest variation among students, with the largest variation associated with the plantar ulcer, which was the smallest of the areas measured. Area CV% for these two images ranged from 6.72% to 7.56% over both measurement sessions. Test-retest variability (CV_{12}%) was also greatest for these two images resulting in their smallest meaningful percentage change ranging between 6.25 to 10.8% for area and S/P determinations. The CV% for all calibration factor determinations was less than 1%. Percentage differences in area values obtained by the same raters during test 1 and test 2 are shown in the last column of the table. The results show that for this estimate, mean percentage differences for all images other than image 6 are less than 1%.

Results of time factor analyses are summarized in **table 4**. During test session 2, measurement times were all less than during session 1(p=0.004) with the overall average time being reduced from 93.4±35.1 seconds for the first session to 67.7±24.4 seconds for the second session (p<0.001). Measurement times ranged from 44.7±9.1 for the plantar ulcer to 81.1±28.5 for a venous ulcer image. This time reduction was independent of image as there was no time-image interaction (p=0.720). Among the images for both sessions, measurement time for image 5 was significantly less than for images 2, 3 and 4 (p<0.01). There was a significant correlation between session 1 and 2 measurement times (r=0.603, p<0.01) and between session 1 and 2 measurement errors (r= 0.607, p<0.01) but there was no significant relationship between measurement time and measurement error.

Table 4. Measurement times.

Image	Measurement Time (sec)	
	Test 1	Test 2
1-Ellipse	99.5±37.1	65.4±26.7*
2-Venous Ulcer	106.3±39.9	73.3±19.9*
3-Venous Ulcer	103.8±26.1	81.1±28.5*
4-Sacral Ulcer	102.6±36.6	77.2±23.8*
5-Plantar Ulcer	65.0±24.7†	44.7±9.1*†
6-Venous Ulcer	83.2±30.9	64.5±19.3*
Overall Average	93.4±35.1	67.7±24.4**

Entries are the mean ± SD seconds to complete a single area measurement procedure. * Significantly less than for test 1 (p=0.004), **Significantly less than for test 1 (p<0.001)
† Measurement time for image 5 was significantly less than for images 2, 3 and 4 during both tests (p<0.01).

DISCUSSION

One new result of the present study relates to the characterization of expected errors when using simple digital planimetry of photographic images to assess wound area. It was found that mean area measurement errors achieved by the test group of 20 student nurses for all images was less than 4% at each test session and was less than 3% for combined sessions. Although this error level is likely acceptably small for most clinical applications, it is instructive to briefly consider possible sources of error. One possible error source is that associated with the estimate of the weight-determined "gold-standard". As noted in the methods section, the weight-determined percentage errors ranged from -0.66% to +0.32% and are therefore not a significant source of error. Other factors potentially contributing to the student measurement process error include the image calibration, the identification of the image or wound margins, and the actual tracing process. As demonstrated (table 1), the coefficient of variation for the calibration factor was less than 1% for all images so that the remaining small error is due to a combination of identifying the wound margins and the actual tracing procedure. The present data set does not allow for separating out these components.

A second new finding is that related to the repeatability of digital planimetry for the assessment of S and the area/perimeter (S/P) parameter. Here the most important result was the determination of the smallest meaningful percentage change (SMPC) in area. This parameter ranged from about 2.5% to almost 11% depending on the specific image being measured. Originally it was thought that the SMPC would be related to the complexity of the wound margin as characterized by its shape factor. This proved not to be true as evidenced by nonsignificant correlations (p>0.5) between SMPC and shape factor for both area and S/P determinations when SMPC and SF were subjected to regression analyses. . A close examination of each image's features suggests that a more important aspect is the level of ambiguity with which the wound margin could be determined. For the ellipse, the two drawn venous ulcers and for the sacral ulcer image, the location of the margin was well defined. Measurements of these resulted in the lowest SMPC, with area SMPC values tightly distributed between 2.42% to 2.62%. Contrastingly, measurement of the plantar and venous ulcer photographic images required the students to make judgments as to what constituted the actual wound margin. Measurements of these images resulted in considerably larger SMPC values. Consequently, we suspect that the largest source of variability, and hence the main determinant of a wound specific SMPC, is the ambiguity of the wound margin selection among evaluators. The percentage difference in area values obtained by the same raters on the two separate evaluation sessions (table 3) suggests that better repeatability results for more complex wound margins would be obtained when the same rater evaluated the wounds on both occasions.

The present study results apply strictly to the outcomes achieved using the software algorithms employed and to the specific group of student nurses who participated. Although the students had all been trained in the principles of wound care and had had rotations through wound care related clinics, their wound care experience was limited. Thus, one of the initial goals of this study, which was to include a large enough sample to provide reasonable generalizability of results, was probably only partially met, in the sense that the results generalize to student nurses with similar training. It would be expected that, at least for those measurements associated with the less well defined wound margins, that more experienced wound care specialists would achieve at least as good an outcome. An investigation into this aspect must await further research.

Implications for Clinical Practice

Pressure ulcers are a significant problem in hospitalized patients as well as those receiving treatment in nursing homes and home health settings. Nurses and therapists in various areas of practice encounter patients with wounds of various types, shapes and sizes. Throughout our entry-level (pre-licensure) program and other programs, students are provided with content regarding the care of patients with alterations in skin integrity, including those with wounds. Careful and accurate assessment is stressed as an essential component from which subsequent treatment decisions and modifications should be made. It is emphasized that information obtained during baseline and ongoing assessments of a wound provides the health care team with data on which the progression or regression of wound healing can be closely monitored. Since multiple members of the health care team may be involved in assessing a wound for change over time the need for objective means of assessment is substantially amplified. As the first-line professional involved in wound assessments, it is beneficial to have a means to objectify and report assessment data. Clear, understandable, relevant, and comprehensive documentation helps to ensure continuity and ultimately better patient outcomes.

The results of this study, done in a very limited sample, support the use of computerized planimetry software as an objective method for ongoing assessment of wounds in clinical practice. Repeatability results and inter-rater reliability support the clinical applicability when multiple practitioners are required to assess wounds of a given patient. Further research is warranted using graduate nurses as well as those certified wound care specialists.

In summary, the results indicate that computerized planimetry of digitized wound photographs using the present software is an accurate and reliable way to measure and document wound areas and an associated wound closure parameter defined as the ratio of wound surface area to perimeter.

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