Three-Dimensional Non-Invasive Wound Measurement Device

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Abstract

The primary objective of this project was to create a device that could assess skin wounds in three-dimensions. Whereas current methods of wound assessment involve only the size of wounds in two-dimensions, a three-dimensional model was desired to provide accurate, concise, and comprehensive assessment of wound sizes based on surface area, volume, and maximum depth to assist clinicians in providing adequate wound healing assessment and treatment.

A grid projection method was selected as the design concept of choice. It involved projecting a grid onto on a wound and capturing a digital image of the wound/grid. Based on the distortions of the gridlines, the surface area, volume, and maximum depth measurements were determined. Ideally, a computer program, such as IMAQ Vision, would have been utilized to assist in surface area, volume and depth calculations. However, due to time constraints, calculations were performed using a mathematical model of the grid projection system in Excel.

Based on the results obtained on simulated wounds, the grid projection system proved useful. However, analysis of the results demonstrated that the system could withstand several improvements. Three simulated wounds were created to determine the accuracy and reproducibility of the grid projection system. Four trials were conducted for each of the three wounds to compare the corresponding surface area, volume, and maximum depth calculations. The average surface area percent difference was 9.91, the average volume percent difference was 8.62, and the average maximum depth percent difference was 4.39.

Original specifications suggested that the method should have an error within ±5%, however, the results demonstrated a ±10% error. To improve the accuracy and reproducibility of the device, a grid pattern of accurate dimensions and an integrated digital camera should be utilized.

Introduction

Skin is an important organ that serves many functions, including protection, prevention of dehydration, sensory inputs, and temperature regulation. Skin is composed of three layers: the epidermis is the outermost protective layer, the dermis is the middle layer which gives skin its tensile strength and flexibility, and the subcutaneous layer is the innermost layer which supports the skin with adipose and connective tissue[1]. When skin is damaged, some or all of these functions may be weakened or destroyed. Skin can become damaged in many ways, including traumatic injury, burns, and chronic wounds. However, of all the causes of wounds, neuropathy related injuries(pressure ulcers) are the most costly and common (e.g. due to diabetes)[2]. Care of skin wounds costs billions of dollars per year. In order to lower the costs, the most effective wound healing methods must be used. However, in order to determine the most effective methods, an objective measure of a wound's current condition must be established.[3] The most obvious choice for such a measurement is wound size, and the size of the wound is indeed currently used as a measure of healing rate. However, current measurement methods are not only imprecise, but measure only the largest 2D dimensions of wounds, not the volumes.[2] There is a demand for a simple-to-use device that measures wounds accurately and in three dimensions.

The goal of this design group was to design and build a prototype of just such a device. The group consisted of Arizona State University bioengineering students Joe Graham, Leslie Grow, and Anu Verma. The mentors for the group were Dr. R. Herman and Mr. S. D'Luzansky.

The steps necessary to design a quality device were determined from two books: *Product Design and Development* and *Design of Devices and Systems*. The steps completed to date include: problem definition, problem evaluation, concept generation, concept selection, and several design iterations.[4,5] In addition, relevant social, ethical, legal, safety, and regulatory issues were explored.

The most important requirements for the design were found to be: non-invasiveness, safety, accuracy, reproducibility, ease of use, low cost, and measurements in x, y, and z directions. The specifications indicate that the device should have an error of less than five percent, cost less than $1000, weigh less than 1 kilogram, and require less than 60 seconds to acquire volumetric wound data.

The four most promising design concepts included: 1) infrared volume measurement of wounds, 2) ultrasound volume measurements, 3) stereophotography to determine wound volume, and 4) the projection of a grid pattern onto a wound and the analysis of the distortions to find the volume.

After careful consideration of the feasibility studies and cost analyses of the design concepts, the grid projection method was chosen as the most feasible and cost-effective.

Current Method of Wound Measurement

Wound healing incorporates a variety of assessment and treatment modalities. In order to determine if a specific treatment works for a patient, there must be some method of wound assessment. The size of a wound is the most obvious choice for such a measure. Currently, in hospital settings, the only way to determine wound size is with a ruler. As seen in *Figure 1*, only the longest, widest, and deepest measurements(by Q tip) of the wound are recorded and used to assess the wound's progress.[2] Besides the variability in measurements due to different clinicians, these measurements are a poor indicator of actual wound size.

An ideal device to measure wound sizes would calculate surface area, volume, and the maximum depth of the wound. Such a device would have to measure in a reproducible fashion even among a large number of users. Finally, the device would have to be easy-to-use and as quick as the current method.

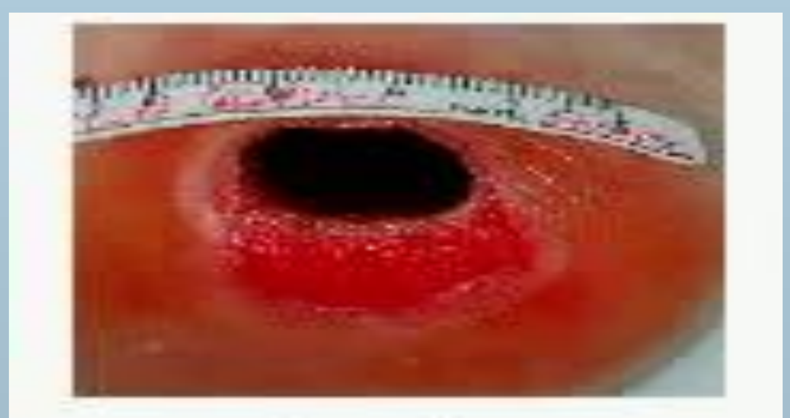

Figure 1: Current measurement method, using a ruler to measure the widest point of a wound.

Design of Grid-Projection Device

The following process was designed to allow the clinician to determine the dimensions of wounds.

<u>Step 1: Record</u>

The clinician uses the device to project a grid onto the wound and then captures a digital photograph of the wound. There is absolutely no physical contact with the wound during this procedure. If the wound at hand is not conducive to volume measurements, a picture can be taken for documentation without volume analysis.

The device was designed to have an integrated digital camera. The prototype, however, requires the use of an external camera. A digital image of the grid projected onto an artificial wound can be seen in *Figure 2*.

<u>Step 2: Analyze</u>

A software program measures the distortions in the grid and calculates the surface area, volume, and maximum depth of the wound.

The final design calls for a software program to make all measurements and perform the volumetric calculations. The prototype version requires the user to make measurements on the image by hand using imaging software. *Figure 3* shows an image ready for measurements.

<u>Step 3: Document</u>

The software saves the image, if requested, and automatically updates the wound information in a database. This step allows the healing process to be monitored by comparison of individual photographs over time.

The final design calls for database software to be included. This software was not developed for the prototype device.

The three-dimensional non-invasive measurement model includes several benefits and incentives:

<u>Client Benefits</u>

•Method used to assess efficacy of treatment—serves as a rationale for treatment method.

•Facilitates active client participation in assessment and treatment process.

•Communicates and teaches, encourages client focused solutions.

<u>Clinician Benefits</u>

Enhances consistency and continuity of care.

Provides objective, accurate data for documentation and measurement.

Aids in the ongoing monitoring of treatment by providing concise client files containing pictures and data history.

Serves as a research tool to test novel treatment approaches.

<u>Cost Effectiveness</u>

•Minimal ongoing expenses.

•Facilitates an effective, preventive approach to the significant financial and personal costs of skin breakdown.

•Enables thorough evaluation and monitoring, increasing client compliance and success of treatment.

•Enables easy file access and file sharing for clinicians

Grid Projection System Benefits

Device Specifications

<u>Materials</u>

Light Source (Xenon Bulb; 2 "C" batteries)

•Battery life @ 70F = 5 hrs, 27 minutes and @ 0F = 1 hr, 34 minutes

•Light intensity (in foot candles at half life*) = 120

*a foot candle is the measure of the illumination of a surface 1 ft. distance from a light source of 1 candle power at half of the battery's life

•Adjustable focus

<u>Dimensions of device and grid</u>

•Height of box = 26.7 cm

•Height of stand = 22cm

•Total height of light w/ stand = 48.7 cm

<u>Camera</u>

•Maximum image resolution: 2400 x 1800; Maximum CCD resolution: 2.4 megapixels; Image type: jpeg

Mathematical Model / Software Algorithm

The process by which the software will calculate the wound dimensions depends heavily upon geometry. *Figure 4* shows a wound with a grid projected onto it. *Point A* is an actual grid intersection recorded by the camera. *Point B* is an interpolation of where *Point A* would be if there were no wound present. *Figure 4* also shows the geometry used to calculate the depth of *Point A*. The ratio of the depth of the point (d_p) to the distance between where the point is and where the point would be with no wound present (d_{pp}) is equal to the ratio between the height of the camera above the surface (h_c) to the distance from the center of the camera's vision to the point of interest (d_{cp}). As such, the depth is defined by the following equation:

$$d_p = (h_c/d_{cp})*(d_{pp})$$

The height of the camera can be calculated from the design of the device. Both d_{cp} and d_{pp} can be measured from the photograph. In the close-up in *Figure 2*, the long line is d_{cp} and the short line is d_{pp}. For the prototype, these distances are measured manually. The final design calls for software that would make all measurements automatically.

Once the depth at each point was measured, the volume is calculated as the sum of the depth of each point times the area of one square of the grid. The surface area is found by adding the areas of each square of the grid where the depth is greater than a set threshold.

Device Testing

In order to test the prototype, three artificial wounds were created and analyzed. The artificial wounds were created by pressing a spherical object into clay. The control measurements were obtained with a liquid dropper for volume, a transparency for surface area, and a ruler for maximum depth.

Four digital images were analyzed for each artificial wound. *Figure 2* is an example of a raw picture. In *Figure 3*, the brightness and contrast were increased to emphasize the grid lines. The white dots represent the intersections of the projected grid lines. The black lines represent an interpolation of where the intersections would be on a flat surface.

After making the necessary measurements, the values were input to an Excel spreadsheet that used the mathematical model to calculate the volume, surface area, and maximum depth of each wound. The results are displayed in *Table 1*.

A graphical representation of the data acquired for one wound can be seen as *Figure 4*.

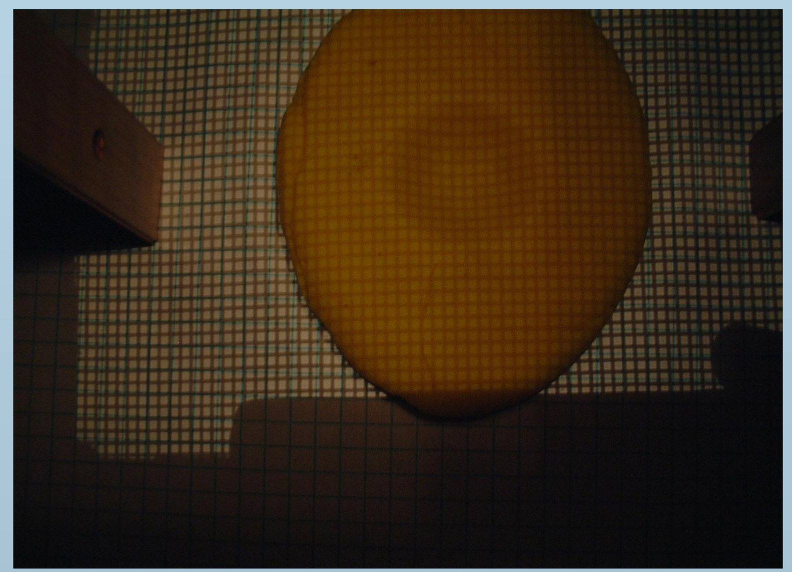

Figure 2: Raw Picture

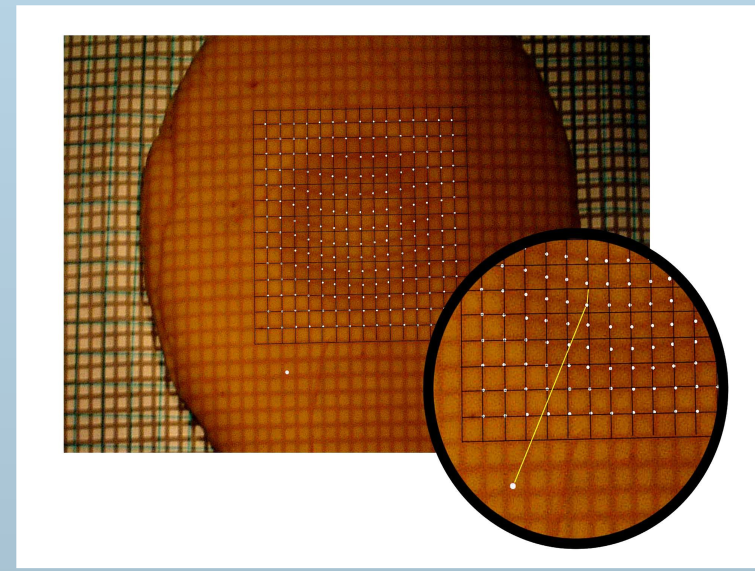

Figure 3: Emphasized Grid Lines

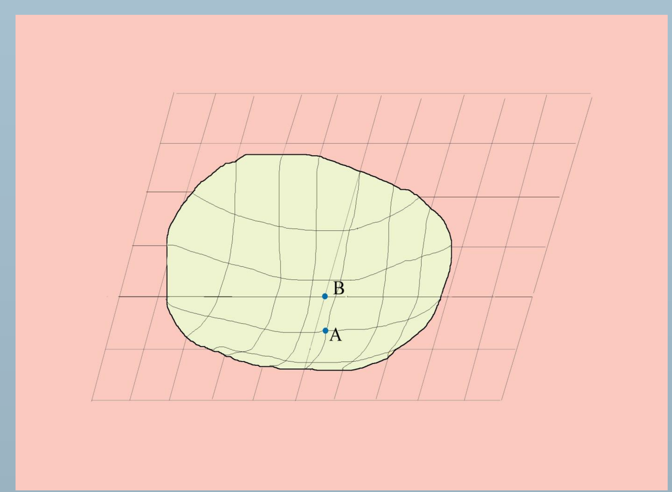

Figure 4: Graphical Representation of Gridlines on Wound

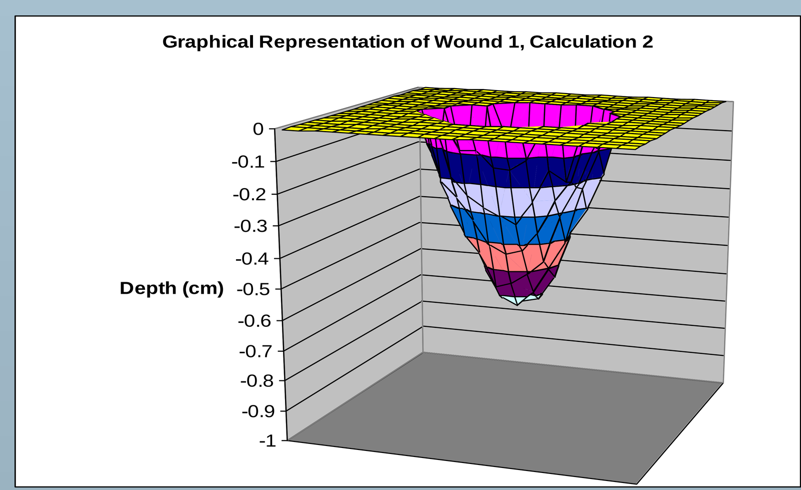

Table 1: Graphical Representation of Wound

Conclusion

Three artificial wounds were created of varying surface area, volume and depth dimensions. Four trials using the grid projection method were carried out for each wound to compare the results of the calculated surface area, volume, and depth measurements. For the three wounds, the average volume measurements were 2.20cm^3, 4.14cm^3, and 6.60cm^3 respectively. The results yielded an average volume percent difference of 8.62. The average surface area calculated measurements were 7.92cm^2, 10.13cm^2, 14.03cm^2, with an average percent difference of 9.91 and the average maximum depth measurements were 0.59cm, 0.94cm, and 1.12cm, with an average percent difference of 4.39.

The overall error was within 10%, a larger value than the value of 5% set by the original specifications for the device. However, the percent error was small enough to conclude that with a few improvements, the grid projection method could be a useful tool to assess wound sizes with a reasonable degree of accuracy and reproducibility. Areas of improvements for the method include a grid pattern of accurate dimensions and the use of an integrated digital camera.

Care of skin wounds is a multi-billion dollar industry. In order to lower the costs of treatment and assessment for patients, an effective method of characterizing a wound's size and condition is essential. The grid projection method offers a system that characterizes a wound based on surface area, volume, and depth, unlike traditional current methods that only assess wound sizes based solely on ruler measurements of the longest and widest portions. With a simple-to-use device that measures wounds with high accuracy and reproducibility in three-dimensions and non-invasively, such as the grid projection method, wound care can be significantly improved. Proper wound treatments can be prescribed to patients, saving the patient valuable time and money.

References

(1) Gray, Henry F.R.S., <u>Gray's Anatomy: Descriptive and Surgical</u>. 15th Edition. New York: Barnes & Nobles Books, 1995.

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(3) Krasner, Diane, Ed. <u>Chronic Wound Care: A Clinical Source Book for Healthcare Professionals</u>. 2nd Ed. Pennsylvania: Health Management Publications, 1997.

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(5) Ulrich, Karl T., and Eppinger, Steven D. <u>Product Design and Development</u>. New York: McGraw-Hill, 1995.