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Use of Thermal Imaging to Identify Deep-Tissue Pressure Injury on Admission Reduces Clinical and Financial Burdens of Hospital-Acquired Pressure Injuries

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ABSTRACT

A deep-tissue pressure injury (DTPI) is a serious type of pressure injury that begins in tissue over bony prominences and can lead to the development of hospital-acquired pressure injuries (HAPIs). Using a commercially available thermal imaging system, study authors documented a total of 12 thermal anomalies in 9 of 114 patients at the time of admission to one of the study institution's ICUs over a 2-month period. An intensive, proven wound prevention protocol was immediately implemented for each of these patients. Of these 12 anomalies, 2 ultimately manifested as visually identifiable DTPIs. This represented a 60% reduction in the authors' institution's historical DTPIs/HAPI rate. Because these DTPIs were documented as present on admission using the thermal imaging tool, researchers avoided a revenue loss associated with nonreimbursed costs of care and also estimated financial benefits associated with litigation expenses known to be generated with HAPIs.

Using thermal imaging to document DTPIs when patients present has the potential to significantly reduce expenses associated with pressure injury litigation. The clinical and financial benefits of early documentation of skin surface thermal anomalies in anatomical areas of interest are significant.

KEYWORDS: hospital admission, deep-tissue pressure injury, hospital-acquired pressure injury, long-wave infrared thermography, pressure injury, revenue preservation, thermal anomaly, thermal imaging

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INTRODUCTION

Deep-tissue pressure injury (DTPI) is a serious type of pressure injury that begins in muscle and/or other tissues over bony prominences, usually as a result of pressure, ischemia, and/or shear stress that leads to cell deformation and ultimately cell death. These injuries are complicated by the potential for reperfusion injury in many patients.[1,2] Inflammatory cytokines accumulate in the ischemic region once perfusion is restored, further injuring the tissue and contributing to the migration of the injury toward the skin surface in the absence of, or despite, rescue measures.[2–4]

The National Pressure Ulcer Advisory Panel added DTPI to its pressure ulcer classification system in 2007[5] and updated its definition in 2016.[6] The definition of DTPI includes what many consider to be the current clinical standard for assessment and documentation:

> intact or nonintact skin with localized area of persistent nonblanchable deep red, maroon, purple discoloration or epidermal separation revealing a dark wound bed or blood-filled blister… The wound may evolve rapidly to reveal the actual extent of tissue injury, or may resolve without tissue loss. If necrotic tissue, subcutaneous tissue, granulation tissue, fascia, muscle, or other underlying structures are visible, this indicates a full-thickness pressure injury (unstageable, stage 3, or stage 4).[6]

The term DTPI is not used "to describe vascular, traumatic, neuropathic, or dermatologic conditions."[6] There are varying reports of how long it takes DTPIs to manifest visually from the time of tissue injury, ranging from 1 to 3 days,[7] 1 to 5 days,[8] or up to 7 days.[9] Because of this variation, patients and providers are placed at a severe disadvantage in managing, and possibly mitigating, DTPIs.

However, an important component of the DTPI definition is that reported "pain and temperature change can precede skin color change,"[6] establishing the potential utility of thermography in identifying early DTPIs, prior to visible skin changes. The reported hallmarks of DTPI development include older patients with a lower body mass index with injuries predominantly

occurring on the skin overlying the coccyx/sacrum, buttocks, and/or heels.[3,10,11] Accordingly, these anatomical areas of interest are the focus of the present study.

Hospitalized patients with pressure injuries incur substantial increases in both lengths of stay and hospital costs.[12,13] Moreover, hospital-acquired pressure injuries (HAPIs) complicate reimbursement for clinical management, can often lead to suspension of rehabilitation activities while the pressure injury is managed, increase the risk of litigation, and contribute significantly to overall costs of care.[13] There is considerable value in documenting pressure injuries as present on admission, in order to properly assign financial accountability for emergent pressure injuries. Of even greater interest is the potential for early identification of areas at risk for DTPIs, which would allow clinicians to proactively apply interventions known to reduce or prevent the further development of pressure injuries and improve patient care.[14–17] Patients in the ICU are at increased risk inasmuch as they often have multiple comorbidities.

The use of long-wave infrared thermography (or thermal imaging) in the skin assessment of DTPIs is well established[9,18–22] and aligns with the National Pressure Ulcer Advisory Panel definition that pain and temperature change often precede skin color changes. Human skin is a near-perfect emitter of infrared radiation, given its emissivity factor of 0.98 at room temperature, making its thermal imaging especially useful.[23] It has been shown that pressure-related discoloration of skin is significantly more likely to progress to pressure injury when the temperature at baseline is below that of adjacent skin.[9]

The reliability and reproducibility of temperature assessments using a commercially available, FDA-approved thermal imaging device (Scout; WoundVision, Indianapolis, Indiana) were recently demonstrated, with intra- and interreader coefficients of variation of 1% and 2%, respectively.[21] In particular, the relative temperature differential has been used as a means to minimize extrinsic and intrinsic variables known to impact absolute skin temperature measurements, by comparing the temperature of an area of interest (ie, possible DTPIs) to a control area of nearby skin known to be normal.[21] Further, the use of thermal imaging has been shown to be particularly useful in the assessment of DTPIs in patients with dark skin.[22]

An interesting clinical quandary in the thermal assessment of DTPIs has been the repeated finding that thermal anomalies in skin at risk of DTPIs can exhibit either increased or decreased temperature.[24,25] Bhargava et al[26] reconciled these seemingly inconsistent findings with a heat transfer model for deep-tissue injury, demonstrating that previously reported thermographic findings could be explained by both ischemic (skin temperature decrease) and inflammatory (skin temperature increase) conditions in the tissue underlying skin areas at risk. Therefore, skin thermography

has proven to be useful in identifying areas at risk of DTPIs by documenting either increases or decreases in skin temperature compared with adjacent normal skin.

The objective of the current study was to use thermal imaging as an adjunct to visual skin assessment techniques in newly admitted ICU patients to improve documentation, increase risk awareness of DTPIs present on admission, enhance interventions to minimize pressure injury development and improve patient care, as well as quantify and mitigate potential adverse financial consequences to the institution.

METHODS

With the prior approval of the Mt Carmel West Hospital (Columbus, Ohio) institutional review board, 114 consecutive patients admitted to ICUs within the institution during the 60-day period from June 27, 2016, and August 25, 2016 (inclusive) received a thermal and clinical assessment of areas at risk of DTPIs (bilateral heels, sacrum, coccyx) by trained study staff. Thermal assessments were performed with an FDA-approved long-wave infrared thermography scanning device (the Scout device).

Each clinician using the device was trained on the proper use of the system by qualified WoundVision staff members. Adhering to manufacturer recommendations (the Scout user manual), images were taken at a 90-degree angle to the skin surface and 46 cm away from the area of interest, as determined by range-finding lasers. The room temperature ranged from 18° C to 29° C and was free from external heating or cooling effects, including direct sunlight and fans or direct heating devices such as heating pads or space heaters. The thermal camera and software were used to evaluate the temperatures of areas of interest based on pixel values, providing an adjunctive tool to reveal and quantify temperature aberrancies that could indicate a disease process not appreciated by visual inspection alone.

Prior to imaging of the sacrum/buttocks area, particularly in patients who had been in a supine position, each subject was turned on his/her side (if possible) for a minimum of 30 seconds (known as "acclimation time"), to allow for any trapped heat to dissipate. Each subject had a reference area identified near the area of interest. A reference area was defined as an area of unaffected tissue proximal to the area of interest that (1) had a temperature variation within itself of no more than 1° C and (2) was not over a bony prominence, large blood vessel, or visible skin anomaly. The reference area is selected because it is presumably affected similarly to the area of interest by the environment and intrinsic host factors. Using a relative value for comparison should mitigate any effects of these factors in influencing skin surface temperature and isolate any temperature variations associated with underlying pathophysiology. Relative temperature differentials (area of interest vs reference area) were collected for each subject's area of interest

wherever feasible. Table 1 summarizes the data collection protocol for this study.

Upon admission to the ICU, patients underwent a standard head-to-toe clinical assessment. In the event that a thermal anomaly was identified, the patient record was updated accordingly, and the patient was immediately started on therapeutic interventions known to assist in mitigating or minimizing further development into a DTPI (Table 1).

All image data were captured and handled using a cloud-based software solution that meets the end-to-end security requirements of the Health Insurance Portability and Accountability Act and Health Information Technology for Economic and Clinical Health Act. Data were only stored temporarily on a local computer and were encrypted while in use. All data transmissions to the cloud were handled in a secure manner that protected the integrity, confidentiality, and availability of the information.

The number of HAPIs reported within the institutional ICUs was collected from July 2015 to June 2016. The monthly average HAPI rate was calculated from these incidence data. Average costs for the management of HAPIs were adapted from the following source, providing an estimate of the institutional costs associated with a single, unreimbursed HAPI:[27] www.ahrq.gov/professionals/systems/hospital/pressureulcertoolkit/putool1.html.

The total number of legal events (actions or litigation) against the institution as a result of HAPIs for the period January 2014 through December 2016, inclusive, was provided by the institution's legal department. Average settlement amounts for each legal event were estimated from publicly available sources (www.ncbi.nlm.nih.gov/pmc/articles/PMC2950802), but the dollar amount of specific institutional legal settlements is confidential.

RESULTS

There were 308 anatomical areas of interest scanned with the Scout device in 114 patients. Providers could not complete all three scans (left heel, right heel, and sacrum/coccyx) for each of the 34 patients, typically because the patient could not be turned or repositioned to visualize the entire area of interest. Using the Scout device, study staff identified a total of 12 thermal anomalies in nine subjects consistent with the nonvisual signs of DTPIs present on admission to the ICU (Table 2). The temperature differentials associated with these thermal anomalies were evenly split between positive (evidence of inflammation) and negative (evidence of ischemia) values. Nine of 12 thermal anomalies occurred in one or both heels in eight of nine patients, indicating a predominance of DTPI risk in the heels. This is consistent with previous reports showing the highest proportion of DTPI risk in the heel compared with other anatomical areas of interest.[10,28] Of the two thermal anomalies that ultimately manifested as DTPIs (both as stage 2), one was a heel (positive temperature differential indicating inflammation), and the other was the ischium (negative temperature differential indicating ischemia).

Thermal Images

Representative visual/thermal scans are shown in Figures 1 to 4. Figure 1 represents visual and thermal imaging of the left heel in subject 3; the thermal image clearly shows an area of inflammation (with a temperature gradient vs adjacent normal skin of +2.0° C). This thermal anomaly, noted as present on admission, manifested to a visually identifiable DTPI on day 4 despite interventions designed to mitigate progression. Note the clearly visible area of erythema inferior/distal to the lateral malleolus in the visual image: this area did not exhibit a remarkable increase in temperature on the thermal image, compared with the increase in temperature clearly evident over the heel itself.

Figure 2 represents visual and thermal imaging of the sacrum/coccyx in subject 83. While the focus of both the visual and thermal images was the protocol-specified area of interest (ie, sacrum/coccyx), there is nonetheless an obvious thermal anomaly (–5.2° C)

Table 1.

MT CARMEL WEST WOUNDVISION SCOUT PROTOCOL FOR ICU ADMISSIONS

1. Upon admission, two nurses conduct a "four eyes" head-to-toe skin and soft tissue assessment.
2. During the assessment, the clinician is to capture a visual/infrared image pair of the sacrum/coccyx, right heel, and left heel (three image sets in total, per patient); in addition, any questionable areas that are prone to pressure injuries may be imaged as the clinician sees fit (eg, if the patient was found down on the right side, then image the right trochanter as well).
3. After the remainder of patient care is provided, a clinician is to analyze the visual/infrared image pairs:
    a. Control area selection: selection of an area of intact, adjacent tissue to achieve a baseline reference point
    b. Profile line: if anomaly is present, documents the location and quantifies the relative temperature differential(s)
4. If an anomaly is identified, the clinician is to
    a. Document any relevant findings and changes to the care plan in the patient record using the following: "Upon admission to the ICU, the patient presented with signs and symptoms of deep-tissue pressure injury of the [anatomical location] as reflected by a [+ or -] [x.x] degree Celsius anomaly of intact skin. Interventions put in place to assist in preventing the manifestation of partial or full-thickness skin loss."
    b. Interventions to be initiated are as follows:
    Sacrum/coccyx: (a) start Venelex (castor oil and balsam of Peru) three times daily, (b) initiate low-air loss mattress, and (c) provide more frequent turns
    Heels: (a) start Venelex three times daily, (b) initiate low air loss mattress, and (c) elevate using pillows or boot
5. If partial- or full-thickness injury manifestation occurs during the patient's stay, and it occurs in the same anatomical location where the existing signs/symptoms were documented as present on admission to the ICU, then the pressure injury is NOT documented as hospital acquired.

Table 2.

SUBJECTS WITH CLINICALLY SIGNIFICANT TEMPERATURE DIFFERENTIALS IN AREAS OF INTEREST

Subject No.	Age (y), Sex	Primary Diagnosis	Comorbidities	Length of Stay (d)	Blanching in Area of Interest	Ventilator Dependent	Anatomical Area of Interest	Temperature Differential (° C)	Progressed to DTPI
3	78, F	Left hip pain	CAD, HTN, tobacco	28	No erythema	Y	Left heel	+2.0	Yes, day 4
8	42, M	GSW	None	16	No erythema	Y	Left heel	−6.0	No
15	54, M	Unresponsive	Ethanol abuse, hepatitis C	1	Blanchable	Y	Right heel	+0.8	No
40	85, F	Left hip fracture	CAD, HTN, KD	19	No erythema	Y	Left heel	−3.4	No
40					No erythema		Right heel	−4.5	No
61	72, F	Anemia	PVD, HTN, RA	15	Blanchable	N	Sacrum/coccyx	+0.9	No
61					Blanchable		Right heel	+1.9	No
75	85, F	Right lower leg ischemia	PAD, HTN, TIA	13	No erythema	Y	Left heel	+1.9	No
83	80, M	Respiratory failure	CAD, DM, CHF	36	No erythema	Y	Right ischium	−5.2	Yes, day 3
87	45, F	Fever	Tumor, DM, MRSA	9	Blanchable	N	Right heel	+1.6	No
87					Blanchable		Sacrum/coccyx	−2.5	No
106	85, M	Sepsis	HTN, DM, GERD	5	No erythema	N	Right heel	−3.2	No

Abbreviations: CAD, coronary artery disease; CHF, congestive heart failure; DM, diabetes mellitus; DTPI, deep-tissue pressure injury; F, female; GERD, gastroesophageal reflux disease; HTN, hypertension; KD, kidney disease; M, male; PAD, peripheral artery disease; RA, rheumatoid arthritis; TIA, transient ischemic attack/stroke.
Note: None of these patients had a history of previous DTPI.

associated with ischemia over the right ischium, which is also in the field of view. This is near a small area of visible erythema, which itself exhibits a slight temperature elevation (approximately 1° C). Despite interventions to mitigate progression, this area of ischemia manifested to a visually identifiable DTPIs on day 3 postimaging.

Figure 3 represents visual and thermal imaging of the right heel in subject 40. Note the significant negative temperature gradient (−4.5° C) versus adjacent normal skin, indicating an area of ischemia. Protocol-specified interventions to mitigate further development of DTPIs were implemented, and this thermal anomaly in the right heel did not manifest to a DTPI despite a significant ischemic temperature gradient upon admission. A similar outcome was achieved in this subject's left heel, in which an ischemic thermal anomaly was also noted (image not shown).

Figure 4 represents visual and thermal imaging of the sacrum/coccyx in subject 37. This is illustrative of the thermal images obtained in the overwhelming majority of patients and depicts an absence of thermal anomalies in an anatomical area of interest. None of the anatomical areas of interest deemed to have insignificant baseline temperature differentials during the course of the study developed into a visible DTPI at any time during the patient's stay.

Institutional DTPI Incidence

A total of 31 HAPIs were reported within the institution's ICUs during the 12-month period July 2015 to June 2016, translating to an average incidence of 2.58 HAPIs per month. Within the study population, during the 2-month study period, 2 of 12 thermal anomalies documented as present on admission progressed to a visually identifiable DTPI, representing an incidence of 1 per month. Of the remaining 10 thermal anomalies identified on admission, none progressed to DTPIs, likely a result of intensive wound prevention procedures implemented once the thermal anomalies were documented. No visually identifiable DTPIs or pressure injuries developed in any of the remaining 105 study patients who, as a result of baseline thermal scanning, were found not to have any thermal anomalies present in anatomical areas of interest.

An important distinction is that, although two visually identifiable DTPIs developed during the 2-month study period, these were in fact *not* considered HAPIs because they were documented as present on admission. Given the historical HAPI incidence, approximately five HAPIs could have been expected during the 2-month study period ($2.58 \times 2 = 5.16$). In fact, only two visually identifiable DTPIs occurred during this period, both of which were documented as present on admission. Therefore, the HAPI rate during the study period was zero.

Intensive wound prevention procedures implemented at admission likely helped mitigate the development of DTPIs in the remaining 7 patients/10 thermal anomalies identified as at risk by thermal imaging. As shown in Table 1, the intervention protocol in the event that an area of interest demonstrated a thermal anomaly was fourfold: (1) moisture control by placing the patient on a low air loss mattress; (2) increase turns to every hour; (3) float the heels off of the bed surface, as indicated; and (4) administer castor oil and balsam peru three times daily. A review of the patient charts indicated that this protocol was followed in every instance.

Figure 1.

BASELINE VISUAL (TOP PANEL) AND THERMAL (BOTTOM PANEL) IMAGES: INFLAMMATION
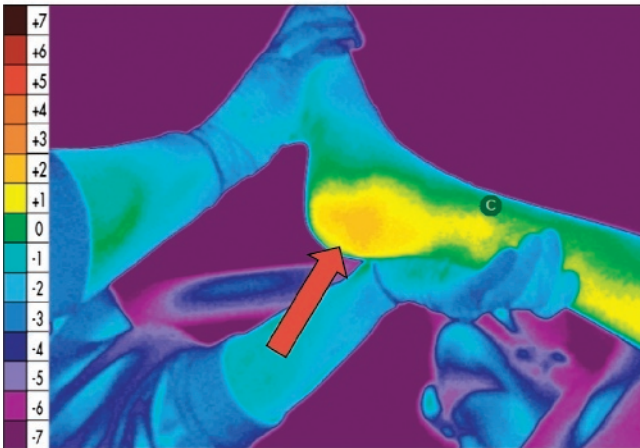
Subject 3, heel; posterior heel progressed to visible deep-tissue pressure injury on day 3.

Ultimately, early detection translated directly into tangible clinical benefits: the DTPI rate decreased significantly during the study period compared with the historical DTPI/HAPI rate.

Revenue Implications

The revenue loss from DTPIs not documented as present on admission (and therefore not reimbursable) is $43,180 per case. Therefore, the two DTPIs in the present study that manifested in skin where a thermal anomaly was noted and documented as present upon admission represent $86,360 in preserved revenue for the institution, because the costs of care for these DTPIs are considered reimbursable.

From January 2014 to December 2016 (36 months), a total of seven documented institutional legal events (indemnity payments,

litigation costs, and other associated payments) were associated with HAPI lawsuits in the authors' institution. This translates to total estimated legal costs of $1,953,000 (based on an estimate of $279,000 per event) or an average monthly cost of $54,250 for HAPI litigation. Again, the two DTPIs documented as present on admission would not represent a legal liability for the institution, translating to $108,500 in preserved revenue.

The estimated total revenue preserved (HAPI reimbursement of 2 DTPIs × $43,180/DTPI = $86,360, plus litigation costs of 2 months × $54,250/mo = $108,500) over the 2-month study period was $194,860 (Table 3). Additional HAPI-associated elements anecdotally noted by study personnel to have been qualitatively impacted include pain, infection, therapy delays, morbidity, length of stay, caregiver time, facility outcome reporting

Figure 2.

BASELINE VISUAL (TOP PANEL) AND THERMAL (BOTTOM PANEL) IMAGES: ISCHEMIA
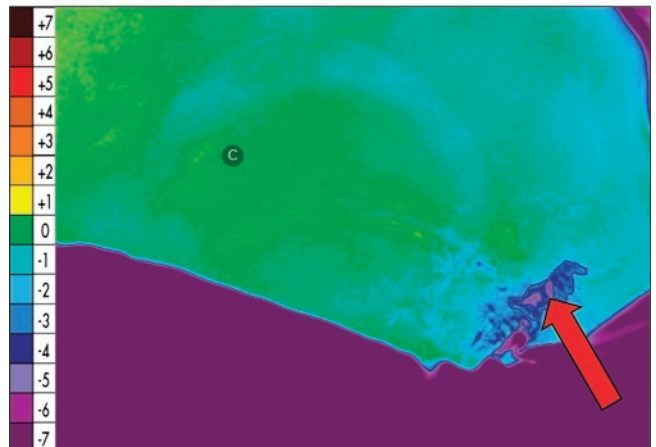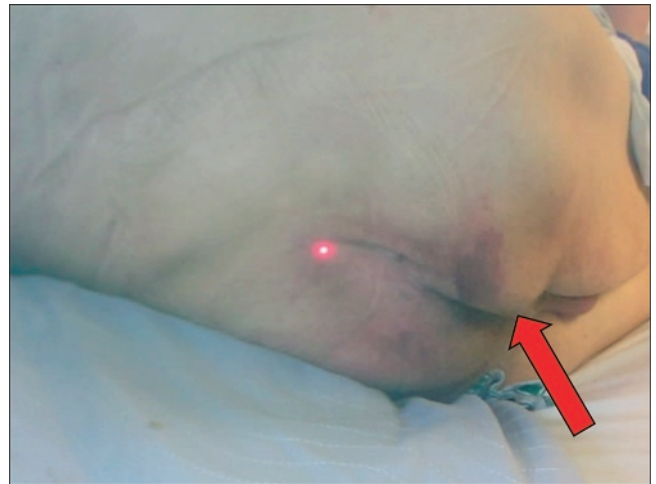
Subject 83, ischium; arrows point to the ischemic area on the buttock that progressed to visible deep-tissue pressure injury on day 3.

Figure 3.

BASELINE VISUAL (TOP PANEL) AND THERMAL (BOTTOM PANEL) IMAGES: ISCHEMIA
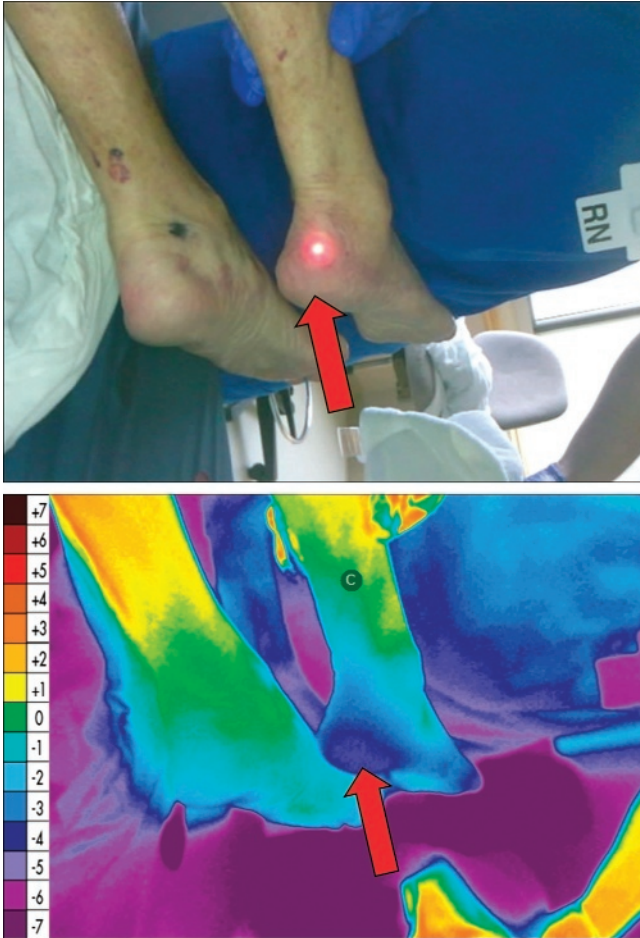
Subject 40, heel; did not progress to visible deep-tissue pressure injury.

(safety/future risk of quality measures), and skin risk factors for future DTPIs.

DISCUSSION

Study authors documented a significant reduction in the impact of DTPIs, both clinically and financially, by implementing a straightforward thermal imaging protocol to detect thermal anomalies in skin areas of interest in patients admitted to the study ICUs. Researchers noted an approximately 60% reduction, compared with historical rates, in the incidence of DTPIs over the 2-month study period. Because clinicians documented thermal anomalies in nine patients in whom there were otherwise no visible signs of DTPIs at baseline assessment, providers could immediately implement additional clinical procedures known to reduce pressure injuries.

Only 2 of 12 thermal anomalies (in two of nine patients) at baseline progressed to a visually identifiable pressure injury. Had all 12 thermal anomalies progressed to DTPIs, the overall incidence would have been approximately 5.2% per month compared with the historical incidence of 2.3% per month.

This result is comparable to previously published rates of progression to necrosis between 3% and 53% in pressure-related discolored areas of skin (ie, visible skin abnormalities) in which thermography showed a higher or lower temperature versus adjacent normal skin; in particular, areas of discolored, intact skin that had temperatures lower than adjacent normal skin were 31.8 times more likely to progress to necrosis than skin that was warmer.[9]

Early clinical intervention in this study is credited with preventing the progression to visible DTPIs in the other 10 thermal anomalies documented at baseline. Of interest is the fact that

Figure 4.

BASELINE VISUAL (TOP PANEL) AND THERMAL (BOTTOM PANEL) IMAGES: NO THERMAL ANOMALY PRESENT
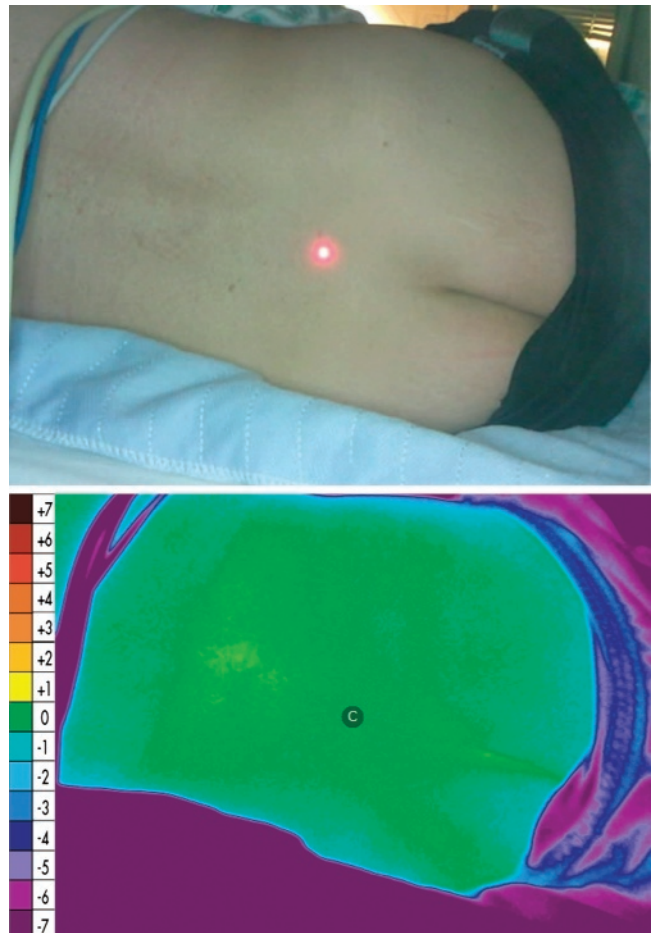
Subject 37, sacrum/coccyx.

Table 3.

PREDICTED VERSUS ACTUAL REVENUE LOSS (DTPI NOT DOCUMENTED AS PRESENT ON ADMISSION)

Outcome Measure	Expected 60-day Outcomes	Actual 60-day Outcomes
DTPI total	5.16	2
HAPI total	5.16	0
Revenue loss from nonreimbursement of emergent DTPI/HAPI	$86,360	$0
Revenue loss from legal event(s) after DPTI/HAPI	$108,500	$0
Total revenue loss	$194,860	$0

Abbreviations: DTPI, deep-tissue pressure injury; HAPI, hospital-acquired pressure injury.

approximately five HAPIs would have been predicted to occur during the course of this 60-day study. Because the two DTPIs that did manifest during the study were documented with the WoundVision Scout as present on admission, the study authors' facility effectively reduced the HAPI rate to zero.

In addition, in this study, the false-negative rate associated with thermal imaging was zero; none of the 105 patients with a documented absence of thermal anomalies at baseline in the anatomical areas of interest later developed visible DTPIs. While this was not an objective of the study, this may be the first report of a false-negative rate with thermal imaging of areas at risk for DTPIs. Further, these findings are consistent with previously reported repeatability and reliability metrics with the same thermal imaging system.[21]

In the research clinicians' hands, the Scout proved to be a sensitive tool for measuring thermal anomalies in anatomical areas of interest. Notably, in subject 3 (Figure 1), there was an area of visible erythema/mottling (perhaps from a prior angioplasty procedure) in the vicinity of the lateral malleolus (within the field of view of the Scout, focused on the heel as the area of interest), which nonetheless did not exhibit any signs of local inflammation (ie, a temperature increase on thermal imaging). This is important because, without an accompanying thermal image, a clinician might incorrectly view the erythema near the malleolus as indicative of inflammation requiring further assessment or intervention and would have missed the abnormality on the heel. In fact, the Scout identified a temperature gradient associated with inflammation on the heel itself, in the absence of any visible signs of inflammation (eg, erythema), enabling staff to implement further interventions to potentially mitigate the development of DTPIs.

Likewise, in subject 83 (Figure 2), although researchers initially focused on the sacrum/coccyx as the specified area of interest, the ischium of this patient was incidentally imaged, and a relative temperature differential/thermal signature indicative of significant ischemia was noted, while the sacrum/coccyx was normal. Clearly, the tool affords some flexibility in evaluating areas near the area

of interest, while using the same reference temperature of adjacent normal skin. This allows clinicians to evaluate multiple anatomical areas of interest and potentially identify incidental thermal anomalies, especially in areas where visible signs of DTPIs are absent.

As shown in Table 2, many of the patients had comorbidities that may influence the relative temperature differentials associated with an area of interest. For example, subject 106 (85-year-old man, primary diagnosis of sepsis) had a history of diabetes mellitus, and thermography demonstrated a negative temperature differential in the right heel (−3.2° C). However, a review of the thermal image (not shown) showed a focal thermal anomaly in the right heel consistent with DTPIs. If the patient had generalized lower extremity ischemia because of peripheral blood flow reductions secondary to diabetes, providers would not have been able to identify a nearby control area ("normal temperature") to generate a temperature differential. Conversely, in subject 61 (72-year-old woman, primary diagnosis of anemia), a history of peripheral vascular disease might lead clinicians to expect a confounding reduction in relative temperature differential in the heels. In fact, this patient demonstrated an increase (+1.9° C) in her right heel temperature, consistent with the inflammatory/reperfusion phase of DTPIs.

Limitations, Cost, and Recommendations for Future Research

A limitation of this preliminary study is that the patients received thermal imaging at a single point in time, upon admission to the ICU. It would, however, be beneficial to conduct sequential thermographic monitoring of areas of interest in a larger sample of patients, given that the precise time of imaging may or may not coincide with the onset of deep-tissue damage.[26] This may be why some of the study participants exhibited temperature increases, and others temperature decreases, associated with DTPIs.

The variations in skin temperature associated with a single event (DTPI) may be attributable to either the presence of ischemia (cooler than normal) or subsequent reperfusion (warmer than normal) in the area of interest.[29] This would be a fruitful area of future research: serial thermal imaging of areas at risk of DTPIs, correlated with the patient's clinical course, to determine if certain thermal signatures are associated with greater or lesser risk for DTPIs, and the specific time course of those events. By combining early identification of thermal anomalies with known interventions designed to mitigate the progression of DTPIs, an institution may lower its HAPI rate significantly.

As previously noted by others, both the visual and thermal images collected over a specific time period can be captured within a typical wound electronic medical record,[30] making them immediately available to all clinicians on the patient care team. Because the Scout software package generates a digital record of each

patient's wound dimensions (length, width, and perimeter) and temperature gradients, this information can easily be included in the patient's record, providing a comprehensive and real-time evaluation of wound status. This allows clinicians to optimize the patient's wound care/prevention plan without requiring time-consuming evaluations in a separate system at a later time.

The estimates of the financial impact of early detection of DTPIs were intentionally conservative. A well-executed retrospective study documented institutional clinical costs of approximately $125,000 per stage 4 pressure ulcer[13] and the Agency for Health Research Quality estimated clinical costs of $20,900 to $151,700 per pressure ulcer.[27] In 2007, medicare estimated that each pressure ulcer added $43,180 in costs to a hospital stay.[27] Because there is tremendous variation in costs to manage pressure injuries depending on stage, and because early detection of DTPIs with thermal imaging should ultimately reduce the costs of managing emergent pressure injuries, the study authors elected to use the Medicare estimate of $43,180 in this analysis, despite this being an older and thus lower estimated cost.

This analysis also included an assessment of the financial impact of litigation directly related to pressure injuries. Previously reported information regarding legal settlements and litigation costs for pressure injury lawsuits tends to aggregate either societal costs or average settlement costs without reporting direct costs to an institution.[31] In this study, the actual number of unique lawsuits or litigation events within the study institution over a specified period of time (36 months) is reported in order to accurately capture these events. Because the actual settlement amounts are confidential, study authors estimated the cost per settlement from published values, which ranged from $168,000 (low) to $279,900 (middle) to $340,000 (high), depending on the 5-year cohorts studied.[31] Authors chose the middle cohort value of $279,900 per settlement as the fairest index for this analysis, insofar as there was no statistical difference between the high, median, and low values previously reported, minimizing the impact of outliers (eg, a single $312 million settlement). Because these values reflect information collected in 2000, it is likely that current legal settlements for pressure injury litigation are much higher. In any event, the result of this analysis was that legal costs associated with HAPIs for which the study institution is liable contribute an additional $52,500 per month to the financial burden associated with this condition. The ability to document DTPIs as a thermal anomaly present on admission thus has the potential to eliminate or reduce this liability for emergent pressure injuries.

Any analysis of interventions designed to reduce medical costs must also incorporate the costs of those interventions in order to accurately and completely assess the cost-benefit. Accordingly, the manufacturer of the Scout (WoundVision) has provided the following annual costs for the devices deployed at the study

institution, including software and image handling: $61,000 (three thermal imaging devices, software package). If the estimated monthly revenue preservation of $97,430 associated with the implementation of the thermal imaging protocol is as described herein and is balanced against a monthly technology cost of $5,083 to generate and process the thermal images, the financial return is significant.

Finally, the nurses' experience with the Scout system was positive: the operator learning curve was fairly short, and the manufacturer provided a great deal of support. The most critical success factor identified to enable rapid staff adoption was ensuring that the staff knew how this could ultimately help patients. Of course, the most important outcome noted in this study was the ability to identify DTPIs in the form of thermal anomalies in anatomical areas of interest and immediately implement clinical procedures to mitigate or reduce pressure injuries. This had a profound positive impact on overall patient care in the authors' institution.

CONCLUSIONS

In this study, researchers reported a significant decline in the incidence of DTPIs compared with historical incidence in the study institution. This is attributed to the use of a commercially available long-wave infrared thermal imaging system to identify thermal anomalies in anatomical areas predisposed to the development of DTPIs and to implement clinical interventions to mitigate or reduce the severity of emergent DTPIs. By documenting DTPIs as present on admission, the institution's HAPI rate was reduced to zero, preserving significant revenue related to both payor reimbursements and legal liability. Most importantly, this study significantly improved the quality of patient care by identifying and managing DTPIs upon admission to the ICU. ●

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