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Forward-looking infrared imaging predicts ultimate burn depth in a porcine vertical injury progression model

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ABSTRACT

Introduction: Current methods of assessing burn depth are limited and are primarily based on visual assessments by burn surgeons. This technique has been shown to have only 60% accuracy and a more accurate, simple, noninvasive method is needed to determine burn wound depth. Forward-looking infrared (FLIR) thermography is both noninvasive and user-friendly with the potential to rapidly assess burn depth. The purpose of this paper is to determine if early changes in burn temperature (first 3 days) can be a predictor of burn depth as assessed by vertical scarring 28 days after injury.

Methods: While under general anesthesia, 20 burns were created on the backs of two female Yorkshire swine using a 2.5 cm × 2.5 cm × 7.5 cm, 150 g aluminum bar, for a total of 40 burns. FLIR imaging was performed at both early (1, 2 and 3 days) and late (7, 10, 14, 17, 21, 24 and 28 days) time points. Burns were imaged from a height of 12 inches from the skin surface. FLIR ExaminIR© software was used to examine the infrared thermographs. One hundred temperature points from burn edge to edge across the center of the burn were collected for each burn at all time points and were exported as a comma-separated values (CSV) file. The CSV file was processed and analyzed using a MATLAB program. The temperature profiles through the center of the burns generated parabola-like curves. The lowest temperature (temperature minimum) and a line midway between the temperature minimum and ambient skin temperature at the burn edges was defined and the area of the curve calculated (the "temperature half-area").

Results: Half-area values 2 days after burn had higher correlations with scar depth than did the minimum temperatures. However, burns that became warmer from 1 day to 2 days after injury had a lower scar depth then burns that became cooler and this trend was best predicted by temperature minima. When data were analyzed as a diagnostic test for sensitivity and specificity using >3 mm scarring, i.e. a full-thickness burn, as a clinically

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relevant criterion standard, temperature minima at 2 days after burn was found to be the most sensitive and specific test.

Conclusions: FLIR imaging is a fast and simple tool that has been shown to predict burn wound outcome in a porcine vertical injury progression model. Data showed that more severe burn wounds get cooler between 1 and 2 days after burn. We found four analytic methods of FLIR images that were predictive of burn progression at 1 and 2 days after burn; however, temperature minima 2 days after burn appeared to be the best predictive test for injury progression to a full-thickness burn. Although these results must be validated in clinical studies, FLIR imaging has the potential to aid clinicians in assessing burn severity and thereby assisting in burn wound management.

1. Introduction

Therapy used for burn patients depends on the depth of the burn. Superficial dermal burns heal spontaneously within three weeks and utilise minimal medical intervention. However, deep dermal burns, as well as full thickness burns, benefit from excision and grafting and can take many months to heal. Furthermore, earlier excision and grafting lead to better patient outcomes, including faster healing, lower incidence of infection, and reduced length of hospital stay [1,2]. Thus, physicians must be able to rapidly assess burn depth in order to provide optimal burn care.

Unfortunately, current methods of assessing burn depth are limited. Most burn surgeons rely on a visual assessment, which has been shown to have only 60% accuracy, even in the eyes of the most experienced surgeons [3]. In light of this knowledge, clinical investigators have evaluated the use of alternate ways to assess burn severity. Laser Doppler imaging (LDI), which can give an indirect qualitative measurement of blood flow through the dermis, has been shown to increase the accuracy of burn depth prediction at time points as early as 3 days [4]. However, LDI is cumbersome and costly and requires the patient to remain still for up to 30 min, which is impractical in situations where patients are experiencing a significant amount of pain. Furthermore, LDI is not accurate during the first 1–2 days after injury. Hence, this technology is not widely used outside of research studies. Indocyanine green angiography is an alternative method for burn assessment. This technology is invasive and costly, and therefore, is not a realistic choice for assessment of burn depth in the clinic. It may find use, however, during surgical debridement in order to reduce the margins of viable tissue that are removed [2,5]

Forward looking infrared (FLIR) thermography has the potential to rapidly assess burn depth in a non-invasive, quantitative fashion. The technology measures tissue thermal emission as radiation in the far IR portion of the electromagnetic spectrum (wavelengths of 7–13 μm). The FLIR image at the skin surface can be viewed as the integral of temperature throughout the layers of the skin, since the camera captures thermal emission from tissue down to a depth of 3 cm. Since deep burns have more blood vessel injury, there will be less tissue perfusion and thus less thermal emission up through the skin [6]. The metabolic rate of cells damaged by thermal injury is also reduced resulting in less emission of heat.

Several groups have reported that thermography has the potential to improve clinical assessment of burn depths [7–9]. These previous studies focused more on exploring the use of thermography in a small set of patients. Each of these groups used a single temperature point in the burn in order to make their judgment. Using more than one temperature point, however, may lead to a better prediction of burn depth. Additionally, these studies used one time point in determining burn wound outcome. Knowing the change in burn wound temperature in the period of time following injury may provide potentially valuable information about the outcome of the burn. The purpose of this study is to determine if the change in burn temperature during the first 3 days after injury can accurately predict burn depth as assessed by vertical scarring 28 days after injury. In addition, we also assessed if the use of multiple temperature points better predicts vertical scarring than a single temperature point. The study also serves to standardize the implementation and interpretation of FLIR thermography as a precedent to a clinical trial.

2. Methods and materials

2.1. Study design

Investigators blinded to injury progression outcome performed burn analysis using FLIR data in a porcine vertical burn progress model [10]. Our study protocol was conducted following Institutional Animal Care and Use Committee (IACUC) Research Review Board approval.

2.2. Animal use

This study utilized two female Yorkshire swine (20–25 kg). Animals were allowed to acclimate for at least one week during which they were given a standard diet until they were fasted overnight prior to experimental procedures. Appropriate housing and care for animals was ensured in our Division of Laboratory Animal Resources (DLAR) in accordance with National Research Council Guidelines [11]. In the animal quarters the ambient temperature is 71.36 ± 0.59 F and humidity is 56.82 ± 2.83 %rh.