Wound size measurement of lower extremity ulcers using segmentation algorithms

Arash Dadkhah, Xing Pang, Elizabeth Solis, Ruogu Fang, Anuradha Godavarty
Optical Imaging Laboratory, Dept. of Biomedical Engineering, Florida International University, 10555 West Flagler Street, Miami, Florida 33174
School of Computing and Information Sciences, Florida International University, Miami, FL 33199

ABSTRACT

Lower extremity ulcers are one of the most common complications that not only affect many people around the world but also have huge impact on economy since a large amount of resources are spent for treatment and prevention of the diseases. Clinical studies have shown that reduction in the wound size of 40% within 4 weeks is an acceptable progress in the healing process. Quantification of the wound size plays a crucial role in assessing the extent of healing and determining the treatment process. To date, wound healing is visually inspected and the wound size is measured from surface images. The extent of wound healing internally may vary from the surface. A near-infrared (NIR) optical imaging approach has been developed for non-contact imaging of wounds internally and differentiating healing from non-healing wounds. Herein, quantitative wound size measurements from NIR and white light images are estimated using a graph cuts and region growing image segmentation algorithms. The extent of the wound healing from NIR imaging of lower extremity ulcers in diabetic subjects are quantified and compared across NIR and white light images. NIR imaging and wound size measurements can play a significant role in potentially predicting the extent of internal healing, thus allowing better treatment plans when implemented for periodic imaging in future.

Keywords: Lower extremity ulcers, near-infrared, optical imaging, image segmentation, region growing algorithm, graph cuts algorithm, hand-held optical scanner, wound size.

INTRODUCTION

Lower extremity ulcers are one of the most common complications which have increased over the past few years. In the United States, at least 4.6 million work days are lost and over $1 billion is spent every year only for chronic venous ulcers. During the long term wound healing process, an objective and quantitative determination of the wound healing rate plays a crucial role in assessing the efficacy of treatments. To date, lower extremity ulcers are visually inspected by clinicians as a gold-standard approach, in order to determine if the ulcers are healing or not. Herein, a near-infrared imaging technique is able to provide physiological (or functional) information of the wound for more effective treatment plan (in the future). In this respect, developing and applying an objective and quantitative approach to image wounds during their periodic treatment, would benefit the clinicians to plan their treatment process effectively.

At the Optical Imaging Laboratory (OIL), a near-infrared optical scanner (NIROS) has been developed for non-contact sub-surface imaging of wounds. Previous studies on diabetic and venous ulcers revealed that the NIR optical contrast can differentiate healing from non-healing wounds. Herein, quantification of the wound size from NIR and white light images is studied. Quantitative wound size measurements from NIR images can be performed using various image segmentation approaches, including graph cuts and region growing algorithms. However, NIR images are contaminated with background noise (from glare effect and/or non-uniform source light distribution). Therefore, it is required to consider a noise removal method to remove or at least reduce background noise prior to applying the segmentation methods.

In this study, graph cuts and region growing methods have been applied to NIR images for wound demarcation. A two dimensional Gaussian model has been used to remove the background noise from NIR images prior to applying wound segmentation. The length and width of the wound from white light images and the segmented NIR images (using graph cuts and region growing methods) have been quantified to compare the wound size measurements in lower extremity ulcers.
2. METHODOLOGY

2.1 Instrumentation

A near-infrared optical scanner (NIROS) (see Figure 1) is used for non-contact sub-surface imaging of wounds. The imager employs LED light sources (different wavelengths between 650-900 nm) to illuminate the tissue surface during imaging studies. An NIR sensitive camera mounted on an articulating arm is used as the detector. Two LEDs of different wavelengths (710-nm and 830-nm) are driven by an LED driver and synchronized with the camera during the data acquisition process. The device acquires diffuse reflected NIR images and evaluates the optical contrast of the wound with respect to its peripheries. A custom-developed Matlab based imaging acquisition and analysis software has been modified in order to automate NIR data acquisition and demonstrate optical contrast for two different wavelengths. Apart from NIR images obtained using NIROS, an endoscopic camera is employed for digital white light image acquisition from the wound.

Figure 1. (a) Near-infrared optical scanner (NIROS) set-up in the clinic: (a) NIR-sensitivity detector and LED source system, (b) LED driver, (c) articulating arm, (d) Laptop

2.2 Subjects & Recruitment:

Clinical non-contact optical imaging studies were carried out on diabetic patients with lower extremity ulcers imaged at two clinical sites, Podiatry Care Partners Clinic, Doral, Florida (with Dr. Francisco Perez-Clavijo as podiatrist) and Wigley Foot & Ankle Clinic, Miami (with Dr. Stephen Wigley as podiatrist). All requirements for the ethical conduct of human subject’s research, including HIPAA forms and written consent forms were obtained from all the subjects using Florida International University’s IRB approved study. A total of 9 healing/non-healing lower extremity ulcers (8 venous leg ulcers and 1 diabetic foot ulcers) from diabetic patients between the ages of 56-75 years were recruited in this study.
2.3 Data acquisition:
For each of the subjects, continuous-wave non-contact optical imaging was performed under rest conditions. Before starting the imaging process, the wound dressing was removed and the wound area cleaned and debrided by the surgeon. The imaging area was chosen such that the wound region and its surrounding area are within the field of view.

2.4 Removal of background noise
Illumination using a non-diffused or collimated LED light source led to non-uniform light source distribution. This non-uniform light source led to background noise in the detected NIR signal. The background noise of NIR image may affect the segmentation of the wound regions from the normal background. The background noise from the diffuse reflected light was non-uniform. During imaging studies, it was observed that the light distribution pattern was consistently similar to a Gaussian distribution. This Gaussian distribution was individually determined from calibration studies involving a homogeneous white diffusing sheet after imaging each of the wound site. The diffuse reflected NIR signals were corrected by this Gaussian distribution. The differences in the reflectivity of the diffuser sheet and that of a normal tissue was estimated from refractive indices of the surfaces and accounted for when removing the background noise. As a result, the source distribution pattern was determined and accounted for during data processing via a two-dimensional Gaussian model, such that the background noise was removed or at least reduced. Figure 2 displays the effect of background noise removal to NIR image using Gaussian model.

![Figure 2. Images of two venous leg ulcers (from 61-year old subject with bilateral venous leg), showing (a,d) white light image, (b,e) raw NIR image (before noise removal) and (c,f) NIR image after noise removal, of the left and right side of the leg, respectively.](image-url)
2.5 Graph cut algorithm

Graph cuts algorithm is a very useful tool employed to any type of image for accurate segmentation. This method guarantees global solution since it is independent of the chosen initial center point when applying the algorithm. Graph cuts method for image segmentation has the underlying common theme of formulating the process as a weighted graph with each vertex corresponding to an image pixel or region and edges corresponding to similarity/dissimilarity between two corresponding pixels/regions. The graph cuts algorithm exploits the important fact that pixels which are close together have similar gray values. Segmentation by graph cuts after removing the background noise revealed the wound boundaries based on tissue oxygenation. In this study, the algorithm was applied to the NIR images before and after the background noise removal. Upon applying graph cuts, the wound region was segmented from the normal skin based on the dissimilarity of gray values between the wound and its normal tissue. Following this, length and width of the wound were quantified in order to compare with the wound size obtained from white light images, and NIR images segmented by region growing method (described in the section below).

2.6 Region growing algorithm

Region growing algorithm is a region-based or pixel-based method for image segmentation. In this pixel-based technique, initial seed points are manually selected by user. The difference between the intensity value of a pixel and mean intensity value of the region (already specified by the user) is computed to determine the similarity level between the neighboring pixels and the new pixel called maximum intensity distance. The smallest pixel value in terms of the variation is then picked and assigned to the neighboring region. This process continues until the difference between mean intensity value of neighboring pixels and new pixel becomes greater than a specific threshold. Accordingly, region growing algorithm segments the region of interest by specifying the region directly, while other segmentation methods, such as thresholding, determine the region by searching for the boundaries between regions in terms of variation in gray levels or color properties. In the current study, only one or two seed points were selected to specify the region to start growing. The two parameters, seed points and maximum intensity distance, play key role in our method to precisely segment the wound from the normal skin. Maximum intensity distance is basically a parameter to specify intensity difference between new pixel and region’s mean. Thus, the variation is considered to define threshold for binary segmentation. In our case, seed points were picked from the wound region and the algorithm begins growing from the initial seed points until the wound is segmented from the normal skin. Similar to graph cuts method, region growing method was also applied to the NIR images after noise removal. Furthermore, the length and width of the wound were quantitatively measured to observe the difference between the results obtained from the white light and the segmented NIR image (using both the image segmentation methods).

3. RESULTS AND DISCUSSION

NIR wound segmentation was carried out on multiple lower extremity foot ulcers. Figure 3 demonstrates the wound demarcation using graph cuts and region growing methods before and after background noise removal. The results revealed that removing the background noise effectively demarcates the wound closer to its visual wound boundaries and not randomly (when background noise was present). After the demarcation, the length and width of each wound was quantified to estimate the wound area and compare the wound size from white light image with the ones obtained from the two image segmentation methods. Figure 4 displays two example cases of non-healing venous leg ulcers from the same subject, where the white light, NIR and segmented images are shown using graph cuts and region growing methods, respectively. In wound 1, the length and width were visually measured from white light image as shown in Figure 4(a). While, in Figures 4(b) and 4(c), graph cuts and region algorithm methods were respectively used to specify the boundary of the wound in terms of gray level similarity between the close pixels to quantify the length and width of the wound from segmented NIR image. Similar procedure for employed for wound 2 as well, as shown in Figures 4(d), (e), and (f). Upon applying the segmentation methods, the shape of the wound demarcated from NIR images closely matches the white light images, although they do not perfectly overlap. Moreover, the wound sizes obtained from segmented NIR images using the two image segmentation methods were different from the white light image. In some cases, it was observed that the demarcated wound region from NIR images using the segmentation methods was larger than the actual wound visually obtained from the white light image. This possibly implies that the NIR images (obtained from sub-surface of the wounds) are revealing that the regions of the wound (healing or non-healing) are greater internally than that visible from the surface, thus causing a greater region demarcated from NIR images. Alternately, the large area can be an artifact from subtracting a flat two-dimensional Gaussian distribution (calibration factor) from a curved leg region, without accounting for the curvature of the leg. Our ongoing effort is to determine the extent of
impact from the curvature of the tissue on wound size, and develop approaches to account for this curvature during data analyses. Additionally, work is carried out to co-register the segmented NIR images onto the white light images for a better comparison of the segmented regions and compare the surface and sub-surface wound healing (or non-healing) nature of the wound. This would be followed by determining the exact area of healing and non-healing within this demarcated wound.

Figure 3. Images of a non-healing venous leg ulcer from a 61-year old diabetic male, showing (a) white light image, (b) raw NIR image, (c) Segmented NIR image before noise removal (by graph cuts method), (d) Segmented NIR image before noise removal (by region growing method), (e) NIR image after noise removal, (f) Segmented NIR image after noise removal (by graph cuts method) and (g) Segmented NIR image after noise removal (by region growing method).

Figure 4. Images of venous leg ulcers, labeled as wound#1 and wound#2 (bilateral leg venous ulcer, male, 61 years old), showing (a,d) white light image (b,e) Segmented NIR image (by graph cuts method) (c,f) Segmented NIR image (by region growing method).
4. CONCLUSIONS
A near-infrared optical scanner (NIROS) developed in our Optical Imaging Laboratory was used to image lower extremity ulcers by non-contact imaging. Since the goal of the study is to demarcate the wound boundary using image segmentation methods, the two image segmentation method, graph cuts and region growing, were employed and applied to the NIR images for wound’s boundary demarcation before and after removing the background noise. After applying the two methods, the wound size was also quantitatively measured in length and width from the white light and NIR images and the results were compared. Since the larger region was demarcated from NIR image using the segmentation methods compared to the white large image, in some cases, there is a possibility that the sub-surface wound (from NIR image) are different in size than the surface wounds. Future work involves coregistration of these NIR images onto white light images in order to compare the wound size obtained using the two image segmentation methods and better understand internal versus surface wound sizes.

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6. REFERENCES