Perspectives on burn scar evaluation and artificial skin
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Reliability and accuracy of practical techniques for surface area measurements of wounds and scars
Abstract

Practical planimetric methods to measure the size of wounds and scars have been studied with respect to the reliability of their measurements. Nevertheless, the accuracy of these measurements are poorly studied. In this study, two practical methods of planimetry are evaluated for their reliability and accuracy with respect to different body areas.

In 20 volunteers, drawings were created that mimicked a skin lesion with a surface area of 25, 50 and 75 square cm. These drawings were applied on three locations with increasing curvature: back, thigh and forearm. The inter-observer reliability and accuracy (validity) of three investigators was established for planimetry by photography and planimetry by tracing on a transparent sheet.

Both techniques showed a good reliability ($r \geq 0.82$, Intraclass Correlation) for 25 square cm areas. Planimetry by photography was more reliable than planimetry by tracings for the 50 square cm areas ($r=0.82$ versus $r=0.72$) and for the 75 square cm areas ($r=0.78$ versus $r=0.48$). Statistically significant differences were found between the accuracy of planimetry by photography and by tracing. Overall, planimetry by photography was more accurate than planimetry by tracing for flat and moderately curved areas (back and thigh). All differences were statistically significant ($p \leq 0.013$) except for the 25 square cm area of the thigh ($p=0.236$). For the extremely curved surface area (the forearm) planimetry by tracing was more accurate than planimetry by photography. These differences were statistically significant ($p \leq 0.014$).

Planimetry by photography is more suitable for surface area measurements than planimetry by tracing except for extremely curved body parts, which must be due to distortion.
Introduction

Planimetry deals with objective quantification of skin lesion surface areas and their changes over time. Planimetry is applicable in wound healing research, where the size of a wound or a scar, as well as the wound epithelialisation rate and the contraction of the scar can be quantified. Practical planimetric methods to measure the size of wounds and scars have been studied with respect to the reliability of the measurements. In essence, nevertheless, the accuracy of planimetry techniques are poorly studied. The effect of the curvature of different body surface areas on the reliability and accuracy of planimetric techniques has not been studied to date.

In this study, two practical methods, planimetry by means of tracing on a transparent plastic sheet and planimetry by constant focal length photography, are evaluated for the reliability and accuracy of measurements with respect to different body regions. Both methods are easy to perform and the surface area, which is traced or photographed, is calculated by means of a scanner and personal computer. Planimetry by means of photography seems advantageous, as it renders an image with colour. Its use becomes questionable in curved regions such as the forearm and leg where the body's natural curvature causes distortion of the image.

We established both the reliability and accuracy of each technique for three different body sites that were selected to represent an almost flat, a moderately curved and extremely curved body part. Instead of evaluating actual wounds and scars, drawings with a fixed size were made on the locations of interest that mimicked a lesion. Because of this, the accuracy, also termed validity, can be calculated by comparing the outcome of planimetry to the true size of the drawings (25, 50 or 75 square cm). The reliability, meaning the reproducibility of the measurements, was assessed by establishing the interobserver agreement of three investigators.
Patients and Methods

We concentrated on three locations with increasing curvature: a flat surfaces area, a thick extremity and a thin extremity, which were represented in this study by the back, the thigh and the forearm, respectively. The interobserver reliability of three investigators was tested for these areas on twenty adult volunteers. These volunteers gave written informed consent before enrolment into the study. A rectangle was drawn on the middle of the back, thigh and forearm with a fixed surface area of 15x5 cm. Within this 'lesion', the centrally located areas of 5x5 and 10x5 cm were marked to allow analysis of smaller 'lesions' within the same drawing.

The following parameters of the volunteer were recorded at the time of measurements: age, weight, length and the circumference of the body part at the locations of measurement.

The drawing of the 'lesions'

A drawing of a rectangle (15x5 cm) was made on the skin together with lines that run widthwise each 2.5 cm (except for the centre, which was unnecessary for the tracings). This design allowed delineation of the middle square of 5x5 cm and a rectangle of 10x5 cm, as shown in figure 1. The drawing was made by using a pliable but non-stretchable template composed of Duoderm (Convatec, Princeton, NJ, USA).

The drawings were applied on the right forearm and the left thigh with the volunteer in a recumbent posture lying on the back. On the right forearm, the template was made with the elbow fully extended and the hand supinated. The middle of the volar site of the forearm was established by measuring the distance between the antecubital fossa and the first carpal-metacarpal joint. The centre of the template was placed in the middle of the volar site of forearm. Another template was made on the anterior site of the left upper thigh, with its centre at two third of the distance between the anterior superior iliac spine and the superior margin of the patella. The template on the back was constructed while the volunteer was lying on the belly. The drawing was made 10 centimetres superior to the pelvic rim with the centre at the vertebral column.
Figure 1 Drawing of 'lesions' on thigh and forearm

Figure 1a and 1b clearly show the effect of image distortion in case of planimetry by photography on thigh and forearm, respectively. Because of the distortion, not one but three photographs were taken (at different angles) for photographic measurement of the surface area during this study.
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Planimetry by tracing

The tracing and photography of study areas were performed in the same position in which each drawing was made. Each observer traced the margins of the 'lesion' directly onto a transparent plastic sheet that was applied on the skin. The sheet was pliable but not stretchable.

Planimetry by photography

With a Polaroid Macro 5 SLR photocamera (Polaroid UK Ltd., Vale of Leven, United Kingdom) three pictures were taken of the 15x5 cm drawing from both lateral and middle 5x5 squares. Photos were taken perpendicular to the surface at a fixed distance resulting in full-size images (1:1 enlargement). The margins of the drawings were then traced on a plastic sheet, scanned and exported to computer-software (Adobe Photoshop, Adobe Systems Inc., San Jose, California, USA). The margins of the lesion were digitally traced. The surface area of a lesion was calculated from the number of pixels.

Statistical Analysis

The data were analysed by the statistical program SPSS for Windows 8.0 (SPSS Inc. Chicago IL USA). The Intraclass Correlation Coefficient (ICC) with its 95% confidence interval was calculated to assess the inter-observer reliability. For the calculations of the ICC, the two-way-random effect model was selected and calculated for absolute agreement of the scores. A paired sample t test was performed for the measured surface areas in comparison with the true surface areas. Both the 95% confidence interval of the difference (CI) and p-value are given. The level of significance was set at 0.05.

Results

Five male and fifteen female volunteers with an average age of 42.9 years (standard deviation, SD:10.6) were enrolled in the study protocol. The average weight was 69.4 kg (SD:9.0) and the height 172.8 cm (SD:8.9). The circumferences of the thigh and forearm were measured to give an impression of their curvature, which was on average 50.4 cm (SD:3.3) and 21.3 cm (SD:1.3) respectively.
Both techniques showed a good reliability ($r \geq 0.82$, Intraclass Correlation) for the 25 square cm areas. All data on inter-observer reliability together with confidence intervals are given per area and location in Table 1. Planimetry by photography was superior to planimetry by tracings with respect to inter-observer reliability for all 50 and 75 square cm areas. The reliability of the tracing technique appeared to correlate negatively with the surface areas as it showed only moderate reliability for larger surface areas, especially in the curved forearm ($r=0.48$).

<table>
<thead>
<tr>
<th></th>
<th>Planimetry by tracing</th>
<th>Planimetry by photography</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICC (95% CI$^*$)</td>
<td>ICC (95% CI$^*$)</td>
</tr>
<tr>
<td>True size</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Back</td>
<td>25 cm$^2$</td>
<td>0.88 (0.70 - 0.95)</td>
</tr>
<tr>
<td></td>
<td>50 cm$^2$</td>
<td>0.78 (0.49 - 0.91)</td>
</tr>
<tr>
<td></td>
<td>75 cm$^2$</td>
<td>0.68 (0.31 - 0.87)</td>
</tr>
<tr>
<td>Thigh</td>
<td>25 cm$^2$</td>
<td>0.88 (0.77 - 0.95)</td>
</tr>
<tr>
<td></td>
<td>50 cm$^2$</td>
<td>0.80 (0.58 - 0.91)</td>
</tr>
<tr>
<td></td>
<td>75 cm$^2$</td>
<td>0.71 (0.40 - 0.88)</td>
</tr>
<tr>
<td>Forearm</td>
<td>25 cm$^2$</td>
<td>0.84 (0.64 - 0.93)</td>
</tr>
<tr>
<td></td>
<td>50 cm$^2$</td>
<td>0.62 (0.19 - 0.83)</td>
</tr>
<tr>
<td></td>
<td>75 cm$^2$</td>
<td>0.48 (-0.04 - 0.77)</td>
</tr>
</tbody>
</table>

Table 1 Inter-observer reliability of three raters by Intraclass Correlation (ICC) for planimetry by tracing and photography.

$^*$CI = Confidence interval

The accuracy of both planimetry techniques was evaluated by comparing the true surface area (25, 50 or 75 square cm) with the measured surface area. All surface areas were converted to a percentage of the true surface area. The average together with the 95% confi-
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dence interval are given in Table 2. In addition, the measurements of planimetry by tracing and photography were compared with the paired sample t test to detect if statistically significant differences occurred between the measurements of both methods. Statistically significant differences were found between the true size (100%) and measured surface areas as indicated in Table 2. Almost all measurements differed significantly between planimetry by tracing and photography. Planimetry by photography resulted in measurements that were significant larger than those of the tracing method, except for the 25 square cm areas of the thigh, and approached the true size better, with the exception of 'lesions' on the forearm.

<table>
<thead>
<tr>
<th></th>
<th>Planimetry by tracing</th>
<th>Planimetry by photography</th>
<th>Photo-tracing</th>
<th>Paired sample t test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>True size</td>
<td>Percentage of true size</td>
<td>Percentage of true size</td>
<td>Difference in percentage</td>
</tr>
<tr>
<td></td>
<td>(95% CI)</td>
<td>(95% CI)</td>
<td>(95% CI)</td>
<td>(95% CI)</td>
</tr>
<tr>
<td>Back</td>
<td>25 cm²</td>
<td>90.2 (88.3 - 92.1)</td>
<td>96.5 (94.2 - 98.8)</td>
<td>6.3 (5.0 - 7.7)</td>
</tr>
<tr>
<td></td>
<td>50 cm²</td>
<td>90.0 (88.5 - 91.4)</td>
<td>95.1 (93.1 - 97.2)</td>
<td>5.2 (4.0 - 6.3)</td>
</tr>
<tr>
<td></td>
<td>75 cm²</td>
<td>91.4 (90.3 - 92.6)</td>
<td>95.8 (94.1 - 97.5)</td>
<td>4.3 (3.2 - 5.4)</td>
</tr>
<tr>
<td>Thigh</td>
<td>25 cm²</td>
<td>98.2 (96.3 - 100.1)</td>
<td>98.9 (97.0 - 100.8)</td>
<td>0.7 (-0.5 - 1.9)</td>
</tr>
<tr>
<td></td>
<td>50 cm²</td>
<td>95.7 (94.6 - 96.8)</td>
<td>98.4 (96.9 - 99.8)</td>
<td>2.7 (2.0 - 3.3)</td>
</tr>
<tr>
<td></td>
<td>75 cm²</td>
<td>96.0 (95.1 - 97.0)</td>
<td>97.2 (95.9 - 98.5)</td>
<td>1.1 (0.3 - 2.0)</td>
</tr>
<tr>
<td>Forearm</td>
<td>25 cm²</td>
<td>92.8 (90.9 - 94.7)</td>
<td>90.8 (89.0 - 92.6)</td>
<td>-2.0 (-3.6 - -0.5)</td>
</tr>
<tr>
<td></td>
<td>50 cm²</td>
<td>91.4 (90.2 - 92.5)</td>
<td>86.8 (85.1 - 88.5)</td>
<td>-4.5 (-5.8 - -3.3)</td>
</tr>
<tr>
<td></td>
<td>75 cm²</td>
<td>92.6 (91.7 - 93.5)</td>
<td>85.0 (83.7 - 86.3)</td>
<td>-7.6 (-8.8 - -6.4)</td>
</tr>
</tbody>
</table>

Table 2 Accuracy of planimetry by tracing and photography

* CI = Confidence Interval; † statistically significant difference between true size (100%) and average measured surface area; ‡ paired sample t test for the difference between planimetry by tracing and photography
Discussion

Effective simple methods of recording and measuring the size of burn wounds or scars are essential for accurate evaluation, clinical follow-up and for research. In this respect it is unclear why common techniques are seldomly studied for their accuracy. The influence of the body curvature on the reliability and accuracy has not been studied sufficiently to date. In contrast to planimetry by tracing, where inaccuracy of the tracing technique is the only plausible cause of error, the accuracy of planimetry by photography is also influenced by the error due to projecting a three dimensional object onto a two dimensional image.

This study was designed specifically to evaluate inter-observer reliability and accuracy for body regions of varying curvature. For practical reasons, we analysed skin 'lesions' of a fixed size. This was the only study design by which the outcome of both methods could be compared to the true size of the lesion. Moreover, the design allowed a fair comparison of the outcome of measurements between different locations.

In general, both techniques seem suitable for clinical application with respect to reliability. Both techniques showed a good inter-observer reliability for relatively small (25 square cm) lesions. Nevertheless, planimetry by tracing results in decreasing inter-observer reliability as the size of lesions increases. This effect is clearly illustrated for the forearm, where the 25, 50 and 75 square cm drawings resulted in an inter-observer reliability of 0.84, 0.62 and 0.48 respectively. We conclude therefore that planimetry by photography was superior, in general, to the tracing technique with respect to inter-observer reliability. In addition, we can safely assume that the intra-observer reliability must be acceptable as intra-observer reliability contains less sources of error than inter-observer reliability.

In concordance with our hypothesis, we found the accuracy of both techniques to be good for the small 5x5 cm squares, even in extremely curved areas. We also hypothesised that planimetry by photography should become inaccurate compared to planimetry by tracing for larger and more curved areas due to distortion. This was only
partially the case because all measurements on back and thigh, except for the 25 square cm area on the thigh, were significantly larger when examined by photography compared to planimetry by tracing, and therefore closer to the true size of the 'lesion'. Nevertheless, planimetry by tracing was more accurate on the curved forearm. Here, significantly less reduction of the surface was obtained compared to planimetry by photography. For the latter, reduction increases proportionally with increasing surface area at the level of the forearm: 9.2, 13.2 and 15.0 percent for the 25, 50 and 75 square cm surface areas respectively. If we look at the 75 square cm areas of the forearm, a significant correlation of 0.662 (Pearson cor-

Figure 2 Distortion in relation to planimetry by photography

Figure 2 shows the correlation of planimetry by photography with respect to the 15x5 cm 'lesions' and the circumference of the forearm. The distortion increases when the circumference decreases (Pearson correlation $r=0.662$, $p=0.001$).
relation, $p=0.001$) between circumference and reduction for planimetry by photography was found that indicated the proposed effect of distortion on planimetry by photography. A scatter-plot (Figure 2) shows the relationship between the measured surface area and the circumference. Linear regression with the circumference of the forearm as an independent variable and the measured surface area as a dependent variable showed that 43.7% (residual mean square, $R^2$) of the total variation is explained by this model. The distortion therefore was a major source of inaccuracy for measurements on the forearm.

No such significant correlation was found between circumference and error of measurements for planimetry by tracing. Whereas planimetry by photography was assumed to be confounded by distortion, planimetry by tracing was expected to give accurate measurements. Tracings of the back were especially disappointing for both the 10x5 cm and 15x5 cm areas compared to planimetry by photography, which is shown by the statistically significant differences between the photographic and tracings methods. Evidently the irregularly contoured regions formed by the paraspinous muscles parallel to the vertebral column influenced the accuracy of the tracings.

This study shows that planimetry by tracing and photography are simple, easily accessible techniques and can be considered as reliable (reproducible) and accurate (valid) tools for measuring small (5x5 cm) surface areas of skin lesions. Planimetry by photography is superior with respect to inter-observer reliability and accuracy for larger surface areas than planimetry by tracing except for the extremely curved body parts such as the forearm. Although planimetry by photography was more reliable for these regions, a higher accuracy was obtained for planimetry by tracing, which is due to image distortion in case of photography. Both techniques, but especially planimetry by photography, may be considered for larger magnifications. In large areas, e.g. involvement of skin in case of burn wounds, planimetry by photography will be more practical and convenient than planimetry by tracing. The choice of technique for recording and measuring of the size of
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pathologic skin lesions is guided by the aims of such studies and may be dependent on the curvature of the body part. At present we consider planimetry by photography as 'gold standard'.

Acknowledgements

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References