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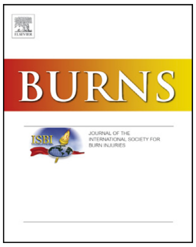

Surgical wound debridement sequentially characterized in a porcine burn model with multispectral imaging

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ABSTRACT

Introduction: Multispectral imaging (MSI) is an optical technique that measures specific wavelengths of light reflected from wound site tissue to determine the severity of burn wounds. A rapid MSI device to measure burn depth and guide debridement will improve clinical decision making and diagnoses.

Methodology: We used a porcine burn model to study partial thickness burns of varying severity. We made eight 4 × 4 cm burns on the dorsum of one minipig. Four burns were studied intact, and four burns underwent serial tangential excision. We imaged the burn sites with 400–1000 nm wavelengths.

Results: Histology confirmed that we achieved various partial thickness burns. Analysis of spectral images show that MSI detects significant variations in the spectral profiles of healthy tissue, superficial partial thickness burns, and deep partial thickness burns. The absorbance spectra of 515, 542, 629, and 669 nm were the most accurate in distinguishing superficial from deep partial thickness burns, while the absorbance spectra of 972 nm was the most accurate in guiding the debridement process.

Conclusion: The ability to distinguish between partial thickness burns of varying severity to assess whether a patient requires surgery could be improved with an MSI device in a clinical setting.

1. Introduction

The standard of care for burn wounds begins with the use of visual and tactile cues to estimate burn depth. After the burn is classified according to its depth, an effective treatment plan can be designed [1]. Typically the classification of superficial and full thickness burns can be made upon presentation, but the classification of partial thickness burns as "superficial" or "deep" is often delayed. This prolongation occurs because of an inability to visualize the full extent of dermal damage until the partial burn has had time to progress.

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It is important to classify partial burn depths quickly and accurately for several reasons. First, treatment protocols vary significantly with superficial (SPT) versus deep partial thickness (DPT) burns. Superficial partial thickness burns require only topical salves and heal spontaneously over 7–21 days, while deep partial thickness burns must be surgically excised and auto-grafted from a donor skin site [2]. Second, it is important to assess whether a burn requires surgical intervention as early as possible to minimize scarring and bacterial colonization of the wounds. The delayed intervention associated with classifying partial thickness burns has been shown to increase the length of hospitalization and risks of infection, metabolic distortions, and organ-failure [3,4]. Finally, multi-region burns are common and will typically contain an amalgamation of burn depths [5]. Excision and grafting of complicated burns require expert planning and careful differential excision to ensure optimal therapy of the entire burn area.

With only 250 burn specialists and 1800 designated burn beds (operating at 95% capacity) in United States hospitals, burn care resources are scarce. Thus, the first line of care for burn patients is often non-specialists whose lack of experience in burn therapy leads to delayed and non-optimal treatment, increasing the rate of complications [6]. Currently, the accuracy of clinical burn depth diagnosis by experts is estimated to be 70–80%, but non-specialists are just 60% accurate [7]. A device that is able to assist with triage by classifying burn type is needed. It will improve burn diagnoses, clinical decision making, and further optimize patient care. Such a tool could also enhance pre-operative planning by providing the clinician with a wound map of burn depth gradients, estimated excision depths, and donor skin area approximations.

The most salient potential solutions to improve burn depth estimation include fluorescent dyes, high frequency ultrasound, nuclear imaging (MRI), photography, thermography, and laser Doppler imaging (LDI) [7]. A side by side comparison of these technologies is presented in Table 1. Laser Doppler imaging is the only technology with an ''indication for use'' statement including the diagnosis of burn wound beds. It is non-invasive, proven to be effective in wound assessment, and currently available to burn specialists. Despite its availability, it is used sparingly and mainly in major burn centers [8]. The most cited disadvantages (requirements for a completely bare wound, motionless patient, and a 48-h delay after the injury) result in low usability in the clinical setting. Acquisition times are also quite slow [9,10]. Thermography, like LDI, is non-invasive and non-contact, but requires the patient to undergo 15-min temperature equilibrium in a thermostatic room, and is currently not appropriate for classifying burn depth [11]. Color photography use in burn assessment is often difficult because it offers nothing more than what the human eye can already perceive and requires a burn surgeon to interpret images. Intravascular dyes such as indocyanin green (ICG) provide information about blood flow in tissues. This technique has been explored in burns and can be used to identify regions of high or low blood perfusion in a burn [12]. This technology is invasive, requires injection of dye for each image acquisition attempt, and some surgeries require multiple injections depending on the number of images desired, which can be expensive and time-consuming.

Notably, another potential solution, multispectral imaging (MSI), measures the reflectance of select wavelengths of visible and near-infrared light burn tissue. Various tissue types consist of a unique combination of tissue components that interact with light differently. These light-tissue interactions produce unique reflectance signatures captured by MSI that can be used to classify burn severity [9]. MSI is also able to assess tissue through topical wound ointments and wrappings as well as tolerate minor patient movement [13]. These characteristics make MSI an attractive solution.

MSI has been previously tested in clinical environments, with the earliest results obtained by Anselmo et al. [13] in 1977 and Afromitz et al. [14] in 1988. These experiments were successful in classifying different burn depths, but the time necessary to complete each acquisition was on the order of weeks to months. With improvements in processing capability and technology over the last several decades, we are prepared to take full advantage of MSI techniques today.

The accuracy of MSI technology depends on the identification of optimal wavelengths of light that are then employed to take advantage of known reflectance spectra to differentiate various tissue types. As discussed in the Theory section of this manuscript, the reflectance spectra of oxyhemoglobin, deoxyhemoglobin, melanin, and other chromophores of skin have been well established [15–17]. Computational studies modeling heat transfer through skin are able to predict the degree of thermal injury that is induced by specific temperatures for predetermined durations. These studies have improved understanding of physiological changes that occur during the burn process

Table 1 – Side by side comparison of technologies proposed for burn imaging.

	Color photography	Thermography	ICG imaging	Laser Doppler imaging	Multispectral imaging
Available now	✓		✓	✓	
Non-invasive	✓	✓		✓	✓
View blood perfusion		✓	✓	✓	✓
Classify burn depth	✓ (via Burn surgeon)				✓
Motion tolerant			✓		✓
Ointment tolerant					✓
Immediate post-injury imaging	✓		✓		✓