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Computerized segmentation and measurement of chronic wound images

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ABSTRACT

An estimated 6.5 million patients in the United States are affected by chronic wounds, with more than US $25 billion and countless hours spent annually for all aspects of chronic wound care. There is a need for an intelligent software tool to analyze wound images, characterize wound tissue composition, measure wound size, and monitor changes in wound in between visits. Performed manually, this process is very time-consuming and subject to intra- and inter-reader variability. In this work, our objective is to develop methods to segment, measure and characterize clinically presented chronic wounds from photographic images. The first step of our method is to generate a Red-Yellow-Black-White (RYKW) probability map, which then guides the segmentation process using either optimal thresholding or region growing. The red, yellow and black probability maps are designed to handle the granulation, slough and eschar tissues, respectively; while the white probability map is to detect the white label card for measurement calibration purposes. The innovative aspects of this work include defining a four-dimensional probability map specific to wound characteristics, a computationally efficient method to segment wound images utilizing the probability map, and auto-calibration of wound measurements using the content of the image. These methods were applied to 80 wound images, captured in a clinical setting at the Ohio State University Comprehensive Wound Center, with the ground truth independently generated by the consensus of at least two clinicians. While the mean inter-reader agreement between the readers varied between 67.4% and 84.3%, the computer achieved an average accuracy of 75.1%.

1. Introduction

Computer-aided measurement of the size and characteristics of chronic wounds is a novel approach to standardizing the accuracy of chronic wound assessment. A chronic wound, as defined by Centers for Medicare and Medicaid Services, is a wound that has not healed in 30 days. An estimated 6.5 million patients in the United States are affected by chronic wounds, and it is claimed that an excess of US$25 billion is spent annually on treatment of chronic wounds. The burden is growing rapidly due to increasing health care costs, an aging population and a sharp rise in the incidence of diabetes and obesity worldwide [1]. As such, there is a need for a timely and accurate method to document the size and evolving nature of chronic wounds in both the inpatient and outpatient settings. Such an application can potentially reduce clinicians' workload considerably; make the treatment and care more consistent and accurate; increase the quality of documentation in the medical record and enable clinicians to achieve quality benchmarks for wound care as determined by the Center for Medicare Services.

The current state of the art approach in measuring wound size using digital images, known as digital planimetry, requires the clinician to identify wound borders and wound tissue type within the image. This is a time-intensive process and is a barrier to achieving clinical quality benchmarks. Our group is developing image analysis tools that will enable the computer to perform this analysis rather than requiring user input. Developing an accurate method of measuring wound size and tissue characteristics serially over time will yield clinically meaningful information in relation to

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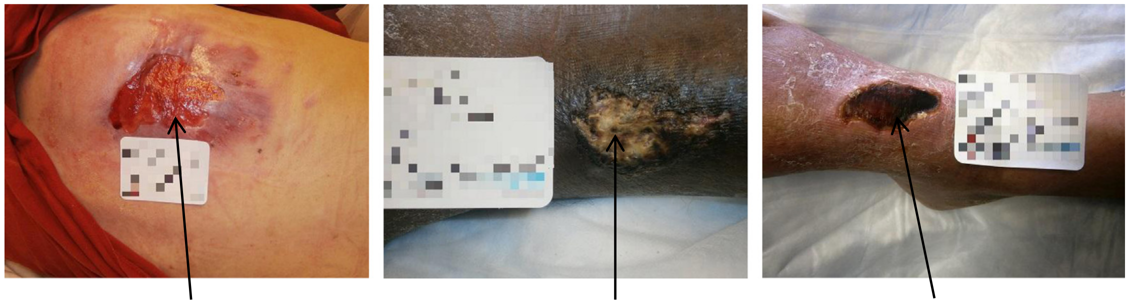

Fig. 1. Most commonly seen tissues in wounds: granulation, slough and eschar.

the progression or improvement of the wound. The focus of the work reported in this paper is the segmentation of the wounds.

A wound exhibits a complex structure and may contain many types of tissue such as granulation, slough, eschar, epithelialization, bone, tendon and blood vessels, each with different color and texture characteristics. In this paper, we proposed a novel probability map that measures the likelihood of wound pixels belonging to granulation, slough or eschar (see Fig. 1), which can then be segmented using any standard segmentation techniques. In this work, we focus on the granulation, slough and eschar tissues as these are the three most commonly seen tissues in wounds. A preliminary version of this work has been reported in [2]. This paper extended the previous work significantly with an extensive literature review, more elaborate explanation of the proposed method, employing two segmentation techniques to show that the probability map is adaptable to many different techniques, comparison with other existing method, comprehensive analyses on inter-reader variability between clinicians, a much bigger dataset used for performance evaluation (which was divided into three sets for analysis purpose), as well as more elaborate discussions on the results.

The paper is organized as follows: Section 2 presents the review of the literature on wound image analysis. In Section 3, we present our proposed probability map approach to wound segmentation and integrate it with two different segmentation techniques. Section 4 and 5 discusses the experimental setup, results and discussion. Finally, Section 6 concludes the paper and describes future work.

2. Literature review

Although wound segmentation from photographic images has been the subject of several studies, most of the work in this area deals with images that are either acquired under controlled imaging conditions [3–4], confined to wound region only [4–7], or narrowed to specific types of wounds [7–9]. Because these restrictions are mostly impractical for clinical conditions, there is a need to develop image segmentation methods that will work with images acquired in regular clinical conditions.

Table 1 summarizes current works in wound segmentation and monitoring as well as existing software tools. Wannous et al. [3] compared the mean shift, JSEG and CSC techniques in segmenting 25 wound images, before extracting color and textural features to classify the tissues into granulation, slough and necrosis using an SVM classifier. The wound images were taken with respect to a specific protocol integrating several points of views for each single wound, which includes using a ring flash with specific control and placing a calibrated Macbeth color checker pattern near the wounds. They reported that both segmentation and classification work better on granulation than slough and necrosis. Hettiarachchi et al. [4] attempted wound segmentation and measurement in a mobile setting. The segmentation is based on active contour models which identifies the wound border irrespective of coloration and shape. The active contour process was modified by changing the energy calculation to minimize points sticking together as well as including pre-processing techniques to reduce errors from artifacts and lighting conditions. Although the accuracy was reported to be 90%, the method is rather sensitive to camera distance, angle and lighting conditions.

In the work by Veredas et al. [5], a hybrid approach based on neural networks and Bayesian classifiers is proposed in the design of a computational system for tissue identification and labeling in wound images. Mean shift and region-growing strategy are implemented for region segmentation. The neural network and Bayesian classifiers are then used to categorize the tissue based on color and texture features extracted from the segmented regions, with 78.7% sensitivity, 94.7% specificity and 91.5% accuracy reported. Hani et al. [6] presented an approach based on utilizing hemoglobin content in chronic ulcers as an image marker to detect the growth of granulation tissue. Independent Component Analysis is employed to extract grey level hemoglobin images from Red–Green–Blue (RGB) color images of chronic ulcers. Data clustering techniques are then implemented to classify and segment detected regions of granulation tissue from the extracted hemoglobin images. 88.2% sensitivity and 98.8% specificity were reported on a database of 30 images.

Perez et al. [7] proposed a method for the segmentation and analysis of leg ulcer tissues in color images. The segmentation is obtained through analysis of the red, green, blue, saturation and intensity channels of the image. The algorithm, however, requires the user to provide samples of the wound and the background before the segmentation can be carried out. Wantanajittikul et al. [8] employs the Cr-transformation, Luv-transformation and fuzzy c-means clustering technique to separate the burn wound area from healthy skin before applying mathematical morphology to reduce segmentation errors. To identify the degree of the burns, h-transformation and texture analysis are used to extract feature vectors for SVM classification. Positive predictive value and sensitivity between 72.0% and 98.0% were reported in segmenting burn areas in five images, with 75.0% classification accuracy.

Song and Sacan [9] proposed a system capable of automatic image segmentation and wound region identification. Several commonly used segmentation methods (k-means clustering, edge detection, thresholding, and region growing) are utilized to obtain a collection of candidate wound regions. Multi-Layer Perceptron (MLP) and Radial Basis Function (RBF) are then applied with supervised learning in the prediction procedure for the wound identification. Experiments on 92 images from 14 patients (78 training, 14 testing) showed that both MLP and RBF have decent efficiency, with their own advantages and disadvantages. Kolesnik and Fexa [10–12] used color and textural features from 3-D color histogram, local binary pattern and local contrast variation with the support vector machine (SVM) classifier to segment 23 wound images based on 50 manually segmented training images. The SVM generated wound boundary is further refined using