# A COMPARISON OF STEREOPHOTOGRAMMETRY WITH CONVENTIONAL TECHNIQUES USED TO MEASURE HEALING IN CHRONIC LEG ULCERS

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## ABSTRACT

A stereoscopic reprojection camera, used for measurement on children's faces, has been modified to fit onto the three dimensional measurement system of the Reflex Metrograph. The cameras are taken into the hospital ward to record the skin ulcers of patients undergoing treatment. The edge length, surface area and volume of the defect can now be measured from the stereoscopic image. Weekly healing rates can then be quantified. These rates are needed for assessment of the many types of treatment available. The measurement method is the only one currently in use which can give sufficient accuracy.

## THE CLINICAL PROBLEM

There are between 400,000 and 500,000 people suffering from chronic leg ulcers in Britain today, and the numbers appear to be increasing[1]. All these ulcers require bandaging and dressing regularly. Currently, over 120 different products are marketed for the treatment of these ulcers[2]. Little is known about the causation of ulcers and even less about their treatment, because, until now, it has not proved possible to measure healing accurately enough. No adequate non-invasive technique has been available for measuring the size of ulcers, so that in any study the end point of complete healing has to be used. This is too slow and expensive to allow comparative methods to be carried out.

The accurate measurement of healing in skin defects is fundamental to their treatment and to research into the rate and quality of healing. It is complicated by the fact that: (1) biological surfaces are not regular, and (2) to avoid contamination, the surface should not come into contact with the measuring instrument. Ideally the measuring system must be able to record irregular surfaces in three-dimensions using a non-contact technique.

There are two conventional methods used to measure skin healing. The first is to lay a sterile transparent sheet onto the wound and then to trace the wound margins[3]. This is simple and cheap, but unacceptable because the exposed tissue may be damaged or contaminated. The second method is to take a 35mm colour slide photograph of the wound with a ruler in the picture to provide scale[4]. Scaled photography suffers major distortions if the skin defect is on a curved surface. Neither system is able to measure skin defects in three-dimensions.

This paper describes the stereoscopic reprojection camera and the measuring system, as well as the mathematical method used to calculate edge length, area and volume of skin defects. The accuracy is assessed by comparison with known values. Direct tracing and scaled photography are then assessed in the same way and their accuracy is compared with the reprojection method. The rates of cutaneous healing found in the clinical situation are measured to determine which of the three systems provides the accuracy required for this type of work.

## THE MEASUREMENT SYSTEM

The principle of the method may be described as follows: a pair of stereoscopic photographs of an ulcer is taken by two fixed focus cameras in a rigid mount[5]. When the photographs have been developed, they are replaced in the cameras. The backs of the cameras are removed and projector lights are placed behind the films. The pictures are therefore reprojected through the lenses, correcting any lens distortion. The films are moved about until the images of fiducial marks on the emulsion project back onto the marks themselves. These fiducials are on a metal frame attached to the cameras, but in the object space which is being photographed. They are therefore imaged onto the film every time a picture is taken. The two pictures are polarised and projected onto a screen. An observer wearing polarising spectacles will now see a 1:1 stereoscopic image of the original object.

The screen is an aluminium disc, carried on the three-dimensional probe of the Reflex Metrograph[6]. It has a central light spot as a reference measuring mark. The operator moves the disk around the image, using free-hand movement for X and Y, and a finger wheel for Z. Since the Metrograph axes are digitised, the operator can pass significant XYZ co-ordinates to the computer by pressing a footswitch.

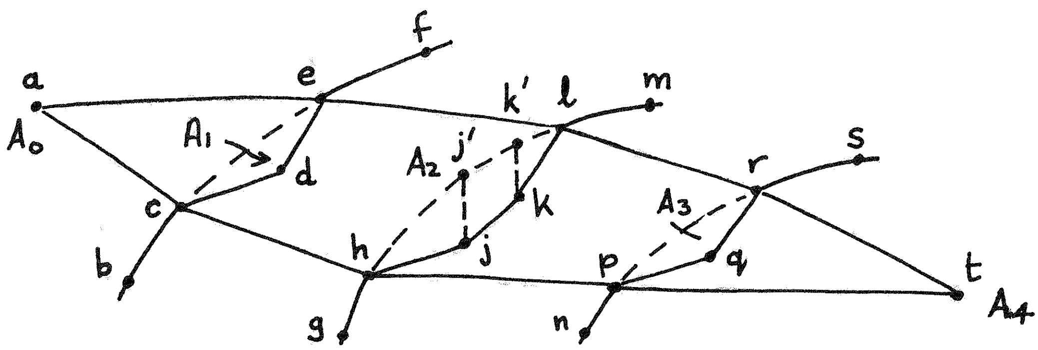


Figure 1  Mathematical model of an ulcer

The skin defect was scanned as follows: the edge point with the minimum X value was recorded (Point a in Figure 1). The X co-ordinate was changed to a position where the operator could see a significant change in shape. A section was recorded on the fixed X value : first a point b was recorded on the good skin, followed by point c on the epithelial edge of the skin defect. Several representative surface points such as d were then recorded, followed by the second edge, e. A normal skin point, f, followed. After all necessary sections had been recorded, the edge point of maximum X (t in the figure), was registered. Edge length was then a c h p t r l e a (straight line joins). The surface area was calculated from the sum of plane triangles, acd,ade,chj,jcd etc, ensuring that all angles were acute whenever possible. The volume of the defect was obtained as follows:

1) a cubic spline was fitted (dashed lines) to the four points on the normal skin for each section in turn, such as g, h, l, m.

2) the depth of the surface points j,k below (or above) this spline was calculated.

3) using the plane figures hjj', jj'k' etc, the area of the depression or elevation was summed. ($A_0$ to $A_4$).

4) treating the areas at a and t as zero, the volume was calulated as the sum of the prisms contained between each successive pair of

sections. The prism volume, between $A_2$ and $A_3$, for example, was

$$\frac{A_2 + A_3}{2} \cdot dx$$

where dx was the difference in X between sections 2 and 3

This rule (Simpson's Rule), is used by civil engineers in calculation of earthwork volumes.

In an earlier study[7], two standard 35mm cameras were used, with a Wild stereocomparator. The surrounding surface was assumed to be linear, i.e. the points h and l were simply joined by a straight line. The current method has improved on the mathematical model, but most importantly, the equipment is operated by a surgeon and no photogrammetric operator is necessary.

## ASSESSMENT OF THE SYSTEM

Artificial leg ulcers were created on plaster casts of human legs for the purpose of evaluating the equipment. Outlines of several different sizes of ulcer were drawn on the legs. The edge length of these ulcers could be measured using a map measuring wheel directly on the leg. In order to check the accuracy of area measurements, pieces of graph paper were glued to the surface of the leg and the area was found by counting squares. To measure volume, pieces of clay of known volume were moulded onto the surface of the leg casts. The computer program measures protruberances in exactly the same way as it measures depressions in a surface (with the sign reversed), so that the known volume could be compared with the volume calculated by photogrammetry.

Twelve ulcers were drawn on the artificial leg, with a range of size from the smallest to the largest commonly measured. The smallest had an edge length of 10mm while the largest was 490mm in circumference. A similar range was provided with regard to the area with a range from 10 to 14 110 $mm^2$. The volume of the artificial ulcers varied from 10 to 649 000 $mm^3$. Each ulcer was measured 10 times.

The accuracy was defined as the difference of the mean of the ten readings taken from the known real measurement of that ulcer, and is a measure of any bias in the measuring system. The precision was taken as the scatter of the ten readings around their mean, reflecting their reproducability. This is presented as the 95% confidence interval which is 1.96 times the standard deviation of the readings.

## CLINICAL ACCURACY REQUIREMENTS

The clinical accuracy required to determine rates of healing using a measuring instrument was found from a clinical trial which was being carried out to study healing in chronic leg ulcers. Several patients undergoing treatment for chronic ulcers were photographed at weekly intervals. One hundred pairs of edge length and area measurements were obtained. Using these results, the distribution of the rate of healing was calculated.

RESULTS

The measurements on the artificial leg using the reprojection method are summarised in Tables 1, 2 and 3. The overall accuracy for linear measurements is better than 0.4%, with a precision of 1.2%. The accuracy of area measurement is better than 1%, with a precision of under 2%. Volume, which is the most difficult to measure, gives an accuracy of just over 5%, with a precision of under 2%.

Using the one hundred records of clinical patients, the median weekly rate of healing of chronic leg ulcers was found to be 14% for edge length, and 15% for area. The range extended from 0% - 70%. Proportional healing rates in smaller ulcers (<400mm²) was found to be much lower than that in larger ulcers.

Table 1 Accuracy & precision of edge length measurement using the reprojection method

| Ulcer No. | Edge Length (mm) | Accuracy % | Precision % |
|---|---|---|---|
| 1 | 10 | 0.5 | 1.2 |
| 2 | 25 | 0.6 | 1.5 |
| 3 | 45 | 0.2 | 1.3 |
| 4 | 75 | 0.4 | 1.1 |
| 5 | 100 | 0.5 | 1.4 |
| 6 | 125 | 0.1 | 1.5 |
| 7 | 160 | 0.4 | 1.1 |
| 8 | 200 | 0.3 | 1.2 |
| 9 | 240 | 0.3 | 0.9 |
| 10 | 290 | 0.6 | 0.9 |
| 11 | 365 | 0.5 | 1.4 |
| 12 | 490 | 0.2 | 1.2 |
| Mean | | 0.4 | 1.2 |

Table 2 Accuracy & precision of area measurement using the reprojection method

| Ulcer No. | Surface Area (mm) | Accuracy % | Precision % |
|---|---|---|---|
| 1 | 10 | 0.9 | 2.2 |
| 2 | 50 | 0.6 | 1.8 |
| 3 | 140 | 0.6 | 2.1 |
| 4 | 405 | 0.9 | 2.1 |
| 5 | 790 | 0.8 | 1.8 |
| 6 | 1 200 | 1.1 | 1.8 |
| 7 | 2 050 | 1.0 | 1.9 |
| 8 | 3 260 | 1.0 | 2.0 |
| 9 | 4 540 | 0.7 | 2.2 |
| 10 | 6 380 | 0.7 | 1.7 |
| 11 | 9 840 | 0.6 | 1.8 |
| 12 | 14 110 | 0.8 | 1.8 |
| Mean | | 0.81 | 1.9 |

Table 3 Accuracy & precision of volume measurement using the reprojection method

| Ulcer No. | Volume (mm) | Accuracy % | Precision % |
|---|---|---|---|
| 1 | 10 | 5.4 | 1.0 |
| 2 | 58 | 5.2 | 2.1 |
| 3 | 210 | 4.9 | 2.5 |
| 4 | 823 | 4.7 | 2.5 |
| 5 | 3 860 | 5.8 | 1.2 |
| 6 | 10 220 | 5.7 | 1.3 |
| 7 | 26 150 | 5.6 | 1.1 |
| 8 | 60 440 | 5.6 | 2.2 |
| 9 | 103 400 | 5.8 | 2.4 |
| 10 | 223 300 | 4.8 | 1.9 |
| 11 | 413 280 | 5.2 | 1.3 |
| 12 | 649 000 | 4.7 | 1.3 |
| Mean | | 5.2 | 1.7 |

## COMPARISON WITH CONVENTIONAL SYSTEMS

In order to compare the reprojection method with conventional techniques, the same artificial ulcers on the plaster casts were measured by direct tracing and scaled photography.

Direct tracing was performed using transparent acetate paper made for overhead projectors. The paper was laid around the limb in as close contact with the leg as possible. The margin of the ulcer was then traced using an indelible felt pen with a narrow tip. The edge length of each tracing was calulated as the mean of three readings taken with a map wheel. The area was also calculated from three readings using an Allbrit fixed arm planimeter. Ten tracings were made of each ulcer and the mean results were calculated.

Scaled photography was performed using 35mm colour slide film in a single lens reflex camera. The photograph was taken by setting the focus on the lens at 0.5 metres, then moving the camera until the leg surface and a 20cm scale ruler lying beside it were in focus. The slides were projected through a standard projector with a zoom lens. The projector was moved close to the screen until the 20cm ruler in the picture corresponded with a 20cm scale mark on the projector screen. Transparent acetate paper was attached to the screen with tape, and the margins of the ulcer were traced onto the acetate using an indelible felt tip pen. Measurements were taken off the acetate paper in the same way as described above. Three photographs were taken of each ulcer. Ten measurements were made from each picture and the mean results were calculated as before.

The results of the three measurement methods are compared, shown in Tables 4 and 5.

The edge length measurements (Table 4), show that the errors in direct measurement and scaled photography rise to levels above 30% on smaller ulcers (<400 mm$^2$) and that even on the ulcers larger than this, the combined error of precision and accuracy rarely falls below 5%.

The results of the area measurement are presented in Table 5. An even greater discrepancy is shown between the accuracy of reprojection and the other two systems. There are large errors (>25%) in tracing and scaled photography in any ulcers with an area < 400mm$^2$.

Table 4 Comparison of accuracy & precision of edge length measurement with the two conventional methods

| Edge Length mm | Reprojection | | Direct Tracing | | Scaled Photography | |
|---|---|---|---|---|---|---|
| | Acc. | Pre. | Acc. | Pre. | Acc. | Pre. |
| 10 | 0.5 | 1.2 | 7.5 | 33.0 | 20.0 | 34.0 |
| 25 | 0.6 | 1.5 | 5.6 | 13.0 | 12.5 | 16.0 |
| 45 | 0.2 | 1.3 | 3.0 | 7.5 | 3.2 | 7.0 |
| 75 | 0.4 | 1.1 | 1.7 | 8.2 | 4.5 | 7.0 |
| 100 | 0.5 | 1.4 | 2.1 | 4.5 | 6.2 | 6.5 |
| 125 | 0.1 | 1.5 | 1.1 | 5.5 | 4.8 | 5.0 |
| 160 | 0.4 | 1.1 | 1.4 | 5.3 | 3.8 | 6.0 |
| 200 | 0.3 | 1.2 | 0.8 | 3.6 | 3.0 | 4.7 |
| 240 | 0.3 | 0.9 | 1.1 | 2.7 | 3.4 | 5.9 |
| 290 | 0.6 | 0.9 | 1.3 | 6.4 | 2.8 | 5.2 |
| 365 | 0.5 | 1.4 | 0.4 | 2.6 | 0.2 | 5.0 |
| 490 | 0.2 | 1.2 | 0.2 | 4.8 | 0.6 | 6.0 |
| Mean | 0.38 | 1.22 | 2.18 | 8.1 | 5.4 | 9.0 |

Table 5 Comparison of accuracy & precision of area measurement with the two conventional methods

| Area mm | Reprojection | | Direct Tracing | | Scaled Photography | |
|---|---|---|---|---|---|---|
| | Acc. | Pre. | Acc. | Pre. | Acc. | Pre. |
| 10 | 0.9 | 2.2 | 60.0 | 75.0 | 43.0 | 80.0 |
| 50 | 0.6 | 1.8 | 29.0 | 40.0 | 23.0 | 26.0 |
| 140 | 0.6 | 2.1 | 16.5 | 21.0 | 10.7 | 17.0 |
| 405 | 0.9 | 2.1 | 10.0 | 18.0 | 16.0 | 17.0 |
| 790 | 0.8 | 1.8 | 5.8 | 12.0 | 8.6 | 34.0 |
| 1 200 | 1.1 | 1.8 | 0.3 | 10.5 | 3.9 | 11.5 |
| 2 050 | 1.0 | 1.9 | 3.7 | 8.6 | 1.6 | 11.0 |
| 3 260 | 1.0 | 2.0 | 5.8 | 10.2 | 4.0 | 11.0 |
| 4 540 | 0.7 | 2.2 | 4.0 | 6.2 | 3.2 | 12.0 |
| 6 380 | 0.7 | 1.7 | 2.9 | 6.7 | 5.1 | 11.1 |
| 9 840 | 0.6 | 1.8 | 0.4 | 4.9 | 10.0 | 10.3 |
| 14 110 | 0.8 | 1.8 | 2.3 | 5.7 | 8.5 | 10.7 |
| Mean | 0.81 | 1.9 | 11.7 | 18.2 | 11.4 | 21.0 |

## Discussion

The results of the tests on the three methods show that:

a) reprojection is significantly more accurate than the conventional methods, regardless of the size of the skin defect.

b) reprojection maintains its accuracy on smaller defects, while errors on the conventional methods increase.

c) on smaller defects, the errors in the conventional measurement methods are larger than the dimensional changes which are being measured.

d) the errors in reprojection remain consistently below the measured rates of healing for all ulcer sizes. This makes it a valuable instrument in work involving measurement of cutaneous healing rates. It may therefore be possible to correlate the rate of healing at various stages with the absolute time to complete healing. This may have fundamental importance for future studies of healing because it may allow the objective assessment of a given treatment program, without having to wait until complete healing has occurred.

The reprojection procedure is time consuming and requires some operator training. There is much room for improvement, particularly in the equipment. A new camera is being built which is more portable, and gives no discomfort to the patient. The Metrograph is being adapted to move under computer guidance, allowing the operator to work from a console instead of the present uncomfortable position. We are also using graphical methods for easier assessment of healing rates, where successive measurements are superimposed.

We have demonstrated that it is possible to measure volume accurately. It is now proposed to carry out further trials of treatment in deep wounds such as bed sores and abdominal wounds, and to determine the relevance of volume to the time taken for a wound to heal. It has never been possible to do this before, as there has never been a non-invasive method for measuring volume. Now that this measuring equipment is available, this opens up a completely new field of clinical study.

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