Multidimensional aspects of burn wound treatment

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Part I

Clinimetric studies on burn wound surface area estimation

Chapter 2

Three-dimensional imaging: a novel, valid, and reliable technique for measuring wound surface area

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ABSTRACT

Background: The aim of this study was to investigate the validity and reliability of a novel three-dimensional imaging technique using Artec MHT™ 3D Scanner for measuring wound surface area.

Methods: The validity was tested by measuring the surface area of 60 stickers (gold standard) on 20 volunteers. Stickers with standardized areas of 2590 mm^2, 7875 mm^2 and 15540 mm^2 were resectivley applied on the thorax, forearm and thigh. For the reliability test 58 burn wounds on 48 patients were assessed twice by two different observers with the Artec MHT™ 3D Scanner. Scanning, post-processing and surface area measurements were performed by two clinicians.

Results: The results for the validity analysis showed an intraclass correlation coefficient of 0.99 and coefficient of variation of the thorax, forearm and thigh were 1.1%, 0.9% and 0.6%, respectively. The reliability analysis showed an intraclass correlation coefficient of 0.99, a coefficient of variation of 6.3% and limits of agreement between measurements of two observers was calculated at 0 ± 0.17 x *mean surface area.*

Conclusion: Three-dimensional imaging using the Artec MHT™ 3D Scanner is a valid and reliable method for measuring wound surface area.

INTRODUCTION

A valid and reliable wound surface measurement is an essential component of wound care. From a clinical perspective, monitoring changes in wound surface area is necessary to observe wound healing and assess effectiveness of treatment.(1) An accurate measurement is also obligatory to permit a comparative assessment of wound surface area for research purposes and eventually establishing evidence-based decision making in wound management. In addition, this information can be used to support an effective communication with patients and between practitioners, particularly because nowadays wound care is managed more and more in a multidisciplinary setting.(1,2)

Essential insight on the clinimetric properties is needed before implementing a novel method for measuring wound surface area. Clinimetric properties refers to the validity (the ability of the technique to measure the actual wound surface area) and the reliability (the consistency of wound surface measurement between observers using this technique).(3)

A variety of techniques are used to measure wound surface area. The simplest method is multiplying the greatest length with the perpendicular greatest width using a rectangle or an ellipse.(4-6) An alternative method is manual planimetry by tracing the outlines of the wound on a transparent grid paper.(2,7) A modification of this method is digital planimetry by retracing the outlines of a wound from a digital photograph after manually tracing the wound boundary on a transparent grid paper. (8-10) A non-invasive method is digital photography in combination with an imaging system, whereby a ruler is photographed near the wound which allows the user to calibrate the imaging system.(11) Stereophotogrammetry is also used for wound surface measurement by assessing three-dimensional geometry of the wound using two or more cameras.(11)

Although considerable research has been devoted to innovations in techniques for measuring wound surface area, current methods have limitations. The ‘length by width’ technique has been shown to overestimate wound surface area by 10% to 70% (5,12,13) and is unreliable for large or irregularly shaped wounds due to the assumption that wounds are either rectangle or ellipse.(14) Manual planimetry is easy to perform and has a good reliability and validity. However this method is not suitable for large wounds and often causes discomfort for the patient.(15,16) Digital photography is non-invasive but limited as a two-dimensional photo representing a three-dimensional structure results in discrepancy when tracing the margins of a wound. Stereophotogrammetry is a non-invasive, valid and reliable method but it is less suitable for extremely curved and/ or large areas.(17,18)

To overcome the limitations of the previously described studies, we introduce a novel class of technique for measuring wound surface area that uses a portable and light-weighted, three-dimensional scanner which creates a coloured, three-dimensional reconstruction of the wound using flash bulb. This technique is non-invasive for the patient, suitable for curved body parts and larger wounds. The wound surface area can be obtained from the three-dimensional image by using a special software program.

Therefore, the main objective of this study was to evaluate the validity and reliability of three-dimensional scanning using Artec MHT™ 3D Scanner for measuring wound surface area.

PATIENTS AND METHODS

Patients and volunteers

Burn patients and volunteers were included from August 2012 until January 2013. Volunteers were recruited from the Red Cross Hospital staff, Beverwijk, the Netherlands. They were asked to allow application of stickers, that resembled burn wounds, on their body for the reliability part of the study. Burn patients were included from the outpatient clinic and ward of the Burn Center of the Red Cross Hospital, Beverwijk, the Netherlands. Burn patients of all ages were eligible for the inclusion as long as no surgical intervention was performed yet. The local ethics committee approved this study.

Artec 3D

The Artec MHT™ 3D Scanner (The Artec Group, San Diego, USA) was used to make a three-dimensional reconstruction of a wound. This device is a non-invasive, handheld measurement tool that projects structured light flashes on a surface and subsequently detects the deformations in the grid of the reflecting light. Using this method, the scanner can detect differences in texture and height that results in a realistic three-dimensional reconstruction of human body curvature. The device also adds a coloured image of the surface scanned by making regular photos every 15 frames. This results in a full-coloured three-dimensional reconstruction of the wound.(19)

With a distance of 40 cm to 60 cm, scanning is performed perpendicular to the skin surface and the device is manually rotated around the patient until the wound is fully visualized. During this process, the patient should remain still to prevent artefacts in the three-dimensional reconstruction. In addition, the patient or the volunteer can take any position during the scanning procedure as long as the device is perpendicular to the wound. Next, the laptop that is connected to the scanner uses a specially designed software program (Artec 3D Studio 9.0) which immediately generates a three-dimensional image (Figure 1). The scanning process usually takes approximately one minute.

In this same software program, it is possible to calculate the area scanned in mm^2 (measurement of the wound surface area). However, the clinician has to mark the boundaries of the wound on the software program to calculate the wound area in mm^2. This process, depending on the wound size, takes between 15 - 60 minutes. An ideal scan condition is an examination room with slightly subdued light. In our study, this setting was constantly maintained.

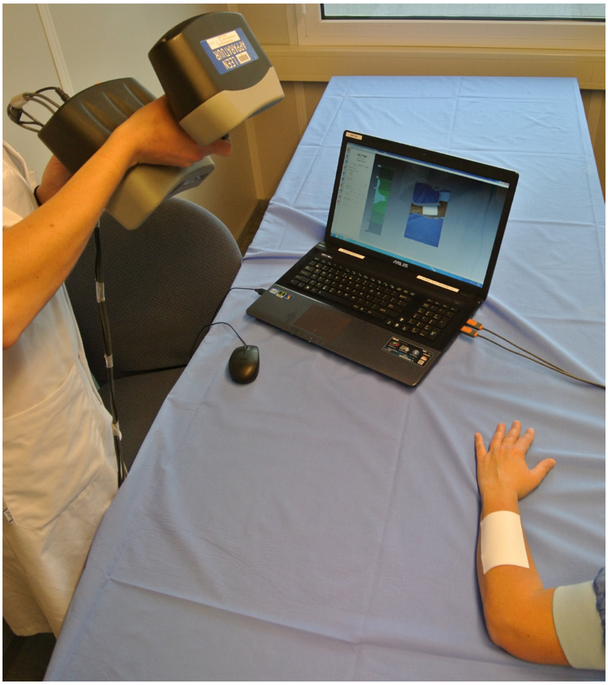

Figure 1. An example of three dimensional scanning of the left arm.

Standardized stickers

In the absence of a gold standard for measuring wound surface area, standardized stickers of known sizes were used to measure the validity of this device. Three different stickers were applied on three different body parts with different curvatures, respectively from a low to a high curvature: the thorax (size: 2590 mm^2), the ventral side of the upper right leg (15540 mm^2) and the dorsal side of the right forearm (size: 7875 mm^2).

Procedure

To evaluate the validity of Artec MHT™ 3D Scanner, three different stickers were applied on the volunteers. The stickers were scanned by one observer and post-processed as mentioned above. The same observer also performed all the measurements. Finally, sticker surface measurements were compared with the actual sticker sizes (gold standard). After the validity part of this study, scan procedure protocol was evaluated to optimise the scanning of the wounds for the reliability measurements. To test the reliability of the Artec MHT™ 3D Scanner, wounds were scanned by two observers (observer A and B). Both observers were researchers at the Burn Center of the Red Cross Hospital and received basic course in performing scan with Artec MHT™ 3D Scanner and using Artec 3D Studio 9.0. These scans were imported into Artec 3D Studio 9.0. Thereafter, observer A performed surface area measurement of the scan of observer B, and vice versa. This resulted in two measurements of each wound. No intraobserver reliability was performed because in general intraobserver reliability is considered to be higher than interobserver reliability.(3) (Figure 2)

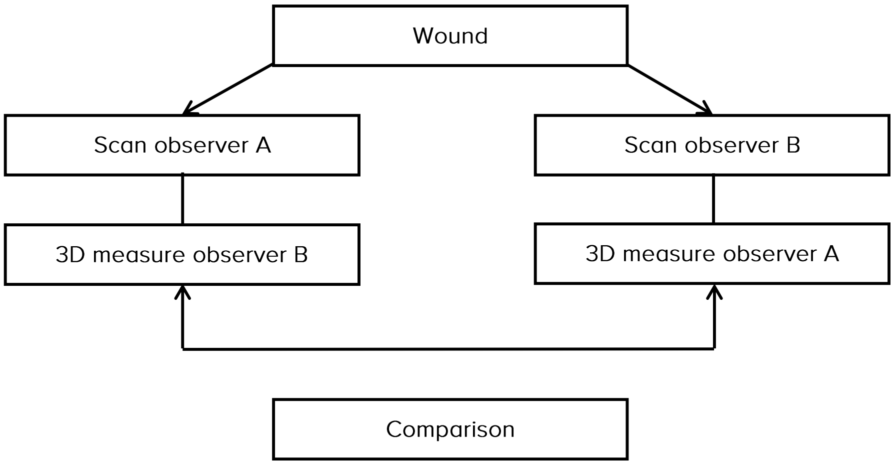

Figure 2. Schematic representation of the reliability analysis.

Statistical procedure

The data were analyzed using SPSS 20.0 (SPSS Inc., Chicago, IL, USA). The interobserver reliability of the Artec MHT™ 3D Scanner was assessed by comparing the patients' burn wound measurements of observer A and B as shown in figure 2. The same statistical approach was used as described in a study by Stekelenburg et al.(18) The most commonly used statistical parameter for interobserver reliability analysis is the Intraclass Correlation Coefficient (ICC) which was defined as the correlation between the surface area ratings of the same burn wound by two observers based on the scans obtained by the same observers. ICC was expressed as a ratio of the wound variance (σ^2_{wound}) and the total variance (σ^2_{tot}) which is a sum of patient's variance (σ^2_{pat}), observer variance (σ^2_{obs}) and random error variance (σ^2_{error}), resulting in the following formula: $ICCagreement = \frac{\sigma^2 wounds}{\sigma^2 wounds + \sigma^2 observers + \sigma^2 error}$.(3)

The values for the variance components were obtained using a linear random effects model in SPSS. Random factors were the observer number (i.e. A or B) and burn wound number. The dependent variable was the burn size measured. In addition to the ICC, the Coefficient of Variation (CV) was calculated. The CV is a normalized ratio of the standard deviation to the mean of the measurements in percentages. The CV is appropriate to use when the measurement error grows with the mean value of the measurement. A low CV indicates a more reliable measurement. Difference between two measurements (y-axis) were plotted against the mean of two measurements (x-axis) in a Bland Altman Plot to provide direct information on the absolute agreement between two observers.(20) Data were considered skewed if the differences between measurements increased with the increasing mean of pairwise measurements. If the measurements have a skewed distribution, data should be log-transformed to approximate a normal distribution in order to calculate the limits of agreement. However, log-transformed data is difficult to interpret in clinical practice. Therefore, limits of agreement were transformed back to original scale by taking anti-logs and plotted together in the clinical and untransformed data conform Euser et al.(21) In this modified Bland Altman plot the limits of agreement represents two divergent lines instead of two parallel lines. To analyze the validity, the ICC and CV per body part were calculated. Differences between the measurement of observer A and the gold standard (actual size of the stickers) on the y-axis were plotted against the gold standard on the x-axis in a Bland and Altman Plot.

RESULTS

Volunteers and patients characteristics

A total of 20 healthy adult volunteers (8 males and 12 females) were enrolled for the validity analysis. The median age was 33 years (range 24 to 61). Eighteen volunteers of Caucasian, one of Asian/Mediterranean, and one of Negroid race, were included. For the reliability analysis, a total of 58 burn wounds from 48 patients were enrolled in this study. Patient characteristics are summarized in Table 1.

Validity

Mean differences and its standard deviation (SD) between measurements of observer A and the gold standard for the thorax, forearm and thigh were 10 mm^2 (41), -44 mm^2 (69) and 20 mm^2 (79), respectively. The ICC was 0.99. The Coefficient of Variation (CV) for the measurement of the stickers on the thorax, forearm and tigh were 1.1%, 0.9% and 1.0%, respectively. However, after evaluating the scan procedure we found that two scans of the forearm were not completely scanned. Thereafter, we amended our scan procedure by confirming that all the scans were completely visible on the monitor before saving them and using them for the reliability measurements. After removing these incomplete scans from our analysis, the CV for the forearm was 0.6% (Table 2). These data were also plotted in a Bland and Altman plot, with the gold standard on the x-axis and the difference between measurements of observer A and the gold standard on the y-axis (Figure 3).

Table 1. Patient and wound characteristics.

Number of burn wounds	58
Number of patients	48
Gender	
Male	32
Female	16
Age (years)	
Median (range)	29 (0.8 - 71)
Burn surface area in mm²	
Median (range)	5965 (442 - 57742)
Burn wounds depth, n	
2nd degree	
- Superficial	10/ 58
- Deep	14/ 58
- Mixed	18/ 58
3rd degree	10/ 58
Mixed 2nd/3rd degree	6/ 58
Burn wound location, n	
Head and neck	6/ 58
Trunk (anterior)	8/ 58
Trunk (posterior)	6/ 58
Upper extremities	20/ 58
Lower extremities	18/ 58

Table 2. Results for validity.

	Thorax	**Forearm**	**Thigh**
Gold standard, mm^2	2590	7875	15540
Mean value observer A mm^2, (SD)	2600	7831	15560
Mean difference mm^2, (SD)[1]	10 (41)	-44 (69)	20 (79)
ICC	0.99	0.99	0.99
CV (%)	1.1	0.9	0.6

ICC: Intraclass Correlation Coefficient, CV: Coefficient of Variation. [1] Mean difference between measurements of observer A and the gold standard.

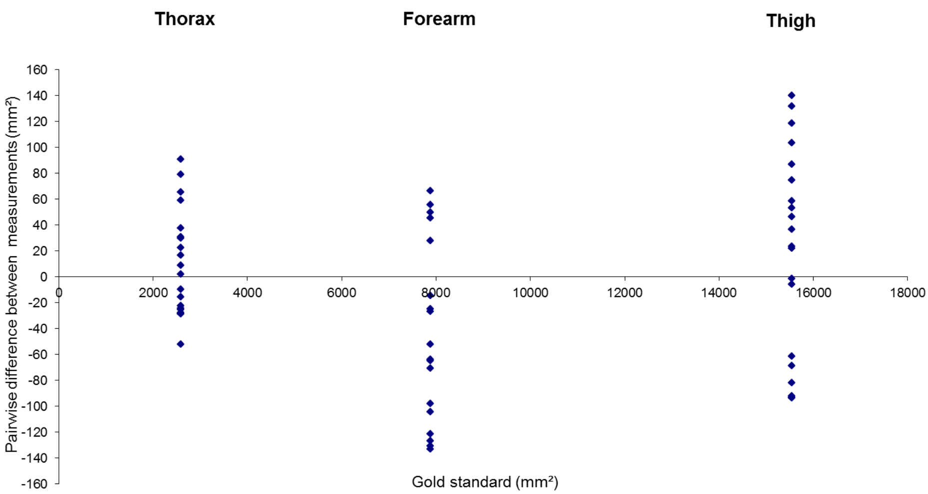

Figure 3. A modified Bland and Altman plot presenting agreement between an Artec measurement by one observer and the actual size of the stickers (without incomplete scans).

Reliability

Our results showed that the ICC was 0.99, which in this study is the correlation between the wound surface area measurement of the same burn wound by two observers based on the scans obtained by the same observers. All mean differences between measurements of both observers was < 251 mm^2. The CV was approximately 6.1%. The estimation of all variance components can be found in Table 3.

Table 3. Results for reliability.

ICC	0.99
CV	6.3%
Variance (Random effect)	
- Wound variance (σ^2_{wound})	1.332
- Observer variance (σ^2_{obs})	0.000
- Random error variance (σ^2_{error})	0.004

ICC: Intraclass Correlation Coefficient, CV: Coefficient of Variation.

A Bland and Altman plot is presented in figure 4 that showed a skewed distribution of the data indicating that the measurement error increased with the size of the wound. A log transformation was performed to obtain an approximately normal distribution in order to calculate the limits of agreement as a function of the mean of the burn surface area. The limits of agreement were 0 ± 0.17 x *mean surface area* and increased with the wound size (Figure 4). In figure 4 the backtransformed limits of agreement were plotted in the clinical and untransformed data.

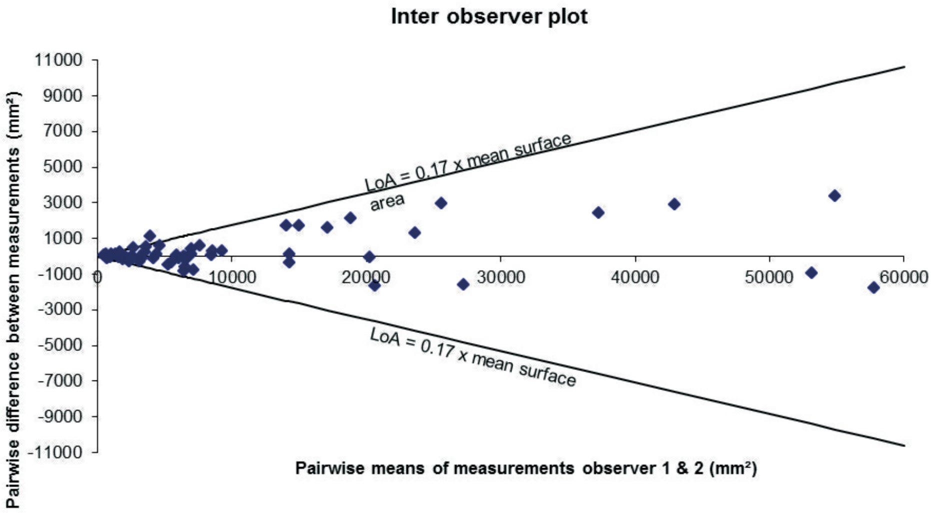

Figure 4. A Bland and Altman plot presenting the inter-observer agreement between the two observers.

DISCUSSION

This study has shown that this novel three-dimensional method using Artec MHT™ 3D scanner and software is a valid and a reliable method for measuring wound surface area.

An excellent ICC of 0.99 found for the validity indicates the 3D method using the Artec MHT™ 3D scanner to be a valid method for measuring wound surface area. In general, an ICC of >0,90 is considered to be acceptable in clinical practice, whereas an ICC >0,7 is recommended for use in research settings(3). Furthermore, the standard deviation of the mean difference increased with the size of the sticker. This finding that is supported by our reliability analysis. We also found that the largest mean difference to be in the forearm, which is the most curved body part in this study. Difficulties in measurement of wound surface area of curved body parts is a well-known problem.(22,23) However, the mean differences in the present study were all negligibly small. The coefficient of variation was found to be very low for all body parts and also decreased with wound size. This finding indicates an acceptable error for the validity analysis. In absence of a 'gold standard' to measure wound surface area, stickers with a standard and known-size were used for the validity analysis. However, a limitation of this setting is that these stickers do not represent wounds in patients.

For the reliability part of this study, a high ICC of 0.99 indicated an excellent reliability of this novel method in both research and clinical practice. Several factors explain the high ICC and the CV in our study. The high quality colour three-dimensional reconstruction of the wound allowed observers to make an accurate digital tracing of the wounds. Also, the Artec 3D Studio software contains important features for a precise tracing, for example enlarging the wound and interaction with the 3D wound model. The agreement between observers for measuring the wound surface area of the same wound were displayed by using Bland and Altman plots and calculating their limits of agreement. As illustrated in figure 3, this analysis has shown that the limits of agreement of 0 ± 0.17 x *mean surface area* were narrow. Narrow limits of agreement indicate an acceptable variation in measurements values between observers.

To our knowledge, there are no other studies using a 3D scanner, by measuring distortions in a beam of structured light and creating a full coloured 3D reconstruction of the wound, for the purpose of wound surface area measurements. Therefore, a comparison with other 3D methods using different methods for measuring wound surface area is not entirely objective. However, the single-measure interobserver ICC of 0.99 in our study was higher than a study using stereophotogrammetry for measuring wound surface area (ICC = 0.747).(24) In contrast, the high ICC and CV in our study are comparable with a similar study on measuring scar surface area with 3D-stereophotogrammetry.(18) Recently, a wound imaging and measurement system called SilhouetteMobile (ARANZ Medical, Christchurch, New Zealand) was introduced. This technique consists of a mobile computing device and camera that captures wound surface area and uses laser technology to estimate wound depth. An interobserver ICC of single-measurement of 0.901 was reported.(25) Another combination of laser projector and a digital camera system by Kecelj-Leskovec et al. showed a standard error of measurement of 9.7% for wound surface area measurement.(26) However, the authors concluded that this device was less suitable for very flat wounds and wounds with irregularity of the surrounding skin.(26)

The Artec MHT™ 3D Scanner is a portable, very easy to handle and light weighted device that can be used at any clinical setting including the operating theatre. Performing a scan requires no wound contact and takes only seconds. The accompanying Artec 3D software guides the user through a phased plan for post-processing of the scans. The obtained scans are highly detailed and full-colour representation of the wound. This 3D representation of the wound provides important visual information regarding the depth, volume and signs of infection of the wound. Also, these scans have a valuable potential to be used for telemedicine. Despite the advantage of this novel 3D system, there are a few limitations that need to be mentioned. The measurement procedure of performing a scan, post-processing of the data and measuring wound surface area takes in the majority of the wounds approximately 15 minutes. However, larger wounds (i.e. > 50 cm^2) could take up to one hour. It should be noted that Artec 3D software is still under development and a newer version provides significant improvements in terms of reducing post-processing time which is the most time consuming process of the measurements. In order to perform a scan, the patient should remain still during scanning. This could be an issue in paediatric patients. However, we were able to scan 10 paediatric patients < 5 years in our study without any limitations.

CONCLUSION

This study shows that three-dimensional imaging using Artec MHT™ Scanner and software is a non-invasive, valid and reliable technique for the measurement of wound surface area. However, further research is warranted to explore the possibilities of this promising technique in clinical practice and research setting and its possible limitations.

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