Image-Based Analysis of Human Tissue Regeneration During Therapy Based on Photobiostimulation and Natural Latex Biomembranes

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Abstract. Diabetes often results in severe ulceration of lower limbs' tissues, a condition described as *diabetic foot*. Recent research has shown that therapy combining photobiostimulation and the use of natural latex biomembranes can significantly improve tissue regeneration and promote healing in otherwise difficult to treat diabetic foot wounds. We propose a method using image processing techniques to supervise wound healing during therapy using photobiostimulation and latex biomembranes. The proposed method analyzes visual aspects related to ulcer's inflammation and tissues regeneration. The algorithms, implemented in Python, are based on digital filters and post-processing techniques that extract the regions of interest (ROIs) and estimate the total ulcer area and tissues characteristics over the treatment sessions. The experimental results suggest that the method can be used to automatically monitor tissue regeneration during the treatment, which can in the future assist the treatment by providing automatic feedback.

Keywords: wound healing, diabetic foot, image processing, photobiostimulation, latex membranes

1 Introduction

Severe ulcerations, most commonly affecting the lower limbs, often result from Diabetes Mellitus (DM) and constitute one of the serious chronic conditions that impact DM patients' quality of life. These ulcerations characterize the so-called *diabetic foot* and have great socioeconomic impacts [1, 2]. On the individual level, it is responsible for several complications, including limitations in moving and performing work, and amputations.

Recent research has shown that, by combining photobiostimulation with the use of membranes made of natural latex, it is possible to significantly increase

the rate of success in healing the wounds associated to the diabetic foot [5, 6]. A project developed at the University of Brasília, called RAPHA®, explores these methods and resulted in a novel piece of equipment that has been investigated for the treatment of wounds, with impacting results [4–6]. The project compares several photobiostimulation protocols and details the procedures for producing and using the latex membranes.

The RAPHA® uses a light emitting diode (LED) and latex biomembranes in specific protocols, combining two techniques that had previously been used in isolation, with validated tissue regeneration and neoformation properties [3–7].

However, the performance evaluation of photobiostimulation and of the use of latex membranes, as a means to enhance diabetic foot wounds' treatment, is usually based on the clinical observation by trained health professionals. An automatic method for evaluating this performance could benefit both the patient, who would receive feedback on his condition and the research on the area, as it could provide objective metrics when comparing different protocols. We propose using digital images taken from diabetic foot, at different treatment stages, in order to evaluate the progress provided by photobiostimulation and the latex membranes. With the impact of digital image processing on science, researchers have sought methods to process and analyze biomedical images [8], both for treatment planning and evaluation. In particular, wound image processing seeks to assist health professionals with appropriate diagnoses and treatments, highlighting the importance of sound and well-established assessments [9].

In this context, we evaluate the use of images taken from the diabetic foot wounds in order to determine the possible correlation between extracted image characteristics and the current treatment stage. The idea is that, since the wound area changes as the treatment advances, our method can allow for the health professional to promote a more acute intervention, if needed, or to change the used protocols, depending on the parameters we extract from the images.

Therefore, our method focuses on estimating the reduction of wound size according to the applied protocol, the improvement rate, the skin appearance, and other aspects, which we supervise using ImageJ®, with scripts in Python.

2 Methods

The study is based on a double-blind randomized controlled trial approved by the local Ethics Committee (protocol 052/2012-2016 – CEP/SES/DF). The intervention uses latex biomembranes and red LED light ($\lambda = 636 \pm 20nm$) applied over diabetic foot ulcers. We performed the clinical research at the Regional Hospital of Ceilândia (HRC-DF) clinic, in Brasília, Brazil.

For evaluating the DM wounds, the research team registered the treatment using digital images taken on a weekly basis, using a Sony DSCH70 digital camera with a resolution of 16.1 megapixels.

The participant selected for the image analysis belongs to the experimental group and was treated on a daily basis using RAPHA® equipment.

We used ImageJ® version 1.51r, from the National Institute of Health, Bethesda, MD, USA, in order to process and analyze several morphological parameters in the sequence of images obtained from the participant.

In the first processing stage, we performed image filtering under Python 3.6, in order to emphasize and then automatically extract the wound's edges. The filters were based on color differentiation, by computing the Hue-Saturation-Luminance (HSL) representation of each image. We then applied a thresholding over the hue values, in order to separate the regions corresponding to inflamed areas; the threshold was empirically set beforehand, by varying the values from the minimum to the maximum hue, and registering the resulting images. Next, we used the ImageJ analyze/measure command, in order to estimate the perimeter of each wound. The entire areas surrounding the lesions were excluded.

3 Results

During the clinical trial, all participants experienced the plastic with the RAPHA® protocol. The patient selected for the study was No. 12, who obtained accelerated and effective healing when compared to patients submitted to other conventional methods of treatment.

Figure 1 shows the images we obtained by applying the filters described in Section 2 to the pictures taken from patient 12 at the beginning of the treatment, after 21 days, and at the end of the treatment. Note that the wound area is emphasized with respect to the surrounding tissue, in the patient's lower limb. In the filtered images, tones of red were proposed to represent different levels of wound inflammation. We can clearly observe a decrease of points with higher levels of inflammation, 21 days after the beginning the proposed protocol.

Figure 2 shows the original pictures taken from the patient. By comparing Figures 1 and 2, we observe that the proposed filters corrected highlighted the wound areas, and allowed us to differentiate the existing levels of inflammation.

Based on the extracted surfaces shown in Figure 1, the analyze/measure command in ImageJ allowed us to compute the corresponding wound areas, as shown in Table 1. Note the wound area reduction during the applied treatment.

Table 1. Measured lower limb wound areas for patient 12, during the phototherapy protocol associated with latex biomembranes. The areas were estimated using ImageJ® applied to the wound areas extracted by our proposed method.

Treatment day	Area (cm^2)
01	19.0
21	16.6
46	11.6

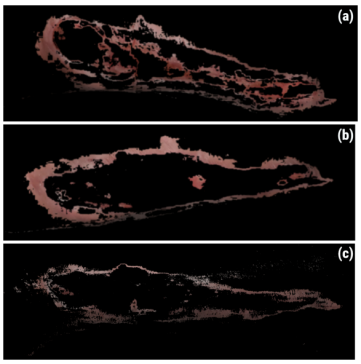

Fig. 1. Wound edges from the participant's lower limb, as extracted using the proposed image filters and using different tones of red to represent different levels of inflammation: (a) result when applying the filters to the image obtained in the first contact with the patient, as he started the phototherapy treatment associated with latex membrane; (b) result after 21 days, with a clear reduction of the affected area and a decrease in the total area with high level of inflammation; (c) the final result, with controlled inflammation and important healing effect.

Fig. 2. The original images taken from patient 12, at (a) the beginning of the treatment, (b) after 21 days, and (c) at the end of the treatment.

4 Conclusion

The healing of diabetic foot ulcers is the subject of great research aiming at efficient cure methods and good quality of the resulting tissue. In this context, the use of image processing techniques may provide objective metrics to evaluate the healing process and compare the efficiency of different treatment protocols.

In order to improve and guarantee the quality of image processing, simple and easy-to-apply methods are recommended so that healthcare professionals can perform them without requiring much time and effort. Patients may also directly benefit from automatic feedback regarding the ulcer evolution.

The developed and evaluated process facilitates the identification of the ulcer, showing the evolution of wound healing using the Rapha® protocol.

Conflict of Interest

The authors declare that they have no conflict of interest.

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