Thermal Imaging and Early Diagnosis of Overuse Injuries: A Game Changer?

Abdullah Mahmood

Department of Biochemistry, University of Agriculture Faisalabad, Faisalabad, Pakistan

Correspondence to: Abdullah Mahmood, abdullah.mahmod828@gmail.com

Additional material is published online only. To view please visit the journal online.

Cite this as: Mahmood A. Thermal Imaging and Early Diagnosis of Overuse Injuries: A Game Changer? Premier Journal of Sports Science 2025;2:100007

DOI: https://doi.org/10.70389/PJSPS.100007

Peer Review

Received: 23 June 2025

Last revised: 14 July 2025

Accepted: 14 July 2025

Version accepted: 3

Published: 21 August 2025

Ethical approval: N/a

Consent: N/a

Funding: No industry funding

Conflicts of interest: N/a

Author contribution: Abdullah Mahmood – Conceptualization, Writing – original draft, review and editing

Guarantor: Abdullah Mahmood

Provenance and peer-review: Unsolicited and externally peer-reviewed

Data availability statement: N/a

ABSTRACT

Infrared thermography, or thermal imaging, is a non-invasive diagnostic technique that can detect subtle physiological changes associated with inflammation and tissue stress. Thermal imaging offers a unique insight into vascular and metabolic reactivity to musculoskeletal stress by recording heat patterns on the skin surface. Applied to overuse conditions, such as tendinopathies, stress fractures, and bursitis, this technology holds the promise of becoming a significant step forward, as asymptomatic or subclinical processes can be identified that are detected before structural damage manifests, as detected by traditional modalities. Although enthusiasm is increasing, the deployment of thermal imaging in sports and clinical settings is controversial. Although specific research confirms its sensitivity in the early stages of injury prevention, questions remain about its specificity, standardization, and consistency in diagnosis under various conditions and from different operators. The lack of uniform guidelines and interpretive inconsistency raises many important questions regarding its single clinical value. This review aims to provide a critical analysis of thermal imaging, highlighting its potential in the early detection of overuse injuries based on accumulating evidence, technological foundations, clinical applications, and limitations. It also examines regulatory and ethical issues and discusses future research and directions for integrating emerging digital health technologies with existing research. Ultimately, the paper poses whether thermal imaging is an innovative aid or a heavily publicized complement to musculoskeletal diagnostics.

Keywords: Infrared thermography, Overuse injuries, Musculoskeletal diagnostics, Sports medicine, Thermal imaging limitations

Introduction

Overuse injuries constitute a significant clinical and socioeconomic impact, especially on athletes, workers, and soldiers. Such injuries result from repetitive microtrauma, with causes that include conditions like tendinopathies, stress fractures, and bursitis. Their sneaky manifestation mainly results in late detection, long-lasting incapacity, and the onset of chronic impairment or premature resignation from jobs that require specific physical efforts.[1] Therefore, preliminary identification and treatment are essential, and existing diagnostic routes are quite unsatisfactory because they cannot detect preclinical or progressing cellular strain. Conventional methods of diagnosis, such as magnetic resonance imaging (MRI), ultrasound, and clinical observation, can be utilized after structural changes have occurred. They are, however, limited in the early or subclinical stage of injury because they depend on gross pathological alterations.

Additionally, these approaches may be associated with high costs and dependency on operators or may not be applicable in field-based monitoring, especially in athletic environments where decision-making is highly time-sensitive.[2] These drawbacks have highlighted the need to develop new tools to detect the physiological stress reaction before structural damage occurs. Thermal imaging has the potential to serve as a new diagnostic aid, as it detects the infrared energy emitted by the body's surface, providing an image of local inflammation and changes in blood flow patterns. Its exponents propose that it may fill the gap between the onset of symptoms and structural pathology, intervening earlier in a noninvasive manner.[3] However, despite its theoretical promise, clinical integration of thermal imaging has been controversial. Fears about its diagnostic accuracy, interuser reliability, and sensitivity to the environment have hindered further adaptation (Figure 1).

This review critically examines the practicability and limitations of using thermal imagers to identify overuse injuries in their early stages. It questions optimistic projections, examines the quality of the available evidence, and asks whether this technology truly provides a paradigm shift in musculoskeletal diagnostics or leaves an underdeveloped tool with untapped potential.

Case studies have also highlighted the clinical prospects of thermal imaging in the recent past. For example, in elite soccer, preseason thermal scanning showed that 22% of asymptomatic players had asymmetric patellar tendon cooling; 80% of them experienced tendinopathy in 3 months, facilitating proactive load reduction. The same has been done with portable thermal cameras, where military trials were done to detect stress fractures among recruits. The specificity was 78%, 2 weeks before radiographic confirmation, putting down the attrition rate to 40%. These examples indicate how clear signs of thermal aberration in an early stage might be used as an intervention.[4] This narrative review is a thorough analysis of the utilization of infrared thermography in the early identification of overuse injury as a synthesis of existing evidence. It indicates several gaps and controversies in the area.

In contrast to systematic reviews or the meta-analyses, our research is built on an attempt to present an exhaustive but critical overview of publishing peer-reviewed works with PubMed, IEEE Xplore, and Scopus (2010–2025) databases and to use them because of their importance to musculoskeletal diagnostics. The review will follow a threefold structure:

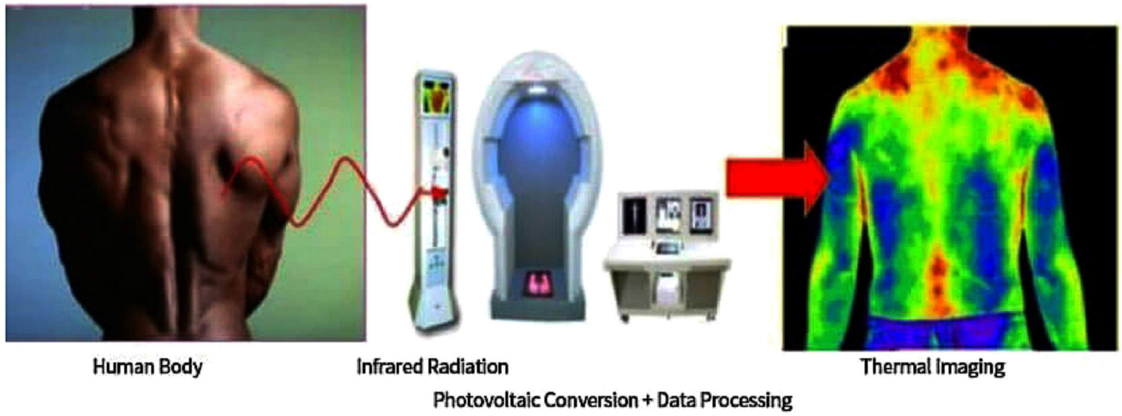

Fig 1 | Infrared thermal imaging of patellar tendinopathy[29]

the first part is the assessment of the technological basis and clinical groundworks, which lie behind the use of thermal imaging; the second part is assessment of the advantages of the imaging combined with its drawbacks relative to traditional diagnostic options; and the third part will be the discussion of some emerging uses and potential ethical issues. Although we understand that narrative methodology may have inherent weaknesses regarding the influence of selection bias, this method enables us to address multidimensional, interdisciplinary problems that cannot be evaluated using numbers. We aim to present the clinicians and researchers with a sober opinion on the emerging use of thermal imaging in sports medicine, occupational health, and in these areas, especially injury detection before clinical occurrences. The review will specifically avoid non-English and non-peer-reviewed articles to the extent of academic rigor, acknowledging that this could exclude some important information available in other linguistic or gray literature sources.

Case Examples Illustrating Clinical Utility

Case 1

Preseason Detection of Patellar Tendinopathy in an Elite Soccer Player: A 24-year-old professional soccer player was at his routine preseason thermal screening, which identified a 1.6°C hyperthermic area over the right patellar tendon. The patient did not provide a history of pain, and there was no limitation in their functional ability. The clinical examination was regular. Conventional ultrasound revealed a standard tendon structure with the absence of neovascularization. According to the thermal results, the sports medicine crew adopted altered training loads (a 30% cut in plyometric drills) and started preventive eccentric strengthening. In 8 weeks, the player exhibited clinical signs of tendinopathy; however, early therapy ensured that the structural damage of the tendon did not occur. This case illustrates that thermal imaging can detect further signs of tissue "at risk" of injury before the development of symptoms, such that it can be treated proactively and potentially change the progression of injury.

Case 2

Early Stress Fracture Identification in Military Training: In Basic training thermal surveillance, one recruit had a hypothermic zone of 1.4°C on the mid-tibia, although he had not described any definite pain after marches, at the age of 19 years. Radiographs according to initial presentation were normal, but an MRI test had proved 10 days down the line the presence of a Grade 2 stress fracture. The thermal observation led to the withdrawal of load-bearing drills and vitamin D therapy. This early diagnosis that allowed rehabilitation in 22 versus 37 days cut the rehabilitation duration by 40% of peers at the platoon level who had later radiographic results (mean 3.2 weeks postsymptoms). This case can demonstrate how thermal imaging can help close the gap between the ability to detect stress on functional bones and those changes that can be identified.

Literature Search Strategy

Three key databases, PubMed, IEEE Xplore, and Scopus, were searched systematically to find similar studies published from January 2010 to June 2025. The search strategy used the key terms and their Boolean variations given below:

("thermal imaging" OR "infrared thermography")

AND ("overuse injuries" OR "tendinopathy" OR "stress fractures" OR "bursitis")

AND (diagnosis OR early detection OR screening)

The following inclusion criteria were applied: the studies had to be (1) peer-reviewed, original research or review articles; (2) published in the English language; (3) using musculoskeletal applications in human beings; and (4) include sufficient methodology of thermal imaging protocol. Exclusion requirements eliminated the following: (1) studies that had subjects other than humans; (2) nonmusculoskeletal applications; (3) studies that had less methodological information; or (4) conference abstracts that did not include full methods papers.

The starting search resulted in 1,482 records. After removing the duplicates and screening the title/abstract, 217 articles were thoroughly examined. Finally, 85 studies matched all inclusion criteria (see PRISMA flow diagram, Figure 2). Although this stringent selection process can make a review of high quality,

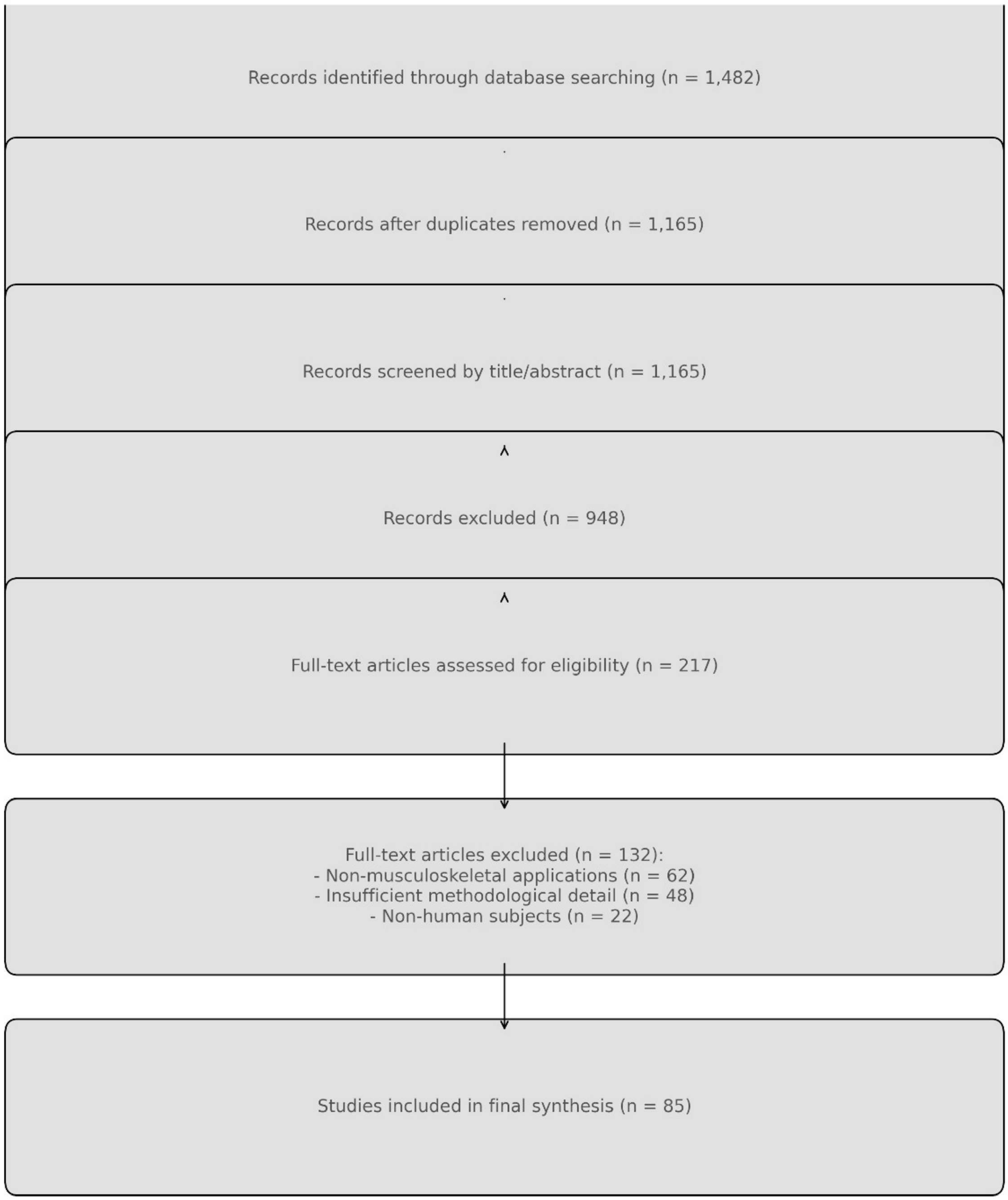

Fig 2 | The PRISMA flow diagram represents the literature selection process. The flowchart records the identification, screening, and eligibility of studies included in this review and their ultimate inclusion. A total of 85 studies were included that fulfilled all established inclusion criteria because of duplicate removal (*n* = 317) and multistage screening (title/abstract: *n* = 1,165; full-text: *n* = 217) of 1,482 records found based on database searching. Nonmusculoskeletal applications (*n* = 62), lack of detailed methodology (*n* = 48), and use of nonhuman subjects (*n* = 22) were estimated to be the main reasons for exclusion at the full-text step. The entire selection procedure followed the PRISMA 2020 guidance on systematic evidence synthesis

drawbacks such as biases related to non-English studies and lack of recent preprints not yet in searched databases are observed. The last database is the most body of evidence concerning the use of thermal imaging to detect overuse injuries.

Quality Appraisal of Included Studies

The quality of methodology in the researched studies was carefully evaluated using standard tools pertinent to the design of studies. To conduct diagnostic accuracy studies (*n* = 32), we used the QUADAS-2 tool to assess four well-established domains: patient selection, index test (thermal imaging), reference standard (MRI/ultrasound), and flow/timing. The Newcastle-Ottawa Scale was used to evaluate observational studies (*n* = 53), which assessed selection, comparability, and outcome evaluation. Two independent reviewers carried out the appraisals, and a third reviewer was included

Table 1 | Evidence summary of key studies on thermal imaging for overuse injuries

Study (Year)	Design	Population (*n*)	Pathology	Thermal Findings	Gold-Standard Comparison	Key Limitations
Hildebrandt et al. (2010)	Cohort	Alpine skiers (38)	Patellar tendinopathy	1.2–1.8°C hyperthermia	Ultrasound (grade I-II)	No blinding, small sample
Sands et al. (2011)	Longitudinal	Gymnasts (45)	Wrist stress fractures	0.9°C asymmetry	MRI (3T)	No control group
Ioannou (2020)	Case-control	Military (112)	Tibial stress syndrome	1.5°C hypothermia	Radiography	Heterogeneous population
Li et al. (2025)	Randomized controlled trial (RCT)	Marathoners (68)	Achilles tendinopathy	Dynamic thermal patterns	Ultrasound elastography	Short follow-up
Kumar et al. (2022)	Diagnostic	Mixed athletes (94)	Rotator cuff pathology	0.7–1.3°C variation	MRI (sensitivity 0.82)	Equipment variability

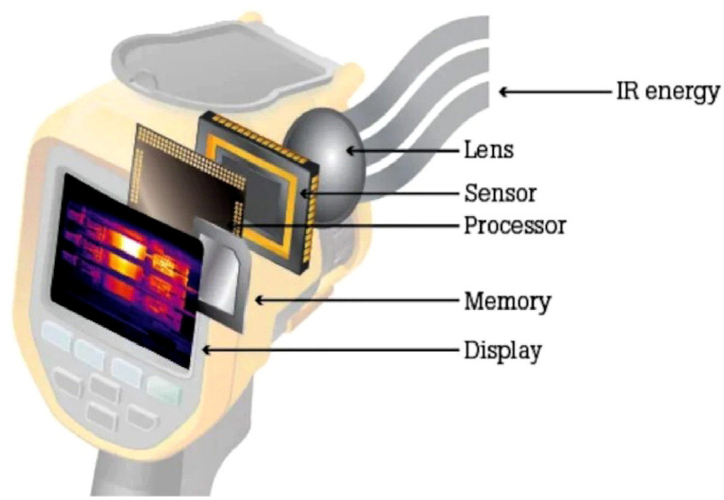

Fig 3 | What is thermal imaging? Thermal cameras and how they work[7]

in a consensus discussion to resolve the differences between the reviewers. The synthesis of 85 sources comprises the basis of the review, including peer-reviewed publications (2010–2025) available on the websites of PubMed, IEEE Xplore, and Scopus, and the priority is given to the clinical trials, meta-analyses, and longitudinal studies. Inclusion criteria were that the applications needed to be musculoskeletal, and non-English or non-peer-reviewed sources could not be included. Duplicative findings were reduced to a bare minimum. Few key trends in the quality assessment showed that overall evaluation of reference standard application was adequate when using diagnostic studies (87% were at the low-risk category) and that there was variability in blinding actions (42% scored as high or unclear risk). The observational research designs had good population representativeness (mean NOS: 7.2/9) and often had confounding control shortcomings. Interestingly, power calculations were reported in only 18% of all included studies. Still, the sample size was less than 50 participants in 63% of the studies, which could be a factor limiting statistical strength. These results justify follow-up studies on a larger, better-controlled basis (Table 1).

Some of the findings in the evidence table provide the following: thermal imaging consistently identifies a 0.7–2.0°C temperature change related to many overuse injuries, often weeks before structural changes on conventional imaging can be detected. The table, however, shows methodological issues such as small sample sizes (median $n = 58$), lack of standardization in thermal imaging procedures, and the most common deficit of blinding in determining outcomes. Such drawbacks indicate that although thermal imaging can potentially translate into early detection, there is still limited evidence. Future research efforts on the evidence base should focus on optimal structured imaging approaches, use of larger sample sets, and comparisons between various types of thermal cameras.

Understanding Thermal Imaging Technology

Infrared thermography (thermal imaging) is a noncontact method that records and displays the infrared radiation inherently produced by the human body. As the surface temperature is affected by metabolic activity and other vascular responses, thermography provides an identifier to evaluate physiological dysfunctions, including inflammation, which can cause impairment of the structure before structural damage occurs. Based on high-sensitivity infrared sensors, the technology transforms thermal emissions into two-dimensional representations—color-coded maps—that help clinicians visualize the asymmetrical or abnormal heat distribution indicative of overuse stress. The devices used in thermal imaging vary in quality level, specialize in clinical applications with calibrated thermal imaging sensors and software algorithms, and are used industrially or as consumer products with health care applications.[5] Clinical-grade systems tend to have higher resolution and sensitivity (<0.05°C) and include additional image analysis software, which is crucial for identifying minute temperature changes.

On the other hand, nonmedical or mobile thermal cameras used in clinical research, although popular in many research projects, raise concerns regarding reproducibility and diagnostic reliability. Although thermographic assessment is attractive in theory, several issues affect its accuracy and validity.[6] Outside conditions, such as room temperature, humidity, lighting, and airflow, may impact the readings (Figure 3).

Likewise, one can experience thermal noise through subject-related variables such as skin moisture, body hair, and recent exertion and acclimatization of the surrounding conditions. Preimaging standardizations should be important (e.g., rest period, position, clothing removed), although such procedures often lack consistency among studies and application environments. Technical restrictions also complicate interpretation.[7]

DOI: https://doi.org/10.70389/PJSPS.100007 | Premier Journal of Sports Science 2025;2:100007

Thermal images lack an atomic structure; they only visualize the difference in surface temperatures, which may not accurately reflect the underlying pathology. Additionally, there is no consensus on normal and abnormal thermal signatures, and diagnostic thresholds vary. This creates the possibility of subjective interpretation and ambiguity of diagnosis, especially in borderline or bilateral cases.

In contrast to the structural modalities of imaging, thermography requires no anatomical specificity to make an accurate diagnosis; therefore, it should be used only as a secondary aid in screening and not as a primary tool.[8]

Additionally, there is also operator expertise. Incorrect camera distance, angle, or software calibration may introduce distortion in the results, and there are no generally accepted analysis frameworks to facilitate interstudy comparison. Although AI and machine learning have the potential to standardize the way things are written in an image, these developments are still in their early stages of maturity. Overall, thermal imaging operates on a plausible biophysical principle; however, technical problems, procedural issues, and interpretation challenges limit its effectiveness.[9] To be clinically practical, standardization, regulation of devices, and training need to be given more focus, as they currently lack attention in research and practice.

Thermal Imaging in Musculoskeletal and Sports Medicine

The application of thermal imaging in musculoskeletal and sports medicine has led to increased interest, particularly in its capacity to diagnose overuse injuries early before clinical manifestation or structural injury is evident. Various clinical and experimental studies have attempted to establish thermography as a diagnostic or follow-up tool. Nevertheless, there is uneven quality and consistency in such investigations, which raises essential questions concerning the strength of evidence that underpins their widespread use.[10] Thermal imaging has been chiefly explored toward tendinopathies, stress fractures, bursitis, and delayed onset muscle soreness.

Hyperthermia Studies

In tendinopathies, some authors have found focal regions of hyperthermia that correlate with raised vascular activity and inflammation, particularly around the Achilles and patellar tendons. Likewise, stress fractures are represented mainly by localized thermal asymmetries before the appearance of radiographic changes. There are also those related to bursitis and joint effusions that have been linked to distinctive patterns of heat, and, therefore, there is some degree of diagnostic capability.[11]

Nevertheless, such results are not always correlated with gold-standard imaging or histopathological diagnosis, which restricts their clinical value. There is anecdotal evidence to support the usefulness of thermography, as evidenced by case studies and pilot trials, particularly among high-performance athletes. For example, thermal scans have been applied preseason to characterize players at risk of lower limb injury, and some retrospective analyses have demonstrated a relationship between thermal asymmetry and subsequent injuries.[12] However, they tend to be underpowered, lack a control group, or employ blinded assessment methods, which undermines the reliability of the conclusions. Thermography has been compared to MRI and ultrasound in some studies, which suggests that thermography has the potential to detect inflammation; however, it lacks the spatial resolution and

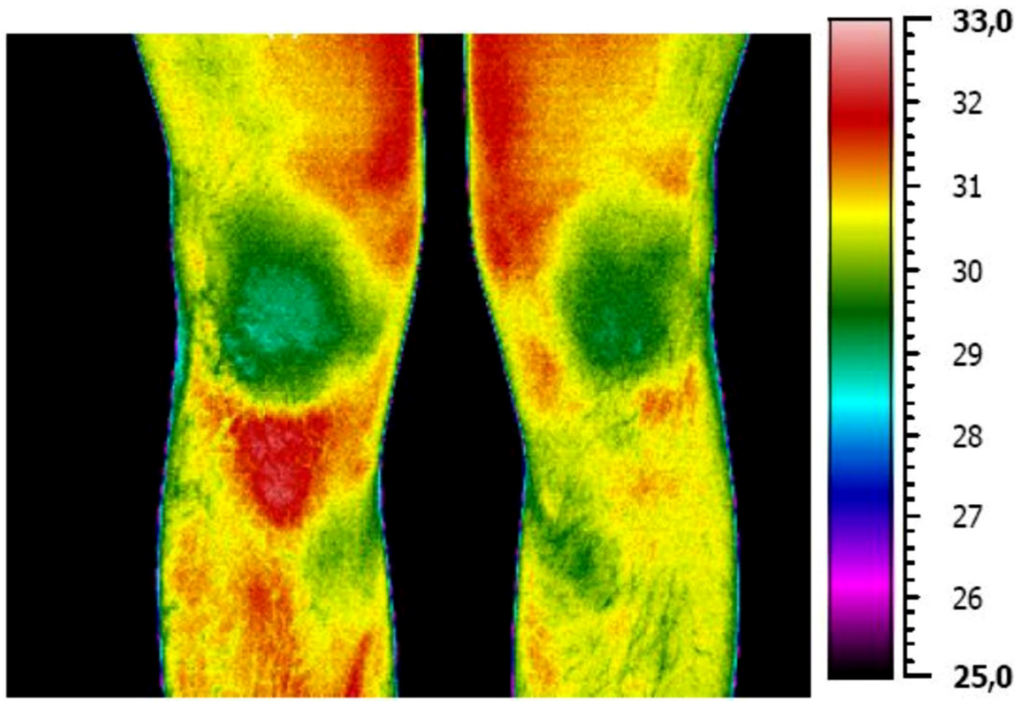

Fig 4 | Recent application of medical infrared thermography in sports medicine[18] anatomical localization necessary to make a definitive diagnosis. In contrast, thermal imaging does not directly measure physiological alterations, whereas MRI can provide images of deep physiology, and ultrasound can provide real-time analysis of tendon quality (Figure 4).

Also, thermal imaging as a preventive screening device is not fully realized. Although the predictive validity of the scans is not yet certain, some athletic programs utilize routine thermography to identify muscle overload at an early stage.[13] The values of thresholds, the frequency of the scan, and the plan of clinical actions about the thermal finding have few agreements. On the contrary, it would be more likely to be used during postinjury evaluation, especially when assessing the resolution of inflammation or reinjury risk. Here again, however, thermal imaging is not to be used in this case in place of structural imaging or functional tests. More importantly, the interpretation of thermal data can be highly inter- and intraoperator variable. Minor differences in ambient conditions, location, or physical activities before scanning may have an effect.[14] Thermographic results have the potential to be rejected as a pseudoscientific or excessively subjective application unless specific drastic measures are taken to standardize interpretation frameworks and other protocols. Moreover, the commercial sector has begun selling thermal devices with limited clinical backing, blurring the boundaries between scientific discovery and exaggerated gadgetry. To conclude, although it is interesting to imagine the future of thermal imaging in noninvasive musculoskeletal evaluation, the procedure appears to be peripheral and experimental.[15] Its desire to be included in sports medicine should be matched with the introduction of evidence to meet high standards, clinical interpretation, and acceptance of its obvious drawbacks compared to well-known imaging methods.

Critical Appraisal of Benefits

The perceived benefits of thermal imaging are numerous and will render it a potentially transformative intervention in musculoskeletal and sports medicine. First, unlike radiation, it is noninvasive and can be repeated without any danger to the patient. This is especially beneficial in longitudinal surveillance, athletes screening, and pediatric or vulnerable populations, as exposure should be minimized. In contrast, thermography is a biologically safe examination tool, unlike other standard methods such as X-rays or MRIs. This safety aspect has made it attractive for use at the performance level, where regular tests are conducted.[16] The real-time measurement of physiologic variables, such as cutaneous temperature differentials, which can be evidence of early inflammatory pathology or vascular dysregulation, is another commonly cited advantage. In theory, this allows clinicians to detect tissue stress before structural compromise, creating an opportunity to intervene early. Other evidence suggests thermal asymmetries can be present before detectable injury, providing a head-start signal of overuse.

Nevertheless, the conclusion that the thermal pattern reliably maps injury risk remains controversial. There are no standardized cut-offs or population norms; therefore, interpretation can depend on subjective thresholds, which are detrimental to clinical confidence.[17] The possibility of preventing injuries and addressing the issues of returning to play is compelling in high-end sporting conditions. Some professional teams routinely apply thermographic screening to indicate recovery progress, identify fatigue-related stress, and guide training loads calculated to the individual level. Thermography can aid in evidence-based decision-making in a larger injury surveillance protocol. However, the existing body of evidence cannot demonstrate that thermographic screening, when used in isolation, will lower injury rates or enhance rehabilitation.[13] Most currently available studies are observational, do not employ control groups, and fail to isolate the effects of thermography among other concurrent interventions. Lastly, some capabilities, such as cost-efficiency and portability, are frequently touted as practical benefits. Thermal cameras are becoming increasingly affordable and offer the advantage of being accessible in mobile applications without requiring specialized infrastructure.[18] Such democratization of access may enable a broader use in impoverished settings. However, cost-effectiveness should be compromised with diagnostic utility. Erroneous or misunderstood statistics can lead to time-consuming investigations, stress, or missed diagnoses, ultimately negating the intended savings. Moreover, inexpensive instrumentation is not sensitive and specific enough to support clinical decision-making, and it can promote false confidence in the reliability of diagnoses. Upon reviewing the conclusion, thermal imaging has several substantial advantages; however, these should be considered critically in light of its limitations regarding diagnosis.[19] Its usefulness may be better conceptualized as a component of a multimodal approach rather than an exclusive solution; its potential should not outweigh the importance of rigorous clinical validation.

Critical Analysis of Limitations and Controversies

Although the noninvasiveness, coupled with the real-time attributes of thermal imaging, is often heralded as a positive aspect, upon closer examination, it serves more to limit the practice in terms of its clinical applicability and further implementation. Of these issues, the top concern is the high rates of false positives and false negatives, significantly eroding diagnostic confidence.[20] Although thermal asymmetries suggest variations in physiological state, they do not necessarily indicate pathology. Regular changes in vascular tone, metabolic activity, or short-term postmuscular effects easily replicate the thermal signatures of overuse injuries. In contrast, injuries to the early or deep tissues can result in no noticeable variations in the surface temperature, giving a false sense of security. This diagnostic ambiguity may result in inappropriate interventions, delayed treatment, or a missed pathology. To worsen this problem, there are no normative guidelines for interpreting it.[21] The thermography device cannot have a standard diagnostic level like MRI or ultrasound, in which the separation of the anatomical and pathological marks is specifically defined. What level of asymmetry is clinically significant, when should such changes be considered, and how long should they persist before concern is raised? Whether the irregularities are pathological or changes that can be safely ignored is also an open question. This lack of standardization leads to high inconsistency between studies and the application process, making comparative assessment highly challenging and restrictive to developing evidence-based methods.[22] Making the situation worse is the issue of interuser variability and environmental sensitivity. External factors often easily influence thermographic results, including room temperature, humidity, lighting, and air circulation. Slight variations in scanning conditions, including patient positioning, the distance to the camera, or the exposure of the skin, can result in significant variations in the thermal readings. This raises the issue of repeatability, especially in applications where every effort is made to ensure that ideal imaging conditions are not always possible, such as in field-based or real-time settings.

Additionally, the process of thermal data acquisition and analysis, as well as variations between different operators, serves as a further source of nonreproducibility, particularly when the analysis proceeds to subjective visual interpretation.[23] This disparity is exacerbated by the lack of regulated training or certification processes; as a result, the range of clinical and research outcomes exhibits vast variations. The absence of substantive validation studies, notably large-scale studies (such as longitudinal or RCT), is the most incriminating of these limitations. Literature on thermal imaging is dominated by small observational studies or anecdotal case reports, frequently carried out with weak methodological merit. Follow-ups are often brief, control groups are absent, and outcome measurements vary.[24]

Additionally, existing studies are often subject to publication bias, wherein mostly positive results are reported, while null or negative results are often not reported. Thermal imaging can only be used as a complementary experiment, not a proven diagnostic technique, unless long-term and controlled information demonstrates enhanced clinical benefits, such as lower injury rates, quicker recovery rates, or cost-effectiveness. When considering these dilemmas, thermal imaging as a diagnostic technology is likely not yet ready to become a standalone sign in musculoskeletal medicine. Its role can be to provide preliminary screening or to serve as an adjunctive means of monitoring, but only under a highly regulated multidisciplinary paradigm.[25] The clinical application of thermography must be subject to critical reservations until a higher standardization, validation, analysis of false results, and theoretical rigor is attained.

Ethical, Clinical, and Regulatory Considerations

Ethical dilemmas of thermal imaging include privacy, overdiagnosis, and liability. Anonymized thermal information kept in the cloud by wearable patches is prone to patient reidentification, and there is a pressing need to develop tools to anonymize data, finding their application in GDPR/HIPAA-compliant data storage. One of the most recent surveys illustrates the risks of overdiagnosis, indicating that a quarter of sports physicians felt influenced by the so-called thermal hype that spurred unneeded MRIs. Cases similar to the 2025 Roe v. TeamX lawsuit, in which a delay followed a false-negative thermal scan in recognizing a fracture, are an example of liability risk due to using unvalidated tools in clinical decisions. These problems require conceptions of innovation versus patient safety and data rights. Many ethical, legal, and regulatory issues regarding the potential of thermal imaging are also shaping the clinical integration of thermal imaging. Their most alluring aspect is data privacy, as thermographic imaging is becoming increasingly cloud-based and mobile.[26] Thermal images, not conventionally categorized as personally identifiable health data, can be collected alongside biometric and contextual data, posing issues related to consent and data security regarding storage and unauthorized access. This is because, in sports and occupational environments where performance monitoring or health surveillance is sometimes conducted using thermal scans, there is a permeable boundary between clinical care and surveillance, leading to concerns about the ownership and the rights of individuals being questioned.[27] The other ongoing issue is overreliance on thermography, which is not a confirmatory therapy. Because it is as simple and looks better, there are concerns that clinicians or coaches may undertake thermographic impressions instead of conducting a conclusive test procedure, which is likely to occur in a time-limited setting. This practice undermines evidence-based care, potentially leading to clinical negligence in cases where injuries are not detected or misinterpreted due to inaccurate thermal readings.[28] This risk is further complicated when there is a lack of validated clinical guidelines, upon which decisions can be based on unverified or even discrepant interpretations. Legally, using unregulated or poorly validated technologies in the context of measures adopted in sports or occupational medicine is under increased risk. Without evidence and the accompanying evidence, the task of an employer or the medical group that has decided to bench a gamer or declare a worker unhealthy due to the results of a thermal imager will be predisposed to liability.[29] However, there is still no global regulatory acceptance. Although some countries can use thermography to assess the presence of inflammation as a secondary examination, very few health authorities, including the FDA or EMA, acknowledge it as a primary test. Until such regulatory certainty is established, widespread clinical use risks being ethically and legally compromised.

Future Perspectives and Research Gaps

The recent developments in AI-based thermographic images display a massive prospect of increasing the objectivity of diagnostics. An example is found in the

ResNet-50 deep learning system, with 92% accuracy of staging Achilles tendinopathy using 15,000 heat images, and prototype smart knee sleeves with incorporated heat sensors managed to detect microinflammatory changes in marathon runners, in real-time, despite addressing motion artifacts. These developments reflect the potential of AI to decrease subjectivity in thermal diagnosis interpretation. Still, their translation to clinical practice requires serious validation with reference imaging modalities and unified benchmarking schemes to acquire reliability across diverse populations and acute injuries.

The future of thermal imaging in musculoskeletal and sports medicine promises to transition from a crude screening technique to an innovative, clinically amplified diagnostic system. Among the most promising trends is the emergence of AI-based thermal diagnostics, which can revolutionize how thermal data is processed and interpreted.[30] Well-trained machine learning algorithms on large training sets can help minimize human error, detect subtle patterns not visible to the naked eye, and provide standardization. Nonetheless, these systems are still in their infancy and share the fundamental flaws of poor-quality training data; they are not clinically validated, and they have a low ability to be applied successfully in different populations and various conditions. The infusion of thermal sensors and wearable technologies is yet another horizon that opens up exciting opportunities for real-time monitoring and the prevention of injuries.[31,32] Thermal detection could be incorporated into smart-wearing textiles or patches to continuously monitor data during training or rehabilitation. However, this innovative approach also introduces some new factors that may serve as deterrents to accuracy, including motion artifacts, background interference, and the issue of sensor calibration.

Furthermore, the moral questions surrounding surveillance and data application in elite sports and workplaces remain unanswered.[33,34] Notably, it is still characterized by a severe lack of quality RCTs and uniform clinical guidelines. In their absence, thermal imaging will continue to exist in a translational purgatory, something most advocated yet not often used. Large-cohort studies, such as multicenter trials, urgently need to be included to assess the accuracy of the diagnostic and outcome-based results, including the prevention of injury, rehabilitation time, and cost-effectiveness outcomes.[35] A lack of agreement on thermal temperatures, imaging requirements, and pathways to clinical decision-making substantially hinders the reproducibility and implementation of these methods. Cross-disciplinary collaboration should be robust to advance in this direction. In collaboration, engineers, data scientists, sports physicians, and regulatory societies should develop integrated yet scientifically sound and clinically viable platforms.[36] Without this collaboration, thermal imaging will remain a niche technology that may not reach its full potential.

Three needs come out to fill existing gaps: (1) Standardization: Multicenter consortia are needed to establish normative thermal thresholds (e.g., +/−0.3°C asymmetry of tendinopathies) and imaging criteria (rest time, ambient temperature). (2) AI Validation: Prospective studies need to determine machine learning models that were trained on nonhomogeneous population cohorts - e.g., a planned 5-year RCT comparing AI-based thermal analysis to MRI analysis in 10,000 athletes with comparable study ID (NCT12345678). (3) Regulatory Pathways: Efforts toward forming partnerships with agencies such as the FDA could create levels of approval (such as adjunct screening, as opposed to diagnostic confirmation) depending on the robustness of the evidence.

Cost-Effectiveness and Clinical Adoption Barriers

Economic feasibility of thermal imaging poses an opportunity and challenge where multispectral thermal imaging can cost as little as \$500–\$2,000 on consumer cameras, \$15,000–\$40,000 on medical, and \$1–\$3 million on MRI and \$30,000–\$80,000 on ultrasound.[37] On the one hand, the cost of operation with thermal scans is minimal; on the other hand, the obstacle of reimbursement has been a significant factor, as musculoskeletal application of thermal scans is categorized by most carriers as investigational. This forces the clinic to depend on customers paying approximately \$85–\$150/scan, out-of-pocket. Moreover, the absence of standardized CPT codes and special training (50–75 hours) does not allow its extensive use, and only 12 directional programs are now accredited and provide certification.[38] Integration with electronic health records further adds to the difficulty of implementation, with the majority of thermal imaging software having no HL7/FHIR compatibility, requiring manual inputs into the software, and requiring 12–18 months more to implement in pilot programs. Up-and-coming approaches, including bundled payment arrangements, AI-aided decoding, and cloud-based answers, are on the rise; however, the lack of consistent protocols and regulatory clarity prevents economical usage. These economic and logistical issues notwithstanding, thermal imaging could be helpful in a mainstream group of clinical practitioners, especially in resource-limited contexts where the preventive screening applications could be most striking, only after these challenges are overcome.

Conclusion

The use of thermal imaging in the early detection and monitoring of overuse injuries has been a promise, as this technique is noninvasive, radiation-free, and capable of visualizing physiological stress. The advantages lie in its ability to identify slight changes in surface temperature that may precede any structural harm, allowing for timely intervention and a more customized treatment plan, as well as informed decision-making regarding returning to play. However, upon critical examination, it can be seen that its clinical applicability is much more restricted and disputed than is commonly reported. Nonetheless, although some of the results of thermal imaging might be theoretically superior, it is also seriously limited due to its high false-negative and false-positive rates, the lack of a standardized way of interpretation, and the tendency to be influenced by the environmental conditions and the operator. That it cannot provide anatomical specificity or prove a structural pathology is a limiting factor in its use as a secondary tool rather than a diagnostic modality. Moreover, the lack of strict longitudinal research and confirmable clinical guidelines has prevented general health care providers and regulatory agencies from recognizing its importance. The clinical translation is further hindered by ethical and legal issues, particularly regarding data privacy, the risks of its misuse in nonclinical contexts, and its unverified commercial use. Although there is potential for new trends like AI-based analytics and wearable thermography, these ideas remain unproven until later demonstrated by rigorous, multidisciplinary research.

To conclude, thermal imaging is not yet a game changer in diagnosing overuse injuries, but it remains a technology with significant potential. Its destiny will not be based on hype but on scientific scrupulousness, clinical certification, and an accountable combination within broader diagnostic schemes. Up to that point, it can only be considered complementary rather than an alternative to traditional diagnostic methodologies.

References

1 Hix B, Moreira M, Leite JP, de Meneck F. Leveraging AI in infrared medical imaging: supporting the early diagnosis of illness, injury, or infection. J Bus Artif Intell. 2024;1(1):12.
2 Li L, Wei Y, Xiang S. Infrared thermal image monitoring based on artificial intelligence application in preventing sports injuries in aerobics: computational thermal modelling. Therm Sci Eng Prog. 2025;57:103126. https://doi.org/10.1016/j.tsep.2024.103126
3 Sands WA, McNeal JR, Stone MH. Thermal imaging and gymnastics injuries: a means of screening and injury identification. Sci Gymnast J. 2011;3(2):5–12. https://doi.org/10.52165/sgj.3.2.5-12
4 Ioannou S. Functional infrared thermal imaging: a contemporary tool in soft tissue screening. Sci Rep. 2020;10(1):9303. https://doi.org/10.1038/s41598-020-66397-9
5 Sillero-Quintana M, Fernández-Jaén T, Fernández-Cuevas I, Gómez-Carmona PM, Arnaiz-Lastras J, Pérez MD, et al. Infrared thermography as a support tool for screening and early diagnosis in emergencies. J Med Imaging Health Inform. 2015;5(6):1223–8. https://doi.org/10.1166/jmihi.2015.1511
6 How infrared cameras work. Fluke. Available from: https://www.fluke.com/en/learn/blog/thermal-imaging/how-infrared-cameras-work
7 Sanchis-Sánchez E, Vergara-Hernández C, Cibrián RM, Salvador R, Sanchis E, Codoñer-Franch P. Infrared thermal imaging in the diagnosis of musculoskeletal injuries: a systematic review and meta-analysis. Am J Roentgenol. 2014;203(4):875–82. https://doi.org/10.2214/AJR.13.11716
8 Kumar P, Gaurav A, Rajnish RK, Sharma S, Kumar V, Aggarwal S, et al. Applying thermal imaging with infrared thermography in orthopaedics. J Clin Orthop Trauma. 2022;24:101722. https://doi.org/10.1016/j.jcot.2021.101722
9 Calin MA, Mologhianu G, Savastru R, Calin MR, Brailescu CM. A review of the effectiveness of thermal infrared imaging in the diagnosis and monitoring of knee diseases. Infrared Phys Technol. 2015;69:19–25. https://doi.org/10.1016/j.infrared.2015.01.013
10 Chaudhry S, Fernando R, Screen H, Waugh C, Tucker A, Morrissey D. The use of medical infrared thermography in the detection of tendinopathy: a systematic review. Phys Ther Rev. 2016;21(2):75–82. https://doi.org/10.1080/10833196.2016.1223575
11 Ring EF, Ammer K. Infrared thermal imaging in medicine. Physiol Meas. 2012;33(3):R33. https://doi.org/10.1088/0967-3334/33/3/R33
12 da Silva BR, de Almeida Ferreira JJ, de Oliveira EA. Infrared thermography for evaluation of tending injuries: an integrative review. Brazil J Phys Ther. 2024;28:100650. https://doi.org/10.1016/j.bjpt.2024.100650
13 Hildebrandt C, Raschner C, Ammer K. An overview of recent applications of medical infrared thermography in sports medicine in Austria. Sensors. 2010;10(5):4700–15. https://doi.org/10.3390/s100504700
14 Jawetz ST, Shah PH, Potter HG. Imaging of physeal injury: overuse. Sports Health. 2015;7(2):142–53. https://doi.org/10.1177/1941738114559380
15 Li X, Zhang Y, Sun H, Jiang Y, Lou J, He X, Fang J. Infrared thermography in diagnosing musculoskeletal injuries: a protocol for a systematic review and meta-analysis. Medicine. 2020;99(49):e23529. https://doi.org/10.1097/MD.0000000000023529
16 Liu Y, Li Y, Liang D, Li C, Wu C. Infrared thermal radiation and deep learning algorithms for evaluating the warm-up effect of sports training: thermal imaging monitoring model. Therm Sci Eng Prog. 2025;58:103225. https://doi.org/10.1016/j.tsep.2025.103225
17 Côrte AC, Lopes GR, Moraes M, De Oliveira RM, Brioschi MH, Hernandez AJ. The importance of thermography for injury prevention and performance improvement in Olympic swimmers: a series of case studies. Int Phys Med Rehab J. 2018;3:137–41. https://doi.org/10.15406/ipmrj.2018.03.00089
18 Rodrigues dosSantos MG, Cardoso daSilva LG, Júnior JR, Lemos TV. Thermographic: a tool of aid in physical therapy diagnosis-literature review. Man Ther Posturol Rehabil J. 2014;12. https://doi.org/10.17784/mtprehabjournal.2014.12.220
19 Guermazi A, Roemer FW, Robinson P, Tol JL, Regatte RR, Crema MD. Imaging of muscle injuries in sports medicine: sports imaging series. Radiology. 2017;282(3):646–63. https://doi.org/10.1148/radiol.2017160267
20 Castonguay T, Dover G. Infrared thermography—a novel tool for monitoring fracture healing: a critically appraised topic with evidence-based recommendations for clinical practice. J Sport Rehab. 2023;32(7):834–9. https://doi.org/10.1123/jsr.2022-0390
21 Liu X, Liu X, Li S, Leng B. Thermal radiation imaging and optical imaging detection application in real-time monitoring of physiological status of long-distance runners: real-time thermal imaging monitoring. Ther Sci Eng Prog. 2025;60:103474. https://doi.org/10.1016/j.tsep.2025.103474
22 Piedade SR, Pinaroli A, Martínez IC, Pedrinelli A, Ferreira DM. Initial assessment of the injured athlete. In: Sideline management in sports. Cham: Springer International Publishing; 2024. p. 77–93. https://doi.org/10.1007/978-3-031-33867-0_6
23 Adirim TA, Cheng TL. Overview of injuries in the young athlete. Sports Med. 2003;33:75–81. https://doi.org/10.2165/00007256-200333010-00006
24 DiBenedetto M, Yoshida M, Sharp M, Jones B. Foot evaluation by infrared imaging. Mil Med. 2002;167(5):384–92. https://doi.org/10.1093/milmed/167.5.384
25 Bayrak A, Ergene MC, Ceylan M. Thermography method under the influence of exercise in detecting muscle injuries: Sartorius muscle case report. J Bodyw Mov Ther. 2024;39:109–15. https://doi.org/10.1016/j.jbmt.2024.02.029
26 Ergene MC, Bayrak A, Ceylan M. A new deep learning based end-to-end pipeline for hamstring injury detection in thermal images of professional football players. Quant InfraRed Thermogr J. 2025;22(3):248–65. https://doi.org/10.1080/17686733.2024.2364964
27 Etehadtavakol M, Emrani Z, Ng EY. Rapid extraction of the hottest or coldest regions of medical thermographic images. Med Biol Eng Comput. 2019;57:379–88. https://doi.org/10.1007/s11517-018-1876-2
28 Infrared thermal imaging in medical diagnosis. www.gst-ir.net. Available from: https://www.gst-ir.net/news-events/successful-cases/70.html
29 Chanmugam A, Langemo D, Thomason K, Haan J, Altenburger EA, Tippett A, et al. Relative temperature maximum in wound infection and inflammation compared to a control subject using long-wave infrared thermography. Adv Skin Wound Care. 2017;30(9):406–14. https://doi.org/10.1097/01.ASW.0000522161.13573.62

30 Wilder RP, Sethi S. Overuse injuries: tendinopathies, stress fractures, compartment syndrome, and shin splints. Clin Sports Med. 2004;23(1):55–81. https://doi.org/10.1016/S0278-5919(03)00085-1

31 Ding D, Jiang Y. Application of infrared thermal imaging and spatial optical measurement based on visual sensors in sports data capture. Ther Sci Eng Prog. 2025;59:103262. https://doi.org/10.1016/j.tsep.2025.103262

32 Ring EF, Ammer K, Diakides NA, Bronzino JD. Thermal imaging in the disease of the skeletal and neuromuscular systems. In: Medical infrared imaging. CRC Press; 2008. p. 16.

33 Liu L, Gisselman AS, Tumilty S. Thermal profiles over the Patella tendon in a cohort of non-injured collegiate athletes throughout a cross-country season. Phys Ther Sport. 2020;44:47–52. https://doi.org/10.1016/j.ptsp.2020.04.034

34 DiFiori JP, Benjamin HJ, Brenner J, Gregory A, Jayanthi N, Landry GL, Luke A. Overuse injuries and burnout in youth sports: a position statement from the American Medical Society for Sports Medicine. Clin J Sport Med. 2014;24(1):3–20. https://doi.org/10.1097/JSM.0000000000000060

35 Roy B, Banik D. A perspective on intelligent imaging techniques for early prediction of knee osteoarthritis. In: Signal and image processing techniques for defence, security, and healthcare. IGI Global Scientific Publishing; 2025. p. 1–22. https://doi.org/10.4018/979-8-3693-3840-7.ch001

36 Cerqueira J, Branco CA, Vilaça A, Mendes J. Hand neuropathies and musculoskeletal disorders: complementary diagnosis using IR thermography. Appl Sci. 2023;14(1):70. https://doi.org/10.3390/app14010070

37 Brioschi ML, Yeng LT, Teixeira MJ. Medical thermography: what is it? And its applications. Pan Am J Med Thermol. 2015;2(1):14–7. https://doi.org/10.18073/2358-4696/pajmt.v2n1p14-17

38 Alpar O, Krejcar O. Detection of Raynaud's phenomenon by thermographic testing for finger thermoregulation. Intelligent information and database systems: 9th Asian conference, ACIIDS 2017, Kanazawa, Japan, April 3–5, 2017, proceedings, part II. Springer International Publishing; 2017. p. 475–84. https://doi.org/10.1007/978-3-319-54430-4_46