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Jose David Medina-Preciado  
Eleazar Samuel Kolosovas-Machuca  
Ezequiel Velez-Gomez  
Ariel Miranda-Altamirano  
Francisco Javier González

# Noninvasive determination of burn depth in children by digital infrared thermal imaging

Jose David Medina-Preciado,<sup>a</sup> Eleazar Samuel Kolosovas-Machuca,<sup>b</sup> Ezequiel Velez-Gomez,<sup>a</sup> Ariel Miranda-Altamirano,<sup>a</sup> and Francisco Javier González<sup>b</sup>

<sup>a</sup>Civil Hospital of Guadalajara, Guadalajara, Jalisco, Mexico

<sup>b</sup>Universidad Autónoma de San Luis Potosí, Coordinación para la Innovación y la Aplicación de la Ciencia y la Tecnología, San Luis Potosí, México

**Abstract.** Digital infrared thermal imaging is used to assess noninvasively the severity of burn wounds in 13 pediatric patients. A delta- $T$  ( $\Delta T$ ) parameter obtained by subtracting the temperature of a healthy contralateral region from the temperature of the burn wound is compared with the burn depth measured histopathologically. Thermal imaging results show that superficial dermal burns (IIa) show increased temperature compared with their contralateral healthy region, while deep dermal burns (IIb) show a lower temperature than their contralateral healthy region. This difference in temperature is statistically significant ( $p < 0.0001$ ) and provides a way of distinguishing deep dermal from superficial dermal burns. These results show that digital infrared thermal imaging could be used as a noninvasive procedure to assess burn wounds. An additional advantage of using thermal imaging, which can image a large skin surface area, is that it can be used to identify regions with different burn depths and estimate the size of the grafts needed for deep dermal burns. © 2013 Society of Photo-Optical Instrumentation Engineers (SPIE). [DOI: 10.1117/1.JBO.18.6.061204]

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## 1 Introduction

One important problem in burn therapy is the correct evaluation of skin burn depth, which can have repercussions on the appropriate choice of treatment.<sup>1</sup>

Traditionally, burns can be classified in the following grades: I (superficial), IIa (superficial dermal), IIb (deep dermal), and III (full thickness of the skin). In clinical practice, even an inexperienced physician has no difficulty in classifying first and third degree burns correctly; however, differentiation between the IIa and IIb wounds is problematic even for the most experienced practitioners.<sup>2,3</sup>

For most burn surgeons, burn depth is better defined by the time to heal, which is linked to the risk of developing hypertrophic scarring. It has been shown that if a partial-thickness burn wound heals within two weeks, scarring is unlikely to occur, but after three weeks, the risk of hypertrophic scar formation is extremely high. But here again, a large number of burns fall into the category that heals between two and three weeks where the likelihood of scarring seems to vary considerably.<sup>4</sup>

Clinical assessment by visual inspection, which relies on a subjective evaluation of the external features of the wound such as wound appearance, capillary refill, and burn wound sensibility to touch and pinprick remains the most frequent technique to measure the depth of a burn wound, although this has been shown to be accurate in only 60% to 75% of the cases, even when carried out by an experienced burn surgeon.<sup>1,4</sup>

Punch biopsy of burn tissue with subsequent histological analysis is frequently considered the “gold standard” of burn-depth assessment, serving as the basis for comparison of other diagnostic modalities.<sup>4</sup> Among the disadvantages of histological analysis are that the structural damage may not necessarily correlate with functional loss and that it is limited by the need for an experienced pathologist to perform the interpretation.<sup>4</sup> Also, histology is restricted to single or multiple small areas and is not practical for mapping large areas of the wound, so the gold standard of biopsy/histology is not likely to attain clinical usefulness.<sup>4</sup>

The diagnosis of burn depth is particularly difficult in children, who commonly suffer scald burns of mixed depth. Therefore the diagnosis of a deep burn may only be made once the burn has failed to heal 10 to 12 days later.<sup>5</sup>

Digital infrared thermal imaging, also known as thermography, is a procedure that detects infrared radiation, which is used to determine the temperature of the emitting surface producing a temperature pattern of the imaged surface. In the case of imaging the human body, the results correspond with the patient's skin surface temperature, which resembles the anatomic area under study; this information has been used for diagnosis,<sup>6,7</sup> for follow-up treatments,<sup>8</sup> and for the study of the physiological functions of healthy individuals.<sup>9</sup>

Burn wounds cause vascular damage to the skin, which reduces the blood perfusion to the skin, affecting its surface temperature pattern. Infrared imaging can be used to assess the depth of the burn by measuring the changes in temperature profiles in a burn wound.<sup>10</sup>

In this work, digital infrared thermal imaging is used to assess the severity of burn wounds in 13 pediatric patients;

Address all correspondence to: Francisco Javier González, Coordinación para la Innovación y la Aplicación de la Ciencia y la Tecnología, Universidad Autónoma de San Luis Potosí, Sierra Leona 550, Lomas 2da. Sección, 78210, San Luis Potosí, San Luis Potosí, México. Tel: +52 (444) 825-0183 ext 232; Fax: +52 (444) 825-0198; E-mail: javier.gonzalez@uaslp.mx.

the results are compared with the histological analysis obtained from punch biopsies in order to determine the viability of using digital infrared thermal imaging in the assessment of burn wounds.

## 2 Materials and Methods

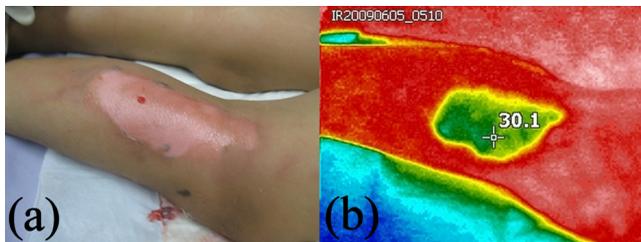
Thirteen pediatric patients (11 boys, two girls), ages ranging from 1 to 16 years (average: 5.7 years), admitted to the burn unit of the Civil Hospital of Guadalajara for scald burns and burns due to direct contact with fire, covering an average of 13.7% of their body (range 6% to 18%) participated in this study. The patients did not present any injuries besides the burn and were admitted during the first 72 h after the burn occurred. Informed consent was obtained from the parents of all participants, and the study was approved by the local ethics committee.

The participants of the study were examined using a digital infrared camera (FlexCam-S, Infrared Solutions Inc., Plymouth, Minnesota) consisting of an uncooled infrared Focal Plane Array of Vanadium-Oxide microbolometers with a thermal sensitivity better than  $0.1^{\circ}\text{C}$ , an accuracy of  $\pm 2^{\circ}\text{C}$  at  $30^{\circ}\text{C}$  and a spectral range from 8 to  $14\ \mu\text{m}$ . This thermal imaging system provides thermal information of a scene in real time with a  $120 \times 160$  pixel resolution that can be saved in digital format for printing or further processing.

The measurements were performed at a constant emissivity of 0.97,<sup>11</sup> it was set to a constant value since Boylan et al.<sup>12</sup> found that the emissivity of burn wounds was 0.01 to 0.03 greater than emissivities of intact skin and that the application of creams such as Bactroban and Flamazine, used in the burn unit, also had little effect on the emissivity.<sup>12,13</sup> Therefore setting the emissivity at the constant value of intact skin does not affect significantly the measurements of burned skin.

Digital infrared thermal measurements were made on the burned region and on a contralateral healthy region with a similar temperature in order to record the difference in temperature,<sup>14-16</sup> this difference is also known as the Delta- $T$  parameter ( $\Delta T$ ). A punch biopsy was taken from the burned region and analyzed by a pathologist trained in burn injuries in order to determine histopathologically the depth of the burn.

All the measurements were taken in the 36 to 72 h time-frame after the burn took place, close to 48 h, which is considered the best time to assess burn wounds.<sup>5</sup> The temperature was measured at the same point the punch biopsy was later performed in order to match the histopathological results with the wound temperature. The temperature did not vary along the 8 mm diameter of the circular area where the punch biopsy was taken; this point measurement was compared to the contralateral region as defined in Refs. 14 and 15.



**Fig. 1** (a) visible and (b) infrared image of a deep dermal (IIb) burn in the leg, which shows a lower temperature in the lesion than the rest of the unaffected tissue (negative  $\Delta T$  value).

Figure 1 shows a visible and infrared image of a deep dermal second-degree burn in the leg with a lower temperature in the lesion than the rest of the unaffected tissue, resulting in a negative  $\Delta T$  value.

## 3 Results

Burn wounds were classified according to the histological analysis. From the 13 burns, six were histologically classified as superficial dermal (IIa) and seven as deep dermal burns (IIb). Thermal imaging results show that superficial dermal burns (IIa) presented increased temperature compared to their contralateral healthy region (average  $\Delta T$  of  $1.7^{\circ}\text{C}$ , standard deviation of  $0.57^{\circ}\text{C}$ ) while deep dermal burns (IIb) presented a lower temperature than the contralateral healthy region (average  $\Delta T$  of  $-2.3^{\circ}\text{C}$ , standard deviation of  $0.83^{\circ}\text{C}$ ), the difference in temperature is statistically significant ( $p < 0.0001$ ) and provides a way of distinguishing deep dermal from superficial dermal burns.

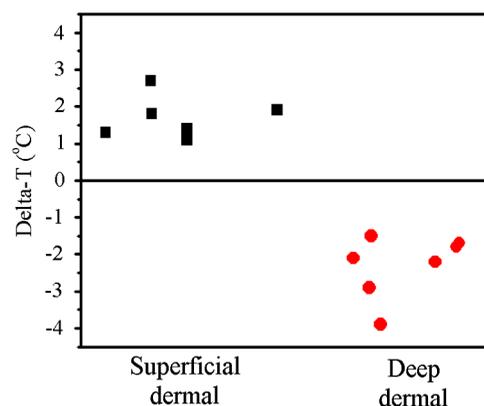
Figure 2 shows the difference in temperature between the lesion and a contralateral healthy region as a function of the histological results for the 13 patients analyzed.

## 4 Discussion

Table 1 shows the results of the clinical and thermographic assessment compared with the histological results; for a  $0^{\circ}\text{C}$  cutoff Delta- $T$  parameter, the thermographic assessment agrees with the histology results in all of the biopsies, while the clinical assessment agreed in five out of six superficial dermal wounds and in three out of seven deep dermal wounds, giving a percentage of clinical effectiveness of 61% (8/13), which agrees with previously reported accuracy values for clinical burn wound assessment.<sup>1,4</sup>

The results in Fig. 2 can be explained due to the fact that deep dermal burns involve blood vessel destruction reducing the amount of blood perfusion to the skin and therefore reducing the skin temperature, while superficial burns still have viable tissue, which generates an immunological response that produces inflammation and increases the temperature of the burn wound.

These results provide a clear way of classifying in a non-invasive manner superficial dermal from deep dermal burn wounds, they are also consistent with results previously published by Renkielska et al.<sup>17</sup> where a  $0.3^{\circ}\text{C}$  cutoff Delta- $T$  parameter was found between burns that heal within three weeks and



**Fig. 2** Delta- $T$  values for burn wounds as a function of their depth according to histological results for the 13 patients that participated in the study.

**Table 1** Percentage of accuracy in the clinical and thermographic assessment of burn wounds compared to the histological results.

Histology results	Thermal imaging assessment (0°C cutoff $\Delta T$ )	Clinical assessment
Superficial dermal (IIa)	100%	83.33%
Deep dermal (IIb)	100%	42.85%

burns that take longer than three weeks to heal. It is worth noting that the results reported in Ref. 17 were obtained from burns made on the skin of pigs, and due to the abrasions suffered by the pigs being caged, the burns might have taken longer to heal. In a controlled hospital environment, burn wounds would heal faster, therefore reducing the 0.3°C cutoff  $\Delta T$  parameter reported in Ref. 17.

It is worth noting that other noninvasive techniques such as laser Doppler imaging (LDI) have also been used in the prediction of burn wound severity. In the case of LDI, a sensitivity of 97% and a specificity of 100% was obtained when performed within three days of the burn injury.<sup>18</sup> Even though LDI is accurate in assessing burn wounds, it is also more expensive and has a steeper learning curve than digital infrared imaging. Also, several scans are needed in order to obtain accurate results.

## 5 Conclusions

Results show there is a significant difference in the thermal pattern of superficial dermal and deep dermal burn wounds, which are particularly difficult to assess clinically; these thermal differences correlate well with histological findings. Therefore digital infrared thermal imaging can be used as a noninvasive procedure to assess burn wounds.

Since digital infrared thermal imaging is a procedure that can image a large skin surface area, this technique could be used to identify regions with different burn depths and estimate the size of the grafts needed for deep dermal burns.

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