Clinical utilization of near-infrared spectroscopy devices for burn depth assessment

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ABSTRACT

The diagnosis of burn depth is based on a visual assessment and can be subjective. Near-infrared (NIR) spectroscopic devices were used preclinically with positive results. The purpose of this study was to test the devices in a clinical setting using easily identifiable burn wounds. Adult patients with acute superficial and full-thickness burns were enrolled. NIR point spectroscopy and imaging devices were used to collect hemodynamic data from the burn site and an adjacent unburned control site. Oxy-hemoglobin and deoxy-hemoglobin concentrations were extracted from spectroscopic data and reported as oxygen saturation and total hemoglobin. Sixteen patients (n=16) were included in the study with equal numbers in both burn wound groups. Point spectroscopy data showed an increase in oxygen saturation (p<0.0095) and total hemoglobin (p<0.0001) in comparison with the respective control areas for superficial burn wounds. The opposite was true for full-thickness burns, which showed a decrease in oxygenation (p<0.0001) and total hemoglobin (p<0.0147) in comparison with control areas. NIR imaging technology provides an estimate of hemodynamic parameters and could easily distinguish superficial and full-thickness burn wounds. These results confirm that NIR devices can successfully distinguish superficial and full-thickness burn injuries.

MATERIALS AND METHODS

Ethics Review Board approval for the study was obtained at the National Research Council of Canada’s Institute for Biodiagnostics and Sunnybrook College Health Sciences Centre. Adult acute burn patients with small total body surface area (TBSA) injuries presenting to the Ross Tilley Burn Centre from October 2001 to March 2002 were considered for enrollment in the study. Burn depth was limited to known clinical diagnosis with eligible patients as superficial and full-thickness injuries. Superficial burns were defined as an area of erythema with brisk capillary refill, intact hair follicles, and pain on air exposure. Superficial burns healed within 7 days with no visible scarring. Full-thickness wounds were defined as white, dry, and leathery with no capillary refill. Patients complain of little pain and have little or no discomfort with palpation of the site. Patients with infected burns, chemical, or electrical burns, documented peripheral vascular disease, and mechanically ventilated patients were excluded. This was necessary to limit the variables introduced in the study design as all of these conditions can affect local blood volume and consequently the results obtained.22-25 Chemical and electrical burns tend to be visually superficial despite the potential for a much deeper injury, making it difficult to give an accurate assessment of burn depth at early time points.27,28

Currently, burn wound depth assessment is clinically based and relies heavily on the experience of the physician. It has been reported that when differentiating indeterminate or partial-thickness wounds, experienced burn clinicians make an incorrect diagnosis 40% of the time.1,2 The diagnostic limitations of the clinical assessment of burn injury have led many researchers to search for an optimum technique to judge burn depth accurately. A wide range of diagnostic tools has been reported in the literature such as laser doppler, various dyes, ultrasonography, thermography, nuclear magnetic resonance, and optical coherence tomography.3-18 To date, none of these technologies have achieved widespread clinical acceptance or utilization.3,5,18

A promising new tool in the area of trauma and burns is Near Infrared (NIR) Spectroscopy and its ability to assess hemodynamic information.19-22 Preclinical work in a porcine model showed that the NIR devices were capable of differentiating all burn depths (superficial, partial thickness, and full thickness) within 3 hours postinjury.23,24 Modifications were then made to the NIR devices to make them compatible within the clinical environment. The prototypes were tested on known clinical entities only (superficial and full-thickness burn injuries) in order to test the practicality and feasibility of NIR in a clinical setting. The primary intent of this article is to focus on the development and testing of a clinical NIR device.
The director of the Ross Tilley Burn Centre (J. F.) identified potential candidates and informed consent was obtained. Before entry into a patient's room, devices equilibrated for 30 minutes, were calibrated and covered with a plastic disposable sheet. At the same time, patients were given analgesia, positioned supine on a hospital bed, and dressings removed by a nurse. All ointments and creams were removed before data collection. At our burn center superficial injuries are treated with Polymyxin B sulfate/Bacitracin antibiotic ointment or paraffin gauze dressings and full-thickness burns treated with silver sulfadiazine (Flamazine®, Smith & Nephew Inc., St., Laurent, Quebec, Canada) cream until surgical intervention. Wound Rep Reg (2007)

NIR spectroscopy devices for burn depth assessment

Two devices, NIR point spectroscopy and NIR spectroscopic imaging, were used for data collection. Measurements were obtained from the burn wound site and a control site (healthy nonburned skin) for each subject. The control site was chosen as one joint/quadrant above or below the burn injury and was used to account for subject variability. The probe has a smaller surface area; therefore, three measurements were obtained within the burn and control area of interest. The suspension of the imaging device over the site of interest allows a larger surface area to be assessed and therefore only one sample was collected for each site. The length of time necessary to collect data from the sites is 16 and 60 seconds, respectively, for the probe and imaging devices. A digital photograph of the burn wound and control area was taken to document the clinical appearance of the burn. Once data collection was finished, the patient was given a questionnaire regarding the technique. The patient feedback questionnaire was designed using a ten-point visual analog scale for four items. These items were an assessment of discomfort during the technique. The patient was given a questionnaire regarding the technique. The patient feedback questionnaire was designed using a ten-point visual analog scale for four items. These items were an assessment of discomfort during the procedure and length of time for the devices. End points of the study for patients included time to complete wound healing (< 7 days for superficial burns) or operative intervention for full-thickness burn wounds. Biopsies were not performed in this patient population.

NIR point spectroscopy

The point spectroscopy probe device consists of a custom-built multifiber optic bundle (Fiberguide Industries, Sterling, NJ). One fiber delivers light via a 100 W quartz tungsten halogen white light source (Oriel, Stratford, CT) to the tissue and four fibers are detection optical fibers. The detection fibers deliver reflected light to the imaging spectrograph (Sciencetech Inc., London, ON, Canada), which disperses the captured light into its spectrum. The charge-coupled device (CCD) detector records the spectrum over the 500–1100 nm wavelength range. Raw reflectance measurements were converted to optical density units through a ratio of the tissue reflectance against a 99% Spectralon® reflectance standard (LabSphere Inc., North Sutton, NH) before data processing. The four detection fibers measure spectra at different depths within the tissue and the results from the probe are presented as concentrations of the variables of interest.

NIR imaging spectroscopy

The NIR imaging device is a camera that takes a sequence of digital images of 532×256 pixels between 650 and 1050 nm at 10 nm increments using a back-thinned full frame transfer CCD camera (Hamamatsu, Newark, NJ). This camera is fitted with a Nikon Macro AF60 lens and a 7 nm bandpass (FWHH) Lyot-type liquid crystal tunable filter (Cambridge Research Instruments, Cambridge, MA). The camera is suspended 60 cm above the area of interest and two tungsten halogen lights illuminate the area of interest. Device calibration was performed using the image of a white side of a Kodak Gray Card (Rochester, NY). The imaging device never contacts the surface of the burn and results are displayed in the form of a hemodynamic image.

Data analysis

NIR technology uses the Beer–Lambert relationship to relate the measured reflectance of light to the chromophore content (oxy and deoxy-hemoglobin). The Beer–Lambert Law states that the attenuation (A) of light is proportional to the concentration (c) of the chromophore as

$$A = e c b$$

where e (cm⁻¹mM⁻¹) is the wavelength-dependent extinction coefficient, c (mM) the concentration of the chromophore in the tissue, and b (cm) the path length of light as it is reflected.

The relative concentrations of Hb and HbO₂ are derived over the spectral range of 740–840 nm by a least squares estimate of the chromophore extinction coefficients to the measured spectrum. To account for tissue scatter variations in the measured spectrum, a linear scatter term (mL + offset) was added to the Beer–Lambert relationship. The NIR point spectroscopy provides Hb and HbO₂ concentrations at each detector (four detector fibers and therefore four data sets) for both burn and uninjured areas. The data processing is similar for the imaging technology as each pixel of the digital image is analyzed for Hb and HbO₂ concentrations. To ensure that the same pixel is being analyzed in every frame, the black dots (registration markers) were aligned for all the frames before data processing. The raw values of Hb and HbO₂ were used to calculate the following: tissue oxygen saturation, SₐO₂ (%)=100 [HbO₂/\(\text{rHb}\)] and tissue total hemoglobin, \(\text{rHb}\) [mM/cm⁻³]=HbO₂+Hb. All computations were performed using MATLAB Version 6 (The Mathworks Inc., South Natick, MA).

Statistical analysis

The first statistical analysis consisted of testing the null hypothesis of no difference between the burn injuries and the control sites. The second approach involved testing the null hypothesis of no difference between superficial and full-thickness burn injuries vs. the alternative hypothesis that the burns are distinguishable at a particular detector position. In the second approach, the difference between
the injured and matched control site was determined for each of the detector positions. Systemic effects that occur between different patients that affect both burn and control sites are taken into account by examining the difference between the responses for the burn injuries. t-tests were used for parametric data and χ² analysis for non-parametric data. Statistical significance was achieved with a p-value < 0.05, and standard error was defined as 95% confidence interval (CI). All statistical computations were performed using Statistica 5.1.

RESULTS

Of the 212 patients admitted to the burn unit during the study period, 22 patients fit the inclusion and exclusion criteria. Of these 22 patients, the data from 16 patients were of sufficient quality to analyze. All patients had to have sufficient data, from both the point spectroscopy and imaging system. If one device yielded insufficient data then the results from both of the devices were excluded. The demographic profile of the study group is summarized in Table 1a. The anatomical locations of the burn wounds were sampled from a variety of areas as summarized in Table 1b.

NIR point spectroscopy

The results from the pairwise comparisons of hemodynamic values between superficial burns and control sites at the four detector positions are reported in Tables 2 and 3. Oxygen saturation values for the superficial burns demonstrated a moderate increase in relation to the control sites for each of the detector positions. The S\textsubscript{O}\textsubscript{2} increase ranged between 0.53% for detector position 1 (p<0.0095) and 4.3% for detector position 4 (p<0.0001). A substantial increase in total hemoglobin was observed at all four detector positions ranging from 45.22% (p<0.0001) at detector 1 to 101.52% (p<0.0001) at detector position 4.

The opposite was observed with the full-thickness burns as reported in Tables 4 and 5. The S\textsubscript{O}\textsubscript{2} values decreased considerably in contrast to the control sites (p<0.0001) for detector positions 2–4, which ranged between 90.03 and 97.19%. Moreover, the total hemoglobin values also reported a decrease (p<0.0001) from 72.16% (p<0.0147) to 92.62% (p<0.0001). Statistical significance, however, was not achieved at detector position 1 for both oxygen saturation and total hemoglobin.

The difference in the responses between superficial and full-thickness burns is given in Figure 1. Analysis of the wounds, taking the control site into account (burn site—control site), indicates a significant change in S\textsubscript{O}\textsubscript{2} between burn depths at three of the four detector positions (p<0.01) but not a significant difference at detector position 1 (p=0.187). Conversely, the total hemoglobin values showed a significant difference at all four of the detector positions (p<0.0001). The control sites utilized in superficial and full-thickness injuries were also compared with no statistically significant difference at any of the detector positions (p>0.05).

NIR imaging spectroscopy

The imaging technology takes a NIR digital image of the burned region. Each pixel of the image is analyzed for physiologic information and is displayed as a grayscale map of the burn wound. Figure 2 displays a digital

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<tr>
<th>Table 1a. Demographics of the patient population</th>
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<tr>
<td></td>
<td>Superficial (n=8)</td>
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<tr>
<td>Male*</td>
<td>62.5%</td>
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<tr>
<td>Female*</td>
<td>37.5%</td>
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<tr>
<td>Age (years)*</td>
<td>39 ± 14</td>
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<tr>
<td>PBD (days)*</td>
<td>2.6 ± 2.6</td>
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<tr>
<td>TBSA (%)*</td>
<td>8.8 ± 6.7</td>
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*Nonsignificant.

PBD, post burn day; TBSA, total body surface area.

<table>
<thead>
<tr>
<th>Table 1b. Anatomical locations of burn wounds</th>
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<tr>
<td></td>
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<tr>
<td>Forearm</td>
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<td>Anterior thorax</td>
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<td>Posterior thorax</td>
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| Table 2. Oxygen saturation (%) superficial burns using NIR point spectroscopy (n=8) |  |
|---------|---------------|---------------|---------------|---------------|---------------|---------------|
|         | SC 1          | SC 2          | SC 3          | SC 4          | Mean          | SD            |
|         | Mean          | SD            | Mean          | SD            | Mean          | SD            |
|         | 0.987083      | 0.006054      | 0.992314      | 0.007024      | -0.005231     | 0.0095        |
|         | 0.978477      | 0.009469      | 0.989200      | 0.009735      | -0.010724     | < 0.0001      |
|         | 0.951904      | 0.018753      | 0.975065      | 0.018992      | -0.023162     | < 0.0001      |
|         | 0.921144      | 0.038257      | 0.961516      | 0.032576      | -0.040373     | < 0.0001      |

t-test for dependent samples significant at p < 0.05.

SC, source collector; NIR, near infrared.
photograph, NIR oxygen saturation, and total hemoglobin images of a control site showing uniform tissue oxygenation and total hemoglobin values. The superficial burn in Figure 3 shows an increase in oxygen saturation and total hemoglobin in comparison with the control site values. The full-thickness burn, as depicted in Figure 4, shows the opposite with a decline in $S_O^2$ and $tHb$ in comparison with the control site. These images clearly illustrate the contrast between superficial and full-thickness injuries. The four circular regions (highlighted by arrows) in both Figures 3 and 4 are not associated with the variables of interest and instead are regions corresponding to registration markers that were placed on and around the injury.

**Patient feedback**

Feedback from 22 patients provided information about the comfort and length of time of the investigation. The length of time for the procedure was satisfactory in the majority of patients (86.4%); however, three patients (13.6%) felt that the procedure was lengthy. Overall, none of the patients complained of pain during the imaging procedure, but four patients (18%) experienced discomfort with the probe. It is reasonable to expect that the patients who were uncomfortable also felt that the procedure was lengthy. Two patients had burns in the sensitive nipple areola complex and one patient was assessed in an uncomfortable position. One patient was an elderly female who could only receive small increments of fentanyl for pain control secondary to her multiple medical problems. None of these four patients described their discomfort as being severe.

**DISCUSSION**

NIR became popular after a publication by Jobsis in 1977, which showed its potential to monitor cerebral

| Table 3. Total hemoglobin (mMcm$^{-1}$) superficial burns using NIR point spectroscopy ($n=8$) |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| SC 1            | SC 2            | SC 3            | SC 4            | SC 5            | SC 6            | SC 7            | SC 8            | SC 9            | SC 10           |
| Mean            | 0.454905        | 0.263935        | 0.212011        | 0.222432        | 0.660624        | 0.445510        | 0.422831        | 0.448247        | 0.660624        |
| SD              | 0.277453        | 0.173380        | 0.187387        | 0.196849        | 0.299832        | 0.183139        | 0.185358        | 0.208177        | 0.299832        |
| Difference      | -0.205720       | -0.181575       | -0.210820       | -0.225815       | < 0.0001        | < 0.0001        | < 0.0001        | < 0.0001        | < 0.0001        |
| p-value         |                |                |                |                |                |                |                |                |                |

$t$-test for dependent samples significant at $p < 0.05$.

S, source collector; NIR, near infrared.

| Table 4. Oxygen saturation (%) full thickness burns using NIR point spectroscopy ($n=8$) |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| SC 1            | SC 2            | SC 3            | SC 4            | SC 5            | SC 6            | SC 7            | SC 8            | SC 9            | SC 10           |
| Mean            | 0.993755        | 0.977521        | 0.950771        | 0.907747        | 0.825806        | 0.097422        | 0.027068        | 0.025502        | 0.167949        |
| SD              | 0.005441        | 0.005504        | 0.018562        | 0.036551        | 0.336092        | 0.084110        | 0.051695        | 0.035319        | 0.199160        |
| Difference      | 0.167949        | 0.880098        | 0.923703        | 0.882245        | < 0.0001        | < 0.0001        | < 0.0001        | < 0.0001        | < 0.0001        |
| p-value         |                |                |                |                |                |                |                |                |                |

$t$-test for dependent samples significant at $p < 0.05$.

SC, source collectors; NIR, near infrared.

| Table 5. Total hemoglobin (mMcm$^{-1}$) full thickness burns using NIR point spectroscopy ($n=8$) |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| SC 1            | SC 2            | SC 3            | SC 4            | SC 5            | SC 6            | SC 7            | SC 8            | SC 9            | SC 10           |
| Mean            | 0.392889        | 0.237649        | 0.174123        | 0.125432        | 0.135297        | 0.017533        | 0.002460        | 0.0034910       | 0.257592        |
| SD              | 0.145215        | 0.188410        | 0.092022        | 0.030472        | 0.105615        | 0.008530        | 0.008516        | 0.018242        | 0.0833          |
| Difference      | 0.257592        | 0.220306        | 0.149483        | 0.090522        | 0.0833          | 0.0147          | 0.0036          | < 0.0001        |                |
| p-value         |                |                |                |                |                |                |                |                |                |

$t$-test for dependent samples significant at $p < 0.0500$.

SC, source-collector position; NIR, near infrared.
Since then, NIR has been used as an investigative tool to assess cerebral and muscle perfusion in neonates and adults along with the determination of endpoints of resuscitation in trauma patients. Its capacity to accurately determine changes in blood volume, oxygenation, and hydration that occur deep within the tissue as a result of impaired circulation or ischemia has been well documented.

To date, very little work has been performed using NIR spectroscopy to determine burn depth. Afromowitz et al. used a multispectral camera to evaluate burn depth using an imaging burn depth indicator (IBDI). This technology imaged patients through a filter that incorporated visible and NIR light at four different wavelengths. The authors used a Kubelka–Munk model to attempt to describe the propagation of light through the tissue. The simplicity of the Kubelka–Munk model has made it a popular method for measuring the optical properties of a scattering sample by diffuse reflectance. Unfortunately, the assumptions of isotropic scattering, matched boundaries, and diffuse irradiance are not typical of the interaction of light in tissue. Also, the Kubelka–Munk model cannot predict the spatial distribution of light due to scattering, as the model assumes that scattered light occurs in only two directions. Moreover, the authors used ratios of reflected intensities to predict burn wound healing in a temporal fashion. Ratio techniques did not provide any information about the physiologic status of the tissue and are difficult to apply beyond a sample population. Eisenbeiss et al. used a similar spectral technology to assess burn depth. The data processing method used was a Fuzzy C-means cluster algorithm used to look for patterns within the spectra and then these patterns are used to classify the burn depth. This algorithm is prone to error as the initial optimization of the classification is based on clinical evaluation of the burn, which has a high level of uncertainty. Therefore, the results obtained are not related to burn depth directly but rather the degree to which objects satisfy imprecisely defined observations. In burn injury, the cluster population will be very different which could influence the clustering results. A small cluster can be very important but it is often not found because the larger clusters determine the overall clustering result. Finally, interpretation of the results from a physiology point of view may be difficult with this approach.

Our technology differs significantly from the two previous studies as the wavelengths of interest are predominantly in the NIR region and consist of more sampled wavelengths (650–1050 nm). Using the Beer–Lambert relationship, the absorption and reflectance of light are used to determine the concentration of oxy-hemoglobin and deoxy-hemoglobin. These variables are then translated...
into tissue oxygen saturation and total hemoglobin parameters, which can provide valuable information about blood volume and oxygenation differences in viable vs. nonviable injuries. In this study, imaging and point devices could differentiate burn wounds based on the changes in the reflected light. A superficial burn shows increased oxygen saturation and total hemoglobin at the site of injury. The opposite occurs with full-thickness burns in which there was no oxygenation or blood flow.

This study represents our preliminary efforts to build devices that could be used in a clinical setting. The devices, therefore, were first tested on known clinical entities (superficial and full-thickness burns) and in patients with small total body surface area burns. Histology was not performed to corroborate the clinical and NIR diagnosis and is a limitation of this work. Biopsies within the area of interest would have added strength to the study and helped to validate the results as they would have been compared with a “gold” standard. In addition, the number of patients included in each group was small. This does not reflect on the clinical applicability of the devices but instead is a reflection of the type and number of patients referred to our burn center. As the regional burn center for the province of Ontario, we generally see larger TBSA burns and superficial burns are not referred to a regional burn center and tend to be seasonal.

Measurements using the devices took place at different time points for the two clinical groups with full thickness data acquired on average 5.5 days greater than superficial injuries. This could be a confounding variable in this study as a burn wound has the capacity to progress over time and therefore it is possible that some of the full-thickness injuries may have been deep partial thickness wounds at the time of injury. However, for the majority of the full-thickness burn patients, the timing of presentation to the burn center was 2 days or less postburn injury (62.5%, n = 5), which is comparable with the superficial group. The capacity of a burn wound to change over time is a challenge to any technology designed to assess depth and may necessitate that multiple measures be acquired to monitor this progression. Although it is not clinically useful to assess a burn wound at 7 days, it was necessary in this study to collect data from burn wounds that were full thickness. This means that the spectra of human full-thickness burn wounds are now known and that the mathematical algorithm is developed to differentiate burn injuries at earlier time points.

The results of this study have also shown that the surface of a full-thickness burn is nonuniform. This caused some variability with respect to NIR point spectroscopy as evidenced by the large error bars at detector position 1 and shown in Figure 2. At this position, light is primarily interrogating into the epidermis, which is destroyed in full-thickness injuries and replaced by a nonviable thick eschar. As deeper more consistent tissue was sampled, the variability was reduced and the burn injuries were discernible. Future work in this area will require modifications in the design of the probe with a longer source collector.

**Figure 3. Near Infrared Imaging Spectroscopy: Superficial Burn.**
Digital photograph and gray-scale tissue hemodynamic images of a superficial burn on the neck. A) Digital photograph. B) Oxygen saturation image showing an increase in oxygenation as represented by white within the burn region (95%). C) Total hemoglobin images showing an increase in hemoglobin at the burn site as represented by grey-white areas (0.06 mMcm\(^{-1}\)). Marked areas (shown by arrows) represent registration markers and are not associated with the superficial burn.

**Figure 4. Near Infrared Imaging Spectroscopy: Full thickness burn.**
Digital photograph and gray-scale tissue hemodynamic images of a full thickness burn of the lower leg. A) Digital photograph. B) Oxygen saturation image showing a decrease in oxygenation as represented by black within the burn region (0%). C) Total hemoglobin images that show a decrease in total hemoglobin within the burn region as represented by dark grey (0.01 mMcm\(^{-1}\)). Marked areas (shown by arrows) represent registration markers and are not associated with the full thickness burn.
separation at detector position number 1. This variability may also be a reflection of the different anatomical sites of the burn wounds in our sample population. The thickness of the skin varies with anatomical location and this was not taken into account in this work.

Tissue on its own exhibits diffuse reflectance, whereby the incident light is scattered in all directions. Acquiring spectroscopic images on a highly reflective surface is confounded by specular reflectance. If the tissue is wet or shiny (skin with ointments), it acts like a mirror. This changes the angle of incidence so that light is directly reflected back to the camera and produces artifacts in the image and renders some of the pixels nonmeaningful. All optical technologies are affected by specular reflectance and clinical prototypes have to account for this loss of data secondary to this phenomenon. This is a limitation of this first prototype and necessitated that wounds be free of all creams and ointments during data collection.

In this study, there are several limitations with respect to the study design and the technology. However, we hope that the limitations do not detract from the potential scientific and medical information that this technology can provide based on a simple noninvasive reflectance of light. Our group is defining the mathematical algorithms necessary for the spectral extraction and analysis of human burn wounds. The purpose of this study is to identify these devices as a new technology and highlight the advantages that NIR spectroscopy and imaging have over other technologies trialed in the arena of burn-depth assessment.

The biggest advantage that NIR has over other technologies to date is its capacity to obtain the concentrations of physiologic parameters within the burn wounds with accuracy. In this study, we limited the concentrations to oxy- and deoxy-hemoglobin but other parameters such as water content can be measured with ease. Other technologies used to assess burn depth rely on changes in temperature, measures of blood flow, or a physical assessment of depth. Thermography uses an infrared camera to determine the surface burn wound temperature and has not been utilized as it is grossly affected by environmental temperatures and has not been shown to be clinically useful in predicting patient outcome. Measures of blood flow include vital dyes and laser Doppler imaging. The injection of vital dyes is invasive, impractical, and has associated risks postadministration of the dye. Laser Doppler measures blood flow through a frequency shift between stationary and moving blood cells within a sample of tissue and the results are presented as perfusion units (PU) or a flux value. Blood flow suggests that the microvasculature of the tissue is intact but does not provide information about the oxygenation of the tissue or the carrying capacity of hemoglobin. In addition, studies performed using laser Doppler are difficult to compare as they report differences in blood flow units (PU’s vs. volts) and the cutoff values to define burn depth categories vary from study to study. Other technologies utilize a physical assessment of depth to determine burn wound classification. High-frequency ultrasound detects medium changes in which a sound wave is reflected in tissue and an interface is created. The interpretation of this interface can be difficult and it is hard to discern whether the deeper signals are deep dermal plexus blood flow or in fact the dermal-fat interface.

An acoustic interface in burn tissue suggests that there is a certain “cutoff” level within the skin whereby everything above a level is nonviable and below is viable. This concept is difficult to apply to burn wounds as they are dynamic with significant variability in all levels of the tissue. Light is attenuated by melanin and it is critical for optical technologies such as NIR to control for this loss of light. In the trauma literature, where NIR spectroscopy has become popular, very few of the NIR technologies described account for melanin content in the sample population. Our devices were specifically designed to account for our multicultural population and an offset term is added to all our mathematical algorithms, which improves the intensity of the signal and the clarity of the spectra obtained. Eschar and interstitial edema have made it difficult for other technologies, such as laser Doppler and ultrasound, to assess blood flow accurately. NIR can penetrate deep into the tissue and can reach depths from 2 to 10 cm, which is appropriate for the interrogation of skin. In addition, NIR is able to measure the water concentration and is therefore not affected by edema.

NIR is not sensitive to motion artifacts and any gross patient movements are controlled through the use of registration markers. This has been a criticism of both laser doppler and optical coherence tomography as patient movement, breathing, and any inadvertent perturbation of the sensor are serious confounding factors leading to variation in measurements from different sites in the same subject and from one site in a single individual at intervals of minutes, hours, and days. NIR imaging does require that the patient remains within the field of view of the camera but movement does not directly affect the results.

NIR spectroscopy is portable, noninvasive, and can be used for any anatomical location. Data collection is short and the devices were comfortable for the majority of patients. NIR was easily incorporated into routine dressing changes and did not interfere with nursing duties. In this study, environmental conditions such as temperature were not measured at the time of data collection. Environmental conditions can affect local perfusion but there have been no studies to date that have assessed the effect of temperature on NIR results in burn patients. The measurement of body systemic and room temperature should be incorporated into all future studies where blood flow and tissue hemodynamics are being assessed.

In conclusion, this study represents our preliminary work using NIR spectroscopy to determine burn depth. The transition from the bench to the bedside has enabled us to develop clinical mathematical algorithms for superficial and full-thickness injuries and to extract hemodynamic information from a simple reflectance of light. Obtaining physiologic information from an acute burn injury in a clinical setting is exciting and the possibility of this technology to assess and differentiate partial-thickness injuries is the objective of our future work.

Acknowledgment

Special thanks to the staff of the Ross Tilley Burn Centre at Sunnybrook Health Sciences Centre.
REFERENCES


