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Sacral Skin Temperature Assessed by Thermal Imaging

Role of Patient Vascular Attributes

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ABSTRACT

PURPOSE: The purpose of this study was to test the hypothesis that temperature differentials measured by thermal imaging of sacral versus a remote skin area in critically ill patients differentiate those with significant vascular disease and risk for pressure injury of the sacral area.

DESIGN: Prospective cohort study.

SUBJECTS AND SETTING: The sample comprised 100 patients (58 men, 42 women) with mean ± SD ages of 70.4 ± 14.4 and 74.0 ± 14.5 years, respectively, who were admitted to a cardiovascular intermediate care unit or a neurosurgical intensive care unit in the southeastern region of the United States.

METHODS: A commercially available thermal imaging system was used to obtain simultaneous standard photographic and infrared thermal images (11 × 14 inches) that included the patient's buttocks and a remote skin area after the patient was off-loaded for about 4 minutes. Images were processed to determine temperature differences between the sacral region (deemed to have an elevated risk for pressure injury) and a remote region of the skin located at least 10-cm proximal to the sacrum, with an average sacrum-to-remote distance of 17.9 ± 3.0 cm that was deemed to be at minimal risk. Prior measurements of healthy subjects showed that sacral skin was on average 0.75°C less than the remote skin site ($\Delta T = -0.75$°C). For the present analysis, a threshold ΔT_{TH} of twice that amount ($\Delta T = -1.5$°C) or more was considered to put a patient at greater than normal risk based on the hypothesis that low sacral temperatures were associated with lowered blood perfusion issues of various clinical conditions. The vascular status of patients who equaled or exceeded this threshold was compared to the other patients.

RESULTS: Thirty-two patients exceeded ΔT_{TH}, with an average ΔT of −1.92°C ± 0.62°C. In 6 patients, ΔT was greater than +1.5°C, with average of +1.98°C ± 0.49°C. The remaining 63 patients had an average ΔT of 0.13°C ± 0.58°C. Chi-square analysis of the proportions of patients exceeding or not exceeding thresholds in relation to their known vascular disease status revealed no significant difference between these subgroups.

CONCLUSIONS: Although infrared thermal screening may provide visually impressive and potentially useful images in some cases, the use of temperature differentials to detect patients at particularly high risk for pressure injury owing to local blood flow is not supported by results of this study.

KEY WORDS: Pressure injury, Pressure ulcer, Pressure ulcer risk vascular status, Sacrum, Skin breakdown, Thermal imaging.

INTRODUCTION

Hospital-acquired pressure injuries (HAPIs) are a common and substantial burden on the health care system, with more than 2.5 million patients in acute care hospitals treated in the United States annually.[1] Managing pressure injury (PI) is estimated to cost the US health system from $9.1 billion to $11.6 billion per year.[2] Beginning in 2008, the US Centers for Medicare & Medicaid Services (CMS) ruled to discontinue reimbursement related to additional costs associated with certain hospital-acquired conditions including a stage 3 or stage 4 PI. According to CMS, the price of managing a single, full-thickness HAPI in acute care (as a secondary diagnosis) costs an additional $43,180.00 per hospital stay.[3] A primary concern to health care providers is the significant health-related costs incurred by those patients suffering from HAPIs. The consequences of HAPIs on a patient's quality of life may include unnecessary pain, costly treatment, increased length of hospital stays, greater comorbidity risk, burden to family, and mortality. It is estimated that each year, up to 60,000 Americans will die prematurely of PI-related complications.[4] The current National Pressure Ulcer Advisory Panel (NPUAP) staging system delineates a stage 1 PI as a pressure-related area of intact, discolored skin, with localized nonblanchable erythema.[5] Stage 1 PIs are considered reversible in that no irreparable tissue damage has occurred. A variant type of PI, referred to by the NPUAP[5] guidelines as a deep tissue pressure injury (DTPI), presents as a darker red or purple area of skin that may be characterized by intact skin or a blood-filled blisters reflecting damage to underlying soft tissue from pressure and/or shear. The depth or character of tissue damage of a DTPI cannot be determined by visual inspection, and variations in pain and temperature may proceed any visually detectable changes in skin color.[5]

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The conflicting nature, given the staging criteria, for distinguishing between these 2 injuries is based solely on observable and palpable characteristics of the skin and is not reflective of their distinctive characteristics. In the case of a DTPI, the outward pattern of necrosis that ensues underneath an area of intact skin has been speculated to progress as rapidly as 48 hours from injury to initial appearance and within 7 to 10 days for further deterioration into a necrotic, full-thickness stage 3/4 HAPI, regardless of interventions.[6,7] Drawing from observations taken from forensic science, Farid[8] reported a 7- to 14-day time span between when the initial tissue injury is thought to occur and the first clinically observable signs of the injury as it progresses toward necrosis.

It has been stated that more than 100 physiological (intrinsic) and nonphysiological (extrinsic) risk factors place adults at greater risk for developing a PI.[9] Malnutrition, hypotension, incontinence, cerebrovascular disease, diabetes, and fractures have been associated with PI development among national inpatient populations, and patients admitted to intensive care units (ICUs) are at greatest risk for developing HAPIs.[10] Kirkland-Kyhn[11] retrospectively reviewed a group of critically ill patients who developed a sacral DTPI that evolved into a stage 3, stage 4, or unstageable HAPI. Kirkland-Kyhn[11] found that the odds of developing a DTPI increased by approximately 7.5% for each mm Hg decrease in diastolic blood pressure, placing those with poor blood perfusion at greatest risk for developing one of these injuries. This finding may indicate greater vulnerability for tissue breakdown, particularly in critically ill patients, as hemodynamic status is progressively impaired. A review by Berlowitz and Brienza[12] suggests that most HAPIs, even those that appear superficial enough to be pressure-induced, developed as a result of a precursory DTPI.

While HAPIs are a known concern for hospitalized patients with vascular disease,[13] it is unknown if all such patients are similarly at risk. To date, there is no noninvasive method that clinicians can use to expediently and efficiently determine which patients with vascular disease are most likely to develop a DTPI. Measuring skin temperature is one potential strategy that may allow health care providers the ability to prospectively determine if an area of intact discoloration will eventually progress into necrosis. A study by Farid and coworkers[14] used thermography to discern between cool and warm surface temperatures of pressure-related areas of intact and discolored skin (suspected areas of a DTPI). Farid's group found that by day 7, areas at the discolored site had cooler temperatures and were 31.8 times more likely to progress to necrosis than adjacent warm regions.[14]

Thermography is a noninvasive and objective technique to index or estimate local hemodynamic status based on skin temperature differentials between and among different sites. An underlying assumption is that tissue regions with blood flow deficits will render skin temperatures less than those in regions not affected. We hypothesized that such temperature differentials are more pronounced in persons with cardiovascular disease (CVD) and related conditions resulting in diminished perfusion pressures due to regional vascular deficits or systemic hypotension. We hypothesized that patients with such conditions have a lower relative sacral skin temperature that can be detected via a rapidly obtained thermal image. We tested this hypothesis by examining temperature differentials between a common area for HAPI formation (sacrum) and a remote skin site. A remote skin site was chosen that was at least 10-cm distant and proximal to the target sacral site and to be in an area well visualized in a photographic image taken of the sacrum and surrounding areas using a commercially available thermal imaging system.

METHODS

We completed a prospective observational study that evaluated a cohort of patients admitted to a cardiovascular intermediate care unit (cardiovascular-ICU step-down unit) or a neurosurgical ICU in the southeastern region of the United States.

Requirements for participation were as follows: (1) adults 18 years or older who were admitted to one of the 2 critical care units described earlier, and (2) individuals willing to remain in a lateral recumbent position for about 4 minutes; this time frame was needed to stabilize the exposed skin to ambient temperature. Exclusion criteria included those deemed intolerant to positioning due to physiological instability or other physiological considerations as determined by their attending RN and those with preexisting sacral PIs. Study procedures were reviewed and approved by the Western institutional review board (WIRB no. 1163595).

Image Capture Procedure

The imaging device was a commercially available, Food and Drug Administration–approved imaging system (Scout SCA100; Wound Vision LLC, Indianapolis, Indiana).[15,16] It produces simultaneous infrared thermal and standard photographic images. Prior to imaging, patients were repositioned to a lateral recumbent position necessary to completely expose the sacral and lower back areas. All clothing or sacral dressings were removed from the patient's backsides, allowing the areas to acclimate to the room air for about 4 minutes. This time window was chosen as a compromise to minimize the discomfort to the patient and yet have as much time as possible to allow for any recovery due to the prior lying time. The ambient room temperature was measured using a handheld digital thermometer, and values were recorded just prior to each subject being imaged; it was fairly constant at 22.2°C ± 0.6°C (mean ± SD).

The buttocks and lower back areas were imaged via a handheld imaging device held at a distance of 18 inches from the skin. Positioning was aided by a device feature that provided a visual image of an overlapping laser target on the skin indicating the proper imaging distance. Nothing was in contact with the subject's skin during the time the image was captured, unless a pair of gloved hands was needed to assist with positioning and exposure of the site. The captured image consisted of a standard digital photograph of an 11 × 14-inch (28 × 35.5-cm) area together with a long-wave infrared thermal image of the same area. This image chosen for subsequent analysis was at or near its center of the target sacral site; we also imaged a remote skin site located proximal to the sacral site and at least 10-cm distant. The thermal image provided a real-time temperature mapping of the entire area. Images were uploaded and stored to a designated computer linked to the imaging device hardware and software. They were stored in the system software using randomly generated subject numbers unrelated to any of the patient's identifying information. Pertinent patient medical history and follow-up information were obtained using the hospital's electronic medical record system.

Image Analysis Initial Procedures

All images were analyzed by a coinvestigator (P.S.) who was not present or involved during the image acquisition phase.

Further, the image analysis was completed prior to any knowledge of the medical condition or past history of the patient. The analysis procedure was standardized as illustrated in Figure 1. Starting with the standard digital image (Figure 1A), a reference point was marked at or near the sacral end of the intergluteal cleft and a reference grid was superimposed over the image (Figure 1B) to define absolute distances as needed. A remote skin site was then selected as a control temperature site (Figure 1C). This site was always selected to be proximal to the target sacral region of interest, with an average distance of 17.9 ± 3.0 cm from the sacrum. We then obtained the thermal image (Figure 1D). A 1-cm^2 circular control area was placed at the previously selected remote point. The average temperature within this control area was subsequently compared to the average temperature in a target area, which is shown inscribed in the sacral region (Figure 1F). Temperature differentials are expressed as follows: ΔT = sacral temperature − control temperature. The system software calculates the average temperatures within the target sacral area and the control area. Examples of patients with different temperature profiles of −1.5°C, +1.5°C, and 0°C when compared to the distal (control) skin area are illustrated in Figure 2.

Data Analysis

Prior measurements of sacral skin temperatures in healthy subjects indicated that sacral skin temperature is on average 0.75°C less than a remote skin site ($\Delta T = -0.75$°C).[17] For the purpose of this analysis, a ΔT of twice that amount ($\Delta T = -1.5$°C) or more was considered to place a patient at greater risk for PI. This value was selected based on the hypothesis that reduced relative sacral temperatures of this magnitude are associated with a clinically relevant decline in local blood perfusion. Comparisons of sacral to control area temperature differentials were used to categorize patients as either high risk for a PI ($\Delta T \geq -1.5$°C) or low risk for a PI ($\Delta T < -1.5$°C). In addition, 3 groups were identified to assess whether temperature differentials were significantly associated with conditions related to impaired blood perfusion to the skin. The first was a prior diagnosis of CVD. We operationally defined CVD as any patient with a diagnosis of coronary artery disease (CAD), peripheral arterial disease, or atherosclerotic heart disease. The second group comprised patients who experienced a mean arterial blood pressure (MBP) of less than 60 mm Hg at any time during their hospital stay. A third group comprised patients who had both CAD and MBP of less than 60 mm Hg (CVD + MBP). The potential consequence of vascular status and temperature differentials was examined by considering the number of patients within each group who had ΔT of −1.5 or less compared to those with ΔT of more than −1.5 using χ^2 analysis. In this analysis, the significance level taken to reject the null hypothesis of equality was less than .05.

RESULTS

The sample comprised 100 patients; 58 were men and 42 were women. The mean ± SD age of male and female participants was 70.4 ± 14.4 and 74.0 ± 14.5 years, respectively. Their average length of hospital stay was 11.9 ± 11.3 days, with the day of imaging being on their 5.4 ± 6.9 hospital-day. Their cumulative Braden Scale for Pressure Sore Risk score was 16.5 ± 4.0; 38 of the 100 had diabetes mellitus. Of the 100 patients, 74 had CVD, 42 had either acute or chronic renal dysfunction, and 15 had peripheral arterial disease. A total of 14 patients went on to develop a sacral PI.

Temperature Differentials

Thirty-two patients had sacral to control area temperature differentials that met or exceeded the −1.5°C threshold. The average temperature differential was −1.92°C ± 0.62°C (range: −1.5°C to −3.9°C). In contrast, 6 patients had a temperature differential that was +1.5°C or more; their average differential was +1.98 ± 0.49°C (range: 1.5°C-2.7°C). The remaining 63 patients had an average temperature differential of 0.13°C ± 0.58°C (range: −0.90°C to 1.3°C).

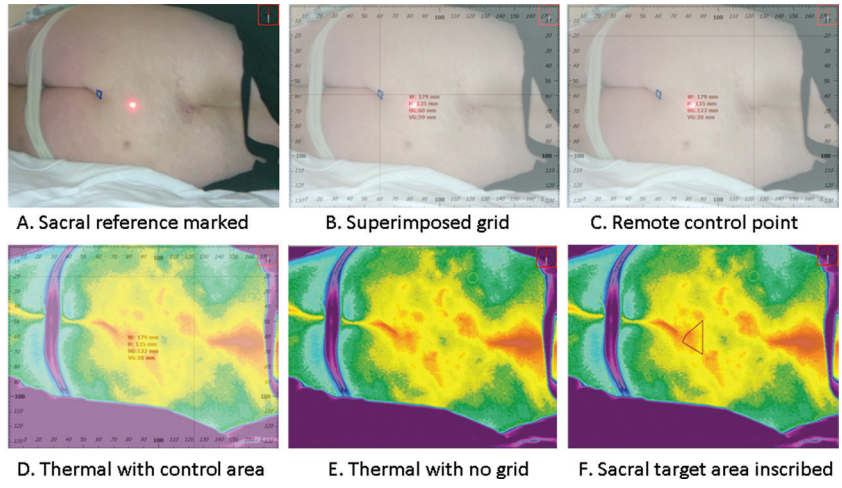

Figure 1. Image analysis preliminary procedures. (A-C) Sample digital images. (D-F) Thermal images. (A) Starting with the standard digital image, a reference point is marked at or near the sacral end of the intergluteal cleft. (B) A reference grid is superimposed to define absolute distances as needed. (C) A remote skin site is selected as a control temperature site. (D) On the thermal image, a 1-cm^2 circular control area is placed for subsequent comparison to the sacral target area. (E) The control area shown without the superimposed grid. (F) Target area inscribed within the sacral region on the thermal image. The system software calculates the average temperatures within the target sacral area and the control area. In this example, the average temperature in the target area was 1.3°C greater than that in the control area. The imbedded text in panels B, C, and D is internal location information and not relevant to the illustrative material shown in the figures.

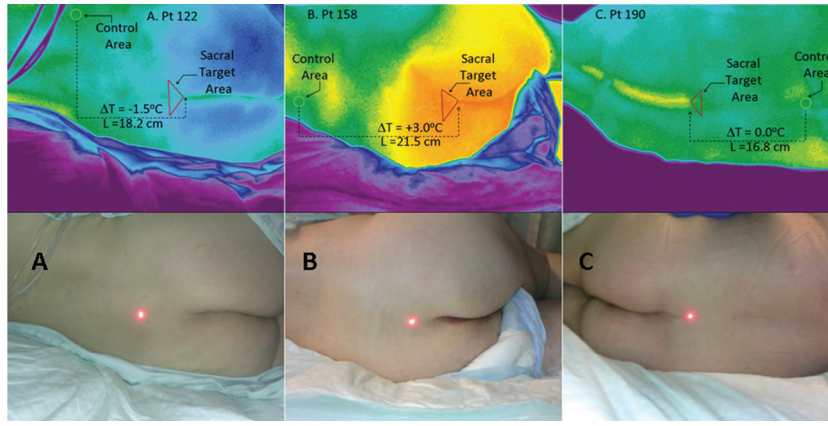

Figure 2. Representative images. Top row shows thermal images, and bottom row shows corresponding digital photograph of the same area. In each case, the superimposed text on the thermal images shows the distance from the control area to the sacral target (L) and the temperature difference (DT) between these areas. (A) Target area 1.5°C less than the control. (B) Target area 1.5°C greater than the control. (C) Target temperature is the same as that of the control.

A significant portion of patients had CVD (n = 74), MBP of less than 60 mm Hg (n = 58), or both CVD and MBP of less than 60 mm Hg (n = 43). The Table summarizes the relationships between the presence or absence of these conditions and a ΔT indicating a clinically relevant difference in perfusion. Analysis via χ^2 indicated no statistically significant differences.

We found no significant differences in temperature differentials in patients with DTPIs. Of the 16 patients with a documented DTPI, 7 had a documented sacral PI but only 2 had prior sacral to control area temperature differences of −1.5°C or less. Moreover, of the 14 patients with a documented PI, 5 were observed to have prior temperature differentials that were −1.5°C or less.

DISCUSSION

We determined whether critically ill patients with vascular impairments would have a lower skin temperature measured via thermal imaging over the sacral skin to a remote skin area with a lower tissue load when placed in a lateral recumbent position. Study findings indicate that patients with or without underlying vascular disease or low perfusion pressures may present with lowered relative sacral temperatures, suggesting that such temperature gradients, in and of themselves, do not differentiate patients with CVD, MBP of less than 60 mm Hg, or a combination of these conditions from patients without these conditions. In addition, temperature differentials did not differentiate which patients with a DTPI went on to develop a sacral PI.

It is our belief that the absence of a clear separation is in part related to the specifics of the underlying vascular deficit. For example, a patient with documented peripheral arterial disease may or may not have a blood flow deficit of the sacral skin based on the location and extent of the underlying vascular lesions. Similarly, patients with documented CAD may or may not have perfusion deficits in the sacral region detectable via thermal imaging. Our findings suggests that a clearer separation may be achievable if more specific and detailed vascular data were available than the broad diagnoses of patients in this study.

LIMITATIONS

The 4-minute window was the maximum time many of the subjects could tolerate lying on their side. While this is a limitation, it is also represents a realistic clinical consideration when evaluating the true utility of such technologies applied in the clinical setting. In order for such devices to be clinically useful, a patient's level of comfort and threshold to tolerate position changes required for imaging must be considered. Thus, although we would have liked to allow a greater time for acclimation to ambient temperature, the methods used in this study is reflective of the acute setting in which the device would theoretically be employed.

TABLE
Relationship Between Temperature and Selected Clinical Conditions Associated With Impaired Perfusion[a]

	$\Delta T \leq -1.5$°C	$\Delta T > -1.5$°C	Total Patients	χ^2	*P*
Group CVD					
With CVD	23	51	74	0.598	.439
No CVD	6	20	26		
Group MBP					
MBP < 60 mm Hg	20	38	58	2.016	.156
MBP ≥ 60 mm Hg	9	33	42		
Group CVD + MBP					
Both conditions	15	28	43	1.268	.260
Neither condition	14	43	57		

Abbreviations: CVD, documented cardiovascular disease; MBP, mean arterial blood pressure.
[a]Numeric entries are the number of patients with the specified condition and differential temperature range between the target sacral area and the control area.

Although the hypothesis of this study is not supported by the current experimental data, our findings do not exclude the utility of thermographic imaging in other settings. Thermal imaging has shown promise in predicting time to healing based on wound bed temperature[18] and as a way to improve PI detection.[19] It has also been evaluated as a way to predict outcomes of patients with discolored skin in nursing facilities.[20] As we learn more about the natural history and multiple factors that influence the development and progression of DTPIs to skin breakdown, we will be better positioned to apply thermography and other detection tools to detect and circumvent these injuries, hopefully, while they may still be reversible.

CONCLUSIONS

We tested the hypothesis that low sacral temperatures would most likely be observed in patients with vascular deficits and that if detected would identify patients at greatest risk of suffering an HAPI. However, the ability of these temperature differentials to distinguish between patients with or without vascular deficits as a measure of increased breakdown likelihood was inconclusive. While the results did not demonstrate a statistically significant reduced skin temperature between the sacrum and remote skin sites, thermographic imaging may have other uses as a potentially useful screening device to measure a patient's sacral region upon admission and throughout his or her hospital stay.

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