REVIEW ARTICLE

Current Use of Infrared Thermography in Orthopaedic and Bone or Joint Trauma Patients–Can We Identify Postoperative Infection? A Narrative Systematic Review

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Abstract

Aim and background: Technological advances have made infrared thermography (IRT) sensitive, noncontact, and low cost for medical applications and it is used in a range of fields. A widening body of research has investigated IRT in the orthopaedic setting, including the investigation of orthopaedic infection. Infrared thermography could provide a rapid, low-cost, objective, noncontact technique to aid in the diagnosis of orthopaedic infections.

Methods: Electronic searches of MEDLINE, CINAHL, and EMBASE from 2000 to 2024 were made. The search strategy aimed to include all studies in adults investigating the use of IRT in orthopaedic and bone or joint trauma patients and those studies which provide baseline values, including in patients with infection. Articles were screened by title and abstract by two authors. Bias was assessed using the Newcastle–Ottawa Scale tool. Studies were heterogeneous; therefore, results were summarised in tables and presented as a narrative synthesis.

Results: The search identified 36 studies. Studies have shown that IRT is useful in fracture or soft tissue diagnosis, detecting periprosthetic infection, and it may have a role in screening healthy subjects. There is still considerable variance in the application of IRT in the trauma and orthopaedic setting.

Conclusion: Infrared thermography is sensitive to skin temperature changes in infected limbs following orthopaedic surgery and may be used as a low-cost, noncontact, irradiation-free screening tool to identify orthopaedic infection in the future. Future studies should identify the cost effectiveness of IRT in clinical practice. Barriers include the low incidence of orthopaedic infection and large number of confounders that can affect IRT readings.

Clinical significance: Infrared thermography can provide rapid information that may be a useful adjunct in the emergency department or outpatient clinics to diagnose a range of orthopaedic conditions, including infection. Current research has yet to demonstrate clinical significance.

Keywords: Infection, Narrative review, Orthopaedic, Systematic review, Thermography.

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Aim and Background

Infrared radiation is emitted by all objects at temperatures above absolute zero. The human body acts as an almost perfect emitter, with emissivity of 0.98.[1] Thermal cameras use radiation emitted from the skin to calculate skin surface temperature. Correlation exists between skin temperatures and limb blood flow.[2,3]

Advances in technology have made thermal imaging sensitive, noncontact, and low cost for medical application. Thermal heat produced by the body can be used in the investigation of a range of conditions.[4] This rapid, reproducible, noncontact technique can be used by nonspecialised personnel. In the future, this tool may be used in the emergency department, on the ward, in outpatient clinics, and by patients and their relatives in the community.[1,2,5–8]

It has been proposed that we should establish baseline thermographic profiles stratified by race, age-group, or the disease of interest. Standardisation of imaging techniques and assessments of normal values in healthy subjects began in the 1970s.[1] Temperature variations of >0.5°C between contralateral regions of interest (ROI) are strongly associated with disorder in that region.[4,8]

Currently, there is no standardised definition of fracture-related infection. We rely on criteria such as the presence of a fistula or sinus, wound breakdown, or pus; in conjunction with criteria that suggest infection such as fever, radiological signs, elevated inflammatory markers, or increased wound drainage. These are often confirmed with surgical exploration and deep-tissue sampling.[9]

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Clinical assessment of wound healing is unreliable. There have been some studies investigating wound healing using infrared thermography (IRT) following abdominal surgery, in diabetic feet, and following hip and knee arthroplasty. There are also several studies that have performed baseline data in healthy populations and investigated the use of an IRT in orthopaedic trauma. There is minimal research investigating orthopaedic infection following fracture or arthroplasty. These cause considerable morbidity, and high cost to the patient, healthcare systems, the clinical team, and society. We present a narrative synthesis of the literature in relation to the current use of IRT in trauma and orthopaedics patients and its ability to identify infection.

Methods

The search followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, and the protocol was prospectively registered (PROSPERO 2021 CRD42021281263). Studies identified in the search were heterogeneous, and therefore, a narrative synthesis was undertaken following the guidance from the Economic and Social Research Council.[10] Data collection items are given below. No funding was received.

Search

A search was performed independently by two authors (TS and AW) of MEDLINE, EMBASE, and CINAHL, between 2000 and January 2024. Duplicates were removed, and studies remaining were screened for relevance using titles and abstracts (AW and CW). The full-text of the remaining studies were reviewed and assessed for eligibility for inclusion in the review. Reference lists of included papers were then hand searched to identify additional studies, which were included in the narrative synthesis.

The keywords are listed below, with full search strategy in Supplementary Tables 1 and 2.

(exp INFRARED PHOTOGRAPHY/OR exp TELETHERMOGRAPHY/ OR exp THERMOGRAPHY/OR (thermograph*).ti,ab OR (telethermograph*).ti,ab OR (thermal imag*).ti,ab AND (exp ORTHOPEDICS/OR (exp INJURY/OR exp MUSCULOSKELETAL INJURY/ OR exp MULTIPLE TRAUMA/OR exp WOUND/))

Study Eligibility Criteria

Inclusion Criteria

- Studies were included of all designs of published and unpublished work, in a language understood by the authors or where translation was available.
- Studies in which IRT was used to provide baseline values in normal joints or bones, including in the postoperative period and in noninfection patients.
- Studies that provided values in orthopaedic and bone or joint patients with infection, including those that provided follow-up values following treatment.

Exclusion Criteria

- Studies published before the year 2000 (as the technology has advanced considerably since).
- Studies not performed in humans.
- Studies from case reports or scientific meetings.
- Studies where only an abstract or conference proceeding were available.
- Studies using contact thermal imaging (e.g., liquid crystal thermography).
- Studies which did not identify baseline values in infected or normal bones or joints.
- Studies with fewer than 10 participants.

Data Extraction and Risk of Bias Assessment

Two independent authors (AW and CW) were used throughout screening, assessment of article eligibility, and inclusion in this narrative review. Disagreements were resolved through help of third author (AB).

Data extraction was undertaken independently by one author (AW) and checked by another (VK), with disagreements resolved through discussion. Studies were summarised in study summary table (Supplementary Table 2). Further data were extracted using predefined criteria into a table (Supplementary Table 3) using Microsoft Excel and the data items listed below.

Data Items

Author, journal, year of publication, number of participants, groups, ROI, lesion assessed, age, sex, exclusions, definition of infection, comparative area to ROI, inflammatory markers, follow-up, wound dressing, thermal camera, environmental measures, environmental adaptation, acclimatisation, imaging position, measuring distance, imaging view, measured fields, techniques to minimise interference, thermographic endpoints, measurement days, software used, value to identify infection, baseline values, performance characteristics, and image background.

Bias Assessment (Newcastle–Ottawa Scale)

The Newcastle–Ottawa scale (NOS) was used to assess study quality. Two authors (AW and AB) rated the studies, and disagreements were resolved through discussion.[11] The authors agreed criteria prior to bias assessment. In relation to "comparability" of cohorts, studies were scored one star for controlling the "main factor." We deemed the main factor to be if the thermographic images were taken in a controlled environment. A second star was awarded if studies controlled for two or more other factors affecting thermography, e.g., comorbidities, smoking status. The rest of the questions were scored in accordance with the standard guidance.[11]

Results

The literature search was performed on 10 February 2024. Studies identified were deduplicated. Titles, abstracts, and full-texts were then screened. A further search of references was undertaken with relevant studies included in the narrative synthesis. The search is summarised in Figure 1. The studies are summarised in the Supplementary Study Summary Table 2. Studies reported baseline values that were often in figures or graphs. These were heterogenous and not extractable; however, studies were still included in the narrative synthesis.

Study Summary Table with Author, Year, Design, Participants, and Key Findings

The core characteristics of included studies are included in Supplementary Study Summary Table 2.

NOS Bias Assessment

The risk of bias assessment found that 31 of the studies were of good or high quality (scoring between 6 and 9 points). This indicated

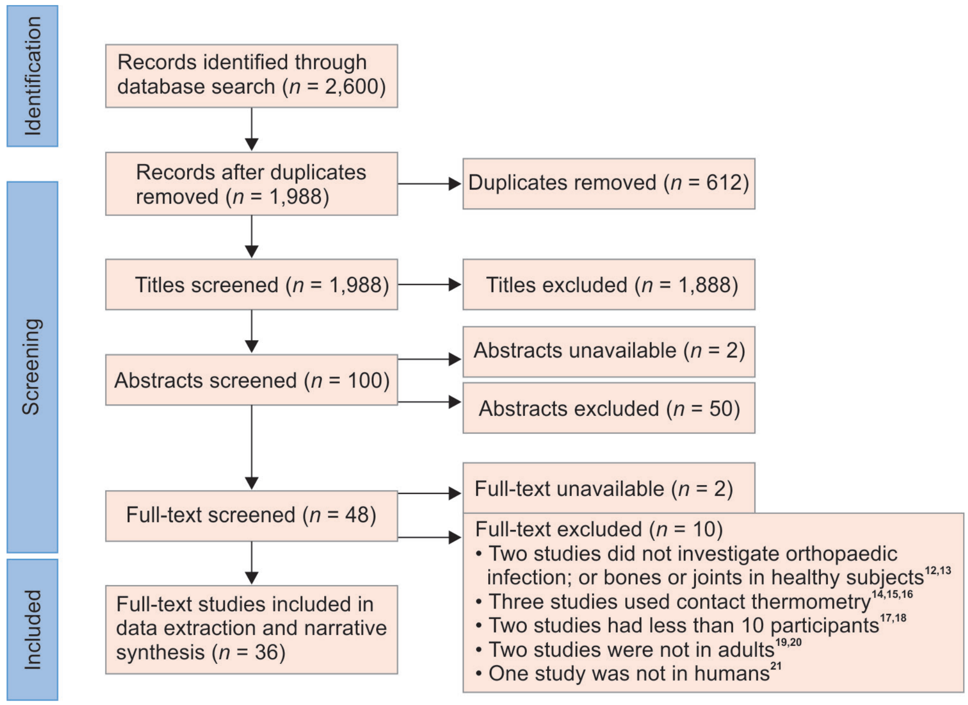

Fig. 1: PRISMA flow diagram of included studies[12–21]

an overall low risk of bias for the included studies. There were no randomised controlled trials with the primary outcomes of using IRT to assess skin temperature included in the review. We found that interrater reliability was moderate with a kappa value = 0.74 (Supplementary Table 4).

Study Summary Table with Extracted Characteristics

A summary of extracted data is included in Supplementary Table 3.

Discussion

As the studies were highly heterogeneous, meta-analysis was not possible; so, a narrative review is presented, as per published guidelines.[10] Emerging themes are discussed below.

The NOS is recommended by the Cochrane Handbook and suggested an overall low risk of bias in 31 studies. This suggests that results were applicable within the context of each study. All studies investigating primary thermographic outcomes were observational. We have demonstrated moderate interrater reliability. The NOS is considered to have poor to fair interrater reliability, but better test–retest reliability.[22]

Themes

Fracture or Soft Tissue Injury Diagnosis

Six studies investigated musculoskeletal disease diagnosis.[2,8,23–26] Sillero-Quintana et al. assessed temperature differences of ipsilateral and contralateral limbs in 201 patients presenting to an emergency department.[8] The IRT detected a range of conditions, including sprains, fractures, arthrosis, meniscal injuries, and pain, up to 1 week post injury. Der Strasse et al. similarly found significant temperature differences, >0.9°C, between ipsilateral and contralateral limbs in 45 patients attending the emergency department with suspected fracture.[23] In children, Reed et al. were able to differentiate soft tissue injuries from fractures.[27] Katz et al. used IRT from ceiling-mounted cameras in the resuscitation room of 164 patients.[2] They compared contralateral lower limb temperatures and followed-up all trauma patients for compartment syndrome. Legs with compartment syndrome (28.70°C) had significantly lower average temperatures than those without (31.86°C, $p < 0.01$). Gabrhel et al.[25] used IRT to assess 57 elbows, comparing ultrasound and clinical examination. All 21 elbows with lateral epicondylitis showed increased temperature relative to the contralateral limb. They showed 91% sensitivity and 95% specificity for IRT detecting elbow conditions relative to clinical examination. Park et al. prospectively used IRT in 100 cases of shoulder impingement and found abnormal thermal changes in 73%.[26] They found that reduced temperatures correlated with reduced range of motion.

The evidence suggests that IRT could be useful in detecting a range of musculoskeletal conditions. We are yet to ascertain normal temperature ranges specific to each condition, performance characteristics compared with standard investigations, and the cost-effectiveness of IRT for diagnosis in clinical practice. Future research should include prospective diagnostic studies.

Detecting Periprosthetic Infection

Seven studies investigated arthroplasty.[7,28–33] Romano et al. investigated wound healing following 80 hip and knee arthroplasties for 12 months.[31] They found that temperature differences between contralateral limbs peaked at 3 days and returned to normal over 90 days. Authors from the same institution compared 40 primary total knee arthroplasties (TKA) with 15 patients with established prosthetic joint infection (PJI).[7] They reported increased contralateral temperature differences (1.7 ± 0.5°C) in patients with infection, irrespective of the presence of clinical signs. They suggested that temperature differences of 1°C may be able to detect PJI. In a third study, Romano et al. investigated patients with painful TKA undergoing revision.[30] There were 36 patients with PJI and 34 patients with aseptic implant failures. Thermographic temperatures for PJI (1.92 ± 1.2°C) and aseptic knees (0.32 ± 0.73°C) were significantly different ($p < 0.0001$). The authors suggested 1°C as the cut off to differentiate between revision for septic and aseptic complications. Windisch et al. investigated 42 TKA patients daily for 7 days, following a medial parapatellar approach TKA.[32] They found that temperatures remained constant medially, but laterally remained elevated from days 2 to 5. They suggested that local compromise of perfusion may limit the postoperative diagnostic application of IRT to sites distant from the surgical wound. Yishake et al. investigated IRT and inflammatory markers in patients following primary and revision TKA, compared with PJI.[33] They reported similar time trends following TKA as Romano et al.[31] Future studies could focus on the detection of temperature differences in the early postoperative course, and validate the 1°C cut offs associated with a high probability of infection, to facilitate earlier identification and treatment.[32] Studies with large populations will be required due to the low incidence of infection, which may limit the feasibility of future research.

Neurological Conditions Including Chronic Regional Pain Syndrome (CRPS) and Carpal Tunnel Syndrome (CTS)

Two studies investigated CRPS and four studies investigated CTS.[34–39] Baic et al. investigated 15 patients with CTS before surgery and 4 weeks after surgery, alongside 15 controls.[36] The authors showed that temperature differences reduced after surgery and could indicate successful surgery. Bargiel et al. investigated the rewarming of hands for 3 minutes in 40 patients with CTS and 40 controls.[37] They used IRT at the finger tips the day before, the day after, and 2 weeks after surgery. Hand rewarming was faster in CTS patients and attributed to increased blood flow. They reported no change in IRT following surgery. Park et al. investigated 304 hands with CTS and 88 controls.[38] They compared thermographic differences between the median and ulnar nerve territories of the same hand, stratified by chronicity and severity. They found significant thermal differences in all patient groups, which were greater earlier in the disease course. The same group investigated 27 patients before and 6 weeks after carpal tunnel decompression.[39] They found no differences between median and ulnar nerve territories before and after surgery. Birklein et al. compared contralateral temperature differences in patients with external fixators for distal radius fractures and patients with established CRPS.[34] They found significant increases in dorsal skin temperature 4 days after fracture, and in CRPS patients at 34.17°C and 35.4°C, respectively. Gradl and Schurmann reported temperature differences >0.5°C in eight out of 10 patients with CRPS, with one patient having a colder affected hand.[35] Temperature increases after CRPS could be mistaken for infection in the hand and possibly elsewhere in the body. Tancredo et al. found that dermatomal IRT readings were lower in patients at least 12 months following spinal cord injuries than controls.[40] Future research should assess the effectiveness of IRT to discriminate between neurological and orthopaedic conditions, including infection, which could be important in common conditions, such as diabetic foot infection. Infrared thermography on its own is likely to have poor specificity. A model combined with inflammatory markers and examination findings, possibly used within a machine learning-based algorithm, could improve performance characteristics and provide low-cost screening for compression neuropathies.

Healthy Subjects

Twenty-seven studies investigated healthy subjects or controls. Four studies assessed healthy populations, with some supplying reference tables.[4,41–43] Niu et al. investigated 57 Taiwanese volunteers and demonstrated lower temperatures in older persons (>60 years), particularly in the extremities, consistent with other studies.[41–43] Niu et al. attributed this to several factors, including reduced peripheral perfusion and autonomic dysfunction.[41] Marins et al. investigated 220 healthy subjects, comparing males and females.[4] They demonstrated laterality, with ventral left-sided temperatures being hotter than dorsal right-sided temperatures. As other studies did not report laterality, we are unable to confirm these findings.[41,43] There were male-to-female differences for 13 of 22 ROIs studied, attributed to differences in body composition. Vardasca et al. compared total body views with regional views.[42] They demonstrated that modern cameras produced similar results for both, with regional views having higher thermal symmetry. Healthy subjects provide useful baseline information, but baseline values should be specific to the population or injury being assessed. Data bank values with validated cut-off values, e.g., temperature differences >3 standard deviations (SDs) from the mean, may prove useful in screening populations for disease in the future.

Reliability of IRT Readings

Zaproudina et al. investigated the reproducibility of IRT measurements of 45 paired ROIs in 16 healthy subjects, between two observers and on 2 consecutive days.[43] They found that interrater reliability was high, with a mean intraclass correlation coefficient (ICC, 0.88). High interrater reliability has also been reported in other studies. Katz et al. found interrater reliability of 0.98 in 164 patients in the resuscitation room.[2] Selfe et al. found interrater ICC of 0.82–0.97 using thermally inert markers, to assist in demarcation of the ROI.[44] Romano et al. reported intra- and interrater variability of 0.2 ± 0.3°C and 0.3 ± 0.3°C, respectively, for measuring the maximum temperature of the anterior knee.[30]

Zaproudina et al. reported that day-to-day reproducibility, although good in core areas, was poor in the distal areas. Mean intrarater reproducibility was 0.47 (0.08–0.78, SD 0.21). It was >0.7 in the core, 0.5–0.7 in proximal extremities, and the forearm and hands were <0.4. Significant intrarater variation could affect the impact of studies investigating trends after surgery. Hildebrandt and Raschner found an intrarater ICC of 0.85 in the anterior knee across 2 days.[45] These studies looked only at intrarater reproducibility on measurements taken on different days. Readings could have been affected by errors in set up and diurnal variation. Zaproudina et al. attributed this low intraobserver correlation due to difficulty in mapping ROIs using software and due to changes in body position. This could be mitigated by allowing subjects to rest their limb throughout imaging.

Rahbek et al. investigated pin-site infections in patients treated with external fixators.[5] They calculated an intrarater agreement of 0.85 in 53 pin sites imaged 1 week apart. Using whole images had increased variation (0.32 vs 0.22) relative to using a local ROI around the pin sites. Conversely, Vardasca et al. found comparable repeatability with whole body and regional views for 11 ROIs (ICC >0.8).[42] With high correlation, whole body views, e.g., from static ceiling-mounted cameras, could be an option for the future and reduce operating costs.[2] The majority of studies have shown high interrater and intrarater correlation when using thermal cameras, even across multiple study days.

How IRT was Applied in the Orthopaedic and Trauma Setting

Considerable work has been done with regard to the standardisation of thermography techniques. Most widely regarded is the work from Ammer and Ring.[1] These are applicable to all thermography studies; however, they are not focussed on orthopaedics or infection. We discuss application of IRT in the context of identifying infection in trauma and orthopaedic patients below.

How ROI was Defined

Current selection of ROIs used in studies is heterogeneous and varies from temperature readings being taken from whole images/multiple body areas, areas of suspected pathology, or single data points over a body part.[2,5,7,8,23–26,28,30–43,45–53] Standardised ROIs may be useful for population screening and identifying subjects for further investigation. However, when investigating specific conditions, they may contain superfluous information from nearby body structures or be affected by incidental pathology. Taking ROIs from whole images reduces the number of pixels, and therefore, number of data points. The ROIs should take up the whole image.[1] The majority of studies marked ROIs by arbitrarily drawing two-dimensional shapes, using software, over areas of pathology. A wide range of ROIs should be used until those with the most clinical utility are identified. Human error may result from inclusion of pixels from the background into the ROI. Software in the future may be able to remove pixels from image background.[8]

How Infection was Defined

Seven studies investigated infection.[5,7,28–31,33] Rahbek et al. investigated pin sites in 13 orthopaedic outpatients with external fixators.[5] They defined and classified infection according to the Modified Gordon Pin Infection Classification.[54] A cut-off value for grade I infection was set to 34C. Romano et al. defined infection as clinical signs and raised inflammatory markers for up to 2 years after hip and knee arthroplasty.[31] However, no patients developed infection. In another TKA study, the same authors defined patients as having septic complications if they had been referred to their institution because of PJI.[7] All 15 septic patients had a positive bacterial culture. They found temperature differences of at least 1.0°C between operated and contralateral limbs in septic patients, including those without clinical signs. In a third study, Romano et al. investigated infected and noninfected revision TKAs.[30] They defined infection as draining fistulae, positive preoperative or intraoperative cultures, or positive histology (>5 leucocyte per high-powered field). Using a 1.0°C IRT cut-off at preoperative assessment, they were able to achieve high accuracy (0.90), sensitivity (0.89), specificity (0.91), positive predictive value (0.91), and negative predictive value (0.88). The remaining studies provided no clear definition for infection, or no definition.[28,29,33] Use of standardised definitions will facilitate comparisons between studies.

How Reference Areas were Defined

Skin temperature is usually measured over an ROI. The value recorded is then compared with a "reference" value. Different reference values are used in the literature. The recorded value may be compared with historic values for that individual (i.e., trend) or the average population temperature (e.g., population mean). Six studies analysed trend.[5,32,40,45,49,50] The use of trend is useful in screening for infection, which is known to cause increased blood flow and temperature. However, increases may be confounded by day-to-day variation.

Temperature differences calculated contemporaneously between pathological ROIs and reference ROIs may be affected equally by individual and environmental variation. The reference areas are categorised into those from contralateral body parts (symmetrical, e.g., limbs) or local reference areas (asymmetrical, e.g., trunk). The majority of authors favoured use of contralateral ROIs.[2,7,8,23,26,28,30,31,33–35,37,41–43,46,47,51–53,55] However, anatomy is not truly symmetrical, and oscillations have been reported.[1] Furthermore, it has been reported that fractures or surgery may cause concomitant temperature increases in the contralateral limb, but to a lesser extent than the operated limb.[8,52] This could be due to a combination of factors, including the body's response to surgery, injury, or due to symmetrical autonomic spinal pathways.[56] Six studies used local reference areas, which may be preferable for the trunk or in multiply injured patients.[2,38,39,48,53,55] Childs et al. were able to predict infection after caesarean section in >70% of patients using local ROIs in the week after surgery.[57] The clinically most useful reference area and appropriate timing for each disease is yet to be established. Large data and artificial intelligence with adaptive modelling are likely to be the way forward.

How Participants were Excluded

The exclusions varied widely across the studies and can be seen in Supplementary Table 2. This is partly due to the heterogenous nature of the studies, but also due to the prevalence of conditions affecting skin temperature. Authors will not have been able to exclude all confounders, and a pragmatic approach is needed. Commonly excluded factors are discussed below.

Peripheral neuropathy was excluded by nine studies and affects autonomic and small sensory nerve fibres, causing abnormalities in thermoregulation.[26,29,34–36,38–40,50] Similarly, peripheral vascular disease and inflammatory arthropathy can affect blood flow and were commonly excluded.[7,8,25,29–33,35,38,39,43,45,51]

Control of Other Factors affecting IRT

Many factors were controlled across the studies. Activities such as alcohol, hot drinks/caffeine, smoking, medication, food supplements, cosmetics/creams, leg shaving, exercise, and heavy meals were avoided to reduce confounding.[4,36,38–40,42,43,45–47,49,53] Controlling the environment was achieved using the same room, temperature, humidity, pressure, and measuring distance.[2,36,49,51] Changes in daily routine were avoided, such as training and nutrition.[45] Furthermore, using a black background or calibrating with a black body was also used.[4,8,43,45] Other attempts to reduce some of the many confounders included avoiding liquid dressings, direct sunlight, skin marks from tight clothing, turning away lights, discarding the first image, wearing minimal clothing, placing hands on cotton towels, removing jewellery, remaining quiet during acclimatisation, avoiding heat reflection from electronic equipment, metal accessories, and controlling for diurnal variation.[7,8,30–32,38,39,42,43,50]

Moreira et al. developed a checklist of items that should be addressed in sports and exercise medicine, including camera calibration as per manufacturer.[58] Patient factors may include age, ethnicity, physical activity profile, menstrual cycle, sex, metabolism, and circadian rhythm. External factors are described above. Pragmatically, it is unlikely to be possible to control for all factors. These uncontrolled confounding factors may diminish differences detected by IRT in orthopaedic infection.

Wound Dressings and Plaster

Orthopaedic studies on IRT have been performed primarily for diagnosing fractures, and for identifying postoperative infection following arthroplasty. Treatment in cast depends on multiple factors, including injury factors, surgical factors, and patient factors. To identify infection, wounds may need to be imaged out of cast, e.g., at 1 or 2 weeks during cast change or using removable splints. Wound dressings affect IRT readings. The National Institute for Clinical Excellence advises that wounds should be untouched for only 48 hours after surgery.[59] Wound epithelisation usually is completed in 1–3 days in acute wounds that are primarily closed.[60] Therefore, removal of dressings in the first few days after surgery to facilitate thermal imaging may increase the risk of infection and may be undesirable for healing. Windisch et al. used IRT with the dressing in place for the first three readings.[32]

Type of Camera, Position, and Distance

Many cameras have been investigated (Supplementary Table 2). Improved camera technology has allowed for better thermal imaging. Newer digital cameras are less affected by angle restrictions, do not require cooling, and are more accurate than their predecessors.[1] Temperature measurements taken from curved surfaces may cause inaccurate measurements, with critical loss of information beyond an angle of 60°.[1] Rahbek et al. measured 42 pin sites from random and different angles and positions with modern cameras and found differences of 1°C.[5] Variation is more pronounced on patients with more muscle or adipose tissue. Standardised camera position at 90° should be used.

A consensus reported that the percentage of ROI within the image should be recorded to enable reproducibility of findings.[58] Studies in healthy populations used standing subjects, with the majority of lower limb studies favouring a supine position. Position superiority is yet to be established.

Measurement distances ranged from 10 cm for specific ROI to 400 cm for whole body images and are largely guided by the manufacturer's instructions.[4,7,30,31] The optimal distance should be used to capture as much of the ROI in the image as possible, to increase the number of pixels.

Acclimatisation

Acclimatisation is the time period given for skin temperature to equilibrate with the environment. Acclimatisation varied from no acclimatisation, with IRT measurements taken from a ceiling-mounted camera during trauma resuscitation to 60 minutes in patients following distal radius fractures.[2,34] Climate temperatures should ideally be between 18 and 25°C to prevent shivering and sweating, and convection should be controlled.[1] If external temperatures and test room temperatures differ by less than 5°C, 10 minutes acclimatisation should suffice.[4] However, an expert panel suggested that 15 minutes minimum should be the standard.[58]

Interference

Infrared reflection from the environment can affect skin emissivity, and therefore, thermography readings. This includes surfaces the ROI or body part are resting on, be that a stool or other parts of the body.[1] Authors controlled interference from background radiation by using rubber floor mats, controlling airflow, room lighting, and placing a matte black surface behind the subject.[4,7,8,30,31,42,43,45,49,51] Ideal conditions produce better quality and more repeatable images. Departmental conditions are more easily controlled than on the hospital ward; however, steps should be taken to minimise interference. In radiography, the use of standardised positions for quality assurance is well established and could be applied to IRT.[1]

Thermographic Endpoints

Minimum and maximum temperatures have been reported to show higher SDs relative to mean temperatures and to be affected by day-to-day variability.[45] Conversely, Romano et al. reported that mean and maximum temperature readings showed very similar trends following TKA, and therefore, maximum readings may suffice.[7]

Artificial Intelligence

Artificial intelligence research and computer vision, where machine learning is used to analyse images, are increasing. The World Health Organization has suggested that IRT could be a safe, noninvasive, noncontact supplementary method to diagnose breast cancer where studies have shown promising sensitivity and specificity with a small numbers of images.[61] Fletcher et al. used mobile thermal imaging with convolutional neural network models to predict surgical site infection following caesarean section in 530 women.[62] Images were collected at 10 days and correlated with clinical findings, with up to 95% sensitivity and specificity.

Prey et al. also used neural networks to identify early surgical site infections.[63] They included 193 patients who underwent a range of surgical procedures. However, as surgical site infections only occurred in five patients, they were unable to develop a satisfactory model. This highlights the difficulty investigating infection in orthopaedic patients. Infection has a very low incidence, and therefore, large numbers of patients will be required, particularly in arthroplasty, where rates are lowest. Investigation of open fractures, revision surgery, or foot and ankle surgery may be considered.

As with machine learning in other areas, there will be a trade-off between complexity and interpretability. Complex models can achieve higher accuracy and precision, however, they are a "black box" where even the creator cannot understand how the model was able to predict the outcome. This is a barrier, particularly in healthcare, where transparency in the decision-making process is expected by patients.[64] Furthermore, models with fewer data are prone to overfitting, which can be why high-performance characteristics are often reported.[65] Nevertheless, artificial intelligence techniques combined with thermography show promise in the future for orthopaedic infection, once these issues have been overcome.

Conclusion

As thermal camera technology improves, its scope for application in orthopaedic practice will increase. Thermography is sensitive to skin temperature changes in infected limbs following orthopaedic surgery. Key questions remain as to the specificity and cost-effectiveness of IRT in orthopaedic infection. Several barriers include the low incidence of infection, the need for studies with large patient numbers, and the large number of confounding factors that can affect thermal camera readings. Further research is needed to establish whether IRT is able to provide a low-cost, noncontact screening tool to identify infection in orthopaedic patients.

Clinical Significance

Infrared thermography is able to detect significant temperature differences in trauma and orthopaedic patients. However, current research cannot demonstrate clinical significance.

Infrared thermography can provide rapid information that may be a useful adjunct in the emergency department, outpatient clinics, or on the ward to diagnose a range of orthopaedic conditions, including infection.

Supplementary Materials

All the supplementary materials are available on the website www.stlrjournal.com.

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