Using Temperature of Pressure-related Intact Discolored Areas of Skin to Detect Deep Tissue Injury: An Observational, Retrospective, Correlational Study

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Abstract
Pressure-related intact discolored areas of skin (PRIDAS) are generally described as an area of nonblanching erythema (Stage I pressure ulcer) or deep tissue injury (DTI), but the validity of these definitions has not been tested. Preclinical studies and forensic observations have shown that skin temperature may help identify nonviable tissue. To investigate the effect of temperature difference between a PRIDAS and its adjacent intact skin and the subsequent development of skin necrosis, an observational, retrospective, correlational study was conducted. Data from all acute care hospital patients with an observed PRIDAS who received a skin integrity consult, including a skin temperature measurement of a PRIDAS site, were abstracted to ascertain if PRIDAS temperature correlated with the development of skin necrosis after 7 to 14 days and to examine the effect of additional patient variables on the progression or resolution of a PRIDAS. Skin temperatures were measured using a commercial, hand-held, infrared thermography camera, and the presence or absence of capillary refill was documented. Among the 85 patients studied, the difference between PRIDAS temperature and adjacent skin ranged from -3.2 °C to +3.0 °C. Of the 55 PRIDAS with a lower temperature at baseline than adjacent skin (“cool”, average -1.2 °C), 29 progressed to necrosis, compared to one of 30 PRIDAS with a higher temperature than adjacent skin (“warm”, average +1.2 °C) (P < 0.001). After adjusting for patient age, skin color, and PRIDAS site, the cool PRIDAS were 31.8 times more likely to progress to necrosis than the warm PRIDAS. Combining the presence/absence of capillary refill and PRIDAS temperature, 0% of 26 patients with signs of blanching and a warm PRIDAS versus 65% of 26 patients with a nonblanching and cool PRIDAS developed skin necrosis (P < 0.001, Fisher exact test for the difference between the two combined values). Research examining the delayed appearance of DTI and large, multicenter, prospective validation studies are warranted. The current National Pressure Ulcer Advisory Panel definition of a Stage I pressure ulcer needs to be amended to reflect the strong relationship to DTI development.

Keywords: retrospective study, pressure ulcer, predictive value of test, erythema, thermography

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Potential Conflicts of Interest: none disclosed

Statistics regarding hospitalization and lengths of stay (LOS) in the United States have shown that hospitalized patients with pressure ulcers require increased LOS of 8 to 9 days and experience a 50% to 100% increase in hospital costs compared to patients who do not have comorbid pressure ulcers during their stay.1 The estimated US and Canada hospital pressure ulcer prevalence rate and facility-acquired prevalence rate for 2008 and 2009 were 13.5% and 6% (N = 90,398) and 12.3% and 5% (N = 92,408), respectively.2 The most recent estimates published by the Agency for Healthcare Research and Quality (AHRQ)1 report the incidence of pressure ulcers in US hospitals increased by 80% since 1993 to more than 503,300 in 2006.

Pressure ulcers start as a pressure-related intact discolored area of skin (PRIDAS). When deep tissue injury (DTI) is present below a PRIDAS, it takes time for skin necrosis to manifest. Farid1 conducted an anecdotal, observational comparison of early DTI development to forensic studies of soft tissue decomposition in decedents. Her description of the progression of PRIDAS over nonviable tissue aligned
closely to forensic studies in that many of the initial non-blanching PRIDAS declined from initial discoloration to a purple demarcated lesion in 7 days and to necrotic skin eschar in approximately 14 days. The term demarcation as used in Farid’s study and in the current study is based on the definition emerging from an experimental animal study\(^2\) describing the formation of the *faux lunatica* by the surrounding healthy tissues after 7 days in reaction to local mycoticaneous tissue death, giving the dead purple tissue a sharp, distinct border. This also is described in another animal study by laizoo\(^5\) as consolidation of the dead tissue after 7 days of full-thickness DTI.

There is a common misunderstanding among many clinicians and lay people that all nonblanchable erythemas and blanchable erythema will resolve with pressure relief. However, if the PRIDAS is an early manifestation of a DTI, the National Pressure Ulcer Advisory Panel (NPUAP)\(^6\) guidelines specify that a DTI will progress to a Stage III or Stage IV pressure ulcer regardless of interventions; pressure relief will not alter the 14-day progression to necrosis (unavoidable DTI).\(^3,6\)

An accurate differential assessment of a PRIDAS is needed to guide both diagnosis and treatment. It is suspected that visual assessments of PRIDAS color vary with different skin shades and ethnic backgrounds, especially in determining the presence or absence of blanching. Misidentifying DTI as hyperemia or a Stage I pressure ulcer, which then advances to a Stage III or Stage IV pressure ulcer, can leave the institution and clinician liable for negligent care or malpractice because it is seen as a progression of the ulcer during the stay and therefore the fault of the institution. Also, the Centers for Medicare and Medicaid Services (CMS) restrict reimbursement for the care required for a Stage III or Stage IV pressure ulcer acquired during the patient’s admission. The CMS does not as yet recognize the significance of a DTI being a precursor to Stage III and Stage IV pressure ulcers.\(^8,9\)

The ability to identify high-risk PRIDAS may promote higher vigilance among the nursing staff regarding pressure relief, frequent assessment, and documentation that may tip the outcome in the patients’ favor, allowing the compromised PRIDAS to recover. More importantly, a cross-sectional study by Dallam\(^10\) quantified pain related to pressure ulcers and noted that correctly identifying skin injury and promptly intervening can reduce patient suffering. Accurately identifying a PRIDAS as a DTI also has implications for the assessment and documentation of pressure ulcers present on admission. Early and accurate identification of DTI attributes subsequent skin changes to the result of natural progression of DTI (decomposition of dead tissues), despite appropriate intervention.\(^3,5\)

One potential strategy to improve the differential diagnosis of PRIDAS is to assess skin temperature to identify nonviable tissue beneath discolored skin. Based on physiology, nonviable tissue is not perfused and, therefore, not warmed by blood flow. Experimental animal studies and forensic pathology (post-mortem findings)\(^5,6\) support a physiologic framework that indicates cool skin temperature is found above nonviable tissue, such as with a DTI. Although skin temperature studies have been done to assess perfusion,\(^11\) no studies to date attempt to link skin temperatures to DTI. A Stage I pressure ulcer is defined by the National Pressure Ulcer Advisory Panel (NPUAP)\(^6\) as “a localized area of nonblanching erythema with intact skin.” The guidelines on pressure ulcer staging provided by the NPUAP are based on consensus and lack scientific validation. Studies are needed that add reliable data to information on the development and progression of pressure ulcers in humans. Clinicians need an early strategy to differentiate and document a PRIDAS that is likely to recover from a PRIDAS that is related to underlying DTI and is irreversible.

**Study Purpose**

The purpose of this study was to investigate the relationship between the relative temperature of a PRIDAS compared to adjacent intact skin (ie, cooler, same, or warmer PRIDAS center compared to surrounding skin) and subsequent development of skin necrosis.

The first research question was: Do PRIDAS that have a cooler center temperature than adjacent intact skin progress to skin necrosis more frequently than PRIDAS that have the same or warmer center temperature than adjacent, intact skin? The related hypothesis was directional: using adjacent intact skin for baseline skin surface temperature, the proportion of PRIDAS with a cool center temperature that progress to skin necrosis would be significantly higher than the proportion of PRIDAS with the same or warmer center temperatures. A secondary research question was: Are there factors that influence progression or resolution of PRIDAS — for example, age, skin color (black/nonblack), and PRIDAS site?
Table 1. Characteristics of sample and pressure-related intact discolored areas of skin (PRIDAS)

<table>
<thead>
<tr>
<th>Variable</th>
<th>PRIDAS with warmer differential as compared to adjacent skin</th>
<th>PRIDAS with cooler differential as compared to adjacent skin</th>
<th>*P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total enrolled; n</td>
<td>30</td>
<td>55</td>
<td>.685</td>
</tr>
<tr>
<td>Age in years (mean)</td>
<td>73.5</td>
<td>74.9</td>
<td></td>
</tr>
<tr>
<td>Males; n (%)</td>
<td>14 (46.7)</td>
<td>21 (38.2)</td>
<td>0.448</td>
</tr>
<tr>
<td>Females; n (%)</td>
<td>16 (53.3)</td>
<td>34 (61.8)</td>
<td></td>
</tr>
<tr>
<td>Race; n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>29 (96.7)</td>
<td>49 (89.1)</td>
<td>0.413</td>
</tr>
<tr>
<td>Black</td>
<td>1 (3.3)</td>
<td>6 (10.9)</td>
<td></td>
</tr>
<tr>
<td>Core temperature (°C); mean ± SD</td>
<td>37.1 ± 1.0</td>
<td>37.0 ± 0.8</td>
<td>0.760</td>
</tr>
<tr>
<td>Serum albumin (g/dL); mean ± SD</td>
<td>2.5 ± 0.8</td>
<td>2.3 ± 0.8</td>
<td>0.257</td>
</tr>
<tr>
<td>Ventilator dependent; n (%)</td>
<td>14 (46.7)</td>
<td>35 (63.6)</td>
<td>0.130</td>
</tr>
<tr>
<td>Nutrition consult completed; n (%)</td>
<td>30 (100)</td>
<td>55 (100)</td>
<td>0.999</td>
</tr>
<tr>
<td>Restraints present; n (%)</td>
<td>6 (20.0)</td>
<td>16 (29.1)</td>
<td>0.360</td>
</tr>
<tr>
<td>Obese; n (%)</td>
<td>7 (23.3)</td>
<td>8 (14.6)</td>
<td>0.310</td>
</tr>
<tr>
<td><strong>Facility service; n (%):</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Critical Care</td>
<td>3 (10.0)</td>
<td>6 (10.90)</td>
<td>&gt;.999</td>
</tr>
<tr>
<td>Medical/Surgical</td>
<td>26 (86.7)</td>
<td>48 (87.3)</td>
<td></td>
</tr>
<tr>
<td>Acute Rehab</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>Admitting diagnosis; n (%):</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiopulmonary</td>
<td>5 (16.7)</td>
<td>7 (12.7)</td>
<td>0.130</td>
</tr>
<tr>
<td>Infection</td>
<td>12 (40.0)</td>
<td>34 (61.8)</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>13 (43.3)</td>
<td>14 (25.5)</td>
<td></td>
</tr>
<tr>
<td><strong>Comorbidities; n (%):</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;2</td>
<td>2 (6.7)</td>
<td>2 (3.6)</td>
<td>0.796</td>
</tr>
<tr>
<td>2 - 6</td>
<td>18 (60.0)</td>
<td>33 (60.0)</td>
<td></td>
</tr>
<tr>
<td>&gt;6</td>
<td>10 (33.3)</td>
<td>20 (36.4)</td>
<td></td>
</tr>
</tbody>
</table>

This is in conflict with the purpose of the Braden Scale, which was originally developed and tested for reliability in determining at-risk patients before they developed pressure ulcers. A prospective, observational study by Sato showed 30% of Stage I pressure ulcers progressed to DTI and deeper ulcers.

**Skin temperature.** Skin temperature normally varies between the trunk and the extremities and between the front and the back of the body. Because of these well-established gradations in surface skin temperature, any comparison of skin temperature should occur in close anatomic approximation. It was the decision of the principal investigator (PI) to do comparative temperatures to those of the PRIDAS on the adjacent normal skin within 5 cm to 10 cm so conditions would best simulate those having an impact on the PRIDAS.

Other factors that influence skin temperature are the temperature of the ambient air, the temperature of objects with which the skin may be in contact (conduction), and the core temperature of the body (ie, if the person is systemically hypothermic or febrile). Thus, any study that examines skin temperature will need to control for ambient temperature and core temperature.

Skin temperature depends on the presence or absence of perfusion of the dermal and subcutaneous tissues. When blood flow is decreased, such as with peripheral vascular disease of the lower extremities, skin temperature is lower. However, when impaired perfusion is restored, data from animal and healthy human studies indicate the return of blood flow is accompanied by an increase in temperature of the skin over the pressure point. The increase in temperature is attributed to a hyperemic response and possibly reperfusion injury/inflammation after temporary capillary occlusion.

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**Literature Review**

According to a retrospective, descriptive study by Jones, dressing costs are increasing exponentially, and expensive dressings (ie, special dressing technology for wound care) can be used indiscriminately, adding additional expense to the care of pressure ulcers. In addition, the CMS withdrew reimbursement for healthcare expenditures related to nosocomial pressure ulcers; the costs incurred subsequent to the occurrence of a pressure ulcer must be absorbed by the institution providing care.

Per the NPUAP definition of Stage I pressure ulcers, the reddened area may indicate patients at risk. This seems to imply that the appearance of the nonblanchable lesion is the point at which pressure-relief interventions are to begin.
In 1991, a prospective, experimental study on healthy human volunteers to develop a model of heat transfer and temperature distribution in the skin and superficial tissues was performed. The results are pertinent to the current study because they support the following concepts and relationships:

1. The primary mechanism of heat transfer in the dermis is convection dependent on blood circulation;
2. Convection heat transfer in skin is dependent on blood flow;
3. A noncontact temperature measurement device to measure skin temperatures was able to detect small temperature changes;
4. Skin temperatures of normal, intact areas of skin in close proximity to each other (e.g., 2 inches) are similar.

Additional empirical evidence supports the ability of skin temperature to reflect the presence and quality of blood flow. In a prospective study on humans, Fossel applied a vasodilator to selected areas on the foot and recorded a simultaneous increase in blood flow and skin temperature. Results from this study lend additional support for the theory that when PRIDAS is a potentially reversible Stage I pressure ulcer, warmer temperatures would be present at the PRIDAS center when the pressure is removed and blood flow returns to the site of pressure.

A prospective histological study by Witowski has shown when pressure is prolonged or great, temporary blood vessel occlusion becomes permanent. Lack of blood supply results in tissue injury. Even with pressure-relieving interventions, a prospective study by Verhovnik suggests that blood flow may not be adequately restored and tissue injury progresses to a nonviable state, manifested by skin necrosis over time. When total blood flow cessation occurs, the PRIDAS on surface skin would remain cool despite pressure-relieving interventions. Data in animal models support progression of injury resulting in cool surface/skin temperatures. In three animal studies, color spectrometry and infrared thermography were used to quantify skin color and skin temperature. Standardized metal discs capable of applying a variety of combinations of pressure and temperature were affixed to standardized areas on the backs of the pigs. Areas of superficial or no injury showed elevated temperatures compared to the surrounding normal skin post-removal of the disc (99% confidence interval). Areas that went on to develop deep necrosis had temperatures substan-
Table 2. Outcomes on follow-up assessment (day 7 – 14)

<table>
<thead>
<tr>
<th></th>
<th>PRIDAS with warm differential</th>
<th>PRIDAS with cool differential</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>30</td>
<td>55</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Progressing to skin necrosis; n (%)</td>
<td>1 (3.3)</td>
<td>29 (52.7)</td>
<td>&lt;0.002</td>
</tr>
<tr>
<td>Capillary refill/blanching present; n (%)</td>
<td>28 (93.3)</td>
<td>20 (36.4)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Demarcation; n (%)</td>
<td>1 (3.3)</td>
<td>27 (49.1)</td>
<td>0.090</td>
</tr>
<tr>
<td>Skin slippage present; n (%)</td>
<td>1 (3.3)</td>
<td>9 (16.4)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Skin color; n (%):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>29 (96.7)</td>
<td>29 (96.7)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Purple</td>
<td>1 (3.3)</td>
<td>11 (20.0)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Eschar</td>
<td>0 (0.0)</td>
<td>18 (32.7)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Figure 1. A glass of ice water held to the forearm of a man creates a cold skin temperature of 76.2°F compared to the normal, adjacent skin temperature of 92.9°F.

Brief “rest period” post-removal of the disc, the skin temperatures of these lesions were lower than the surrounding skin. These data suggest the center of a PRIDAS that is cool after a brief rest period is more likely to be associated with DTI. No published data exist regarding whether humans also display cooler skin surface temperatures when PRIDAS signifies a DTI.

Infrared thermography was used to measure skin surface temperature in the Ferreira study.24 Infrared thermography is described as “a real-time temperature measurement technique used to produce a colored visualization of thermal energy emitted by the measured site at a temperature above absolute zero.”24 Ryan35 describes the principles of thermography as being based on cellular metabolism: “Body heat is produced by cellular metabolism and is distributed by blood and lymph to the rest of the body, and particularly to the overlying skin, for loss by radiation and convection to the surrounding air... areas of impaired blood supply show a loss of temperature due to retarded cellular metabolism. Heat loss by convection cannot easily be measured, but heat radiation in the infrared section of the spectrum can be measured accurately and shown on a screen, from which a pictorial representation can be made.”

Verhonnick et al32 published the first article on the use of infrared thermography in human volunteers to measure vascular responses to warmth, cold, and pressure in an attempt to assess risk of pressure ulcer formation. In their preliminary report, the authors cite the resolution and information obtained on the induced lesions and the advantage of being able to appreciate the temperature patterns of the contextual tissues as unique benefits of infrared thermography. Thermography has undergone significant technological advances, including the use of infrared thermographic cameras/thermometers that perform a computerized analysis of temperature patterns emanating from solid surfaces.

Methods

An observational, retrospective, correlative study was conducted of recorded skin temperature observations on PRIDAS during routine consults. The study was approved by the institutional review board of Staten Island University Hospital where the records were generated. Consent was waived as personally identifiable data were not collected for this report and skin temperature observations were part of standard documentation for skin integrity consultation during the study period. The investigator tracked the medical record numbers of patients who met the inclusion criterion and periodically retrospectively extracted the data for the study. Linkage data to patient identity were destroyed once data collection and preliminary analyses were completed.

Setting. The study was conducted in an urban 714-bed university hospital comprised of two facilities, 10 miles apart. Only patients admitted to medical/surgical, ventilator, and critical care units were included, because these units regularly use skin integrity consultation services. Each medical/surgical unit had a subspecialty predominance of patients (eg, renal, cardiac/telemetry, medical geriatric, and oncology).

Sample. All records of patients with a PRIDAS identified during skin integrity consult assessments between August 2009 and February 2011 were included in this analysis. Initial reasons for consultations were to assist nursing staff in identifying DTI (an educational initiative) and to examine and assess patients
with extensive and/or nonresolving skin integrity issues. All consultants were documented in the patients’ progress notes.

Inclusion criteria. Inclusion criterion was a record of a directly observed PRIDAS measuring at least 4 cm² by the PI and hospitalization >6 days. If a patient had more than one PRIDAS documented at initial assessment, only data on the largest PRIDAS per patient were obtained as part of the routine skin integrity consult, only one PRIDAS per patient was included in the study.

Exclusion criteria. Patients were excluded if they had a lower extremity PRIDAS and chart documented lower extremity peripheral vascular disease. Patients with blisters or disrupted skin over the PRIDAS were excluded, because these injuries do not meet the definition of PRIDAS (ie, they are not intact skin). Patients also were excluded when PRIDAS occurred over scar tissue, because little is known about the transmission of temperature via scarred skin versus normal skin. Patients with PRIDAS that presented as potential diabetic foot ulcers (by history) were excluded because abnormal vascular dynamics are common in this patient population.

Patients were assigned a study number unrelated to any of the patients’ identifying information. The PI was the only person with knowledge of the patients’ identifying information so, in the event study data needed to be re-confirmed, the medical record could be re-reviewed during the study period only.

Procedure. All data were acquired and recorded during routine skin integrity consultation. The skin integrity consultations occurred in response to a call from nursing staff when there was concern about a patient’s skin condition. PRIDAS were found incidental to the initial assessment. It was not common practice for the nurses to request a skin integrity consult regarding discolored areas that had not advanced to an obvious, demarcated DTI. The PI maintained a handwritten log of potential patient records for study follow-up. Study inclusion during daily consultations. The PI abstracted the data and forwarded the data to the statistician to be entered into a database in the STATA 8.2 program (StataCorp, College Station, TX) for accumulation and analysis at the end of the study.

The following PRIDAS variables were abstracted from the patient records: size, site, and color; skin temperatures of PRIDAS center and normal adjacent skin (5 cm to 10 cm from the margin of the PRIDAS); PRIDAS capillary refill status (positive = <3-second color change from pale/blanched to pink or baseline color when fingertip pressure is applied; negative = blanched status persisting >3 seconds or no blanching at all with fingertip pressure, in accordance with relevant NPUAP guidelines); and presence/absence of demarcation. Demographic data abstracted included reason for admission; patient age; skin color; gender; number of comorbidities; core body and ambient room temperatures; number and stage of other, nonstudy pressure ulcers; Braden Risk Score at time of assessment; patient’s restraint status; presence of mechanical ventilation; body mass index (BMI); and serum albumin at the time of consult. At follow-up 7 to 14 days after the initial assessment, the following data points were abstracted: the presence/absence of demarcation, color of the study PRIDAS, and presence or absence of necrosis.

Skin temperatures were not measured during the follow-up assessment. The demographic and PRIDAS appearance data collection tool were investigator-designed. Members of the research committee assisted in refining the tools, which were then piloted by the PI to test for ease of use. The PI performed skin and temperature assessments and recorded the findings as part of the skin consult, which is a permanent part of the patient’s medical record.

Skin temperature measurement. A commercial, handheld infrared thermographic device was used (the Flir T7, Flir Systems, Boston, MA), originally selected for its clinical utility in the PI’s practice and based on the manufacturer’s reports of reliability and validity (available at: www.professionalequipment.com). This device was purchased from Professional Equipment online. It is calibrated by the manufacturer (Flir) before shipping and automatically recalibrates itself approximately every 75 seconds while in operation.

Skin and ambient room temperatures were obtained with the
Table 4. Presence of skin necrosis of pressure-related intact discolored areas of skin (PRIDAS) by initial capillary refill assessment after 7 to 14 days

<table>
<thead>
<tr>
<th>Presence of capillary refill (blanching) on initial assessment</th>
<th>Presence of skin necrosis (7 - 14 days later)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Yes n (%); 55 (64.7)</td>
<td>43 (78.18)</td>
<td>12 (21.8)</td>
</tr>
<tr>
<td>No n (%); 30 (35.3)</td>
<td>12 (40.0)</td>
<td>18 (60.0)</td>
</tr>
<tr>
<td>Total n (%); 85 (100)</td>
<td>55 (64.7)</td>
<td>30 (35.3)</td>
</tr>
</tbody>
</table>

Figure 3. This PRIDAS on a patient’s left heel has a skin temperature of 28.1°C and an adjacent skin temperature of 30.3°C, a temperature differential of 2.1°C. This PRIDAS progressed to necrosis.

noncontact, noninvasive Flir i7 infrared camera/thermometer, which has a temperature sensitivity of <0.1°C at a distance of 2 feet and an adjustable emission factor that can be set to the exact emissivity of skin. The physical property of emissivity, or normal heat radiation properties of solid surfaces, determines accuracy of the infrared temperature measurement. A perfect emissivity value is 1.0. Because the emissivity of skin (.97) so closely approximates the perfect emissivity, thermography is an excellent tool for the assessment of skin perfusion. A major advantage of using the Flir i7 over conventional infrared thermometers to measure temperatures of PRIDAS and normal skin is the ability to set the temperature range to allow variable sensitivity. The PI set the range at 26.8°C to 37.8°C to detect very small differences in temperature. The sensitivity of this device allows detection of the actual temperature margins of the PRIDAS, whereas the human eye is only equipped to see the discolored margins of the PRIDAS. The device was used in accordance with the manufacturer’s directions (www.professionalmedical.com) (see Figures 1 through 4).

Statistics.

Sample size calculation. Assuming, based on experience, the rate of progression to necrosis in the groups of PRIDAS warmer centers (warm PRIDAS) and cooler centers (cool PRIDAS) compared to the surrounding skin is 20% and 80%, respectively, and assuming, based on experience, the ratio of number of warm PRIDAS to that of cool PRIDAS is 2:1, a total of 40 warm PRIDAS and 20 cool PRIDAS were calculated as required to achieve statistical power of 95% based on a 5% significance level. (The values warm PRIDAS and cool PRIDAS were based on animal studies and experience.) Taking into account an attrition rate of approximately 20%, a total of 75 PRIDAS was estimated to complete this study.

Statistical analysis. The proportion of PRIDAS that progress to skin necrosis in the two groups were compared using the chi-square test for the first hypothesis.

Results

The total number of patients in the study was 85. All records meeting inclusion criteria were included; there was no attrition. Ten additional records over the original plan of 75 participants were collected when the proportion of warm-to-cool PRIDAS did not occur at the rate predicted during study planning (see Discussion).

The patients in each group (warm PRIDAS versus cool PRIDAS) were similar in age, skin color, gender, race, serum albumin levels, and BMI. The majority of patient consults (87%) occurred in patient care areas with the largest volume of admissions — ie, the medical/surgical units. The most outstanding differences between the two groups (warm PRIDAS versus cool PRIDAS) were the increased percentage of patients with cool PRIDAS who were on ventilators as compared to patients with warm PRIDAS, and the increased percentage of patients with cool PRIDAS who had an admitting diagnosis of infection as compared to patients with warm PRIDAS. However, neither of these differences reached a level of statistical significance. The characteristics of the patients and their PRIDAS are summarized in Table 1.

Thirty (30) PRIDAS had warm centers and 55 PRIDAS had cool centers when compared to adjacent skin (see Table 2). None of the PRIDAS had the same temperature as adjacent skin. The mean temperature difference between warm PRIDAS and cool PRIDAS when compared to adjacent skin was 1.20°C and -1.20°C, respectively (P <0.001).

The proportion of cool PRIDAS that progressed to skin necrosis was significantly higher than the proportion of warm PRIDAS (52.7% versus 3.3%; Pearson chi-squared value [1 degree of freedom] = 20.7; P <0.0001). Patients with black skin color had a slightly higher odds ratio (7.7 times more likely to progress to necrosis) than white patients, but the difference did not reach a level of statistical significance (see Table 3). Although not all PRIDAS with a cool center progressed to necrosis, the majority showed discoloration, demarcation, and other signs of DTI at days 7 to 14.
Table 5. Incidence of skin necrosis after 7 days by baseline pressure-related intact discolored areas of skin (PRIDAS) temperature and capillary refill (blanching)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Capillary refill negative and warm PRIDAS</th>
<th>Capillary refill negative and cold PRIDAS</th>
<th>Capillary refill positive and warm PRIDAS</th>
<th>Capillary refill positive and cold PRIDAS</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 (75.0)</td>
<td>1 (25.0)</td>
<td>9 (43.62)</td>
<td>17 (65.38)</td>
<td>26 (100.0)</td>
<td>55 (64.71)</td>
</tr>
<tr>
<td>4 (100.0)</td>
<td>0 (0.0)</td>
<td>26 (100.0)</td>
<td>26 (100.0)</td>
<td></td>
<td>30 (35.29)</td>
</tr>
<tr>
<td>17 (58.62)</td>
<td>12 (41.38)</td>
<td>29 (100.0)</td>
<td></td>
<td></td>
<td>85 (100.0)</td>
</tr>
</tbody>
</table>

a warm center. No PRIDAS were found to have the same temperature as the adjacent skin (data not shown).

Originally, the PI expected a preponderance of warm PRIDAS (warm defined in comparison to the adjacent skin temperature), but in actuality, cool PRIDAS outnumbered warm PRIDAS by 2:1 at initial assessments. An additional 10 records were examined to verify that cool PRIDAS was a consistent occurrence and not an artifact of consecutive enrollment. The additional 10 patients exhibited the same ratio of warm PRIDAS to cool PRIDAS and are included in this report. One explanation for the unexpected low number of warm PRIDAS may be that this level of skin injury (hyperemia) is very superficial and most often resolves. According to the NPUAP guidelines, a Stage I ulcer may be an indicator of a high-risk area, implying it is not an indicator of an actual or underlying, potential pressure ulcer. Quick resolution was unlikely to trigger a skin integrity consult, so few warm PRIDAS were examined by the PI.

The historical, essential assessment of PRIDAS to assign stages has been blanching versus nonblanching, also described as positive capillary refill versus negative capillary refill. In the original guidelines established by the International Association of Enterostomal Therapists (IAET), 38 "persistent erythema" was labeled a Stage I pressure ulcer. In 1993, the NPUAP defined a Stage I as "nonblanchable erythema." The results of this study indicate that capillary refill is insufficient to detect DTI beneath an intact but discolored skin lesion. More than 20% of PRIDAS with blanchable erythema progressed to necrosis, while 47% of nonblanchable skin injuries did not progress to necrosis. These results add weight to a recent consensus among pressure ulcer experts calling for the discontinuation of pressure ulcer staging. 39

A more accurate approach to identifying DTI under PRIDAS than blanching is needed. This study supports the use of thermography to determine the viability of tissue when a Stage I skin injury is apparent. That is not to suggest that capillary refill is not useful. In this study, when used together, positive capillary refill and a warm PRIDAS center, with warm defined in relationship to intact, adjacent skin, 100% of PRIDAS progression can be ruled out.

The NPUAP definition of Stage I pressure ulcer is controversial because it was initiated as a consensus, not based on scientific evidence and research. The finding that 47.27% of the cool PRIDAS recovered is consistent with the scenario put forth by Farid 1 and the findings of Jiang et al. 29 on reperfusion injury. The results of the current study suggest that combining thermography with capillary refill assessment can increase the accuracy of staging. PRIDAS with cool centers and negative capillary refill can be considered suspected DTI until actual clinical outcomes are apparent; and
when both surface skin temperature (comparing PRIDAS center with intact adjacent skin) and blanching were used, the prediction rate for subsequent necrosis increased to 65.38%.

One patient not included in the study presented with a cool PRIDAS on the dorsal foot over the navicular bone (2 cm²) at the time of a skin integrity consult. This is an area without much subcutaneous padding — i.e., basically skin over bone. Although the patient was discharged before a follow-up consult could be performed a week later in the hospital, he was followed up incidentally a week later during wound care rounds in the nursing home where he had been admitted. The area was almost healed and had not opened into a wound, but substantial redness and superficial layers of dry, peeling dead skin could be observed; apparently, this PRIDAS was one that was able to recover.

The study did not compare surgical patients and nonsurgical patients. Very few patients studied were status post surgery except for tracheostomy and percutaneous gastrostomies. Two patients had been admitted for hip fractures: one was lost to follow-up and dropped from the study, but the other presented with PRIDAS on both unilateral buttock and same-side heel. Both of these PRIDAS were cool as compared to the adjacent normal skin and both became necrotic after 7 days. Only the buttock PRIDAS was entered into the study.

**Incidental findings.** Use of thermography was helpful in detecting other patient conditions not yet visible on examination. One such incidentally found condition was an infarcted lower extremity below the knee. When the reddened heel was assessed with the thermography camera, the scan showed the leg was room temperature from mid-calf and below. A similar observation was made when using the thermography to examine an ulceration on the second toe of a patient whose great toe on the same side had already been amputated. Instead of discovering a hot, inflammatory reaction on camera as was expected, the second toe and the fifth toe were noted to be much cooler than the other toes, triggering a vascular workup that resulted in successful bypass surgery. On nursing home wound rounds, the thermography camera was useful in detecting deep abscesses on the buttocks and perianal/sacral areas that are more common in the elderly (infectious processes show up “hot” in relation to surrounding tissues). This was helpful in treatment and kept these areas from being labeled as emerging DTIs or Stage III or Stage IV ulcers after incision and drainage.

This study demonstrated the value of skin surface thermography in PRIDAS in identifying previously undetected DTI. Replication is urged to extend findings to other settings and populations. With additional data, thermography may emerge as the method of choice (PRIDAS center temperature) to determine the presence or absence of DTI beneath an apparent Stage I pressure ulcer. Findings supported that cool PRIDAS are moderately associated with undiagnosed DTI.

**Limitations**

Several factors can influence skin temperature. These factors were taken into consideration during the data collection. The temperature of the center of the PRIDAS and adjacent skin temperatures were close together in distance (5 cm) and simultaneously exposed to the potential effects of internal and external temperature differences. The net impact of ambient, core, and gradient temperature (from skin not near PRIDAS) was calculated to be essentially nonexistent. This judgment is supported by finding the same mean difference between warm PRIDAS and adjacent skin and cool PRIDAS and adjacent skin (i.e., ± 1.20° C).
This study used a single device to measure surface skin temperature; it is not known if other thermography or temperature-measuring devices would yield similar results. Also, many PRIDAS <4 cm² that precede a DTI may not be detected by the thermography camera because of the conduction of heat from the surrounding tissues. However, on consult, all PRIDAS were documented, including the temperatures (center and adjacent) and, even though these PRIDAS were not included in the study, it was discovered that the camera was sensitive enough to record lower temperatures where present on most ulcers.

Implications for Practice
This study underscores the changes in the local physiology of human tissues subjected to pressure trauma that heretofore were only suspected based on results of preclinical studies. The findings also suggest that warmer PRIDAS have a much better chance of recovering from pressure than cooler PRIDAS. By employing the techniques used to collect the data in this study, clinicians have the ability to predict the outcome of blanchable and nonblanchable PRIDAS with a higher degree of certainty. Accurate identification of PRIDAS potential to progress to necrosis underscores the actual severity of Stage I, nonblanchable erythema damage to the underlying tissues — ie, 65% of lesions progressed to skin necrosis even though all patients were placed on special, integrated, computerized pressure-relief surfaces and additional prevention interventions were consistently observed. It is not clear if one or all of these interventions contributed to recovery of the PRIDAS that did not progress. Nevertheless, based on this study, a PRIDAS requires close monitoring. When incorporating skin temperature into routine assessment, the actual temperature needs only be taken upon first discovery of the PRIDAS. Follow-up monitoring would consist of assessment for recovery or progression. The large number of PRIDAS that recovered may be due to early intervention, but more information about the timelines and bundling of interventions is needed. This study also has important implications for nurse educators. The results suggest that physiological terminology, including PRIDAS, reperfusion injury, and the forensic term time since death as applied to localized dead tissue changes can be introduced into discussions of pressure ulcer development.

Implications for Research
These study results provide a starting point for future research into the detection and progression of DTIs and confirm that local tissue death reflects the same progressive decomposition that forensic pathologists and anthropologists have described with regard to the whole human body. The time frame used for follow-up of study PRIDAS closely reflects the time line of decomposition dependent on the major variables of temperature and moisture. Additional research to further develop the picture of PRIDAS progression and to test the prospective validity of thermography is needed. Developing measures to identify serious pressure-related skin injury, especially on admission or after a critical decline in condition, is essential to prevent complications, provide effective care, and promote patient comfort. One area that needs further exploration is the use of ultrasound to detect DTIs before skin changes occur. Although this study found that the PRIDAS appear very early in relation to when the DTI appears (7 days), ultrasound may find that the period between the development of the DTI at the level of the bone and the appearance on the skin may actually be longer.

Another detection method that warrants further study is the feasibility and predictive validity of including comments on the soft tissues over the sacrum, buttocks, and hips whenever a CT scan of the abdomen or pelvis, a frequently ordered test, is performed. The term used by radiologists to describe nonspecific changes/disorders in the muscle attached to bone is enesthesiopathy. At the authors’ facility, more than a few DTIs were found incidentally on CT several days before any skin changes. MRIs would be even more sensitive to soft tissue changes. However, thermography of skin by the clinician at the bedside to augment capillary refill findings in the examination of a PRIDAS is the most sensitive tool in this venue and can be used immediately on recognition of the reddened area, eliminating delay.

An incidental finding by the PI, when reassessing study patients on days 2 through 6, before performing the 7- to 14-day study follow-up, was that the PRIDAS often disappeared before the appearance of the DTI. This underscores the importance of assessing PRIDAS when first discovered and the need for research in this area. It is not known how many DTIs actually resolve before the skin changes appear — ie, no skin changes or only minor signs, for example, a dimple from subcutaneous scarring, occur.

Further understanding of the pathophysiology of pressure-related skin injury is needed. It is possible that the ability of half of the cool PRIDAS to recover occurred as a...
result of reperfusion where there was no injury. It may be that reperfusion first manifests as cool. The phenomenon of reperfusion injury is relatively new to the study of DTI development. Although reperfusion plays a major role in revascularization procedures, less is known about the role of reperfusion interventions for pressure ulcers — ie, is reperfusion affected by patients' comorbidities, age, or other factors? Additional research with thermography in specific populations may help build understanding of pathology and target effective interventions.

Another interesting observation made by critical care nurses that requires additional research is that patients who receive therapeutic hypothermia in the field for acute cardiac failure related to acute myocardial infarction and survive rarely have an incidence of DTI during their first week of admission, even under the most extreme conditions of hypothermia of the tissues (shock). This would be another skin temperature avenue to explore: preventive manipulation of skin temperature for DTI prevention.

Conclusions

The results of this study suggest skin temperature measurement of PRIDAS compared to the normal adjacent skin can assist in the detection of underlying skin necrosis. Cool PRIDAS are 31.8 times more likely to progress to necrosis than warm PRIDAS. When a warm PRIDAS with a positive capillary refill was identified, potential skin necrosis was ruled out at a rate of almost 100%. These findings impact on the current NPUAP staging guidelines' definition of Stage I pressure ulcers, because what is considered an at risk lesion by the guidelines is apparently an early presentation of a DTI with all the implications for progression to Stage III and Stage IV ulcers. Thermography is a promising technique to more accurately stage discolored, intact skin and identify DTI. With further, larger multisite replication and prospective validation studies, nurses may have an improved approach to identifying patients with DTI before necrosis manifests 7 to 10 days after initial presentation of skin discoloration.

References