

Medical thermography in the diagnosis of pressure ulcers: a narrative review

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ABSTRACT

Background Pressure ulcers are a common complication in healthcare, with a global prevalence of approximately 12.8%. Traditional risk assessment methods (Norton, Braden, and Waterlow scales) show limited predictive accuracy (sensitivity 46.8–82.4%, specificity 27.4–67.5%). There is a need to complement them with more objective diagnostic methods such as infrared thermography (IRT).

Aim A review of potential applications of infrared thermography in the early diagnosis and monitoring of pressure ulcers.

Methods A selective search of PubMed, Scopus, and Web of Science databases was conducted, focusing mainly on English and Polish articles from 2015 to 2025, using the terms “thermography”, “infrared imaging”, “pressure ulcers”, “diagnosis” and “wound monitoring.”

Findings IRT enables non-invasive assessment of skin temperature distribution, detecting functional changes before visible symptoms appear. Temperature drops ($\Delta T \leq -0.1^\circ\text{C}$) in at-risk areas predict pressure ulcer development more accurately than traditional scales. Hypothermic areas of non-blanching erythema are 31.8 times more likely to undergo necrosis. IRT also identifies deep tissue damage, predicts undermining, and assesses healing potential. AI algorithms enhance the diagnostic accuracy of IRT (overall accuracy ~84.6%).

Conclusions IRT is a valuable complement to traditional pressure ulcer assessment methods, allowing early detection of subcutaneous changes regardless of skin color.

Implications for clinical practice Implementation of IRT is recommended upon admission of high-risk patients, interpreting temperature differences relative to adjacent skin areas, and immediate intervention upon detection of thermal anomalies.

Keywords thermography, infrared imaging, pressure ulcers, diagnosis, wound monitoring

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KEY MESSAGES

- Discussion of the potential applications of infrared thermography for the diagnosis of chronic wounds and pressure ulcers.
- Prediction of pressure ulcer development in pressure areas, as well as identification of undermining and deep tissue damage using IRT (detection of abnormalities before clinical symptoms appear)

INTRODUCTION

Pressure ulcers (PUs), also known as pressure injuries (PIs), are characterised by localised damage to the skin and/or underlying tissue, typically over a bony prominence. They represent one of the most common complications occurring in healthcare settings worldwide. The global prevalence of PUs is estimated at approximately 12.8%. In Europe, the average prevalence is reported at 10.8%, with a range from 4.6%

to 27.2%, depending on the country and type of facility.¹⁻³ Between 1990 and 2017, standardised incidence rates of pressure ulcers have increased, in some countries by as much as 40%.^{2,3} Notably, a decrease in stage I ulcers alongside an increase in stage IV ulcers has been observed, suggesting a potential decline in effective prevention and management of pressure ulcers.^{2,3}

Pressure ulcers contribute to increased mortality, reduced quality of life, prolonged hospitalisation, and poorer overall health outcomes. Given the substantial personal, social, and economic burden associated with PUs,⁴⁻⁷ early identification of individuals at risk and prompt implementation of preventive measures upon hospital admission are critical. Risk assessment is the first step in PU prevention. Unfortunately, traditional risk assessment methods rely predominantly on standardised tools such as the Norton, Braden, and Waterlow scales. While widely used, these scales exhibit limited predictive accuracy,

with sensitivities ranging from 46.8% to 82.4% and specificities from 27.4% to 67.5%, the Braden scale showing the highest overall performance, followed by the Norton and then the Waterlow scale.⁸⁻¹⁰ A Cochrane review found no conclusive evidence that the use of risk assessment tools alone reduces the incidence of pressure ulcers.⁹

Although risk scales may help stratify patients by level of risk, and visual skin inspection of exposed areas can aid in the early detection of pressure-related damage, both methods are subject to the examiner's clinical skills and judgment. Moreover, visual assessment may be challenging in individuals with darker skin tones and is ineffective in identifying deep tissue injuries (DTIs), which can develop in the absence of visible surface changes. While traditional risk assessment scales remain widely used, their limitations highlight the need for complementary, more advanced and objective diagnostic tools⁸⁻¹⁸ (Table 1). The integration of novel, efficient, and cost-effective technologies such as infrared thermography (IRT)¹⁹⁻²² and artificial intelligence (AI)²³⁻²⁶ may enhance assessment accuracy and enable early detection of both PUs and DTIs. One increasingly studied tool is medical infrared thermography (MIRT), a non-contact method of visualising skin surface temperature. It may allow detection of pathological tissue changes caused by pressure, such as ischemia and inflammation.

Therefore, this narrative review aims to examine the potential applications of infrared thermography in the early diagnosis and monitoring of pressure ulcers.

LITERATURE SEARCH STRATEGY

A selective literature search was conducted in PubMed, Scopus, and Web of Science to identify studies on the use of medical thermography in the diagnosis and monitoring of pressure ulcers. The search primarily included English and Polish articles published between 2015 and 2025, using terms such as “thermography,” “infrared imaging,” “pressure ulcers,” “diagnosis,” and “wound monitoring.” While the focus was on the most recent research, relevant older studies were also considered to provide foundational context. Studies were included if they addressed infrared thermography in the assessment, diagnosis, or monitoring of pressure ulcers in humans and were published in peer-reviewed journals. Exclusion criteria comprised studies on non-human models, unrelated clinical contexts, and conference abstracts without full text. Titles and abstracts were screened for relevance, followed by full-text review, with additional references identified through manual bibliography searches.

MEDICAL INFRARED THERMOGRAPHY: BASIC PRINCIPLES AND CLASSIFICATION

The diagnostic use of temperature in medicine dates back to antiquity. Hippocrates observed that localised differences in body surface temperature may indicate disease. Modern developments have translated this ancient insight into advanced technologies such as IRT, which enables non-invasive assessment of skin temperature distribution through the detection of infrared radiation emitted by the human body.²⁸⁻³¹ IRT is based on the physical principle that all objects with a temperature above absolute zero emit electromagnetic radiation, primarily in the infrared spectrum.^{29,30,32,33} Human skin emits IR radiation in the range of 7–14 μm , which is

invisible to the naked eye but can be captured by sensitive thermal cameras. These devices convert IR radiation into digital images—thermograms—that visually represent surface temperature distributions in color or grayscale gradients. High-resolution, high-sensitivity cameras can detect temperature differences as small as 0.05°C.^{29,30,33,34} MIRT uses these images to detect abnormalities in skin temperature, which reflect underlying physiological or pathological processes. The human core temperature is tightly regulated around 36.6°C, whereas the skin temperature is more variable and influenced by local blood flow, metabolic activity, tissue composition, and thermoregulatory mechanisms controlled by the hypothalamus. Variations in perfusion, such as vasoconstriction or vasodilation, directly affect local skin temperature and thus IR emission.³⁵⁻⁴¹

In clinical practice, MIRT does not rely on absolute temperature values, which are affected by environmental and individual factors, but rather on relative comparisons—such as temperature asymmetry between symmetrical body regions or gradients between pathological and adjacent healthy tissues.^{20,28,30,40,42-43} A typical physiological temperature difference (ΔT) between corresponding areas of the body is minimal, ranging from 0.12 to 0.67°C.⁴² Significant asymmetry or abnormal thermal patterns may suggest inflammation (positive gradient), ischemia, or necrosis (negative gradient).^{20,28,33,34,43,44} Thermograms reflect only functional changes, such as alterations in blood flow or metabolic activity, and do not depict anatomical structures. However, this sensitivity to functional disturbances enables early detection of pathologies that may not yet be visible through structural imaging techniques^{28,29,32,40} (Figure 1.).

MIRT can also be classified based on the method of data acquisition into three types:^{28,31,35,44-46}

— **Passive thermography** records the natural thermal radiation of the skin without external stimulation. It is the most common form in clinical settings, including for wound and inflammation assessment.

— **Active thermography** uses external stimuli (such as cold air, heat, or IR light) followed by observation of the tissue's thermal response. This method can reveal subtle functional differences not visible under resting conditions.

— **Dynamic thermography** involves monitoring temperature changes over time, such as after the removal of a cooling agent or during physical activity. It provides insight into thermoregulatory dynamics and microcirculation.

The quality of thermographic data depends heavily on the imaging equipment. There are two main types of thermal cameras used in medicine:^{33,47}

— **Cooled infrared cameras**, which use cryogenically cooled detectors to offer extremely high sensitivity and resolution. They are more expensive and are typically used in research or specialised diagnostics.

— **Uncooled infrared cameras**, which operate at ambient temperatures using microbolometer sensors. While they offer slightly lower sensitivity, they are more practical for routine clinical use due to their portability, affordability, and ease of operation.

All forms of MIRT share a core advantage: they offer real-

Table 1. Overview of Pressure Ulcer Risk Assessment Tools and Diagnostic Methods: Sensitivity, Advantages, and Limitations

Method	Description	Sensitivity/Specificity	Advantages	Limitations
Braden Scale ^{8,10,11}	Risk assessment based on six factors: sensory perception, skin moisture, activity, mobility, friction and shear, and nutrition status	57.1% / 67.5%	Most widely used globally; Best studied; Relatively high predictive validity	Requires user training; Less accurate in patients with advanced diseases; Does not detect DTI
Norton Scale ^{8,9,10}	Risk assessment based on five factors: physical and mental condition, activity, mobility, and incontinence	46.8% / 61.8%	Simple and quick to use; Well known in Europe; Useful for initial risk screening	Lower validity index than Braden but still useful; Too general, not PU-specific; Omits key risk factors (such as nutrition); Does not detect DTI
Waterlow Scale ^{10,11}	Risk assessment based on a broad range of factors, including: body weight, age, mobility, appetite, skin condition, and others	82.4% / 27.4%	Detailed, includes multiple factors; High sensitivity	Low specificity (may overpredict risk); Overloaded and complex; Low inter-rater reliability; Does not detect DTI
CBO Scale (Dutch Guideline, CBO-modified Norton) ^{12,13}	Modified Norton scale with additional elements	No clear data	Enhanced version of Norton Scale; Recommended in Dutch guidelines	Based on Norton (only slight improvement in accuracy); Rarely used outside the Netherlands; Does not detect DTI
Douglas Scale ¹⁴⁻¹⁶	Assesses: nutrition, activity, sphincter and urinary control, pain, skin condition, consciousness	100% / 64–90%	Adapted for ICU conditions; Includes critically ill patients	Little known outside ICU settings; Limited validation data in general populations; Does not detect DTI
NIRS (Near-Infrared Spectroscopy) ¹⁷	Non-invasive assessment of tissue perfusion and oxygenation via near-infrared light absorption	Promising results; no exact sensitivity/specificity values reported	Detects early perfusion changes; Monitors tissue metabolism	Requires specialised equipment; Expensive; Signal interpretation requires experience
Laser Doppler Flowmetry (LDF) ¹⁸	Measures skin microcirculation using a laser, enabling dynamic real-time perfusion assessment	No numerical data; high sensitivity in detecting microcirculatory impairment; correlation with PU healing confirmed	Non-invasive; Assesses extent and severity of PUs; Enables monitoring and prognosis	Requires specialised equipment; Spatial variability of perfusion may affect repeatability
Infrared Thermography (IRT) ¹⁹⁻²²	Imaging of skin surface temperature distribution. Detects early changes: local hypothermia (ischemia) / hyperthermia (inflammation)	85% / 89%	Contact-free; Objective; Detects changes up to 48 hours before visible signs; Detects DTI	Requires standardisation; Requires skin acclimatisation; Requires trained personnel
AI + Image Analysis (YOLO, CNN) ²³⁻²⁶	Automated analysis of clinical or imaging data (such as thermograms)	Classification accuracy: 90%+	Automated; Fast; No subjectivity	Requires large datasets; Requires clinical validation
Pressure Sensors / Sensor Mats ²⁷	Detection of pressure and patient positioning via sensors—system alarms when threshold is exceeded, indicating ischemic risk	No standardisation; effectiveness depends on calibration and alarm threshold	Enables continuous pressure monitoring; Early risk alerts; Customisable thresholds; Pressure distribution documentation	High purchase cost; Requires calibration; Potential for false alarms; Patient comfort issues (rigid mats); Challenging in patients with involuntary movements; No data on PU prediction sensitivity/specificity

Legend: DTI = Deep Tissue Injury; PU = Pressure Ulcer; ICU = Intensive Care Unit; NIRS = Near-Infrared Spectroscopy; LDF = Laser Doppler Flowmetry; IRT = Infrared Thermography; AI = Artificial Intelligence; YOLO = You Only Look Once; CNN = Convolutional Neural Network.

time, functional, non-contact, and non-invasive imaging. Current literature identifies at least 38 medical conditions across 13 specialties where MIRT is clinically useful—including vascular, neurological, oncological, and notably, wound care applications. In chronic wound assessment, it provides valuable physiological markers of perfusion, healing potential, and early inflammatory changes (see Table 2).^{28,30,31,32,35,40-46}

Thus, MIRT stands as a promising adjunct in the monitoring and management of wounds and pressure ulcers, enabling earlier detection and more personalised therapeutic approaches.

INFRARED THERMOGRAPHY FOR WOUND PROGNOSIS AND DIAGNOSIS

Wound diagnosis

IRT enables noninvasive, quantitative wound assessment by mapping skin temperature. In burn injuries, IRT effectively measures depth and predicts healing. Meta-analyses report pooled sensitivity of ~84% and specificity ~76% for identifying deep burns—outperforming standard clinical assessment.⁴⁸⁻⁵⁰ Thermographic imaging within 48 hours of injury can predict healing within 2–3 weeks.^{50,51} Dang et al⁵² reported significant agreement between IRT and laser Doppler imaging for burn depth and ~99% specificity for predicting rapid healing. Deeper burns often appear cooler than superficial ones; a persistent temperature difference (ΔT) between the affected area and surrounding tissue may indicate delayed healing.^{51,52} IRT thus supports clinical decisions, helping to avoid unnecessary excision and guiding timely interventions (such as grafting).⁴⁹⁻⁵²

Inflammation dynamics and thermal changes

IRT excels in tracking inflammation, which raises local skin temperature. At surgical pin sites, inflamed or infected areas showed ~0.9 °C higher temperatures than clean controls.⁵³ A scoping review found that postoperative temperature peaks after ~2 weeks often signalling infection.^{53,54} Therefore, serial thermography may detect subclinical inflammation before overt symptoms. During wound healing, the thermal gradient typically declines (periwound $\Delta T \rightarrow 0$); persistent hot spots suggest chronic inflammation or infection.^{55,56}

Applications in postoperative and chronic wounds

Beyond burns, IRT is useful in surgical⁵⁶⁻⁵⁹ and chronic

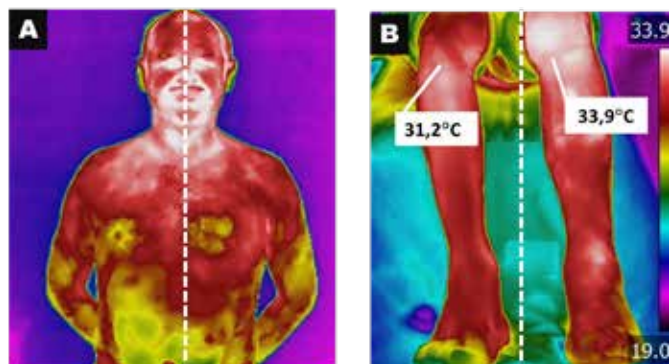


Figure 1. Thermal symmetry of the human body.

1A. A healthy human body shows symmetrical distribution of skin surface temperature.

1B. Thermal asymmetry of the legs— inflamed left knee; temperature gradient of 2.7°C. Thermal abnormalities were detected incidentally and preceded the onset of pain by over a week.

(Source: Authors' archive; IRT camera: FLIR Systems, Wilsonville, OR; model T650sc; 640 × 480 pixels.)

wounds.⁶⁰⁻⁶⁷ In colorectal surgery, IRT identified delayed healing within four days: infected wounds showed lower peak temperatures and incomplete peri-incisional warmth.⁵⁷ In orthopedics, IRT detects hot spots over infected prostheses, offering a low-cost screen for deep infections.^{58,59}

Chronic wounds, such as diabetic foot ulcers (DFUs)⁶⁶ and venous leg ulcers (VLUs),⁶⁰⁻⁶⁴ also exhibit thermal signatures. Neuroischemic DFU patients show elevated toe and foot temperatures versus healthy controls. One study found that feet with neuroischemic ulcers showed higher localised temperatures than healthy limbs, which may reflect inflammatory activity and altered thermal patterns associated with both neuropathy and ischemia.⁶⁶ In VLUs, larger wound area and bacterial load correlate with higher periwound temperature. Each additional bacterial species increased skin temperature by ~0.95 °C ($p < 0.001$).⁶⁰⁻⁶² Persistent elevation suggests poor healing prognosis, while cooling implies recovery.

Detection of superficial and deep infections

IRT detects both superficial and deep tissue infections. Superficial infections cause local hot spots; deeper infections like osteomyelitis or infected hardware produce persistent or new hot zones. At surgical sites, long-lasting warmth around pins or prostheses may indicate underlying infection.^{53,54,56,58} A recent review confirmed IRT's sensitivity to such changes, highlighting its value in screening for periprosthetic or fracture-related infections.⁵⁶⁻⁶⁰

Monitoring therapeutic response

IRT also allows for the quantification of treatment response. As wounds heal or therapies (such as revascularisation, debridement or exercise) take effect, thermal patterns shift. In one study, range-of-motion therapy for partial-thickness burns led to a significant ΔT drop (from 0.60 °C to 0.01 °C over 3 weeks; $p < 0.001$), correlating with wound contraction.⁵⁵ After vascular intervention, temperature rises within 24 hours signal reperfusion,³⁰ whereas cold zones may indicate ischemia or failing flaps. Serial thermograms thus provide objective evidence of therapeutic efficacy. A declining thermal asymmetry reflects healing; rising hot spots may require treatment changes.^{55,67}

In summary, IRT is a reliable, non-contact adjunct for wound evaluation. It assesses burn depth, tracks inflammation, monitors surgical and chronic wounds, detects infections, and evaluates treatment effects. By visualising thermal dynamics, IRT enhances clinical assessment and supports timely, data-driven interventions throughout the healing process.

INFRARED THERMOGRAPHY IN PRESSURE ULCERS

Predictive thermal patterns in preulcerative skin (PRIDAS)

Infrared thermography can reveal pressure-damaged skin before it breaks down. For example, Farid et al⁶⁸ showed that “cool” PRIDAS lesions (nonblanchable erythema) were dramatically more likely to ulcerate than “warm” ones. In 85 cases, 29 of 55 PRIDAS with ~1.2 °C lower temperature than adjacent skin progressed to necrosis versus only one of 30 in the warmer group (cool PRIDAS were 31.8x more likely to progress).⁶⁸ Likewise, Cai et al⁶⁹ monitored 415 ICU patients daily and found sacral skin cooler by ≥ 0.1 °C (vs reference) predicted pressure injury far better than the Braden Scale. Patients below this -0.1 °C threshold had a significantly higher

PI incidence (Kaplan-Meier and Cox analyses). In practice, then, a localised hypothermic spot on intact skin (often nonblanchable) should raise concern for impending deep tissue injury and trigger preventive measures (Figure 2).

Early detection of deep tissue injury

Pressure injuries often begin as subdermal damage before skin changes appear. Long-wave IRT can visualise these occult injuries as focal hot or cold spots. In a blinded prospective study, Simman and Angel⁷⁰ scanned patients' sacra and heels serially: all four anatomical sites that later developed deep-tissue pressure injuries were identified by IRT before any visual sign. Similarly, Koerner et al¹⁹ implemented thermal scans on ICU admission. Among 114 patients they detected 12 thermal anomalies; after instituting intensive off-loading protocols, only 2 of those sites (17%) became overt DTIs—a ~60% reduction in their historical DTI rate. Early thermal documentation also had financial impact: classifying these injuries as “present on admission” preserved hospital reimbursement and reduced litigation costs. Together, these studies show that routine IRT screening (for example, on admission or daily in at-risk units) can detect deep injury before skin breakdown, enabling timely intervention.^{19,70,71}

Thermal indicators of undermining and necrosis

Abnormal edge temperatures on existing ulcers predict complicated wounds. Kanazawa et al⁷² found that ulcers with a cold wound edge were much more likely to develop undermining. In their cohort of stage III/IV ulcers, eight of 11 with cooler edges developed undermining within 1–2 weeks, versus two of 11 without (relative risk ≈4.0, sensitivity 0.80, specificity 0.75). In other words, an ulcer with a marked cold spot at its periphery had ~4× the risk of undermining. Likewise, skin hypothermia often heralds necrosis: as Farid et al showed, the coolest PRIDAS sites (large cold areas) had the highest necrosis rates.⁶⁸ (By contrast, a warm peri-wound skin usually indicates active inflammation and is less likely to fail.)

In summary, thermographic cold spots at the margin of an ulcer are a strong warning of occult tissue death that may soon undermine or necrotise (Figure 3).

Wound edge versus center temperature: prognosis of healing

Thermal gradients within a wound also carry prognostic information. Recent cohorts confirm that relatively warm edges predict better healing. Lin et al⁷³ followed 156 pressure ulcers and recorded bed, edge and normal-skin temperatures. They found that a higher periwound-to-normal-skin temperature (a “hot” margin) on Day 1 predicted much faster healing. In Cox regression, wounds with even a slightly positive periwound temperature (above normal) healed 8.79 times faster (HR=8.79, 95%CI 4.53-17.05) than those that were cooler. Another study showed that pressure ulcers whose periwound skin was warmer than the wound bed healed more readily than those with inverted gradients.⁷⁴ Conversely, ulcers with relatively cooler edges tended to stagnate. In practical terms, a “hotter” margin (suggesting good perfusion) favors repair, whereas a hypothermic edge is a poor prognostic sign.^{73,74}

Clinical protocols and outcomes

Studies suggest clear IRT protocols for high-risk patients. Typically, thermal images are obtained at baseline (for example on ICU admission or pre/post surgery) and then daily or with repositioning. If a site's temperature differs by a preset threshold (for example, ≥1.0-1.2°C above or below adjacent tissue), enhanced off-loading and support surfaces are applied. In one pilot, Parker et al⁷⁵ combined IRT (±1.2°C criteria) and subepidermal moisture scans for cardiac surgery patients. Of 20 monitored cases, only one new pressure ulcer (5%) occurred—far below expected—because IRT flagged early changes and prompted intensified prevention. Likewise, Cai et al recommend daily sacral thermography in ICUs; using a -0.1°C cutoff they could trigger mattress changes and repositioning before redness appeared.⁶⁹

Table 2. Example of medical uses of infrared thermography

Disorders diagnosed by inflammation (increased blood flow)
<ul style="list-style-type: none"> • Surgical site infections (SSIs), including deep tissue, bone, and implant-associated infections—inflammation is a strong early predictor • Inflammatory conditions of the paranasal sinuses and oral cavity in otolaryngology • Inflammation of the oral cavity, periodontium, and temporomandibular joints in dental diagnostics • Supportive diagnostics in dermatology and allergology: contact dermatitis, atopic dermatitis, and standard skin allergy tests • Autoimmune diseases associated with inflammatory processes: Charcot neuroarthropathy, hidradenitis suppurativa, systemic lupus erythematosus
Disorders diagnosed by perfusion abnormalities
<ul style="list-style-type: none"> • Ischemic conditions in vascular diseases, including peripheral artery disease (PAD), diabetic angiopathy, Raynaud's phenomenon, and ischemic ulcers • Post-angioplasty monitoring (angioplasty surveillance) • Assessment of coronary perfusion and intraoperative monitoring of cardiac function • Evaluation of burn depth and extent • Detection of deep tissue injuries (for example, muscle or subcutaneous tissue damage) • Early identification of pressure ulcers

Note: based on ^{19,20,22,28-31,33,35,40,41,44,46,47,49,53,54,58,86-90}

These protocols translate to real gains. Early IRT intervention has repeatedly cut DTI/HAPI rates by roughly half. For example, Langemo's ICU program showed a ~60% drop in DTI incidence after implementing admission thermal scans and aggressive follow-up care. Importantly, detecting injury on admission also avoids "hospital-acquired" labels and lost reimbursement.¹⁹ In summary, incorporating IRT into standard practice (with defined temperature thresholds and responses) enables earlier identification of tissue damage, reduces progression to severe ulcers, and can lower costs and improve outcomes.^{19,69}

AI-ENHANCED THERMOGRAPHIC EVALUATION OF PRESSURE ULCERS

Recent studies have increasingly applied deep learning to automate the analysis of thermal images for pressure ulcer assessment. Object-detection networks of the YOLO (You Only Look Once) family, for example YOLOv5 and YOLOv8, have been trained to localise and stage pressure injuries in thermographic images.^{24,25,76} These systems can achieve high precision: one YOLOv5-based model reported a mean average precision (mAP@0.5) of 76.9% (with class-wise AP ranging from 66% to 99.5%).²⁵ A later YOLOv8-based approach demonstrated even stronger performance (overall accuracy ~84.6%, mAP@50 ≈ 90.8%) while running on a mobile platform that returns a diagnostic result in roughly 3 seconds.⁷⁶ In addition to detection, AI-driven image enhancement techniques have been employed to improve thermogram quality. For example, denoising autoencoders and GAN-based super-resolution algorithms can enhance low-resolution thermal images, yielding clearer thermograms and potentially increasing diagnostic sensitivity.⁷⁷ Deep convolutional neural networks have likewise been used to classify and segment ulcer images with excellent accuracy. In one study, Liu et al⁷⁸ trained an Inception-ResNet-v2 CNN on photographs

of pressure ulcers, achieving about 98.5% accuracy for distinguishing erythematous (reddened) tissue and about 97% accuracy for identifying necrotic tissue.⁷⁸ Similarly, a three-dimensional CNN applied to pressure ulcer images achieved a Dice similarity coefficient of ~92% and an area-under-curve of 0.95 when segmenting different tissue types.⁷⁹ Ensemble approaches have also shown promise: for example, Rostami et al⁸⁰ combined multiple CNN classifiers in a stacked model and reported maximum accuracies of 96.4% for binary wound classification and 91.9% for three-class categorisation. Collectively, these findings illustrate that AI-enhanced analysis of wound images—whether thermographic or photographic—can reliably capture key wound features and stages with high precision. Such results underscore the potential of deep learning-augmented thermography as an objective, reliable tool to support clinical decision-making in the monitoring and management of pressure ulcers.^{24-27,76-82}

INFRARED THERMOGRAPHY VERSUS OTHER IMAGING METHODS

Infrared thermography differs significantly from traditional imaging techniques used in the assessment of wounds and pressure ulcers. While it does not provide direct information on tissue structure, IRT allows for contactless measurement of skin surface temperature distribution, enabling the early detection of inflammation and perfusion disturbances before visible clinical changes occur. This makes IRT a useful tool for identifying early complications.

Ultrasound (US) enables visualisation of soft tissue structures at various depths, supporting structural assessment, such as wound depth, tissue thickness, and the presence of fluid or inflammatory infiltration. High-frequency ultrasound can detect deep tissue damage several days before visible skin changes appear, which is valuable for PU prevention. Portable US devices allow bedside examinations, but image quality depends heavily on the operator's expertise, and high-frequency probes have limited penetration, reducing their ability to image deeper structures.^{63,82-85} Magnetic resonance imaging (MRI) offers superior soft tissue contrast

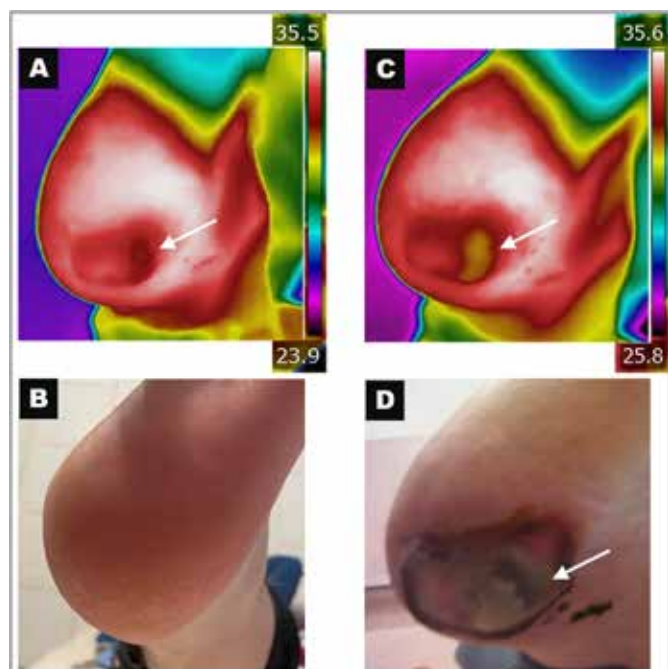


Figure 2. Predicting tissue damage using IRT.
 2A. Infrared thermographic image of a heel with fading redness in an ICU patient— arrow indicates a "cool temperature gradient".
 2B. Corresponding digital image of the same heel, with no visible abnormalities.
 2C–D. IRT and digital images of the same area taken 7 days later.
 (Source: Authors' archive; IRT camera: FLIR Systems, Wilsonville, OR; model T650sc; 640 × 480 pixels.)

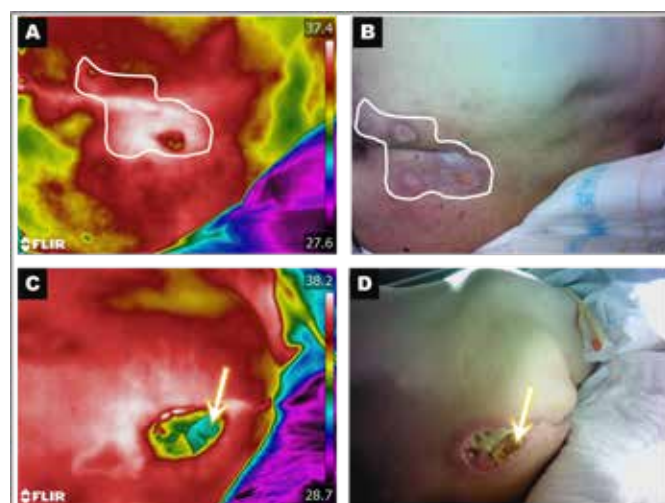


Figure 3. "Warm" and "cool" temperature gradients between the lesion and surrounding skin.
 3A–B. Warm periwound temperature gradient, indicating progression of the healing process (epithelialisation phase).
 3C–D. Arrow indicates a cool area suggestive of undermining and necrosis.
 (Source: Authors' archive; IRT camera: FLIR Systems, Wilsonville, OR; model T650sc; 640 × 480 pixels.)

and is considered the gold standard in the evaluation of complex wounds. It allows for accurate visualisation of edema, necrosis, and deep inflammatory changes, as well as complications such as fistulas, abscesses or osteomyelitis. However, MRI is expensive, time-consuming, and requires patient transport to the imaging suite, limiting its use in unstable or immobile patients. Optical coherence tomography (OCT), particularly its dynamic version (D-OCT), provides micrometer-scale resolution of superficial skin layers and enables real-time visualisation of microcirculation.⁸⁵ It can detect microstructural and functional changes in the wound bed, such as vessel density, perfusion, and reepithelialisation. Nevertheless, its limitations include shallow penetration depth (only a few millimeters) and the high cost of equipment. In contrast to these structural imaging methods, IRT offers a non-invasive assessment of skin microcirculation by detecting thermal gradients over larger areas. It can identify zones of hypoperfusion before macroscopic changes become apparent.⁸⁴ Compared with conventional clinical photography, IRT provides functional insight into physiological processes, as confirmed by the meta-analysis conducted by Cauras et al.⁸⁶ Unlike capillaroscopy, which targets specific microvascular points, IRT enables a comprehensive assessment of perfusion in and around the wound area.⁸⁷ However, it does not replace structural imaging methods and should be regarded as a functional complement for diagnostic and wound healing monitoring purposes.

LIMITATIONS

Despite promising results, the use of IRT in PU assessment faces several important limitations that constrain its clinical implementation and the generalisability of research findings.

One key issue is the heterogeneity in thermographic devices, including variations in resolution, sensitivity, and calibration protocols, which may lead to inconsistent temperature readings across studies. Additionally, there is no standardised method for defining regions of interest (ROI) or interpreting thermal data, making comparisons between studies difficult and limiting the reproducibility of findings. Methodological limitations are also notable: many studies are single-center, involve small and demographically homogeneous samples, and often lack representation of individuals with darker skin tones, in whom early-stage PUs are particularly difficult to detect visually. Similar concerns apply to artificial intelligence-based approaches, which often rely on small, non-diverse datasets and lack external validation, potentially limiting model generalisability and clinical robustness. Moreover, the absence of uniform image annotation protocols and inconsistencies in ground truth definitions hinder the development of reliable AI models. Furthermore, the overall quality of available research is limited by small sample sizes, inadequate control groups, and varied study designs, reducing the strength of evidence supporting IRT's diagnostic value.

In addition to these limitations, practical challenges further complicate the routine use of IRT in clinical settings. Although acquiring a thermogram is technically straightforward and quick, the process requires at least 15 minutes of patient acclimatisation in a thermally neutral environment. The patient must remain in a fixed position without touching the area of interest, which can be difficult—particularly when multiple ROIs need to be assessed, or when imaging hard-to-access anatomical locations, such as the sacrum or trochanteric region. These requirements can make the examination time-consuming and demanding for clinical staff.

Table 3. Recommended conditions for Infrared Thermographic Examination (IRT)

Category	Requirements and recommendations
Patient preparation	<ul style="list-style-type: none"> Remove clothing, jewellery, and accessories from the area to be examined at least 15 minutes prior to imaging Allow sufficient acclimatisation time, especially if there is a temperature contrast between outdoor and indoor environments Remove wound dressings, rinse and dry the wound thoroughly. Avoid invasive or painful procedures immediately before IRT to prevent vasoconstriction caused by catecholamine release Thermograms should include the wound bed, periwound skin (immediate margin), and normal surrounding skin (3–5cm control area) Ensure pressure relief from the examined area for at least 15 minutes; for repeated measures, maintain the same time of day and patient position Prevent contact of the skin with surfaces (such as armrests, upholstery) Avoid factors affecting thermoregulation (such as hot meals, caffeine, alcohol, nicotine or physical exertion) for at least three hours before the test. Do not apply creams, medications, cosmetics or makeup to the area on the day of the test
Examination environment	<ul style="list-style-type: none"> Ambient temperature should remain stable within 20–24°C, with fluctuations no greater than ±0.5–1.0°C Relative humidity: 45–55%. Minimise air movement and external heat sources (such as heaters, open doors, unnecessary lighting, sunlight) Use blackout curtains if needed Room size: at least 6m² (preferably 3x4m).
Equipment	<ul style="list-style-type: none"> Use medical-grade infrared cameras operating in the mid-wave infrared (2.5–5.6 µm) or long-wave infrared (7–13 µm) ranges and minimum 320 × 240 pixels. Select devices and software designed for clinical applications to ensure accuracy, reliability, and compliance with medical standards

Note: Recommendations summarised based on published thermographic imaging guidelines and clinical research.^{20,29-33,35,44,49,88-90}

Moreover, interpreting thermograms reliably necessitates specific training, and a lack of standard education or certification can lead to inconsistent assessments. The high cost of professional-grade thermal imaging equipment and maintenance also represents a barrier to widespread adoption (Figure 4).

These limitations highlight the need for large-scale, multicenter trials with standardised protocols to fully establish the clinical utility of IRT (including AI-enhanced thermography) in early PU detection across diverse populations and care settings.

CLINICAL RECOMMENDATIONS BASED ON REVIEWED EVIDENCE

Despite the aforementioned limitations and the clear need for further high-quality research, the current body of evidence allows for the formulation of preliminary practical recommendations. These may support the clinical integration of IRT as a complementary tool in the early detection and prevention of PUs.

Based on the reviewed literature, the following guidelines are proposed:^{20,29-33,35,44,49,88-90}

1. Implement IRT at the point of admission, particularly in high-risk settings such as intensive care units, geriatric wards, and long-term care facilities, to support early risk stratification.

2. Use IRT as a complementary tool, rather than a standalone screening method.

Experts advocate integrating thermographic skin temperature assessment with traditional visual inspection and validated risk assessment scales (such as Braden, Norton). Notably, temperature anomalies may precede visible changes by up to 48 hours and offer greater sensitivity in early-stage detection.

3. Define a critical hypothermic threshold for skin temperature.

A thermal difference of $\Delta T \leq -0.1^\circ\text{C}$ between the ROI and surrounding intact skin should be interpreted as a high-priority indicator of ischemia and increased risk of tissue necrosis.

4. Always compare the ROI to a nearby reference region.

Interpreting relative temperature differences between at-risk and adjacent unaffected skin is more reliable than relying on absolute temperature values.

5. Initiate preventive interventions immediately upon identification of thermal anomalies, including repositioning, pressure-relieving surfaces, and increased monitoring frequency to reduce progression to ulceration.

6. Document all thermal findings systematically, as precise temperature records may help determine the onset and likely cause of tissue damage—for example, distinguishing between hospital-acquired and pre-existing ulcers upon admission.

7. Provide patient acclimatisation according to the guidelines.

Always assess the same area of interest

8. Ensure the use of high-resolution thermal cameras (minimum 320 × 240 pixels).

Lower-resolution devices may reduce sensitivity, especially in small or early-stage lesions.

These recommendations underscore the clinical utility of IRT as an adjunctive diagnostic modality, with potential to improve early detection, guide timely interventions, and enhance documentation in PU management.

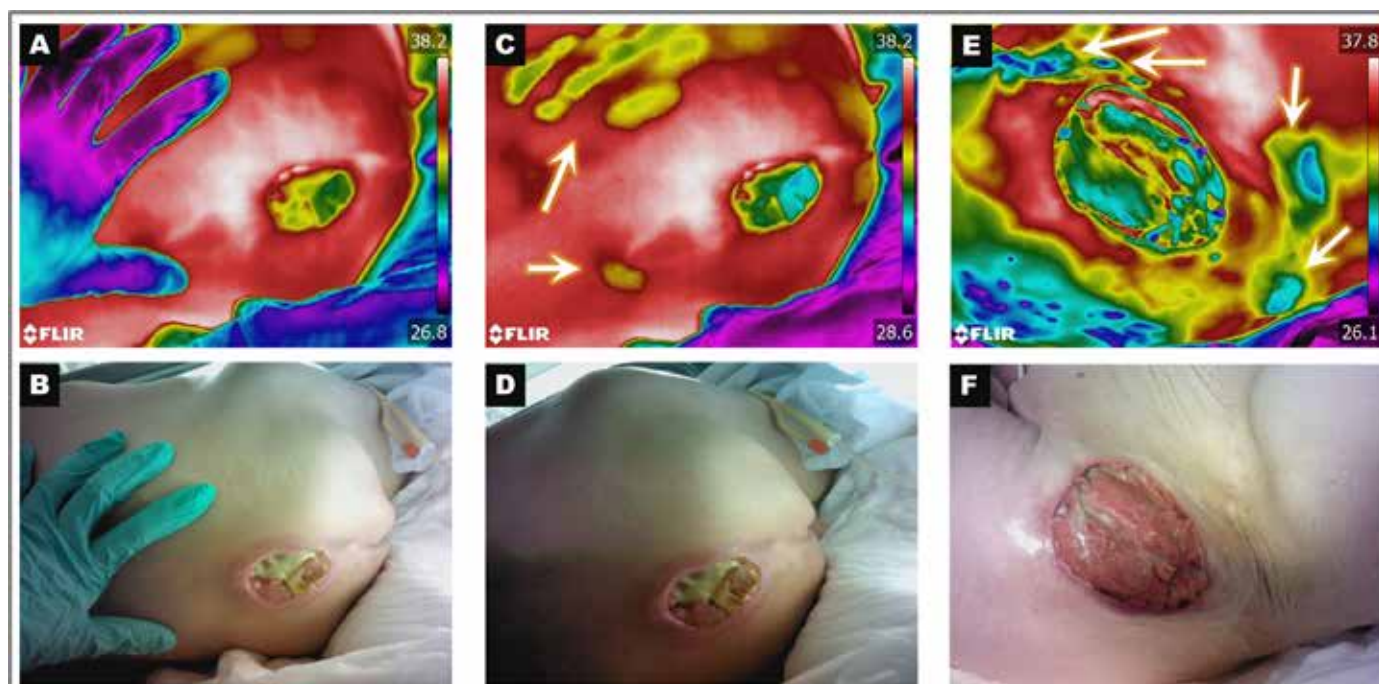


Figure 4. Examples of improper skin acclimatisation and preparation before IRT imaging.

4A–B. Direct contact with the examiner’s warm hand immediately before imaging.

4C–D. Arrows indicate areas where heat transfer from the hand affected temperature readings, impairing interpretation.

4E–F. Inadequately dried skin and wounds – arrows indicate moist areas potentially misinterpreted as “cold-ischemic”.

(Source: Authors’ archive; IRT camera: FLIR Systems, Wilsonville, OR; model T650sc; 640 × 480 pixels.)

CONCLUSIONS

Evidence from studies using IRT for pressure ulcer diagnosis has demonstrated that it is an effective predictor of PU development. While clinical assessment scales (such as Norton and Braden) predict general risk levels, IRT provides information about risk at specific anatomical locations, regardless of skin color and visual assessment, including areas where DTI symptoms are hidden. The advantage of thermographic assessment stems from its functional evaluation of abnormalities and the ability to identify them in the subclinical phase. Our experience shows that temperature changes may precede other clinical symptoms (such as pain) and visual signs of ischemia, undermining and infection. Therefore, IRT can complement visual assessment, detect abnormalities more accurately, and direct care toward actual needs and efficient use of financial resources in pressure ulcer treatment.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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