

The Effectiveness of Thermography-Based Foot Care Interventions for Preventing Diabetic Foot Ulcers in Patients with Diabetes Mellitus: A Systematic Review

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Abstract

Background: Diabetic foot ulcers are serious complications of diabetes mellitus associated with morbidity, disability, and lower-limb amputation. Infrared thermography offers a non-invasive approach for detecting thermal changes associated with inflammation, neuropathy, and vascular impairment before ulcer formation.

Objective: To systematically review the role of infrared thermography in the early detection, prevention, and monitoring of diabetic foot ulcer risk.

Methods: A systematic review was conducted using PubMed, Scopus, ScienceDirect, and Google Scholar for studies published between 2020 and 2026. Study selection followed PRISMA guidelines, and methodological quality was assessed using Joanna Briggs Institute Critical Appraisal Tools. Data were synthesized using narrative thematic analysis.

Results: Of 687 records identified, 612 remained after duplicate removal, 72 underwent full-text assessment, and 10 studies met the eligibility criteria. Infrared thermography detected plantar thermal asymmetry (0.2–1.0°C), identified early inflammatory changes, and supported diabetic foot ulcer risk classification. Integration with artificial intelligence and mobile-based thermography improved diagnostic performance, with CNN-based models achieving accuracy of up to 88%. However, evidence regarding its effectiveness as a standalone intervention for ulcer prevention remained inconsistent.

Conclusion: Infrared thermography shows potential as a non-invasive tool for early detection and monitoring of diabetic foot ulcer risk. However, evidence supporting its standalone preventive effectiveness remains limited. Standardized measurement protocols, integration with clinical assessment, and further high-quality prospective studies are required.

Keywords: Diabetes Mellitus; Diabetic Foot; Foot Ulcer; Infrared Thermography; Early Diagnosis

INTRODUCTION

Diabetes mellitus (DM) is a chronic metabolic disease and a major global health challenge due to its increasing prevalence and the substantial morbidity, disability, and mortality associated with its complications (Chew *et al.*, 2023). Therefore, DFU management should not focus solely on wound care after ulceration has occurred but should also emphasize risk identification, early detection of tissue changes, and preventive interventions before ulcer formation (Senneville *et al.*, 2024). Early detection is particularly important because physiological changes in the foot may occur before tissue damage becomes clinically visible, providing an opportunity for timely preventive intervention (Tard *et al.*, 2023). This approach is highly relevant to nursing practice, as nurses play an important role in diabetic foot assessment, risk identification, monitoring of foot conditions, patient education and self-care, and the implementation and evaluation of preventive interventions. Foot temperature monitoring has also emerged as a promising approach for early detection and may contribute to reducing the risk of DFU among individuals with diabetes who are at moderate to high risk (Golledge *et al.*, 2022).

The magnitude of this problem is closely associated with the growing global burden of diabetes. Indonesia also faces a substantial diabetes burden, with approximately 20.4 million adults aged 20–79 years living with diabetes in 2024, placing the country fifth worldwide in terms of the number of adults with diabetes; this number is projected to increase to approximately 28.6 million by 2050 (Kapoor, 2026). Alongside the increasing number of individuals with diabetes, DFU represents an important complication requiring serious attention. Epidemiological evidence from Indonesia indicates that the prevalence of DFU varies according to the population and healthcare setting; a recent systematic review of Indonesian studies reported DFU prevalence ranging from approximately 9.08% to 16.2% in tertiary referral hospitals and approximately 12% in regional hospitals (Suriadi, 2026). These findings indicate that the large population of individuals with diabetes, both globally and nationally, may be accompanied by a substantial burden of diabetic foot complications, highlighting the need for effective early detection and prevention strategies before ulceration progresses to more severe complications (Suriadi, 2026).

The development of DFU is a multifactorial process involving chronic hyperglycemia, peripheral neuropathy, vascular impairment, foot deformity, increased plantar pressure, and repetitive trauma. Sensory neuropathy reduces or eliminates protective sensation, causing excessive pressure, friction, or minor injuries to remain unnoticed, whereas motor neuropathy may result in foot deformities and biomechanical alterations that increase pressure on specific plantar areas. Autonomic neuropathy may also reduce skin moisture, resulting in dry skin that

is more susceptible to fissures, while peripheral arterial disease compromises tissue perfusion and impairs oxygen and nutrient delivery and tissue repair (Apelqvist *et al.*, 2024). Repetitive mechanical stress on vulnerable tissue can subsequently trigger a local inflammatory response and an increase in temperature at affected sites before visible skin breakdown occurs. These temperature changes may indicate a pre-ulcerative state, providing an opportunity to identify high-risk areas before the development of an open wound (Apelqvist *et al.*, 2024). When these early changes are not detected or preventive interventions are delayed, persistent mechanical stress and inflammation may lead to progressive tissue damage, ulcer formation, infection, impaired healing, and, in severe cases, lower-extremity amputation (Hulshof, Netten and Pijnappels, 2020). Therefore, detecting physiological changes in the diabetic foot before ulcer formation is an essential component of interrupting the progression of diabetic foot complications.

Several strategies have been developed to prevent DFU, including regular foot examinations, patient education and self-care, therapeutic footwear, offloading, risk-factor management, and foot temperature monitoring (Sacco *et al.*, 2024). Skin temperature monitoring may serve as an early warning system because localized temperature elevations can reflect inflammation and tissue stress before ulceration becomes clinically apparent (Camarena *et al.*, 2024). In this context, infrared thermography provides a non-invasive and contactless approach for visualizing plantar temperature distribution and identifying thermal asymmetries that may indicate inflammation or tissue changes before ulcer formation (Camarena *et al.*, 2024). Recent studies and systematic reviews have demonstrated the potential of infrared thermography for identifying individuals at risk of DFU and facilitating earlier preventive interventions, with emerging approaches incorporating digital technologies and automated image analysis (Muralidhara *et al.*, 2022). However, existing evidence varies in imaging devices, measurement sites and protocols, temperature thresholds, patient characteristics, and evaluated outcomes. Furthermore, previous reviews have predominantly focused on thermography as a predictive or diagnostic tool for identifying pre-ulcerative conditions, while its role across the broader continuum of early detection, risk identification, monitoring, and prevention of DFU has not been comprehensively synthesized. The novelty of this systematic review lies in integrating current evidence on infrared thermography across these interconnected roles while considering its potential implications for nursing practice.

Attention was given to its role in detecting early abnormalities, assessing ulcer risk, monitoring foot conditions, and supporting preventive strategies in individuals with diabetes mellitus. In addition, the review explored limitations in the existing evidence and considered the relevance of these findings to nursing practice.

METHODS

Study Design

This systematic review evaluated recent evidence concerning infrared thermography for diabetic foot assessment. The included literature addressed early recognition of foot abnormalities, identification of individuals at risk, follow-up of foot conditions, and ulcer prevention among people with diabetes. Evidence was obtained from experimental, quasi-experimental, observational, and technology-oriented research involving thermographic assessment. Publications from 2020–2026 were included to represent current developments and clinical applications of this technology.

The review process comprised systematic literature searching, study selection according to predefined eligibility criteria, methodological quality appraisal, data extraction, and evidence synthesis. Study identification and selection were conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The methodological quality of eligible studies was assessed using the appropriate Joanna Briggs Institute (JBI) Critical Appraisal Tools according to each study design. Relevant data were subsequently extracted and synthesized to determine the role and current evidence regarding infrared thermography in diabetic foot ulcer detection, monitoring, and prevention.

Search Strategy

Relevant publications were identified through a comprehensive search of five electronic databases: PubMed, Scopus, ScienceDirect, CINAHL, and Google Scholar. The search was restricted to studies published from 2020 to 2026. The PICOS approach, encompassing Population, Intervention/Exposure, Comparison, Outcome, and Study Design, was used to organize the literature search and establish the study eligibility criteria (Table 1). To maximize the retrieval of potentially relevant publications, controlled vocabulary from Medical Subject Headings (MeSH) was used when available alongside appropriate free-text keywords. These terms were connected through the Boolean operators AND and OR. The search expression applied was: ("Diabetes Mellitus" OR "Type 2 Diabetes Mellitus" OR "Diabetic Foot" OR "Diabetic Foot Ulcer" OR "Foot Ulcer") AND ("Thermography" OR "Infrared Thermography" OR "Thermal Imaging") AND ("Early Detection" OR "Screening" OR "Monitoring" OR "Prevention" OR "Preventive Foot Care"). Because database platforms differ in their indexing structures and search functions, the query format was adjusted separately for each database while retaining the same core concepts.

All records retrieved from the databases were compiled and screened for duplicates. The remaining records were screened based on titles and abstracts, followed by full-text eligibility assessment according to the predefined inclusion and exclusion criteria. The study selection process was documented using the PRISMA flow diagram.

Table 1. PICOS Framework for Study Eligibility

PICOS Component	Description
Population (P)	Patients with type 1 or type 2 diabetes mellitus who were at risk of developing diabetic foot ulcers, had pre-ulcerative foot conditions, or had a history of diabetic foot ulcers.
Intervention/ Exposure (I/E)	Use of infrared thermography or thermal imaging for diabetic foot assessment, including temperature monitoring, detection of thermal asymmetry, identification of pre-ulcerative changes, risk assessment, or thermography-guided preventive foot care.
Comparison (C)	Standard diabetic foot assessment, conventional clinical examination, other screening or monitoring methods, usual care, baseline measurements, or no comparator, depending on the study design.
Outcome (O)	Early detection of pre-ulcerative changes or thermal abnormalities, identification or classification of diabetic foot ulcer risk, changes in plantar foot temperature or thermal asymmetry, diagnostic performance of thermography, incidence or recurrence of diabetic foot ulcers, and outcomes related to ulcer prevention.
Study Design (S)	Randomized controlled trials, quasi-experimental studies, prospective or retrospective cohort studies, cross-sectional studies, diagnostic accuracy studies, and relevant technology-based or observational studies evaluating infrared thermography for diabetic foot assessment, monitoring, or prevention.

Eligibility Criteria

The eligibility criteria were established based on the PICOS framework and the objectives of this systematic review. The inclusion and exclusion criteria applied during the study selection process are presented in Table 2.

Table 2. Inclusion and Exclusion Criteria

Criteria	Inclusion Criteria	Exclusion Criteria
Publication period	Studies published between 2020 and 2026.	Studies published before 2020.
Language	Articles published in English or Indonesian.	Articles published in languages other than English or Indonesian.
Availability	Full-text articles available for assessment.	Articles for which the full text could not be accessed.
Population	Patients with type 1 or type 2 diabetes mellitus who were at risk of diabetic foot complications, had pre-ulcerative conditions, or had a history of diabetic foot ulcers.	Studies involving non-diabetic populations or conditions unrelated to diabetic foot complications.
Intervention/ Exposure	Studies evaluating infrared thermography or thermal imaging for diabetic foot assessment, screening, risk identification, monitoring, or preventive foot care.	Studies using thermography for purposes unrelated to diabetic foot assessment, such as musculoskeletal disorders or other non-diabetic conditions.
Outcomes	Studies reporting outcomes related to early detection of thermal or pre-ulcerative changes, diabetic foot ulcer risk identification, temperature changes or thermal asymmetry, ulcer incidence or recurrence, diagnostic performance, monitoring, or prevention of diabetic foot ulcers.	Studies that did not report outcomes relevant to early detection, risk identification, monitoring, or prevention of diabetic foot ulcers.
Study design	Eligible research designs included randomized controlled trials, quasi-experimental research, cohort and cross-sectional studies, diagnostic accuracy research, as well as other observational or technology-oriented investigations relevant to the review.	Editorials, letters to the editor, opinions, research protocols, case reports, non-systematic literature reviews, and other publications without original relevant data.
Thermography procedure	Studies providing sufficient information regarding the application or assessment of infrared thermography.	Studies that did not adequately describe the thermography procedure or its application to diabetic foot assessment.

Table 3. Study Data Extraction

Author, Year	Study Design	Population and Sample	Duration/Frequency or Assessment Procedure	Main Findings
Petrova et al., 2020	Single-blind multicentre controlled clinical trial (RCT)	110 patients with DM, neuropathy, and a history of ≥ 1 diabetic foot ulcer	Thermography and foot evaluation were performed monthly for 12 months	After 12 months, 62% of the intervention group and 56% of the control group remained ulcer-free. There was no significant difference in reducing diabetic foot ulcer recurrence or improving ulcer-free survival ($p > 0.05$).
Lucya et al., 2024	Quasi-experimental study	30 older adults with hypertension aged 60–80 years	5 days; 30 minutes per session	There was no significant difference in ulcer incidence between the intervention and control groups (6 vs 8 cases; $p = 0.573$). The thermography-based protocol was not effective in preventing diabetic foot ulcers at the primary healthcare center.
van Doremalen et al., 2020	Proof-of-concept study	8 patients with DM and active diabetic foot ulcers	Single assessment using a 3D imaging system and infrared thermography	The study successfully generated the first 3D thermographic images of diabetic feet. Ulcer-related inflammation, three early signs of ulceration, and two high-risk areas were identified. Visual validity was rated as good in six cases and fair in two cases. The technology showed potential for supporting early detection of diabetic foot ulcer risk.
Hutting et al., 2022	Prospective exploratory study	7 patients with DM and moderate-to-severe diabetic foot infection (IWGDF grade 3–4)	Thermographic measurements were performed during the first 4–5 days of hospitalization	A slight reduction in thermal asymmetry was observed, from 1.8°C to 1.5°C; however, this change did not reach statistical significance ($p = 0.515$). Thermal asymmetry also showed no relationship with infection severity or laboratory markers, including CRP and WBC levels. These findings suggest that infrared thermography had limited value for monitoring changes in diabetic foot infection during hospitalization.
Morales-Ramírez et al., 2026	Literature study	20 patients with diabetes mellitus and diabetic foot conditions	Thermographic measurement	Infrared thermography is a non-invasive method with potential to detect temperature changes related to inflammation, neuropathy, angiopathy, and tissue damage in the diabetic foot. Despite its potential, the use of thermography in clinical practice is still constrained by variations in measurement procedures and by environmental and physiological conditions that may affect temperature readings. Artificial intelligence and portable devices may enhance the use of thermography for diabetic foot monitoring.
Pradhana et al., 2024	Computational experimental study (CNN performance analysis)	Dataset of diabetic foot thermograms analyzed using pre-trained CNN models (MobileNetV2, VGG16, InceptionV3, and ResNet101)	Testing was conducted using three image-processing scenarios: original images, Adaptive Histogram Equalization (AHE), and Gamma Correction	Gamma Correction improved CNN performance in detecting diabetic foot ulcers. MobileNetV2 achieved 88% accuracy, while VGG16 achieved the highest precision at 92%. Gamma Correction also reduced training time and improved image-processing efficiency. The combination of thermographic images and CNN models showed potential for early diabetic foot ulcer detection in clinical practice.

Author, Year	Study Design	Population and Sample	Duration/Frequency or Assessment Procedure	Main Findings
Aminuddin et al., 2025	Quasi-experimental one-group pretest–posttest design	106 Indonesian wound care specialists	Participants completed an asynchronous LMS-based education	Knowledge scores increased significantly after the intervention (52.0 ± 10.3 to 85.2 ± 10.6 ; $p < 0.001$). Significant interactions were also found between time and sex ($p = 0.046$) and between time and type of certification ($p = 0.014$), indicating that online education improved knowledge regarding diabetic foot ulcer prevention.
Ilo, Ronsi & Mäkelä, 2020	Comparative cross-sectional study	118 patients with diabetes mellitus and 93 healthy individuals (controls)	Single assessment using infrared thermography (IRT), ankle-brachial index (ABI), and toe pressure (TP) with a standardized protocol across five foot areas	Patients with DM had higher foot temperatures and greater inter-foot temperature differences than controls ($p < 0.001$). Temperature changes were associated with vascular status, including neuropathy, neuroischemia, and angiopathy. IRT showed potential as a non-invasive screening tool for detecting vascular abnormalities in the diabetic foot.
Sandi et al., 2020	Multisite cross-sectional study	100 patients with diabetes mellitus from 10 primary healthcare centers in Makassar, Indonesia	Single assessment using mobile phone-based infrared thermography across four foot zones (MPA, LPA, MCA, LCA) to analyze DFU risk according to IWGDF categories	Significant differences in foot temperature were found among DFU risk groups ($p = 0.018$). Temperature differences of $0.2\text{--}1.0^\circ\text{C}$ differentiated risk categories. The MPA, LPA, and MCA zones showed significant differences across risk levels. Mobile phone-based thermography was effective for early detection of DFU risk in community settings.
Alwashmi et al., 2025	Cross-sectional observational study	200 participants (100 patients with DM without diabetic foot ulcers and 100 healthy controls; final analysis 98 vs 98)	Single assessment using an AI-powered infrared thermography system to analyze plantar foot temperature patterns	Plantar temperature profiles differed significantly between participants with diabetes mellitus and healthy controls ($p < 0.001$). The DM group showed greater temperature variability ($18.1\text{--}35.6^\circ\text{C}$) and higher inter-foot temperature differences (1.78°C vs 0.47°C ; $p < 0.001$). AI-powered thermography identified thermal abnormalities in 10% of patients with DM despite the absence of visible ulcers, demonstrating potential for early detection of diabetic foot complications.

Study Result

Study Selection

A total of 687 records were identified through searches of four electronic databases, comprising Google Scholar ($n = 200$), PubMed ($n = 156$), Scopus ($n = 184$), and ScienceDirect ($n = 147$). Before screening, 75 duplicate records were removed, leaving 612 records for title and abstract screening.

During the screening stage, 540 records were excluded because they were not relevant to infrared thermography in diabetic foot assessment, did not address outcomes related to diabetic foot ulcer detection, monitoring, or prevention, or did not meet the predefined eligibility criteria. Consequently, 72 reports were sought for full-text retrieval, all of which were successfully retrieved and assessed for eligibility.

Following full-text assessment, 62 reports were excluded because they did not meet the inclusion criteria, including inappropriate study populations or outcomes, use of thermography for purposes unrelated to diabetic foot assessment, or insufficient methodological relevance. Ultimately, 10 studies were included in the systematic review (Figure 1).

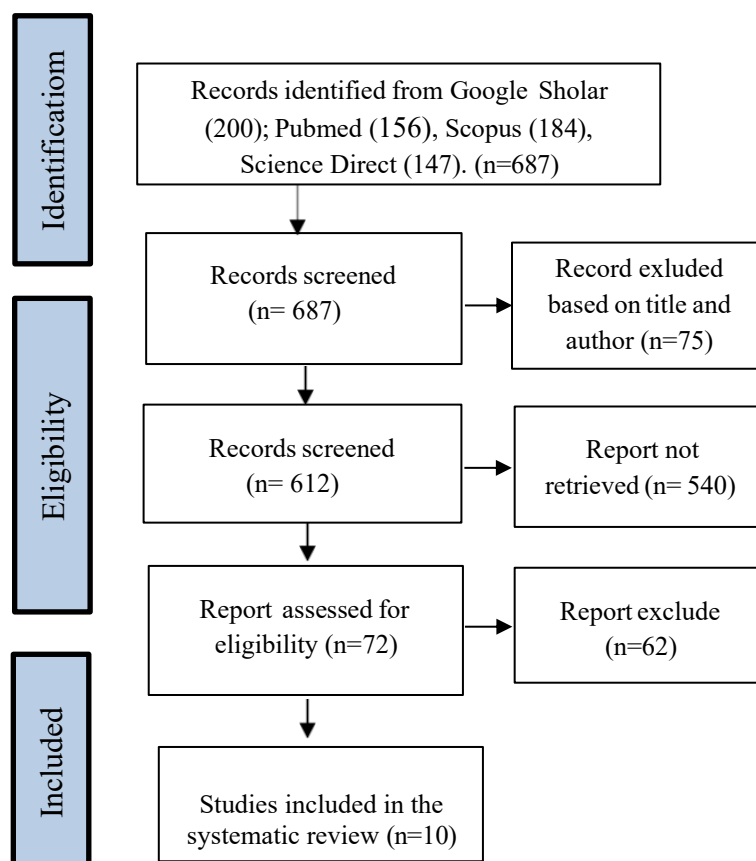


Figure 1. Flow Prism Diagram

The included studies represented a range of research designs, comprising one randomized controlled trial, two quasi-experimental studies, three cross-sectional studies, one computational experimental study using artificial intelligence, one proof-of-concept study, one prospective exploratory study, and one literature-based study. Collectively, these studies provided evidence regarding the role of infrared thermography in the early detection, risk assessment, monitoring, and prevention of diabetic foot complications.

Study Characteristics

The 10 studies included in this systematic review were conducted across seven countries, comprising Indonesia (n = 3), the Netherlands (n = 2), Brazil (n = 1), the United Kingdom (n = 1), Finland (n = 1), Mexico (n = 1), and Saudi Arabia (n = 1). The studies were published between 2020 and 2026 and involved diverse populations, including patients with diabetes mellitus with or without diabetic foot complications, healthy controls, and healthcare professionals. Across studies reporting participant-level data, a total of 788 participants were

represented, with sample sizes ranging from 7 to 211 participants. One computational study analyzed a dataset of diabetic foot thermographic images and was therefore not included in the total participant count.

The included studies employed diverse methodological designs, comprising one randomized controlled trial, two quasi-experimental studies, three cross-sectional studies, one prospective exploratory study, one proof-of-concept study, one computational experimental study using convolutional neural networks, and one literature-based study. Infrared thermography was primarily investigated for early detection, risk assessment, and monitoring of diabetic foot complications, particularly through the assessment of plantar temperature differences and thermal asymmetry. Several studies also explored emerging applications, including three-dimensional thermography, mobile phone-based thermal imaging, and artificial intelligence-assisted thermographic analysis, highlighting the potential integration of thermography into clinical and community-based diabetic foot assessment.

Methodological Quality

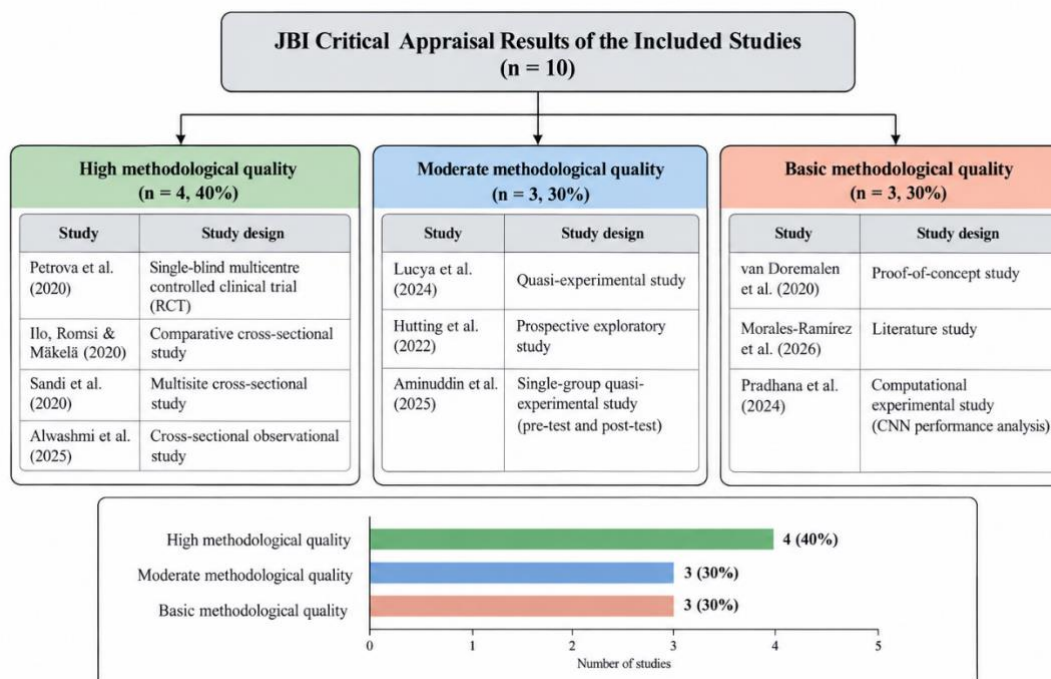


Figure 2. Summary of JBI Critical Appraisal Results of the Included Studies (n = 10).

Based on the Joanna Briggs Institute (JBI) critical appraisal, the methodological quality of the 10 included studies varied, with four studies (40%) classified as high quality, three (30%) as moderate quality, and three (30%) as basic/lower quality (Figure 2). High-quality studies generally employed controlled or comparative designs, relatively larger samples, standardized outcome measurements, and appropriate statistical analyses, thereby strengthening the reliability and internal validity of their findings; however, limitations related to blinding and potential

variability in thermographic measurements remained. Moderate-quality studies mainly used quasi-experimental or exploratory designs and provided relevant outcome assessments, but were limited by incomplete randomization, relatively small sample sizes, or the absence of control groups. Basic/lower-quality studies primarily consisted of proof-of-concept, computational experimental, and literature-based investigations that contributed to emerging approaches such as three-dimensional thermography and artificial intelligence-assisted image analysis; nevertheless, their exploratory nature, limited clinical validation, and restricted generalizability reduced the overall strength of the evidence. Overall, the evidence was considered sufficiently informative for narrative synthesis, although differences in methodological quality should be considered when interpreting the findings.

DISCUSSION

1. Infrared Thermography in the Early Detection Foot Ulcer Risk

The findings of this systematic review indicate that infrared thermography has potential as a non-invasive method for the early detection of diabetic foot ulcer (DFU) risk in patients with diabetes mellitus. Across the included studies, alterations in plantar temperature and temperature asymmetry were consistently associated with conditions related to DFU risk. These thermal changes may occur in response to inflammatory processes, impaired microcirculation, and neuropathic alterations that precede visible tissue breakdown. Therefore, the authors consider infrared thermography a potentially useful approach for identifying patients at increased risk of DFU before overt ulceration develops.

(Doremalen *et al.*, 2020), who demonstrated that imaging-based assessment could identify inflammatory areas, early signs associated with ulcer development, and regions at increased risk of tissue damage. Similarly, Ilo, (2020) reported that patients with diabetes exhibited higher foot temperatures and greater temperature differences between the extremities than healthy individuals. These thermal abnormalities may reflect underlying vascular and neuropathic alterations involved in the pathophysiology of diabetic foot complications (Ilo, 2020). In the authors' view, these findings suggest that temperature abnormalities should not be considered merely superficial changes, but may represent measurable manifestations of underlying pathological processes that contribute to DFU development.

The present review also found that relatively small temperature differences may have clinical value in identifying DFU risk. (Sandi, 2020) reported temperature differences ranging from 0.2°C to 1.0°. This finding supports the potential role of thermal assessment in distinguishing different levels of diabetic foot risk. The authors suggest that this approach may be particularly relevant for screening because temperature assessment is non-invasive and may

facilitate earlier identification of patients who require more intensive foot monitoring and preventive interventions.

Furthermore, the findings indicate that the integration of infrared thermography with artificial intelligence may enhance the identification of thermal abnormalities associated with DFU. (Pradhana, 2024) reported that the integration of thermographic images with a Convolutional Neural Network (CNN) achieved an accuracy of up to 88% in identifying diabetic foot ulcers. Consistent with this finding, (Alwashmi *et al.*, 2025) reported that an artificial intelligence-based system identified thermal abnormalities in some patients with diabetes who had not yet exhibited clinical signs of ulceration. These findings suggest that automated image analysis may improve the interpretation of complex thermal patterns that may be difficult to recognize through conventional visual assessment alone (Senneville *et al.*, 2024). In the authors' opinion, combining thermography with artificial intelligence may increase its clinical utility as an objective screening approach, particularly for detecting subtle abnormalities before visible tissue damage occurs.

Foot temperature alterations and thermal asymmetry have potential as early indicators of DFU risk in patients with diabetes mellitus. Previous studies consistently support the association between abnormal thermal patterns and pathological processes related to diabetic foot complications. Based on this evidence, infrared thermography may serve as a complementary screening tool for early risk identification and stratification rather than as a stand-alone diagnostic method. Its non-invasive nature and potential integration with automated image analysis may support earlier preventive interventions and potentially reduce progression toward more severe diabetic foot complications.

2. Infrared Thermography in Diabetic Foot Care

The findings of this systematic review indicate that infrared thermography has potential to support the prevention and monitoring of diabetic foot ulcers (DFUs), although its effectiveness in preventing ulcer occurrence remains inconsistent. Thermography enables the identification of localized temperature elevations that may indicate inflammation or excessive mechanical stress before visible tissue breakdown occurs. In principle, early recognition of these thermal abnormalities may provide an opportunity for preventive measures before tissue damage progresses. In the authors' view, the preventive value of thermography therefore depends not only on detecting abnormal temperature patterns but also on whether these findings are followed by appropriate and timely clinical interventions.

Evidence regarding its preventive effectiveness, however, remains inconclusive. (Petrova *et al.*, 2020) reported that thermographic monitoring over a 12-month period did not result in a

significant difference in ulcer recurrence compared with the control group. Similarly, (Lucya, 2024) found that a thermography-based prevention protocol did not significantly reduce the incidence of DFUs. These findings indicate that identifying thermal abnormalities alone may be insufficient to prevent ulcer development. The authors suggest that thermography should therefore be regarded primarily as a tool for identifying changes associated with increased risk rather than as an independent preventive intervention.

The limited preventive effect observed across the included studies may be explained by the multifactorial pathogenesis of DFUs.. Preventive management therefore requires appropriate interventions, including pressure reduction or offloading, appropriate footwear, foot-care education, and management of modifiable risk factors. In the authors' opinion, this may explain why thermographic monitoring alone does not consistently reduce ulcer incidence: its clinical benefit is likely to depend on how effectively abnormal findings are translated into comprehensive preventive actions.

The changes in thermal asymmetry during treatment were not significantly associated with infection severity, C-reactive protein (CRP) levels, or leukocyte counts. This finding indicates that changes in surface temperature may not directly correspond to changes in systemic inflammatory markers or clinical infection severity. In addition, thermal patterns may be affected by local physiological and pathological conditions, which may complicate their interpretation. The authors therefore consider thermography more appropriate as a complementary monitoring tool rather than a substitute for clinical assessment and established laboratory indicators of infection (Hutting *et al.*, 2020).

Overall, the findings of this systematic review suggest that the principal value of infrared thermography in DFU prevention and monitoring lies in its ability to identify thermal abnormalities associated with areas at risk of tissue damage. Current evidence does not support its use as a stand-alone method for preventing ulceration or monitoring infection. In the authors' opinion, infrared thermography may provide greater clinical value when incorporated into a comprehensive and multidisciplinary diabetic foot assessment that includes clinical examination, patient education, pressure management, and management of other relevant risk factors. In nursing practice, thermography may serve as an objective adjunct to diabetic foot assessment, enabling nurses to recognize potentially vulnerable areas earlier and initiate or recommend appropriate preventive interventions.

3. Technological Advances in Infrared Thermography for the Diabetic Foot

The findings of this systematic review indicate that technological advances have expanded the potential application of infrared thermography in diabetic foot assessment. Across

the included studies, thermography has been integrated with three-dimensional (3D) imaging, artificial intelligence (AI), machine learning-based image analysis, and portable smartphone-based devices. These developments are intended to improve the identification and interpretation of thermal abnormalities while facilitating more practical and accessible diabetic foot assessment. In the authors' opinion, these technological advances may address some limitations of conventional thermography by improving image interpretation, reducing dependence on subjective assessment, and extending its potential application beyond specialized clinical settings.

One important technological development is the integration of thermography with 3D imaging. (Doremalen *et al.*, 2020) demonstrated that three-dimensional imaging enabled a more comprehensive visualization of temperature distribution and anatomical characteristics of the diabetic foot. This approach facilitated the identification of inflammatory areas and regions potentially associated with an increased risk of tissue damage (Sanada, 2021). Compared with conventional two-dimensional thermal assessment, combining spatial and thermal information may provide a more detailed representation of areas requiring clinical attention (Bayareh *et al.*, 2021). The authors therefore suggest that 3D thermography may enhance diabetic foot risk assessment by allowing thermal abnormalities to be interpreted in relation to their anatomical location.

The integration of thermography with AI represents another important development identified in this review. (Pradhana, 2024) reported that the application of a Convolutional Neural Network (CNN) to thermographic images achieved an accuracy of up to 88% in identifying diabetic foot ulcers. Similarly, (Alwashmi *et al.*, 2025) demonstrated the potential of AI-powered infrared thermography to identify thermal abnormalities in patients with diabetes, including abnormalities detected before clinically apparent ulceration. AI-based image analysis can facilitate the recognition and classification of complex thermal patterns by automatically extracting relevant image features. In the authors' opinion, this integration may improve the objectivity and efficiency of thermographic assessment and potentially support healthcare professionals in identifying patients who require further clinical evaluation (Muralidhara *et al.*, 2022b).

Smartphone-integrated thermal camera could identify differences in foot temperature across diabetic foot risk categories based on the International Working Group on the Diabetic Foot (IWGDF) classification (Sandi, 2020). The portability of smartphone-based thermal imaging may facilitate its application outside specialized healthcare facilities and provide opportunities for its use in primary care and community settings. From the authors' perspective, portable thermography may be particularly relevant for expanding access to diabetic foot

screening; however, its clinical implementation should be accompanied by standardized image acquisition, appropriate interpretation, and subsequent clinical assessment when abnormalities are detected.

More recent evidence further demonstrates the continuing development of portable and AI-assisted thermographic approaches. (Morales-ramírez, 2026) reported the application of technological approaches combining thermographic assessment with automated analysis for diabetic foot evaluation. Such integration may facilitate more efficient and potentially continuous assessment of thermal changes. Nevertheless, technological improvements alone do not establish clinical effectiveness, and the performance of these systems may depend on image quality, acquisition protocols, algorithms, patient characteristics, and clinical context (Camarena *et al.*, 2024). In the authors' opinion, further validation in larger and diverse populations is required before AI-assisted and portable thermographic systems can be routinely implemented in diabetic foot care.

Overall, this systematic review demonstrates that the technological evolution of infrared thermography has broadened its potential application in diabetic foot assessment. The integration of 3D imaging, AI-based analysis, and portable devices may improve the visualization, interpretation, and accessibility of thermal assessment. However, these technologies should currently be considered complementary tools rather than replacements for comprehensive clinical assessment. The authors suggest that their greatest potential lies in supporting earlier risk identification and more objective diabetic foot assessment, while future studies should determine their clinical effectiveness, standardization, feasibility, and applicability across different healthcare settings.

4. Challenges and Clinical Implementation of Infrared Thermography

The findings of this systematic review indicate that, despite the potential of infrared thermography for the early identification of diabetic foot ulcer (DFU) risk, several challenges may limit its routine clinical implementation. (Morales-ramírez, 2026) reported variations in the thermal parameters used for diabetic foot assessment, including mean foot temperature, temperature differences between corresponding regions of both feet (thermal asymmetry), and temperature distribution within specific anatomical regions. Such methodological heterogeneity may limit direct comparisons across studies and contribute to variability in the interpretation of thermographic findings. In the authors' opinion, standardized image acquisition, temperature measurement, and interpretation protocols are therefore essential before thermography can be more widely integrated into routine diabetic foot assessment.

Another challenge concerns the influence of environmental, physiological, and clinical

factors on thermographic measurements. Foot surface temperature may be affected by ambient temperature, humidity, recent physical activity, peripheral neuropathy, and vascular alterations, potentially influencing the thermal patterns observed during examination (Wnuk-scardaccione, 2026). These factors highlight the importance of controlling measurement conditions and interpreting thermographic findings within the patient's broader clinical context. Accordingly, thermography should be integrated with established diabetic foot assessments, including foot inspection, neurological assessment, and evaluation of vascular status. The authors consider this combined approach important because thermography identifies thermal abnormalities but does not independently determine the underlying cause or provide a complete assessment of DFU risk.

The findings of this review also reveal a gap between the ability to identify thermal abnormalities and the achievement of improved clinical outcomes. (Petrova *et al.*, 2020) and (Lucya, 2024) reported that thermography-based monitoring or prevention strategies did not result in a statistically significant reduction in ulcer occurrence or recurrence compared with control conditions. These findings suggest that early risk identification alone may not be sufficient to prevent DFU development. Preventive outcomes are likely to depend on whether abnormal findings are followed by appropriate interventions, such as pressure reduction or offloading, appropriate footwear, patient education, foot-care practices, and management of relevant clinical risk factors. In the authors' opinion, thermography should therefore be considered a decision-support tool within a comprehensive prevention strategy rather than an independent intervention expected to reduce ulcer incidence by itself.

Successful clinical implementation also depends on the competence of healthcare professionals who perform thermographic assessment and interpret its findings. (Aminuddin *et al.*, 2025) demonstrated highlights the importance of education and training when introducing new technology into clinical practice. In the authors' view, adequate training may help nurses perform thermographic assessments more consistently, recognize abnormal thermal patterns, and appropriately integrate the findings with other clinical assessments and preventive interventions.

Variability in measurement and interpretation methods, susceptibility to environmental and patient-related factors, uncertain effects on ulcer-related clinical outcomes, and the need for healthcare professional training remain important considerations. Therefore, the authors suggest that future clinical implementation should prioritize standardized thermographic protocols, professional training, and integration with comprehensive diabetic foot assessment and evidence-based preventive care. Within nursing practice, thermography may be particularly valuable as an adjunctive assessment tool that provides objective thermal

information to support earlier identification of patients requiring further assessment or preventive intervention.

CONCLUSION

This systematic review indicates that infrared thermography has potential as a non-invasive complementary tool for the early identification of diabetic foot ulcer risk in patients with diabetes mellitus. Changes in foot temperature and thermal asymmetry may help identify areas at risk of tissue damage before clinically apparent ulceration. However, current evidence regarding its effectiveness in preventing ulcer occurrence and monitoring disease progression remains inconsistent. Therefore, infrared thermography should be considered an adjunct to comprehensive diabetic foot assessment and preventive care rather than a stand-alone diagnostic or preventive method. Future research should focus on standardized thermographic protocols, clinically relevant temperature thresholds, and larger prospective studies to determine its effectiveness, accuracy, and clinical utility across diverse healthcare settings.

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