Enhance wound healing monitoring through a thermal imaging based smartphone app

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Abstract:

In this paper, we present a thermal imaging based app to augment traditional appearance based wound growth monitoring. Accurate diagnose and track of wound healing enables physicians to effectively assess, document, and individualize the treatment plan given to each wound patient. Currently, wounds are primarily examined by physicians through visual appearance and wound area. However, visual information alone cannot present a complete picture on a wound’s condition. In this paper, we use a smartphone attached thermal imager and evaluate its effectiveness on augmenting visual appearance based wound diagnosis. Instead of only monitoring wound temperature changes on a wound, our app presents physicians a comprehensive measurements including relative temperature, wound healing thermal index, and wound blood flow. Through the rat wound experiments and by monitoring the integrated thermal measurements over 3 weeks of time frame, our app is able to show the underlying healing process through the blood flow. The implied significance of our app design and experiment includes: (a) It is possible to use a low cost smartphone attached thermal imager for added value on wound assessment, tracking, and treatment; and (b) Thermal mobile app can be used for remote wound healing assessment for mobile health based solution.

Keyword list: wound healing monitoring, thermal imaging, smartphone app, wound index, blood flow.

1. Introduction

Every year, approximately 6 million Americans suffer from chronic wounds. The majority of these wounds are the result of diabetes, immobilization, or circulatory problems. Not only are non-healing wounds painful, but they are expensive to treat. There are approximately 140,000 patients hospitalized every year with wounds, with an average hospital stay of 20 to 30 days. The cost of wound care in the US is over $3 billion annually.

Physicians frequently find wounds frustrating to treat because the physiology of wound healing is complex and only partially understood. Visual appearance and geometric shape of a wound contain a wealth of information about its cause, severity, length of time, change of status, and prognosis for healing. Clinicians often use visual inspection or wound area measurement to evaluate the status of skin tissue. However, while epidermal color and shape variation is proven useful to help physicians assess healing status, to fully judge the effects of hyperemia, hematoma, local inflammation, secondary infection, and tissue necrosis, it is important to include other modalities. Researches on using ultrasound, Doppler, and thermal imaging were conducted for better wound understand. However, the practicality of using these modules are often lacking due to costs and complexity of the system.

In this paper, we present the performance evaluation on our smartphone based thermal imaging app. The thermal app is designed to reduce system cost yet improve the capabilities of wound healing diagnosis and monitoring. Our app tracks the relative temperature change of a wound, it can also compute the wound healing index to track the healing trend. In addition, the app can compute the blood flow rate of a wound and have the potential to generate similar 2D blood flow data similar to that from an expensive Doppler system.

2. Methods

We developed our app using the mobile camera operable thermal camera FLIR ONE from FLIR on Android OS. Since our app can capture 2D texture and thermal image at the same time, our app is able to automatically extract the wound region on a given thermal image. To assess wound conditions, the app will evaluate the following three wound parameters: relative temperature of the wound with respect to the surrounding skin, wound thermal index, and wound blood flow rate. The app can track these parameters over time for the healing status assessment.
Relative wound temperature: since the absolute wound temperature varies under different environment temperature and the food intake of a wound sufferer, it is more meaningful to measure the wound temperature relative to the normal skin temperature.

Thermal Index: The thermal index/wound inflammatory index (TI) was proposed by Bharara, et. al to evaluate wound healing process. The authors were able to demonstrate the effectiveness of healing through clinical wound studies. Thermal Index = $\frac{(\Delta T \cdot a)}{A}$, where $\Delta T$ is temperature difference between wound and mean body temperature, $a$ is area of the isotherm (highest or lowest temperature) in the wound area; $A$: area of the wound bed. It was shown that, a healing wound will have closer 0 thermal index value than a non-healing wound.

Blood Flow Rate: Since thermal dissipation was proven to be directly related to heat transfer and blood flow rate in wounds, thermal image can also be applied to obtain blood flow rate. It is proven that there is a definite relationship between the blood flow rate and heat or thermal temperature as $\frac{dVs}{dt} = \frac{K}{d^2} \cdot \frac{dT_s}{dt}$, where $Vs$: skin blood flow rate, $T_b = 310k$, blood temperature in the core, $Cs$: the heat capacity of skin, $K_c = 0.168 \text{ k cal/m/h/k}$ (thermal conductivity of skin) $d$: depth of one temperature point from skin surface, and $T_s$: the skin temperature. We can calculate the discrete-time approximation to the derivative of the temperature $\frac{dT_s}{dt}$ as the difference between a pair of images normalized by the number of sample frames between the respective acquisition times.

Our goal is to validate the effectiveness of our mobile app for monitoring and assessing a skin wound. 12 rats were used for our experiments. Each rat has two wounds, one for control and one for treatment. Wounds were created using a 12mm biopsy punch to achieve a full thickness wound. The skin was excised down all dermal layers to the panniculus carnosus leaving the muscle intact for our excisional wounds. Our treatment consists of a non-viral DNA plasmid encoding for HIF-1alpha. If transfection of the cell is successful, the treatment will upregulate angiogenesis, creating new vessels and increasing blood flow to the wound, as well as aid in wound closure. The untreated wounds were given a dose of an empty vector plasmid (plasmid without HIF1-alpha) diluted in saline. With this, there should not be any effect besides having the same vehicle (plasmid) as the treated constituting our control for this experiment.

Figure 1a shows the wound locations on a rat. The left side wound is for control. For the 12 rats, the wound diameters are around 19mm. The wound depth are under ~4mm. Figure 1b shows our data collection with our app on a rat.
3. Results

Thermal imaging on 24 rat wounds (treated and untreated) were collected over 3 weeks of time frame through our thermal app. A total 7 data collections were conducted throughout the wound healing period. All wounds were healed after about 2 weeks. The app computed and tracked the relative temperature, thermal wound index, and blood flow rate for all the wounds.

Figure 2a shows the temperature difference tracked on a rat. As we can see that initially, the temperature difference is bigger than zero, as the wound heals, the difference is decreasing, and finally reaches to zero or the same as skin temperature.

Figure 2b shows the progression of thermal index, the thermal index changes from negative to positive, and gradually approaches zero.

![Figure 2. Relative temperature and thermal index.](a)

We made a few important observations from these two charts: 1) Both measurements (relative temperature difference and thermal index) decrease to close to zero eventually as the wound heals. This makes sense since as a wound heals, its blood flow or the observed skin temperature should approach to that of the surrounding normal skin. 2) Unfortunately, even though we observed some differences between the treated and untreated (control) wounds, the differences on all the tracked parameters between treated and untreated wounds were small. This was actually expected since the new chitosan for the DNA plasmid was used during the experiment for the treatment process. The treatment method turned out not very successful by itself.

We have also tracked the blood flow rates for both treated and untreated wounds. We found statistically insignificant difference between the treated and untreated wounds due to the failed treatment method.

4. New or breakthrough work to be presented

A smartphone based thermal app using attachable thermal imager from FLIR ONE is able to present useful data for clinicians to track wound healing status and the effectiveness of a treatment. The work will have significant implication on its usefulness on mobile health based chronic wound monitoring and treatment for patients at home or remotely located.

5. Conclusions

We present a thermal imaging based app to augment traditional appearance based wound assessment method. Using relative temperature, wound thermal index, and blood flow rate, the app is able to track the healing status with identifiable trend. Due to the ineffective treatment method in our experiments, we have noticed small trend difference for treated and untreated wounds. However, we believe that the difference between an effectively treated wound and an
untreated wound will be more noticeable. With further studies, we believe that the trend will be helpful for clinicians to assess wound growth status and treat wound effectively.

6. Acknowledgements

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7. References:

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