RESEARCH PAPER

Wound Measurement Techniques: Comparing the Use of Ruler Method, 2D Imaging and 3D Scanner

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Abstract The statistics on the growing number of non-healing wounds is alarming. In the United States, chronic wounds affect 6.5 million patients. An estimated US \$25 billion is spent annually on treatment of chronic wounds and the burden is rapidly growing due to increasing health care costs, an aging population and a sharp rise in the incidence of diabetes and obesity worldwide.¹ Accurate wound measurement techniques will help health care personnel to monitor the wounds which will indirectly help improving care.^{7,9} The clinical practice of measuring wounds has not improved even today.^{2,3} A common method like the ruler method to measure wounds has poor interrater and intrarater reliability.^{2,3} Measuring the greatest length by the greatest width perpendicular to the greatest length, the perpendicular method, is more valid and reliable than other ruler based methods.² Another common method like acetate tracing is more accurate than the ruler method but still has its disadvantages. These common measurement techniques are time consuming with variable inaccuracies. In this study, volumetric measurements taken with a non-contact 3-D scanner are benchmarked against the common ruler method, acetate grid tracing, and 2-D image planimetry volumetric measurement technique. A liquid volumetric fill method is used as the control volume. Results support the hypothesis that the 3-D scanner consistently shows accurate volumetric measurements in comparison to standard volumetric measurements obtained by the waterfill technique (average difference of 11%). The 3-D scanner measurement technique was found more reliable and valid compared to other three techniques, the ruler method (average difference of 75%), acetate grid tracing (average difference of 41%), and 2D planimetric measurements (average difference of 52%). Acetate tracing showed more accurate measurements compared to the ruler method (average difference of 41% (acetate tracing) compared to 75% (ruler method)). Improving the accuracy in measuring chronic wounds might improve overall care of patients with non-healing wounds. This study consistently shows that the 3-D scanner is a more accurate, quicker, and safer method for measuring wounds.

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Introduction

Wounds represent a major and escalating health problem.¹ Diabetic foot ulcers, venous ulcers, and pressure ulcers can cause serious morbidity and even mortality.¹ Non-healing ulcers increase the risk of amputations.⁴ Every 30 s, one limb is being amputated somewhere in the world.⁵ The vast

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Figure 1 2-D camera method for wound model 6.

majority of amputations are preventable with appropriate care.⁶ Accurate wound measurement techniques will help clinicians monitor the wounds which will indirectly improve care of patients with wounds. The currently-used techniques for measuring wounds are not accurate.^{2,3} A common method like the ruler method has inconsistent measurements limited by subjective interpretation and inter observer variability.^{7,8} Another deficiency with this method is that wounds of various shapes and area fit into the same linear $L \times W$ dimensions and usually such measurements are only mathematically accurate for a square or rectangle.⁹ Acetate tracing method is more accurate than the ruler method but it also has its disadvantages. These common measurement techniques are time consuming with variable inaccuracies. In this study, volumetric measurements from a non-contact 3-D scanner are benchmarked against the common ruler

method, acetate grid tracing, and 2-D image planimetry volumetric measurement techniques. A liquid volumetric fill method is used as the control volume.

Methods

Six target clay plates representing different size and volume of wounds were created by boiling wax crystals, putting in target clay plates and letting them dry. A screwdriver was used to chip out pieces of wax and shape each wound differently (Figs. 1–6). Each target clay plate was labeled from 1 through 6. Each target wound model was marked at the 3 o'clock, 6 o'clock, 9 o'clock, and 12 o'clock positions with a sharpie marker.

Figure 2 Ruler method, Wound model 1.

Figure 3 Ruler method, Wound model 2.

Figure 4 Ruler method, Wound model 3.

Figure 6 Ruler method, Wound model 5.

Volumetric Measurements

60 ml of water was placed in a beaker; a 10 cc syringe was used to draw water from the beaker and fill each wound to its edges with water. Then water was suctioned out with the syringe from each target clay wound model and volume of water in each wound model was recorded on an excel spreadsheet (Table 1).

Ruler Method

Measurements were recorded for the ruler method using the ruler to measure the longest length (12 o'clock to 6 o'clock), widest width (9 o'clock to 3 o'clock), and deepest depth for each wound. Depth was measured by placing the Q-tip at the deepest area in the wound. Volume was calculated and then recorded in mm^3 on an excel spreadsheet by multiplying length, width, and depth in millimeters (Table 2) (Fig. 5).

Acetate Tracing Method

Acetate Tracing Grid was evenly placed on a target plate. Each wound was then traced with indelible marker

Figure 5 Ruler method, Wound model 4.

on the grid. Complete boxes were counted and incomplete boxes were approximated that were covering the entire wound area. Depth was measured using the Q-tip to measure the deepest depth. Volume was calculated in mm^3 by multiplying length, width, and depth in millimeters. Data was recorded on an excel spreadsheet (Table 3).

2D Camera Method

D3100 digital camera was used to take pictures of each target wound model such that the target wound bed model, scale, and label are fully visualized and the entire wound surface and the label filled the frame and were in focus. Same positioning, view and magnification were used for each wound model. All six pictures were downloaded on the computer; application ImageJ was also downloaded on the computer (<http://rsbweb.nih.gov/ij/download.html>). Once the ImageJ file was opened, the first wound picture was selected on an open screen. The straight line button was clicked from the toolbar and a line was created for 1 cm using the ruler in the picture. "Analyze" was selected from the toolbar and then "Set Scale" was selected. "10" was typed in the known distance and "mm" was typed in the Unit of Length. "Ok" was selected. The straight line button was clicked again and line was created for the

Table 1 Water Volumetric Measurement

Wound #	mL
Wound 1	9
Wound 2	13
Wound 3	11
Wound 4	11
Wound 5	10.6
Wound 6	2.4

Table 2 Ruler Measurement

Wound#	Length	Width	Depth	Volume
Wound 1	44	38	10	16.72
Wound 2	46	49	11	24.794
Wound 3	46	40	14	25.76
Wound 4	40	43	14	24.08
Wound 5	37	55	12	24.42
Wound 6	23	20	14	6.44

longest length (12 o'clock to 6 o'clock) and for widest width (9 o'clock to 3 o'clock). Length and width were measured for each wound model and recorded on an excel spreadsheet. The depth was measured using the Q-tip to measure the deepest depth. Volume was calculated in mm^3 by multiplying length, width, and depth in millimeters. Data was recorded on an excel spreadsheet (Table 4) (Fig. 7).

3D Scanner Method

A 3-D Scanner was used to scan all images of target wound model. All six 3-D images were transferred to the computer and a 3-D Volumetric Measurement Software was downloaded. The data was loaded into the volume measurement software. The boundary of the "wound" was selected. The program automatically found the "top" of the wound based on the selected points. The volume was calculated using the technique, 3D Reimann Sum and all data were recorded on an excel file (Table 5) (Fig. 8) (http://quiz.uprm.edu/visual3d/manual/int_rec_coor/var_rul_rei_sum_3D.html).

Comparative Results With Various Methods Compared to Volumetric Measurements

The percentage difference was calculated from the collected data in the excel file and compared to the standard Volumetric Measurement (Table 6). The Formula used for calculating the Percentage Difference was taken

from the following link: <http://www.phy.ilstu.edu/slh/percent%20difference%20error.pdf> (Table 6). Average Percent Difference of all methods were compared to water volumetric measurements and recorded in an excel file (Table 7). Graphs were made to visualize and compare data between different measurement techniques (Graphs 1–3).

Wound Volume by Measurement Technique

% Difference (Water Fill as Reference)

Average % Difference (Water Fill as Reference)

Results

Data recorded from all measurement techniques on the excel file were analyzed by calculating volume in mm^3 . In this study, volumetric measurements from the non-contact

Table 3 Acetate Planimetric Tracing Measurement

Wound #	Area (mm)	Depth	Volume (mL)
Wound 1	115	10	11.5
Wound 2	160	11	17.6
Wound 3	130	14	18.2
Wound 4	110	14	15.4
Wound 5	120	12	14.4
Wound 6	40	14	5.6

Table 4 2-D Picture

Wound #	Length	Width	Depth	Volume
Wound 1	38.646	40.508	10	15.65472
Wound 2	38.838	37.718	11	16.11381
Wound 3	39.803	36.197	14	20.17049
Wound 4	40.5	41.327	14	23.43241
Wound 5	60.925	25.551	12	18.68034
Wound 6	15.931	17.792	14	3.968221

Figure 7 Ruler method, Wound model 6.

Figure 8 3-D Scanner measurement.

3-D scanner were benchmarked against the common ruler method, acetate grid tracing, and 2-D image planimetry volumetric measurement technique. A liquid volumetric fill method was used as the control volume. The following results were derived from this study:

1. The 3-D Scanner volumetric measurements consistently showed measurements closer to benchmark volumetric measurement by waterfill technique (average of 11% difference) (Graph 3).
2. The 3-D Scanner volumetric measurement technique was found to be better than Ruler Method Volumetric measurement compared to benchmark volumetric measurement by waterfill technique (average difference of 75% by ruler method to 11% by 3D Scanner method) (Graphs 1 and 2).
3. The 3D Scanner volumetric measurement technique was found to be better than Acetate Tracing Volumetric measurement compared to benchmark volumetric measurement by waterfill technique (average difference of 41% by Acetate tracing compared to 11% by 3D Scanner method) (Graphs 1 and 2).
4. The 3D Scanner volumetric measurement technique was found to be better than 2D planimetric volumetric measurement compared to benchmark volumetric measurement by waterfill technique (average difference of 52% by 2D planimetric measurement compared to 11% by 3D Scanner method) (Graphs 1 and 2).
5. Acetate tracing volumetric measurement technique was found to be more accurate measurements compared to

presently used ruler method volumetric measurement technique when compared to benchmark volumetric measurement by waterfill technique (average difference of 41% by Acetate Tracing compared to 75% by Ruler method) (Table 7 and Graph 1)

Discussion

Wound measurement is an important component of wound assessment that provides baseline measurements to measure and predict treatment outcomes. Accurate area measurement and the percentage of area reduction of the wounds are useful parameters for differentiating between wounds that are or are not responding to treatment.⁶ Research focusing on the development of a standardized method for measuring wounds and reporting wound healing rates will help increase the accuracy of healing documentation and prediction.⁶ An accurate method with good inter-rater and intra-rater reliability is most desirable. Rogers et al found standard, manual length $\times$ width measurements showed overestimation by roughly 40%.¹⁰ In this study,

Table 5 3-D Scanner

Wound #	Volume (mL)
Wound 1	9.05
Wound 2	10.426
Wound 3	11.823
Wound 4	11.69
Wound 5	8.2
Wound 6	2.256

Table 6 Comparative Results With Various Method Compared to Volumetric Measurements Results

Wound #	Water	Ruler	Acetate	2D	3D
Wound 1	9	16.72	11.5	15.65472	9.05
Wound 2	13	24.794	17.6	16.11381	10.426
Wound 3	11	25.76	18.2	20.17049	11.823
Wound 4	11	24.08	15.4	23.43241	11.69
Wound 5	10.6	24.42	14.4	18.68034	8.2
Wound 6	2.4	6.44	5.6	3.968221	2.256

Table 7 Percent Difference With Respect to Water

Wound #	Water (%)	Ruler (%)	Acetate (%)	2D (%)	3D (%)
Wound 1	0	60	24	54	1
Wound 2	0	62	30	21	22
Wound 3	0	80	49	59	7
Wound 4	0	75	33	72	6
Wound 5	0	79	30	55	26
Wound 6	0	91	80	49	6
Average	0	75	41	52	11

target wound models were kept irregular with variable depth as shape causes significant variation on the manual calculation by Length $\times$ Width.^{11,12}

This study using clay plate target wound models showed that Volumetric measurement by 3D scanner measurement technique compared to benchmark volumetric measurement by waterfill technique (average 11% difference) than the available wound measurement techniques like ruler method (average 75% difference), acetate grid tracing (average 41% difference) and 2D planimetric measurements (average 52% difference). 3D scanner measurements consistently showed accurate volumetric measurement in comparison to standard volumetric measurement by water-fill technique.

While wound area measurements are one necessary component in determination of healing progress, other factors like wound bed color, fibrosis, and edema are clinical predictors of wound improvement.¹³ Advancing in wound evaluation technology including 3D scanner measurement techniques may help to advance the ability of clinicians to examine and diagnose patients by telehealth.¹⁴

Conclusion

Chronic wounds are a huge public health concern. Improving the accuracy in measuring these chronic wounds might help in overall care of the patient. This study consistently showed that the 3-D scanner method to measure wounds was a more accurate, quicker, and safer method. The 3D scanner can accurately measure wounds and can be widely used throughout the health care industry by health care providers who take care of wounds on a daily basis. The future studies should be done with animal or human subjects to verify it's applicability in the real world. Also, future studies should include multiple clinicians

taking these measurements to determine inter-rater and intra-rater reliability.

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