A Reliability Study Using a Long-Wave Infrared Thermography Device to Identify Relative Tissue Temperature Variations of the Body Surface and Underlying Tissue

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ABSTRACT

OBJECTIVE: This study assesses the ability of the Scout (WoundVision LLC, Indianapolis, Indiana), an FDA-approved visual and thermal imaging device and software analysis tool, to provide clinicians with a reliable and reproducible way to incorporate long-wave infrared thermography and relative temperature differential into clinical wound assessment by consistently identifying control areas against which to measure wound temperature.

METHODS: This laboratory-based study utilized 3 adult wound care professionals experienced in control area selection. Twenty-six previously collected wound images were used for the study. The 3 readers placed a control area on each of the 26 wounds 3 different times (n = 78 independent placements) to establish within-reader agreement. To establish between-reader agreement, the readers again placed a control area on each of the 26 wounds (n = 26 independent placements).

OUTCOME MEASURES: This study evaluates 2 aspects of the Scout device’s reliability: (1) within- and between-reader agreement of initial patient encounter control area images and (2) between-reader agreement of follow-up encounter control area images.

RESULTS: The control area measurements were very consistent both within (percent coefficient of variation [%CV] approximately 1%) and between readers (%CV approximately 2%). The average maximum temperature within-reader %CV was 1.14% and the between-reader variation was %CV 1.97%. The average minimum temperature had a within-reader %CV of 1.1% and the between-reader coefficient of variation was 2.01%. The within- and between-reader average difference in mean temperature was 0.14°C and 0.29°C, respectively. The largest mean temperature difference observed within-readers was 0.68°C, and the smallest difference was 0.01°C. The largest difference observed in between-reader mean temperature was 0.96°C, and the smallest was 0.03°C.

CONCLUSIONS: This study demonstrates that clinicians can repeatedly and reliably perform a relative temperature differential analysis using the Scout device to determine an appropriate control area for wound temperature assessment.

KEYWORDS: control area, long-wave infrared thermography, relative temperature differential, temperature, wounds

INTRODUCTION

Long-wave infrared thermography (LWIT, or thermal imaging) is a temperature measurement technique that visualizes the thermal energy emitted by the human body surface. Thermal images taken of the skin surface are constructed from electromagnetic wavelengths in the long-wave infrared range of 7 to 14 μm, which are “read” in real time after the values are converted into pixels within a digital image. The use of LWIT along with digital imaging allows both physiologic and anatomic assessment of skin and subcutaneous tissue abnormalities and/or existing open wounds.1

The physiologic principles assessed by LWIT are based on the body heat produced by cellular metabolism and its distribution by blood to the rest of the body, and particularly to the overlying skin, for loss by radiation and convection. In cases where blood supply is impaired, the impaired areas will show temperature loss due to stunted cellular metabolism.2 Accordingly, when an area experiences increased or decreased blood supply, it will show an increase or decrease in thermal energy that can be measured by LWIT. The thermal energy being measured by LWIT is converted to a thermal image, from which temperature can be measured.
The LWIT method can be used in conjunction with other common methods of perfusion evaluation including skin color, patient condition, and capillary refill. Previous tools used to evaluate temperature include the back of the clinician’s hand (manual palpation) and contact thermometers. Manual palpation has historically been the criterion standard for assessment of tissue temperature (assessment of inflammation or lack thereof). Murff et al3 reported in 1998 that this method is a nonobjective means of temperature assessment, even in controlled environments. This method also presents concerns related to cross-contamination from continuous contact between a clinician’s hand and a patient’s body surface. A similar concern of cross-contamination arises in a contact thermometer between a clinician and patient or between patients.

The importance of LWIT measurement in the assessment of skin and underlying tissues is temperature’s direct correlation to the physiologic processes of circulation, microperfusion, and ultimately metabolic activity. In a healthy person, these processes are regulated to maintain a homeostatic balance. When a stimulus such as disease occurs, the body’s physiologic processes are disrupted, causing them to become pathophysiologic in nature. The combination of disturbances caused by the disease and the body’s attempt to control these mechanisms results in impairment and irregularity, which causes a homeostatic imbalance.4

An example of impairment and irregularity is reperfusion injury (ie, the return of blood supply to tissue after an ischemic event that results in oxidative damage). The homeostatic imbalance is reflected in aberrations of the desired functions of circulation, microperfusion, and metabolic activity that ultimately manifest in the form of changes in temperature. Because disease changes often cannot be seen with the naked eye, temperature measurement (or LWIT) becomes a very important parameter in the physiologic assessment of the skin and underlying tissue.

The thermal energy of a body surface is a reflection of the presence or absence of perfusion of the dermal and subcutaneous tissues.5 Because tests of adequate perfusion are a common part of the patient assessment process, clinicians may use LWIT to measure the hyperperfusion and hypoperfusion of skin and subcutaneous tissue. This enables the identification of aberrations and/or existing open wounds relative to the average level of perfusion of an unaffected, adjacent body surface. The clinician selects the regional, adjacent area of intact tissue as a control and comparator for baseline body surface temperature measurement. This control area can be used to regularly and reliably assess the impact of the physiologic parties and disparities of existing wounds and suspected wounds.

The 2014 International Prevention and Treatment of Pressure Ulcers: Clinical Practice Guideline6 recommends including assessment of skin temperature in every skin assessment and particularly for individuals with darkly pigmented skin. The guideline states that localized heat, edema, and change in tissue consistency in relation to surrounding tissue are warning signs for pressure injury development.7,8 An independent review of this guideline revealed that in total there were 822 references to perfusion and circulation, ischemia and necrosis, capillary perfusion and occlusion, oxygenation and hypoxia, and infection and osteomyelitis, all of which have a direct pathophysiologic correlation to temperature. For example, under pressure injury and infection assessment, the guideline notes that clinicians should have a high index of suspicion for local wound infection in the presence of increased heat in the tissue around such an injury.6

Limitations of Temperature Measurement
Temperature measurement does have its limitations. In some medical applications, having a single, absolute value for temperature is very useful (eg, using a mercury thermometer to measure core temperature). However, when using LWIT, clinical application should not focus on absolute temperature value, because of the many intrinsic and extrinsic variables (such as body region and ambient temperature that can affect the ability to capture temperature with 100% accuracy). One way to minimize these intrinsic and extrinsic variables is to use control areas to determine a relative temperature differential (RTD).

Relative Temperature Differential
The RTD method was developed to identify the quantitative temperature differences that exist in and around a wound and assess how these temperature differences change over time. To quantify the RTD, a control area must be selected. A control area is a regional, adjacent area of intact tissue (or intact tissue of similar proximity on the contralateral body region) believed to be least affected by the wound. Assuming a good control area is selected, the RTD provides clinicians with repeatable and reproducible data to assess relative circulation, microperfusion, and metabolic activity.

Say a clinician wishes to assess a patient’s lower-extremity wound using LWIT in an attempt to identify an increase or decrease in perfusion and blood flow in response to a treatment. Comparing absolute temperature measurements of the lower-extremity wound at a baseline encounter and a follow-up encounter would provide the clinician with incomparable and unreliable data. This is because there is no way to minimize the variables that could affect the wound’s temperature on any given day (eg, the examination room could be warmer on the day of follow-up than on the day of baseline). However, by selecting a control area, the data can be normalized and
compared. With RTD, all intrinsic and extrinsic variables can be accounted for, and the clinician can longitudinally compare temperature change through ratio analyses and other normalization algorithms.

**BACKGROUND**
Achieving RTD via selection of a control area through a reliable methodology can provide clinicians with valuable data when assessing suspected wounds and the status of existing wounds that they otherwise would have no ability to obtain. This study assesses the ability of the Scout (WoundVision LLC, Indianapolis, Indiana), an FDA-approved visual and thermal imaging device and software analysis tool, to provide clinicians with a reliable and reproducible way to incorporate LWIT and RTD into clinical wound assessment.

**Regulatory Information**
The FDA-approved Scout device is a combination digital and long-wave infrared camera. The Scout enables the clinician to capture simultaneously a visual image and an infrared image that can be uploaded and stored with a patient’s electronic medical record. It measures and records body surface size and thermal intensity data. The digital camera captures the visible light, and the infrared camera captures the infrared radiation emitted by the body.

The Scout’s digital camera is indicated for the use of capturing visual images to measure the diameter, surface area, perimeter, and volume of a part of the body or 2 body surfaces. The long-wave infrared camera is indicated for the purpose of capturing thermal images to measure the thermal intensity data of a part of the body or 2 body surfaces. Neither component of the Scout touches the patient. This study was institutional review board-approved and was conducted in compliance with good clinical practice and all applicable regulatory requirements. All investigational staff members were trained on the protocol and the proper use of the device and software. There was no anticipated benefit to the study subjects who participated in this study. However, the images collected may lead to the improved care in the future.

**Prior Studies**
The Scout’s ability to accurately and repeatedly assess wounds has been examined in previous studies. When measuring wound size through the visual images (anatomic assessment), the device examined was proven to be accurate, clinically feasible, safe for patients, and easy to learn and use. Its wound measurement techniques (length × width, surface area, and perimeter) were also proven to be valid, reliable, and sensitive enough to document change over time for clinical and/or research purposes. A different study proved the device is very precise in measuring temperature by combining both visual and thermographic modalities. This method is reproducible both within and between readers.

The studies mentioned previously prove the device’s ability to combine the visual and LWIT measurements (anatomic and physiologic assessment). This allows clinicians to combine clinical judgment with quantitative and objective documentation of wound size and temperature and empower clinicians with knowledge that is otherwise unattainable by current clinical methods.

**OBJECTIVES**
No existing study addressed the ability of the Scout to reliably and repeatedly obtain a control area to compare to the wound site. Therefore, this study had 2 primary objectives. The first objective was to establish within- and between-reader agreement of the Scout’s control area placement on a thermal image during an initial patient encounter. The second objective was to establish between-reader agreement of the Scout’s control area placement on a thermal image during follow-up patient encounters. The overall goal was assessment of accuracy of the Scout’s control area placement on a thermal image on initial and follow-up encounters.

Although comparing temperatures between the wounds and the control areas would have seemed prudent, statistically this would not have changed the data because of the nature of RTDs. For example, suppose that reader 1 selected a control area with a mean temperature +0.2°C warmer than reader 2’s control area. Comparing the mean temperature difference of their control area selections to that of the same injured site would show no difference.

**DESIGN**
The study took place in a laboratory setting, utilizing previously obtained images, and the readers included 3 wound care nurses who were familiar with proper use of the software and control area selection. The background of the readers varied in age and wound care experience; however, all of the readers received the same training by a WoundVision professional on the use of the Scout software and proper selection of a control area.

A retrospective design was used because it allowed for the greatest control of variability in wound appearance and temperature over time. Therefore, the study images were chosen from a library of previously collected images taken in an inpatient and outpatient setting. Twenty-six wounds were photographed initially (n = 26 encounters) and during various follow-up encounters (n = 76) for a total of 102 visual and infrared images.
Inclusion criteria for this study were subjects who provided written informed consent, were 18 years or older, and had a wound. Exclusion criteria for this study were subjects who were pregnant and/or did not speak English. Consent for wound photograph use in research studies was obtained at the time the photographs were taken. Proper imaging protocol instructed the readers not to initiate any treatments, therapies, or cleansings until after the images were captured.

Wound images were excluded from the study if they were blurry, taken in such a way that the suggested control area was not available in each subsequent image, or included obstructive objects (such as clothing or dressings). The time between assessments and image acquisition was not standardized for the purposes of this study; some of the subjects included in this study had more follow-up encounters than others. The variability in frequency is due to unanticipated events such as discharge in the inpatient setting or missed appointments in the outpatient setting.

**METHODS**

**Within- and Between-Reader Agreement of Initial Patient Encounter Images**

To establish within-reader agreement (intrarater reliability) of the Scout’s control area placement from an initial patient encounter, 3 different readers were asked to place a control area on each of the 26 independent wound image sets 3 separate times for a total of 78 independent placements. To establish between-reader agreement (interrater reliability) of the Scout’s control area placement from an initial patient encounter, each reader was asked to place a control area on each of the 26 independent wound image sets for a total of 26 independent placements.

Figure 1 shows an exemplary image on which readers were to select control area placement. To select a control area, a user places a small circle onto the tissue they believe is representative of the best comparator area. The size of the control area is a 438-pixel circle (approximately 1.5 cm in diameter). After selection of a control area, a mean temperature value is calculated based on the 438 pixels within the circle.

**Between-Reader Agreement of Follow-up Encounter Images**

To establish between-reader agreement (interrater reliability) of the Scout’s control area placement from follow-up patient encounters, 3 different readers were asked to place a control area on each of the 76 follow-up image sets for a total of 26 longitudinal wound evaluations. Figure 2 shows an exemplary longitudinal image set from 3 patient encounters where readers were asked to place a control area based off of their selection on the prior encounter. The increased ease of use for interpreting thermal images by switching from an absolute image to a relative image can also be seen in this example.

The Scout captures grayscale thermal images within a temperature range of 22°C to 42°C. Absolute temperature images (grayscale) are reflective of a true temperature reading, which can be affected by many intrinsic and extrinsic variables at any given moment in time. The scale for interpreting and quantifying the temperature data in these images is called grayscale pixel value, and it ranges from 1 to 254. The color palette for interpreting these images is a light-to-dark grayscale. As an example, a pixel value of 1 represents the bottom of the scale. It is completely black and represents 22°C. A pixel value of 254 represents the top of the scale. It is completely white and represents 42°C. All pixel values between 1 and 254 (252 variations of gray) represent temperature values between 22°C and 42°C. With a temperature range of 22°C and 254 unique values, the sensitivity in detectable temperature differences is 0.08°C (20°C ÷ 254 pixel values = 0.08) or 12.7 pixel values per 1°C.
Relative temperature images (color) are reflective of temperature difference(s) as compared with absolute temperature value. The scale for interpreting and quantifying the RTD in these images is made available after selection of the control area (baseline). The absolute temperature of the control area is calculated, and a conversion is made to compare every pixel value within the image with this value. The color palette for interpreting these images is centered on the color green (baseline), with yellow, orange, and red at the top (warmer) and light blue, blue, and purple at the bottom (cooler). As an example, if the temperature value of the control area is 30°C (pixel value of 101.6), every pixel in the image is reflected as warmer/cooler than 30°C. Therefore, an area within the image that has a temperature value of 27°C (pixel value of 63.5) would instead be shown as −3°C and colored a medium blue. An area within the image that has a temperature value of 35°C (pixel value of 165.1) would instead be shown as +5°C in a medium red.

**Measurements**

As previously stated, all readers were trained on the operation of the Scout prior to using the software features. The Scout control area feature is designed to provide users with RTD as an alternative to absolute temperature data. Readers were trained on proper selection of a control area, which is defined as the selection of adjacent tissue (or in some cases contralateral tissue) on the thermal image that does not show signs of wounding. Adjacent tissue is defined as tissue that does not show signs of wounding but is in the same anatomical region as the wound and periwound. In other words, a control area is selected on adjacent, intact tissue in order to create a baseline that compares the viable tissue with the vulnerable tissue (healthy [good] vs unhealthy [bad]).

There is no defined distance from the wound for proper selection; however, it is optimal that the selection is proximal to the wound in order to avoid any effects from the wound itself (eg, circulation is more likely to be disturbed on the distal side of the wound because of the way in which blood flows through the body).

Selection of a control area accomplishes 2 important things. First, it makes interpretation of the thermal image easier through the creation of more defined distinctions and a simpler color palette. Second, as previously stated, it minimizes the intrinsic and extrinsic temperature variables associated with absolute temperature. Intrinsic variables include the normal cycle of thermal production, age, comorbidities, body region, medications, and core
temperature. Extrinsic variables include the ambient temperature, humidity, air convection, climate adaptation of the tissue, configuration of the body surface, and substrate temperature of the microbolometer. Eliminating these variables and shifting from absolute to relative temperature allow for longitudinal comparison of the area of interest in the form of images, graphs, and quantitative data.

**End Points**
The primary end point is mean temperature (pixel or Celsius value), which is defined as the average of all control area pixel temperatures; 12.7 pixel values is equivalent to 1°C.

**Data Analysis**
Data were handled according to WoundVision, LLC, data management procedures, and the statistical package used was SAS (SAS Institute, Cary, North Carolina). The statistical analyses were focused on describing the variability observed within and between users during control area identification on the thermal image. Descriptive statistics were used to establish within- and between-reader agreement from initial patient encounter. These statistics included mean, variance, SD, and percent coefficient of variation (%CV) over all the wounds and by reader for each wound. Within-reader agreement is defined as each wound measured 3 times for each operator independently. Between-reader agreement is defined as the average for each operator compared with the other operators for each wound.

Descriptive statistics were also used to establish between-reader agreement of Scout’s control area placement from follow-up patient encounters. The descriptive statistics included mean, variance, SD, and %CV over all the wounds and by operator. Between-reader agreement is defined as the mean pixel value/°C for each reader compared with the other readers for each wound.

An analysis-of-variance model was run to determine the differences of within- and between-reader agreement. The model used reader and image as fixed effects, as well as fixed effect for the replicate measurements within reader. The Intraclass Correlation Coefficient (ICC) was derived from the overall mean squared error and the mean squared error of image and reader. The results of the model indicate that there is no significant difference within readers but difference between readers.

**RESULTS**

**Within- and Between-Reader Agreement of Initial Patient Encounter Images**
The results are very similar both within and between readers. The %CV for the mean temperature both within and between readers averages approximately 2%: 1.06 and 1.92, respectively (Figures 3 and 4). When examined individually, the minimum within-reader %CV was 0.10%, whereas the maximum within-reader %CV was 2.32%. For between-reader agreement, the minimum %CV was 0.13%, and the maximum between-reader %CV was 7.19%.

As shown in Table 1, the within-reader %CV for mean temperature is 1.06%. The minimum observed %CV was 0.10%, and maximum was 2.32%. The average difference in mean temperature within readers is 1.79 pixel values (or 0.14°C). The minimum observed average difference in mean temperature is 0.07 pixel values (or 0.01°C), and the maximum is 8.60 pixel values (or 0.68°C).

Also shown in Table 1, the between-reader %CV for mean temperature is 1.93%. The minimum observed %CV was 0.13%, and maximum was 7.19%. The average difference in mean temperature between readers is 3.70 pixel values (or 0.29°C). The minimum observed mean temperature difference is 0.33 pixel values (or 0.03°C), and the maximum is 12.24 pixel values (or 0.96°C).
Between-reader Agreement of Follow-up Encounter Images

When provided a reference point on the initial image, there was no significant difference observed in the performance between readers across all 76 wound images. The between-reader %CV for mean temperature was approximately 2% (Figure 5). When examined individually, the minimum between-reader %CV was 0.00%, and the maximum between-reader %CV was 6.88% (Table 2).

The overall average difference in mean temperature between-readers is 3.29 pixel values (or 0.26°C) (Table 2).

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Table 1.
WITHIN- AND BETWEEN-READER AVERAGE AND %CV FOR MEAN TEMPERATURE (PIXEL VALUES)

<table>
<thead>
<tr>
<th></th>
<th>Within reader</th>
<th>Between reader</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Difference in Mean Temperature</td>
<td>1.79</td>
<td>3.70</td>
</tr>
<tr>
<td>Mean Temperature %CV</td>
<td>1.06%</td>
<td>1.93%</td>
</tr>
<tr>
<td>Minimum Difference in Mean Temperature</td>
<td>0.07</td>
<td>0.33</td>
</tr>
<tr>
<td>Minimum Mean Temperature %CV</td>
<td>0.10%</td>
<td>0.13%</td>
</tr>
<tr>
<td>Maximum Difference in Mean Temperature</td>
<td>8.60</td>
<td>12.24</td>
</tr>
<tr>
<td>Maximum Mean Temperature %CV</td>
<td>2.32%</td>
<td>7.19%</td>
</tr>
</tbody>
</table>

Abbreviation: %CV, percent coefficient of variation.

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Figure 5.
WITHIN- AND BETWEEN-READER MEAN AGREEMENT

Between-reader %CV for mean temperature averaged across all 3 readers. Mean %CV and horizontal reference line is 2.00170208%.
The minimum observed mean temperature difference is 0 pixel values (or 0.00 °C), and the maximum is 12 pixel values (or 0.96 °C). The mean temperature variation is similar to the within- and between-reader differences observed in method 1. By providing a reference point initially, the variability between readers is reduced, and the average mean temperature variation across all 76 images is approximately 0.25 °C.

The analysis-of-variance model indicated that there is no significant difference within readers, but there is a difference between readers (Table 3). The ICC is 0.94. Consistent with the %CV in Figures 3 and 4, the %CV from the regression model is 2.5%.

**DISCUSSION**

Clinically, temperature differences between a wound and a control area can provide significant information on the presence or absence (as well as degree) of inflammation and/or infection in a wound. It can also provide an indication of the underlying perfusion to the area. That being said, skin temperature changes resulting from a pathologic process can be a matter of degrees. The interpretation of very similar temperatures may be normal or pathologic, depending on the clinician and the type of wound. The authors recommend that this be addressed in a future prospective study utilizing actual patients with a wound in a clinical setting.

**Within- and Between-Reader Agreement of Initial Patient Encounter Images**

The control area measurements were very consistent both within and between readers. The within-reader variability for mean temperature is low, with a %CV of approximately 1%. The between-reader variation for mean temperature was also good, with %CV in Figures 3 and 4, the %CV from the regression model is 2.5%.

**Table 2.**

<table>
<thead>
<tr>
<th>Average Difference in Mean Temperature</th>
<th>Mean Temperature %CV</th>
<th>Minimum Difference in Mean Temperature</th>
<th>Minimum Mean Temperature %CV</th>
<th>Maximum Difference in Mean Temperature</th>
<th>Maximum Mean Temperature %CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.29</td>
<td>2.00%</td>
<td>0.00</td>
<td>0.00%</td>
<td>12.00</td>
<td>6.88%</td>
</tr>
</tbody>
</table>

Abbreviation: %CV, percent coefficient of variation.

**Table 3.**

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<tr>
<th>Source</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F</th>
<th>Probability &gt; F</th>
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</thead>
<tbody>
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<td>48.4518</td>
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<tr>
<td>Corrected</td>
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<td>129866.89</td>
<td>575.8666</td>
<td></td>
<td></td>
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<tr>
<td>Total</td>
<td>227</td>
<td>129666.89</td>
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<td></td>
</tr>
</tbody>
</table>

Abbreviation: df, degrees of freedom.

**Figure 6.**

**WITHIN- AND BETWEEN-READER MEAN, MAXIMUM, AND MINIMUM TEMPERATURE DIFFERENCE**

Within- and between-reader average, maximum, and minimum difference in mean temperature for methods 1 and 2 (both methods assessed independently). Average %CV and horizontal reference line is 2.00170208.
a %CV of approximately 2%. The average maximum temperature had a within-reader %CV of 1.14% and between-reader %CV of 1.97%. The average minimum temperature had a within-reader %CV of 1.10% and a between-reader %CV of 0.201%.

The within- and between-reader average difference in mean temperature was 0.14°C and 0.29°C, respectively. The largest mean temperature difference observed within readers was 0.68°C, with the smallest difference being 0.01°C. The largest difference observed in between-reader mean temperature was 0.96°C, and the smallest difference as 0.03°C (Figure 6).

The results for this outcome demonstrate that control area selection may be delineated repeatedly by the same reader and reproducibly by different readers. Thus, clinicians can utilize RTD as a reliable measurement when using the Scout device for LWT in assessment of tissue or wounds in order to extrapolate findings to presence or absence of blood flow, perfusion, and metabolic activity in the wound, periwound, and wound site.

**Between-Reader Agreement of Follow-up Encounter Images**

When provided an initial control area, longitudinal selection of subsequent control areas were found to be extremely consistent between readers. The between-reader variability for mean temperature was low, with the %CV approximately 2% and an average difference in mean temperature of approximately 0.26°C. The largest mean temperature difference observed between readers was 0.94°C, and the smallest difference was 0.00°C (or no difference at all; see Figure 7). When assessing for a difference between readers, there were no statistically significant differences observed (\( p > .91 \)) (Tables 3 and 4).

The results from method 2 (between-reader agreement) demonstrate that when provided a view of the same control area selection from a previous encounter different readers can reproducibly select the same area as a control. This suggests that clinicians could use RTD as a reliable method to assess tissue temperature in the evaluation of wounds.

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**Table 4. BETWEEN-READER MEAN MEASUREMENTS AND 95% CI**

<table>
<thead>
<tr>
<th>Reader</th>
<th>Mean Pixel Value</th>
<th>SD</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reader 1</td>
<td>137.32</td>
<td>24.07</td>
<td>±5.41 Pixel values</td>
</tr>
<tr>
<td>Reader 2</td>
<td>138.61</td>
<td>24.15</td>
<td>(or ±0.43°C)</td>
</tr>
<tr>
<td>Reader 3</td>
<td>137.14</td>
<td>23.77</td>
<td>±5.34 Pixel values</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(or ±0.42°C)</td>
</tr>
</tbody>
</table>

Abbreviation: CI, confidence interval.

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**Figure 7. SUSPECTED DEEP TISSUE INJURY**

The image set on the top represents a nonvisible suspected deep tissue injury (DTI) captured present on admission. After recognition and documentation, the image set on the bottom shows the success of the intervention to mitigate the progression to a full-thickness pressure injury. Prior studies suggest that thermography can assist in the detection of underlying skin necrosis and as an objective, noninvasive, and quantitative means of early DTI diagnosis.

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**Figure 8. SURGICAL SITE INFECTION**

These image sets represent a surgical site infection with abscess. The RTD image on top reveals a strong increase in heat prior to intervention. The image set below confirms the positive response from an incision and drainage of the abscess and antibiotic therapy.
can reliably compare longitudinal changes in RTD through the use of LWIT with the Scout. The physiologic changes, as represented by relative temperature, can then be integrated as an adjunctive tool to aid clinicians in their decision-making as it relates to optimal care plans, treatment, and interventions for wounds and wound prevention.

CONCLUSIONS
This study demonstrates that clinicians can repeatedly and reliably perform an RTD analysis using the Scout device to determine an appropriate control area. With repeatable and reliable relative temperature data, clinicians can compare healthy and unhealthy tissues to quantitatively measure an area of interest’s progression or regression. For example, a single snapshot of relative temperature data could provide valuable clinical insight such as the confirmation of a suspected subcutaneous tissue aberration not visually present. Also, measuring and comparing an existing open wound over time can help clinicians better understand the pathophysiologic principles of the healing processes. Measuring RTD enables the clinician to complete a skin assessment that yields information beyond what the international guidelines recommend. The images in Figures 7 to 10 provide examples of 4 different scenarios where using LWIT to assess temperature can aid in wound assessment.

Figure 9.
OBJECTIVE WOUND ASSESSMENT

Encounter #1: Prior to NPWT

Encounter #2: 5 days after continued NPWT

Encounter #3: 17 days after continued NPWT

The longitudinal image series depicts an amputation as a result of a crush injury. The RTD images allowed for the objective assessment of the chosen therapy, negative-pressure wound therapy (NPWT). In this example, clinicians used thermography to confirm the chosen treatment was promoting revascularization. The revascularization seen here causes perfusion and metabolic activity, ultimately increasing temperature. This increase in temperature manifests as inflammation. Conversely, when there is no vascularization, there can be no perfusion and metabolic activity, which ultimately results in a decrease in temperature. The decrease in temperature manifests as inadequate tissue perfusion or, in some situations, ischemia.

Figure 10.
LIMB SALVAGE

Post-below-the-knee amputation

Post-above-the-knee amputation

This pair of images represents a thermographic image set of an extremity after a below- and above-the-knee amputation (BKA and AKA). Prior to the initial BKA, the physician strongly recommended beginning with an AKA. The RTD image on top aligns with the recommendation as it reveals a strong decrease in lower-extremity circulation. After surgical revision to an AKA, the image set on the bottom shows improvement in circulation and further confirms that an initial AKA would have been optimal treatment. Prior studies demonstrate that the thermographic method is a reliable indicator of the level of a major limb amputation.

REFERENCES
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