34th Annual International Conference of the IEEE EMBS
San Diego, California USA, 28 August - 1 September, 2012

# A 3D Assessment Tool for Accurate Volume Measurement for Monitoring the Evolution of Cutaneous Leishmaniasis Wounds*

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*Abstract*— **Clinical assessment and outcome metrics are serious weaknesses identified on the systematic reviews of cutaneous Leishmaniasis wounds. Methods with high accuracy and low-variability are required to standarize study outcomes in clinical trials. This work presents a precise, complete and noncontact 3D assessment tool for monitoring the evolution of cutaneous *Leishmaniasis* (CL) wounds based on a 3D laser scanner and computer vision algorithms. A 3D mesh of the wound is obtained by a commercial 3D laser scanner. Then, a semi-automatic segmentation using active contours is performed to separate the ulcer from the healthy skin. Finally, metrics of volume, area, perimeter and depth are obtained from the mesh. Traditional manual 3D and 3D measurements are obtained as a gold standard. Experiments applied to phantoms and real CL wounds suggest that the proposed 3D assessment tool provides higher accuracy (error <2%) and precision rates (error <4%) than conventional manual methods (precision error < 35%). This 3D assessment tool provides high accuracy metrics which deserve more formal prospective study.**

## I. Introduction

Leishmaniasis infection is a parasitic disease which continues to be a major health problem affecting 12 millions of people worldwide [1]. Cutaneous leishmaniasis (CL) is one of the most common forms of leishmaniasis after visceral clinical manifestations and is endemic in the jungle and Andean regions of South America where more than 14,000 cases are reported annually [1].

CL infection produces ulcerative wounds that may persist for months or years resulting in disfiguring scars that produce psychological consequences and the loss of employment opportunities [1,2]. A typical CL lesion consists of an ulcer with a central depression and raised, indurated and defined borders [1,2]. The mainstay of treatment of CL is based on pentavalent antimonial salts which have regular success rates (60% - 80%) and produce secondary adverse effects in the patient [1]. Therefore, new treatments are researched to speed up the healing process and, at the same time, decrease the dimensions of the wound [1].

Clinical improvement of CL wounds is defined in terms of the reduction of lesion size and inflammation [3]. Measurement of area is maybe the only quantitative indicator of improvement/worsening because other clinical criteria like erythema or induration depend subjectively on the experience of the clinician. This metric is obtained by performing manual measurements with conventional metric tape, caliper or traces over a transparent sheet placed on top of the wound. The procedure suffers from high variability, needs direct contact with the wound and only gives limited 2D information of CL wound's evolution as is deduced from [4,5].

According to medical researches of the *Instituto de Medicina Tropical Alexander von Humboldt* (IMTAvH – Perú), it is hypothesized that volume metrics could give more relevant information about clinical improvement of CL wounds than 2D metrics. Therefore, accurate and low variability wound assessment tools are necessary to estimate volume metrics in clinical trials.

In this paper, a complete 3D wound assessment tool is developed. This tool is able to obtain metrics of volume, superficial area, border perimeter and depth of CL wounds. Section II explains the implementation of the 3D tool, including details of the image processing algorithms, considerations taken while measuring the metrics and the experiments to assess accuracy and precision of the 3D system. Results are interpreted in Section III and, finally, conclusions are given in Section IV. This article is based on the thesis work presented in [6].

## II. Methodology

### A. 3D wound models acquisition and definition of metrics

Three dimensional meshes of the CL wounds were obtained with the commercial scanner Next Engine Laser Scanner HD (NextEngine Inc., California, USA) with a resolution of 10k DPI[2] and 0.13mm of accuracy. The acquisition time was around 67s per wound. During the scanning procedure, the wound was located 16.51cm in front of the scanner. Shiny surfaces were removed. The data was exported using the .XYZ file format which contains information of the point coordinates of the 3D model [7].

According to [1,2], a typical CL wound has raised and defined borders. Fig. 1.a shows a CL wound with its cross section indicating the border, healthy skin around the ulcer and the hypothetical healthy skin over the ulceration. Since any volumetric metric needs a reference, we propose to

*Research supported by Interdisciplinary Project DGI 2010-0105 and Supporting the Development of Thesis Program (PADET-2010) from the Pontificia Universidad Católica del Perú.

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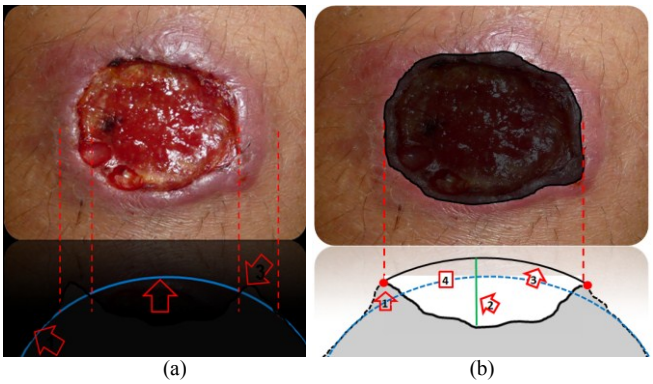


(a) (b)

Figure 1. Definition of metrics in a cutaneous leishmaniasis (CL) wound. In (a) a cross section of the wound is presented where (1) is the healthy skin, (2) is a fictosius reconstruction of heathy skin and (3) represents the border of the wound. In (b) metrics are presented: (1) border, (2) depth, (3) surface area of the recostructed healthy skin and (4) the volume encapsulated by the erosion and covering surface.

calculate a covering surface (with its shape similar to the healthy skin) which may encapsulate the erosion around its border. This idea was previously used in [8,9] and helps standardizing the measurement procedure. This is the first step to calculate the metrics of interest from the wound as presented in Fig 1.b: volume, area of surface, perimeter and depth.

### B. 3D preprocessing step

The 3D models obtained from the laser scanner consist of a cloud of points irregularly distributed and corrupted with distortion and holes due the presence of irregularities in the skin like hairs and brightness of the perspiration in the ulcer. Then, a Taubin λ|μ filtering procedure (λ=0.5, μ=-0.53, 10 iterations) is applied to the point cloud to remove high frequency distortions while preserving salient shape features and keeping the surface in the same position [10]. Finally, a regularization procedure based in bi-cubic interpolation is applied to the new filtered 3D point cloud to obtain a regular 3D grid with 0.3mm of separation between points.

### C. Segmentation

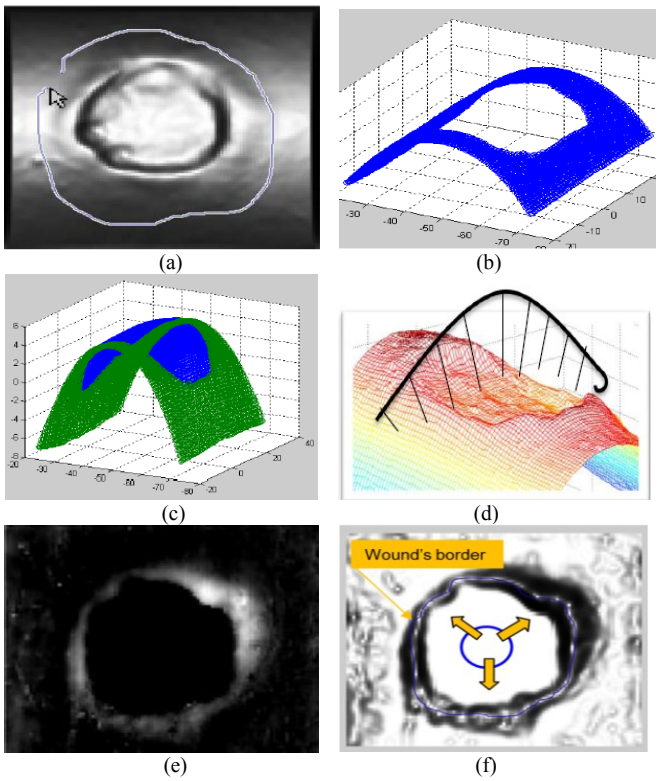
In this step, the border of the wound is found in order to separate the ulcer from the healthy skin as was previously explained.

*Manual segmentation:* First a raw manual segmentation is performed by a human to obtain shape information of the portion of the 3D point cloud considered as healthy skin. A range image which represents the distance between the 3D model and a plane reference is obtained. The gradient of the range image is used as a guide to trace a continuous line around the ulcer trying to separate ulceration and healthy skin as is presented in Fig. 2.a. Here, it is easy to distinguish between both regions. The result of this step is presented in Figure 2.b. Then, spline interpolation is applied to the previous segmentation to estimate the covering surface which tries to emulate the healthy skin over the ulcer (see Fig. 2.c).

*2D projection procedure:* A 2D projection of the 3D point cloud over the estimated surface is obtained and show in Fig. 2.e. This procedure is performed by mapping the distances between each point of the 3D model and the curved surface in a 2D space as is shown in Fig. 2.d. After thresholding, this projection (Fig. 2.e) represents the border of the wound. This is possible because the border of a CL wound is located above the healthy skin around the ulceration as shown in Fig. 1.

*Border detection:* A Geodesic Active Contour (GAC) [11] is utilized to find the border in the 2D projection shown in Fig. 2.f. The contour is initialized with a circle in the interior of the ulceration area represented in the 2D projection and its parameters were adjusted subjectively in order to converge in the peak area of the border. For the majority of the cases, the GAC parameters c=1 and Δt=1 allowed convergence and good results as it is shown in Fig. 2.f (gradient of the 2D projection) where the active contour converges in the white contour of the 2D projection which represents the border of the CL wound. Finally the border is scattered in Fig. 3.c.

*Segmentation procedure:* Once the border in found, all the 3D points that falls into the border are defined as ulcerative and are separated from the rest of the 3D model.




(a) (b) (c) (d) (e) (f)

Figure 2. Segmentation procedure. In (a) manual segmentation to obtain information of healthy skin in the 3D model is performed. In (b) the result of segmentation procedure of (a) is shown. In (c) covering surface is estimated via spline interpolation with information of (b). In (d) a 2D projection of the ulcer to the curved surface from (c) is performed. The result of the previous step is shown in (e) which represents the border of the CL wound. Finally, (f) represents the gradient map of (e) in which the active contour algorithm is applied.

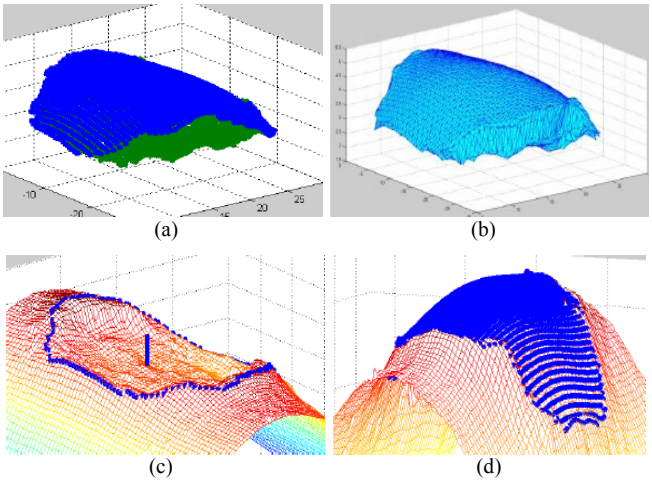


Figure 3. Estimation of metrics. (a) shows the segmented erosion of the wound encapsulated with the covering surface obtained by spline interpolation. In (b) a tetrahedron mesh is applied to find the wound's volume. In (c) the perimeter and depht are found. Finally, (d) shows the area of the surface covering the wound.

### D. Estimation of metrics

Once the ulcer of the wound is isolated, it is encapsulated with the covering surface through the border (see Fig. 3.a). Then, a 3D Delaunay tessellation is applied in order to obtain a tetrahedron mesh in the interior of the point cloud formed by the union of the covering surface and the ulcer. The volume of the wound is calculated as the sum of all the tetrahedron volumes (see Fig. 3.b).

Estimation of the perimeter is performed by the simple sum of the distances between each point which defines the 3D border found in the segmentation step. The surface area (see Fig. 3.d) consists in the sum of every triangle area of the covering surface constrained by the border of the wound. Finally, the depth is defined as the major distance between each point in the ulcerative region and the covering surface. All the metrics are shown in the Fig. 3.

### E. Experimental design

*First experiment – to test accuracy and precision of the system using a phantom:* In order to calculate the accuracy and precision error, two phantoms of different sizes of an ideal CL wound were manufactured. The phantoms are made of Ertalyte material with 0.5mm of manufacturing precision and were designed based on basic geometrical primitives like cylinders and spheres. Ten measurements of volume, surface area, border perimeter and depth were executed in each phantom using the proposed 3D system.

*Second experiment – to test precision (variability) of the system and compare to a traditional method using real wounds:* 3 observers were trained by an expert physician to:

- Operate the 3D laser scanner to obtain 3D meshes of CL wounds.
- Measure the CL ulcer volume using gel injection. This method introduces gel in the ulceration using a syringe until the gel has filled the erosion [5].

Each observer performed both types of measurements for three times on each CL wound per day; 8 measurements within the 21 days of patient treatment were taken. Five patients consented to participate in the study. All were followed up for 21 days of antimonial treatment. The study of variability of manual measurements in CL wounds in patients was approved by the Cayetano Heredia Hospital Ethics Committee. 40 measurements were taken in total.

*Third experiment – to assess the evolution of the volume of the wound in patients and compare to traditional methods:* Rate of change in the metrics is evaluated. The correlation between metrics obtained by the 3D system and the conventional method was achieved by means of Pearson Correlation (r) and intra-class correlation coefficient (ICC).

## III. Results

### A. First experiment: to test accuracy and precision of the system using a phantom

Relative accuracy and precision error was calculated in 10 measurements of two phantoms with different sizes. The results are shown in Table I. The achieved accuracy error is less than 1.2% and the precision error is less than 2% for all the metrics in both phantoms.

### B. Second experiment – to test precision (variability) of the 3D system and traditional method using real wounds

Inter-variability and intra-variability errors were calculated in both methods (gel injection and 3D system) for 40 wounds. The results (see Table II) show a maximum inter/intra-variability error less than 4% using the 3D system method proposed in this research, as opposed to a maximum of 34.4% using the conventional gel injection method.

### C. Third experiment – to assess the evolution of the volume of the wound in patient and compare to traditional methods

Volume evolution is expressed in terms of percent reduction with respect to the initial volume of the CL wound during the treatment. Fig. 4 shows the evolution of volume in one patient. The volume decreases three times faster than the surface area. Albeit the limited data, these results suggest that 2D metrics are not enough to describe clinical improvement in CL wounds due the reduction in size is more pronounced in depth or volume rather than in surface area.

Intra-class Correlation Coefficient (ICC) applied between the two methods (gel injection and 3D system) provides information of similitude in volume measurements while Pearson Correlation (r) provides information of similitude in the tendency of volume evolution. The results for four patients are shown in Table III. High percentages in Pearson Correlation indicate that both methods have the same tendency, while ICC values suggest that numeric measures are not similar due to the high variability in the conventional method.

TABLE I. FIGURE 4. ACCURACY AND PRECISION ERROR CALCULATION OF THE 3D SYSTEM DONE IN TWO PHANTOMS OF A CUTANEOUS LEISHMANIASIS WOUND. THE NUMBER OF MEASURES DONE IS 10 PER PHANTOM (P).

| P | Metrics | Assessment of the 3D system | | | | |
|---|---|---|---|---|---|---|
| | | *Real metric* | *Mean* | *Standard deviation* | *Precision error* | *Accuracy error* |
| 1 | Volume ($mm^3$) | *1900* | *1922.37* | *37.94* | ***1.97%*** | ***1.18%*** |
| | Area ($mm^2$) | 710 | 711.08 | 2.81 | **0.40%** | **0.15%** |
| | Perimeter (mm) | 101.3 | 101.15 | 0.134 | **0.13%** | **0.14%** |
| | Depht (mm) | 5.8 | 5.74 | 0.107 | **1.87%** | **0.92%** |
| 2 | Volume ($mm^3$) | *900* | *905.36* | *5.416* | ***0.60%*** | ***0.61%*** |
| | Area ($mm^2$) | 350 | 347.44 | 1.155 | **0.33%** | **0.73%** |
| | Perimeter (mm) | 70 | 70.40 | 0.169 | **0.24%** | **0.57%** |
| | Depht (mm) | 4.5 | 4.552 | 0.029 | **0.64%** | **1.16%** |

TABLE II. INTER AND INTRA VARIABILITY TEST OF THE 3D SYSTEM AND THE CONVENTIONAL GEL INJECTION METHOD DONE IN VOLUME MEASUREMENT. THE NUMBER OF MEASURES DONE IS 40 PER METHOD.

| Metrics | Variability of volume in CL wounds | | | |
|---|---|---|---|---|
| | ***Maximum Inter*** | ***Minimum Inter*** | ***Maximum Intra*** | ***Minimum Intra*** |
| Gel injection | *34.4%* | *3.84%* | *20.4%* | *1.60%* |
| 3D system | *3.49%* | *2.1%* | *2.79%* | *1.37%* |

TABLE III. ICC AND PEARSON CORRELATION VALUES DEVELOPED BETWEEN VOLUME METRICS MEASURED WITH 3D SYSTEM AND CONVENTIONAL GEL INJECTION METHOD DURING THE PATIENT TREATMENT.

| | ICC and Pearson Correlation (r) test | | | | |
|---|---|---|---|---|---|
| | ***Patient 1*** | ***Patient 2*** | ***Patient 3*** | ***Patient 4*** | ***Patient 5*** |
| N° of measures | *4* | *4* | *5* | *5* | *5* |
| r | *0.87* | *0.93* | *0.96* | *0.79* | *0.89* |
| ICC | *0.66* | *0.90* | *0.65* | *0.72* | *0.69* |

Even though these initial results are promising, a more careful study is needed to test the usage of this algorithm for the evaluation of CL wounds. Future work will also focus on reducing human intervention. Color and range images can be used to perform an automatic separation between healthy skin and the wound. Parameter selection of the GAC is still a critical point which needs a deeper analysis and validation. Subjective selection of these parameters could introduce a high variability on the measurements and failure to adapt these parameters to the particular CL image could end in an erroneous segmentation.

## IV. CONCLUSION

The present 3D system tool provides higher accuracy (error <2%) and lower variability (error <4%) in measuring the volume of a CL wound compared to the traditional gel injection method (variability error <35%). Other metrics have also been estimated (border perimeter, surface area and depth) with high accuracy and precision without producing direct contact with the wound. In addition, volume change might be a better indicator to assess the reduction of size and improvement of CL wounds than traditional area based metrics.

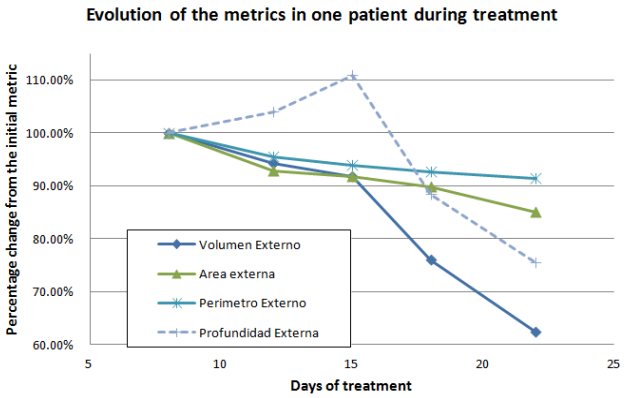



Figure 4. Evolution of CL wound metrics of one patient during the treatment measured with the 3D system. Changes in volume decrease three times faster than area metrics.

## ACKNOWLEDGMENT

The authors would like to thank the support of the Interdisciplinary Project DGI 2010-0105 and the Undergraduate Thesis Development Grant (PADET-2010) from the Pontificia Universidad Católica del Perú, and Juvenal Ormachea and Leslie Casas from the Laboratory of Medical Image Research of the Pontificia Universidad Católica del Perú for their continuous support.

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