



Enhancing Early Detection of Diabetic Foot Complications: Evidence from a Specialized Diabetes Center in King Abdulaziz Hospital at Jeddah First Health Cluster (J1), 2026

Dr Samera A Mugharbil⁽¹⁾, Dr Atif K. Rawas⁽¹⁾, Dr. Jamala A. Bawahab⁽¹⁾, Dr. Saeed A. Youldash⁽¹⁾, Dr. Abdullaha Beiruty⁽¹⁾, Dr Suhad A. Aljuhani⁽¹⁾, Dr Nora D. Alnofie⁽¹⁾, Ms Fatin S. Alahmadi⁽¹⁾, Ms Layan H Alshardi⁽¹⁾, Ms Mada A. Awam⁽¹⁾

(1)Jeddah First Health Cluster -J1 Diabetic Center in King Abdulaziz Hospital,Ministry of Health, Saudi Arabia

Abstract

Background: Diabetic foot complications are a major cause of ulceration, infection, hospitalization, amputation, and reduced quality of life. Early identification of neuropathic, vascular, and thermal abnormalities may strengthen preventive diabetic-foot care.

Aim: To assess demographic, clinical, thermal, and risk-classification findings among patients attending the Diabetic Center at King Abdulaziz Hospital, Jeddah First Health Cluster, and to describe six-month progression among moderate- and high-risk patients.

Methods: A retrospective observational study used routinely documented medical records and available thermal-imaging reports. Baseline demographic, clinical, IWGDF risk-classification, and thermal-imaging data were assessed cross-sectionally. TFScan-generated patient risk classification was available for all 105 participants, whereas complete detailed thermal parameters required for the thermal findings analysis were available for 102 participants. An exploratory six-month retrospective review of documented outcomes was conducted only among patients classified at baseline as having moderate or high diabetic-foot risk, comprising 25 patients. No patient was contacted, prospectively assessed, or subjected to a research intervention by the research team.

Results: Most participants were aged 46–60 years (46/105, 43.8%), male (66/105, 62.8%), had Type II diabetes (99/105, 94.2%), and had diabetes for 11 years or more (49/105, 47.6%). Obesity and overweight affected 43 (40.9%) and 37 (35.2%) patients, respectively. Retinopathy occurred in 74/102 (72.5%), neuropathy in 69/102 (67.6%), and poor HbA1c control in 45/102 (44.1%). TFScan-generated patient risk classification was available for all 105 participants; moderate and high risk were assigned to 18/105 (17.1%) and 7/105 (6.7%), respectively. Detailed thermal findings were available for 102 participants, among whom thermal asymmetry was identified in 7/102 (6.9%), hyperthermia in 6/102 (5.9%), and hypothermia in 4/102 (3.9%). During follow-up, 19/25 (76.0%) patients remained stable, while 3/25 (12.0%) developed a new wound or ulcer.

Conclusion: The study identified a substantial burden of diabetic-foot risk factors. AI-supported thermal screening may support early risk stratification when combined with comprehensive clinical assessment and multidisciplinary follow-up.

Keywords: Diabetes mellitus; diabetic foot; thermal imaging; neuropathy; risk stratification; early detection; Saudi Arabia.

Introduction

Diabetes mellitus represents a major and expanding global health burden, with current estimates indicating that approximately one in ten adults worldwide, equivalent to 537 million individuals, are affected.¹ Projections suggest a continued upward trajectory, with the number expected to reach 643 million by 2030 and further escalate to 783 million by 2045^[1]. The situation is particularly concerning in the Middle East and North Africa (MENA) region, where prevalence rates exceed global averages, affecting nearly one in six adults, or approximately 73 million individuals ^[1]. Despite notable advancements in pharmacological management, monitoring technologies, and integrated care models, both the prevalence of diabetes and the

incidence of its associated complications continue to rise, reflecting persistent gaps in prevention, early detection, and long-term disease control ^[1]. Among the spectrum of diabetes-related complications, diabetic foot ulceration (DFU) remains one of the most prevalent and clinically significant conditions. Epidemiological evidence indicates that nearly one-third of individuals living with diabetes will develop a DFU at some point during their lifetime ^[2]. This complication is not only common but also characterized by a high rate of recurrence. Even after successful healing, recurrence rates are substantial, reaching approximately 40% within one year, 60% within three years, and 65% within five years ^[2]. These figures highlight the chronic and relapsing nature of diabetic foot disease, underscoring the need

for sustained surveillance and preventive strategies [2].

The clinical and economic consequences of DFUs are profound. Lower extremity amputation represents the most severe outcome, often resulting from unresolved or complicated ulcers [3]. Amputations are associated with increased morbidity, reduced quality of life, and elevated mortality rates. In addition to the human burden, the financial implications are considerable. Diabetic foot care constitutes the largest component of diabetes-related healthcare expenditures. According to Armstrong et al., approximately one-third of all costs associated with diabetes management are attributable to foot care alone [4]. This disproportionate economic burden reflects the complexity of treatment, the need for multidisciplinary care, and the extended duration of management required for DFUs. Consequently, effective prevention and early detection strategies have the potential to yield substantial improvements in patient outcomes while simultaneously reducing healthcare costs. However, existing diagnostic and screening tools are often limited in scalability, particularly in terms of time efficiency, accessibility, and practicality within routine clinical workflows [5].

In contemporary clinical practice, the detection and assessment of diabetic foot complications rely heavily on a set of traditional diagnostic approaches. Each method offers specific benefits but is also associated with notable limitations, particularly in the context of early detection and comprehensive risk stratification. One of the most widely used tools is the monofilament test, which is designed to assess loss of protective sensation (LOPS), a key indicator of peripheral neuropathy. While this test is simple, inexpensive, and easy to administer, its utility in early detection is constrained. It primarily identifies advanced sensory loss and does not account for other critical risk factors such as peripheral arterial insufficiency or structural foot deformities [6,7]. Moreover, the accuracy of the monofilament test is influenced by several variables, including the technique and consistency of the examiner, as well as patient-specific factors such as edema, skin temperature, and callus formation [7]. These limitations reduce its sensitivity in detecting early or intermittent neuropathic changes, thereby necessitating its use in combination with additional diagnostic modalities to achieve a more comprehensive assessment. Another commonly employed method is the ankle-brachial index (ABI), a non-invasive test used to evaluate peripheral arterial disease (PAD), which is a significant contributor to the development and progression of DFUs. While ABI is widely recognized for its simplicity and utility in general populations, its diagnostic accuracy in individuals with diabetes is subject to debate [8]. One of the primary challenges lies in the presence of medial

arterial calcification, a condition frequently observed in diabetic patients, which can lead to artificially elevated ABI values and, consequently, false-negative results [9,10]. This limitation raises concerns regarding the reliability of ABI as a standalone screening tool in diabetic populations, particularly for identifying individuals at high risk of ulceration. Therefore, reliance solely on ABI may result in underdiagnosis of PAD and delayed intervention.

Duplex ultrasonography (DUS) is another diagnostic modality frequently utilized to assess vascular status. It combines traditional ultrasound imaging with Doppler flow analysis, enabling clinicians to evaluate both the anatomical and hemodynamic characteristics of blood vessels. DUS can effectively identify the location and severity of arterial stenosis or occlusion. However, its application in diabetic populations is not without challenges. Certain arterial segments, particularly in the distal lower extremities, may be difficult to visualize due to anatomical complexity or technical limitations [11]. Additionally, the presence of calcified vessels in diabetic patients reduces vessel compliance and interferes with ultrasound wave transmission, thereby compromising image quality and diagnostic accuracy. [12]. As a result, while DUS provides valuable information, it may not always offer reliable assessments in this patient group, necessitating supplementary diagnostic approaches. Angiography is widely regarded as the gold standard for vascular imaging and provides highly detailed visualization of arterial structures. It plays a critical role in the diagnosis and management of advanced diabetic foot complications, particularly when revascularization is being considered [13]. Despite its diagnostic precision, angiography is associated with several drawbacks that limit its routine use. The procedure involves exposure to ionizing radiation, which poses cumulative health risks, especially with repeated use. Additionally, it is an invasive and resource-intensive procedure, often requiring contrast administration, specialized equipment, and, in some cases, hospital admission. These factors contribute to increased cost and reduced feasibility for widespread screening or early-stage assessment.

Routine clinical foot examination remains the cornerstone of diabetic foot assessment and is widely endorsed by international guidelines, including those issued by the International Working Group on Diabetic Foot (IWGDF) [14]. These guidelines recommend that all individuals with diabetes undergo at least one comprehensive foot examination annually. During these assessments, clinicians perform visual inspection of the feet, evaluate pedal pulses, and assess protective sensation using tools such as monofilament. Based on these findings, patients are categorized into risk groups, which inform follow-up intervals and preventive

strategies.¹⁴ While this approach is fundamental to clinical practice, it is inherently limited by its episodic nature and reliance on clinician expertise. Variability in training, experience, and clinical judgment can lead to inconsistencies in assessment outcomes across different healthcare settings. Furthermore, subtle or subclinical changes, such as localized inflammation, increased tissue stress, or early perfusion abnormalities, may not be detectable during routine examinations, particularly in the intervals between scheduled visits [15]. This gap highlights the need for more sensitive and continuous monitoring tools. In this context, human medical thermography has emerged as a promising adjunctive modality for the detection and monitoring of diabetic foot complications. This technique is grounded in decades of technological advancement in infrared imaging, alongside the development of standardized protocols for image acquisition and interpretation [16,17]. Thermography enables the visualization of temperature variations across the skin surface, which can reflect underlying physiological processes such as inflammation, infection, or altered blood flow. Unlike many traditional diagnostic tools, thermography is non-invasive, non-contact, and does not involve exposure to radiation [18]. It is also relatively rapid and can be performed without direct patient discomfort, making it suitable for repeated use in both clinical and community settings.

The clinical utility of thermography in diabetic foot assessment lies in its ability to detect early signs of tissue stress and inflammation before the onset of visible ulceration. This capability offers a significant advantage in preventive care, as early intervention can reduce the risk of progression to more severe complications. The American Academy of Thermology (AAT) has established guidelines to standardize the use of thermographic imaging in diabetic populations [19]. These guidelines outline recommended procedures for image acquisition, environmental control, and interpretation criteria, thereby enhancing the reliability and reproducibility of results [19]. Thermography is increasingly being integrated into clinical practice worldwide for screening, early detection, and ongoing monitoring of diabetic foot conditions. Despite these advancements, challenges remain in translating thermographic technologies into routine clinical workflows. Issues related to cost, accessibility, and the need for specialized training may limit widespread adoption. However, ongoing innovations, including portable and automated thermal imaging systems, have the potential to address these barriers and improve scalability. As the burden of diabetic foot complications continues to grow, there is a clear need for diagnostic approaches that are not only accurate but also efficient, accessible, and capable of facilitating early intervention.

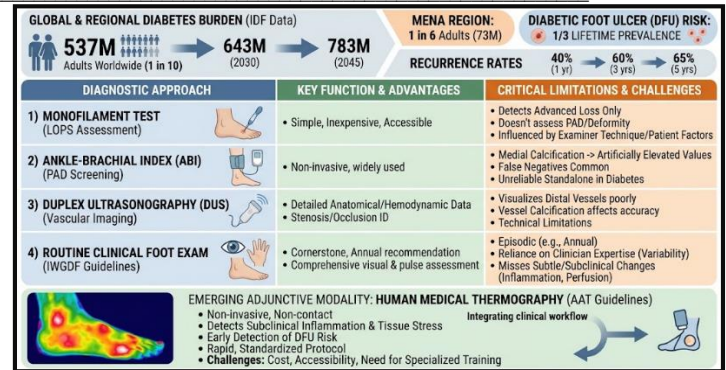


Figure-1: Role of Thermography Vs. Traditional Diabetic foot Assessment.

Study Problem

Diabetic foot complications continue to represent a major clinical and public health concern within Saudi Arabia, particularly in high-volume tertiary care settings such as the Jeddah First Health Cluster (J1) at Diabetic Center in King Abdulaziz Hospital. Despite the availability of established screening protocols, a substantial proportion of patients with diabetes present with advanced-stage foot lesions, indicating deficiencies in early detection and preventive care. Conventional diagnostic approaches, including routine clinical examination, monofilament testing, and vascular assessments, primarily identify established neuropathy or ischemia but demonstrate limited sensitivity in detecting early, subclinical changes such as localized inflammation, abnormal pressure distribution, and microvascular dysfunction. These limitations contribute to delayed diagnosis and increased risk of ulcer development, infection, and subsequent lower limb amputation. Furthermore, the episodic nature of current screening practices, combined with variability in clinician expertise and assessment techniques, introduces inconsistencies in risk stratification and patient management. High recurrence rates of diabetic foot ulcers further underscore the inadequacy of existing monitoring strategies. In this context, thermal imaging technologies present a promising alternative. The present study retrospectively assessed baseline demographic, clinical, and thermal-imaging data from patients who had previously undergone AI-supported thermal imaging, using the available images and clinical data to characterize diabetic-foot risk and thermal findings. Importantly, all patients included in the sample inherently meet the predefined inclusion criteria, ensuring a representative population for analysis.

Study Significance

The significance of the present study is grounded in its potential to address critical gaps in the early detection and management of diabetic foot complications within a high-risk population. Given the rising prevalence of diabetes in Saudi Arabia and the substantial burden associated with diabetic foot

ulcers, the identification of effective, scalable, and non-invasive screening tools is of paramount importance. The integration of AI-supported thermal imaging technology into clinical practice has the potential to transform current screening paradigms by enabling the detection of early inflammatory changes before the onset of visible tissue breakdown. Such capability may facilitate timely preventive interventions, thereby reducing the incidence of ulceration, infection, and amputation. In addition, the use of objective thermal imaging may enhance the standardization of clinical assessments, minimize inter-observer variability and improve consistency across healthcare providers. From a health system perspective, early detection and prevention of diabetic foot complications are expected to contribute to significant cost savings by reducing the need for advanced treatments, prolonged hospitalizations, and surgical interventions. Moreover, the findings of this study may provide evidence to support the adoption of innovative diagnostic technologies within national clinical guidelines and contribute to the advancement of diabetic foot care practices in the region. The study also holds academic value by generating context-specific data that can inform future research and policy development in the field of diabetic foot management.

Aim and Objectives

The main aim of this study is to evaluate the performance and clinical utility of an AI-supported thermal imaging system in supporting early detection and risk stratification of diabetic foot complications among patients attending the Diabetic Center at King Abdulaziz Hospital within the Jeddah First Health Cluster.

To achieve this aim, the study addressed the following objectives:

- To evaluate the performance of the AI-supported thermal imaging system in identifying thermal abnormalities relevant to early diabetic-foot risk assessment.
- To examine AI-supported thermal imaging findings and TFScan-generated risk classifications in relation to available conventional clinical risk assessments.
- To describe the ability of the AI-supported thermal imaging system to stratify patients into diabetic-foot risk categories and to explore documented six-month outcomes among patients classified as moderate or high risk.

Study Questions:

The study is guided by the following primary research question: “How does an AI-supported thermal imaging system contribute to early diabetic-foot risk assessment and risk stratification among patients in the study setting?”

In alignment with this main question, the following sub-questions were addressed:

- What thermal abnormalities relevant to early diabetic-foot risk assessment are identified by the AI-supported thermal imaging system?
- How do AI-supported thermal imaging findings and TFScan-generated risk classifications relate to available conventional clinical risk assessments?
- How are patients distributed across TFScan-generated diabetic-foot risk categories, and what documented six-month outcomes occur among those classified as moderate or high risk?

Chapter Two

Literature Review and Previous Studies

Literature Review:

The global health landscape is currently facing an unprecedented challenge in the management of diabetes mellitus, a condition that has transcended its status as a chronic metabolic disorder to become a primary driver of global disability and healthcare expenditure. Statistics indicate that approximately 537 million adults worldwide are currently living with diabetes, a figure that is projected to escalate to 783 million by the year 2045. Within this expanding patient population, the diabetic foot ulcer (DFU) represents one of the most severe and costly complications, with a lifetime incidence rate of approximately 33% among those diagnosed with diabetes. The clinical trajectory of a DFU is often fraught with high recurrence rate, estimated at 40% within the first year and up to 65% within five years of initial healing—and carries a five-year mortality rate that rivals several forms of aggressive cancer. The economic burden is equally staggering, with diabetic foot care accounting for nearly one-third of all diabetes-related healthcare costs. In regions like the Middle East and North Africa (MENA), where the prevalence of diabetes is particularly acute, the urgency for proactive, scalable, and objective screening tools has never been greater. The emergence of the Thermal Foot Scan (TFScan), an artificial intelligence (AI)-powered thermographic system, represents an emerging adjunctive approach in this domain, offering a non-invasive, objective, and highly accurate method for identifying the subclinical physiological changes that precede overt ulceration and amputation [20,21].

Pathophysiological Determinants of Plantar Thermography

The clinical utility of infrared thermography in the context of the diabetic foot is predicated on the fundamental relationship between tissue temperature, perfusion, and inflammation. In a physiologically normal foot, the skin surface temperature is maintained through a delicate balance of arterial supply, venous return, and sympathetic nervous system regulation. Healthy individuals typically exhibit a symmetrical "butterfly" thermal pattern across the plantar surface, where temperature variations between corresponding regions of the left and right feet are minimal. However, the onset of diabetic foot syndrome disrupts these homeostatic mechanisms through two primary pathways: neuropathy and peripheral vascular disease (PVD) [22]. Neuropathy, particularly when affecting the autonomic fibers, leads to a loss of sympathetic tone in the microvasculature, resulting in unregulated blood flow and a localized increase in skin

temperature, often referred to as a hyperthermic state. Conversely, peripheral artery disease (PAD) restricts the delivery of warm arterial blood to the extremities, leading to localized or diffuse hypothermia. The synergy of these two conditions creates a complex thermal landscape where hyperthermia may signal pre-ulcerative inflammation or neuropathic stress, while hypothermia indicates critical perfusion deficits. Infrared thermography identifies these variations by capturing the infrared radiation emitted by the skin, which is directly proportional to the quality of tissue blood perfusion and metabolic activity. Research has consistently demonstrated that significant temperature asymmetries—specifically a difference 2.2° C (4.0° F) between corresponding regions of the feet—are highly predictive of impending tissue breakdown. This threshold serves as the clinical cornerstone for the TFScan system's risk stratification algorithm [22-24].

Technical Architecture and AI Integration in TFScan

TFScan is defined as a Software as a Medical Device (SaMD) that integrates high-resolution infrared hardware with advanced computer vision and machine learning frameworks. Unlike traditional medical thermography, which relied on bulky, stationary, and expensive equipment, TFScan utilizes portable, smartphone-compatible sensors—such as those developed by Teledyne FLIR LLC—to capture detailed thermal images of the plantar surface. The technical sophistication of the system lies in its ability to automate the interpretation process, which has historically been a significant bottleneck in the clinical adoption of thermography due to the limited number of trained human thermographers. The software component employs a multi-stage AI pipeline to process the captured thermograms. First, the system utilizes computer vision algorithms to isolate the plantar region from the background, effectively suppressing noise and sensor artifacts. Once segmented, the AI extracts quantitative thermal features, including absolute temperature asymmetry and regional variations across specific vascular territories. These features are then analyzed using deep learning models, such as convolutional neural networks (CNNs) like ResNet50 and EfficientNet, which have been trained on vast datasets to distinguish between normal thermal patterns and those indicative of pathology. This automated approach not only minimizes inter-observer variability but also enables real-time, objective classification of a patient's risk level [25-26].

Diagnostic Performance and Empirical Validation

The diagnostic accuracy of the TFScan system has been evaluated through a series of rigorous clinical trials, comparing its performance to traditional "gold standard" reference assessments.

One of the most significant studies in this regard is a diagnostic accuracy study involving 100 adult patients with diabetes undergoing routine screening. In this cross-sectional analysis, the TFScan system's risk scores were compared against clinical evaluations performed by experienced diabetic foot nurses utilizing the International Working Group on the Diabetic Foot (IWGDF) risk stratification categories. The results demonstrated that the AI system showed strong agreement with clinical expert risk classification in that study. The 100% sensitivity and 100% NPV are particularly critical for a

Table 2.1: Diagnostic Performance of TF Scan.

Performance Metric	TFScan Value	Clinical Significance
Sensitivity	100%	Ability to identify all true moderate-to-high risk cases
Specificity	96.8%	Ability to correctly exclude low-risk cases
Negative Predictive Value (NPV)	100%	Confidence that a "low risk" result is accurate
Positive Predictive Value (PPV)	66.7%	Precision in identifying true positives among flagged cases
Correlation (ρ)	$\rho = 0.973$	Alignment between AI and human expert risk scores

The Angiosome Concept and Targeted Perfusion Analysis

A key innovation of the TFScan framework is its use of the angiosome concept for thermal mapping. An angiosome is a specific anatomical unit consisting of skin, subcutaneous tissue, fascia, muscle, and bone supplied by a unique source artery. By segmenting the plantar surface into these vascular territories, TFScan can identify compromised blood supply at a granular level, which is often invisible during a traditional visual or tactile examination [27]. The system focuses on four primary angiosomes of the foot, which are critical for maintaining tissue viability and are frequently the site of initial ulceration:

1. **Medial Plantar Artery (MPA) Angiosome:** Covers the medial sole and the first toe.
2. **Lateral Plantar Artery (LPA) Angiosome:** Covers the lateral sole and the remaining toes.
3. **Medial Calcaneal Artery (MCA) Angiosome:** Covers the medial heel.
4. **Lateral Calcaneal Artery (LCA) Angiosome:** Covers the lateral heel.

Research involving TFScan has shown that individuals classified as high-risk exhibit significantly greater temperature deltas in these specific vascular territories. For instance, temperature asymmetries exceeding 2.2°C in the MPA or LPA zones are strong indicators of underlying inflammation or perfusion deficits. This ability to visualize "silent" vascular and inflammatory changes allows for targeted interventions, such as specific

screening tool. These figures indicate that the TFScan system did not miss a single case identified as being at moderate-to-high risk by the clinical expert. In the context of diabetic foot management, where early detection is paramount to prevent amputation, the cost of a false negative is substantially higher than that of a false positive. The high specificity (96.8%) further ensures that healthcare resources are not overwhelmed by unnecessary referrals, while the strong correlation ($\rho = 0.973$) validates the system's utility as a reproducible adjunct in clinical settings [20].

orthotic offloading or referral for further vascular imaging, before tissue necrosis occurs [27].

Comparative Analysis with Traditional Screening Tools

To fully appreciate the role of TFScan in modern diabetic foot care, its performance must be contrasted with the traditional tools currently utilized in primary and secondary care. While methods like the 10g monofilament test and the ankle-brachial index (ABI) remain standard, they possess inherent limitations that can lead to late-stage detection and missed opportunities for prevention. The 10g monofilament test is designed to identify loss of protective sensation (LOPS), a major risk factor for DFUs. However, a systematic meta-analysis of 19 comparative trials revealed that the pooled sensitivity of the monofilament test is only 53%, meaning it misses nearly half of the patients with peripheral neuropathy. Furthermore, the test is subjective, dependent on clinician technique, and only assesses neurological status, leaving vascular and inflammatory risks unaddressed. In contrast, TFScan provides a physiological "whole-foot" assessment that captures both neuropathic (hyperthermia) and vascular (hypothermia) indicators while providing complementary physiological information. Similarly, the ABI is the traditional non-invasive method for diagnosing PAD. However, its reliability is severely undermined in diabetic populations due to medial arterial calcification. Calcified vessels become non-compressible, often resulting in falsely normal or even elevated ABI scores (e.g., >1.3), even in the presence of severe ischemia. Thermography is not affected by vessel wall calcification, as it measures the end-result of blood flow—skin temperature—rather than vessel compressibility. Studies comparing

infrared thermography to color Doppler ultrasonography for PAD diagnosis have reported a sensitivity of 97.62% and a specificity of 91.67%, suggesting that thermographic systems like TFScan

may provide complementary physiological information for vascular assessment where ABI interpretation is limited [28].

Table 2.2: Comparative Analysis with Traditional Screening Tools.

Diagnostic Tool	Focus Area	Reported Sensitivity	Principal Limitation in Diabetes
10g Monofilament	Neuropathy/LOPS	53%	Subject: misses vascular/inflammatory risk
ABI	Macro-vascular/PAD	91% (Non-Diabetic)	Inaccurate due to vessel calcification
Duplex Ultrasound	Vascular Structure	Variable	Difficult to visualize distal vessels
TFScan	Physiological State	100%	Requires protocol-controlled environment

Large-Scale Screening and Risk Stratification Evidence

TFScan has also been evaluated through a multicenter cross-sectional study conducted across four major regions in Saudi Arabia (Riyadh, Qassim, Madinah, and Al-Baha), involving a cohort of 1,120 individuals with diabetes. This study aimed to evaluate the system's performance in identifying high-risk individuals in a diverse, real-world population and to correlate TFScan results with known clinical risk factors. The findings from this large-scale deployment indicated that while the majority (90.7%) of participants were categorized as very low or low risk, 9.3% (104 patients) were identified as being at moderate or high risk for diabetic foot complications. The high-risk group exhibited a significantly greater prevalence of major comorbidities compared to the low-risk group:

- **Peripheral Artery Disease:** 20.2% in high-risk vs. 0.8% in low risk.
- **Cardiovascular Disease:** 57.7% in high-risk vs. 30.8% in low risk.
- **Neuropathy:** 11.5% in high-risk vs. 3.6% in low risk.
- **Foot Deformities:** 14.4% in high-risk vs. 0.6% in low risk.
- **Symptoms of LOPS:** 51% in high-risk vs. 34.8% in low risk.

Thermal analysis revealed that temperature asymmetries of 2.2° C were present in 7.1% of the total cohort, but these abnormalities were overwhelmingly concentrated in the moderate and high-risk groups. This concentration of clinical and thermal abnormalities within the TFScan-identified high-risk categories was consistent with separation of participants into clinically relevant risk categories. This allows for a "triage" approach to care, where higher-risk individuals are funneled into more intensive podiatric management and advanced diagnostic pathways, while lower-risk individuals may continue routine risk-based surveillance according to the applicable clinical pathway [20].

Advanced Computational Frameworks: TCI and Deep Learning

The ability of TFScan to achieve high accuracy is driven by the application of sophisticated computational models to thermal data. One such model is the Thermal Change Index (TCI), a quantitative indicator developed to characterize the diversity of thermal changes in the plantar region of diabetic patients compared to healthy controls. The TCI is calculated using the temperature values from the four primary angiosomes:

$$TCI = (CG_{ang} - Dm_{ang})/4$$

Where CG_{ang} represents the temperature of the angiosome in the control group and DM_{ang} represents the same in the diabetic subject. The TCI values are used to classify thermograms into five levels, with Class 1 ($TCI < 2$) representing healthy patterns and Class 5 ($TCI > 5$) representing severe thermal abnormality. Beyond basic indices, researchers have developed specialized deep learning architectures such as the Diabetic Foot Thermogram Network (DFTNet). DFTNet was designed specifically to handle the high thermal similarities between neighboring disease classes, outperforming conventional architectures like AlexNet and GoogLeNet. Furthermore, hybrid models that combine traditional feature extraction (like Bag of Features, BOF) with deep CNN representations have achieved accuracy rates of up to 98.51% and precision of 100% in identifying pre-ulcerative conditions. These models are particularly effective because they can identify subtle, non-linear thermal patterns that are often missed by human clinicians, who may suffer from "sensory overload" or "optical illusions" when interpreting large numbers of thermograms [23].

Clinical Standardization and Protocols for Accuracy

The precision of infrared thermography is highly dependent on standardized acquisition protocols, as skin temperature can be influenced by environmental factors, patient activity, and physiological variables. To maintain clinical grade accuracy, TFScan follows guidelines established by the American Academy of Thermology (AAT).

Table 2.3: Clinical Standardization and Protocols for Accuracy.

Protocol Parameter	Clinical Requirement	Scientific Rationale
Ambient Temperature	19°C – 25°C	Ensures stable heat exchange with surroundings
Relative Humidity	< 70%	Prevents moisture/evaporation artifacts on skin
Acclimatization	10 – 15 Minutes	Allows skin to reach equilibrium with ambient air
Patient Position	Supine/Legs free	Avoid contact-induced thermal changes
Pre-test Restrictions	No smoking/caffeine (4 hours)	Avoids vasoactive alterations in blood flow

Adherence to these point-of-care guidelines ensures that the detected temperature differences are pathological rather than environmental. For example, studies have shown that without proper acclimatization, a patient's core body heat or the warmth from their shoes can mask the subtle hypothermia of PAD or the localized hyperthermia of inflammation. When protocols are strictly followed, even low-resolution smartphone-based sensors have demonstrated "almost perfect agreement" (ICC > 0.98) with high-end, research-grade thermal cameras costing ten times as much [30].

Behavioral Impact and Patient Empowerment

Beyond its diagnostic capabilities, Thermal visualization has also been explored as a potential aid to patient education and adherence. One of the primary challenges in diabetic foot care is that neuropathy often leaves patients "insensitive" to their own condition; because they cannot feel pain, they may not perceive the urgency of prescribed offloading or footwear changes. Thermodynamic visualization provides a "window" into the invisible stress occurring beneath the skin. Case studies have shown that patients become significantly more compliant with treatment recommendations once they can visualize the abnormal heat patterns or "hot spots" generated by high-pressure areas on the F-Mat or TFScan profiles. For instance, a patient with a 15-month non-healing ulcer achieved complete healing within one month after being shown their thermal/pressure profiles, as the data provided immediate feedback on the efficacy of modified orthotics. This "visualization effect" transforms the screening process from a passive clinical exam into an interactive educational tool, empowering patients to take an active role in their own limb preservation [31].

Future Directions:

The current body of evidence primarily supports the use of TFScan for cross-sectional risk stratification and early detection. However, the future of technology lies in longitudinal prediction and remote monitoring. Longitudinal studies are currently exploring whether textural analysis of thermal images taken at week 1 can predict the healing trajectory of a DFU at week 12. Integrating AI with longitudinal data from wearable sensors—such as thermocouples and pressure sensors in "smart" socks—could enable continuous real-time surveillance. Recent research has shown that home-based temperature monitoring

can reduce the risk of ulcer recurrence by up to 50%. The accessibility of TFScan, as a smartphone-based system, makes it an ideal candidate for telemedicine applications. In remote or resource-limited settings, where access to specialized diabetic foot nurses is limited, the ability for a local healthcare worker or the patient themselves to capture a thermal image and receive an automated, AI-driven risk score could significantly bridge the gap in care [20].

Clinical Limitations and Methodological Considerations

Despite its significant advantages, the clinical implementation of TFScan must be approached with an understanding of its current limitations. Most large-scale studies to date have been cross-sectional in nature, which allows for the identification of risk but does not provide long-term "causal" evidence for ulcer development. Additionally, some data points in these studies rely on patient self-reports for comorbidities, which can introduce reporting bias. The complexity of diabetic foot syndrome also means that thermography should be viewed as a "complementary" tool rather than a replacement for a comprehensive clinical exam. For example, thermography may not be able to differentiate between a localized infection and non-infectious inflammation without additional clinical context. Furthermore, the system's effectiveness depends on the availability of a reference—if a patient has bilateral complications that are perfectly symmetrical, the system may not detect an "asymmetry" even though both feet are at high risk. Advanced algorithms that analyze absolute temperature distributions, rather than just asymmetry, are currently being refined to address this "symmetrical pathology" challenge [20].

Conclusion

Published evidence suggests that TFScan and related thermographic approaches may provide useful adjunctive information for diabetic-foot screening and risk stratification. Reported studies have described high sensitivity and negative predictive value in selected settings; however, these findings should be interpreted in the context of study design, reference standards, and population characteristics. By combining regional thermal mapping with automated analysis, TFScan may help clinicians identify temperature patterns associated with inflammation or altered perfusion that warrant further

clinical assessment. Its role is therefore best considered complementary to established diabetic-foot examination rather than a replacement for conventional neurological, vascular, and structural assessment. Integration into routine clinical workflows should be accompanied by standardized acquisition protocols and multidisciplinary clinical interpretation. Further prospective longitudinal validation is needed to determine how well automated thermal findings predict future ulceration and patient outcomes.

Research Gaps:

Research into AI-powered thermography, particularly the TFScan system, reveals several critical gaps that currently limit its widespread clinical adoption. First, current evidence is predominantly derived from cross-sectional studies, which restricts the ability to establish causal inferences regarding the progression from subclinical thermal asymmetry to overt ulceration. Longitudinal validation is essential to confirm the system's predictive power for future complications over extended periods. Second, many existing studies rely on self-reported clinical data and relatively small cohorts, potentially introducing bias reporting and limiting model generalizability. Methodologically, the "symmetrical pathology" challenge remains significant; since technology primarily identifies contralateral asymmetry, cases with bilateral, identical vascular or neuropathic damage may go undetected. Furthermore, there is a lack of large-scale validation in uncontrolled home environments where ambient factors vary more than in standardized clinical settings. While AI models for predicting healing trajectories are emerging, they currently lack high accuracy during the early stages of ulcer management. Finally, research into multi-modal monitoring—integrating thermography with real-time pressure or shear sensors—is still in its infancy, and evidence regarding long-term patient acceptability and clinical uptake remains limited.

Chapter Three

Methodology and Study Design

Study design and objective:

This retrospective observational study used a cross-sectional assessment of baseline demographic, clinical, and thermal-imaging data, followed by an exploratory retrospective review of six-month documented outcomes among patients classified as having moderate or high diabetic-foot risk. Previously acquired TFScan data and corresponding clinical data were analyzed. TFScan-generated patient risk classification was available for all 105 participants, while complete detailed thermal parameters required for the thermal findings analysis

were available for 102 participants. These data had been collected as part of routine clinical assessment at the Diabetic Center, King Abdulaziz Hospital. The study evaluated TFScan-generated risk classification and detailed thermal findings alongside available clinical diabetic-foot risk information. The International Working Group on Diabetic Foot (IWGDF) clinical risk-classification framework informed interpretation of the documented clinical risk data.

Thermal imaging system:

A smartphone-based thermal imaging system had previously been used to acquire plantar images and generate patient-level risk classifications. The TFScan-generated risk classification output was available for all 105 participants. For the separate detailed thermal findings analysis, complete thermal parameters were available for 102 participants. The system was used analytically to extract:

- Temperature asymmetry
- Thermal gradients
- Distribution patterns

Risk levels were generated based on predefined thresholds.

Study setting and recruitment:

Data were retrieved from a specialized diabetic center within the Saudi Arabian healthcare context (King Abdulaziz Hospital, Jeddah First Health Cluster - J1).

Study Population

Inclusion:

- Adults ≥ 18 years
- Diagnosed with diabetes

Exclusion:

- Active ulcers
- Infection
- Current/major amputation

Sample Size

All 105 eligible patients who had undergone TFScan during the study period were included using a total sampling approach, as they met the predefined inclusion criteria. TFScan-generated patient risk classification was available for the full sample (N=105). Complete clinical data and complete detailed thermal parameters for the corresponding clinical-risk and thermal findings analyses were available for 102 participants; therefore, these analyses used N=102.

Ethical considerations:

Ethical approval was obtained from the relevant Institutional Review Board (reference A02512; Approval No. 07/05/2026). Given the retrospective nature of the study and the use of previously collected medical-record data, no direct patient contact or prospective research assessment was performed by the research team. All data were

handled in accordance with ethical standards, with confidentiality maintained through coded identifiers and secure data management.

Data collection:

Data were retrieved from existing medical records using structured clinical and demographic data. Variables included age, sex, body mass index, duration of diabetes, glycemic control indicators, and comorbidities such as neuropathy or peripheral arterial disease. Thermal imaging had been conducted under standardized environmental conditions, including controlled room temperature and adequate acclimatization before image acquisition. Imaging procedures had been performed by trained healthcare professionals following standardized protocols. Clinical assessments had been documented using established diabetic-foot screening and risk-classification criteria. Baseline demographic, clinical, thermal-imaging, and risk-classification data were extracted retrospectively. TFScan-generated patient risk classification was available for all 105 participants, whereas complete detailed thermal parameters were available for 102 participants and were used for the detailed thermal findings analysis. Six-month documented outcomes were also reviewed retrospectively from existing medical records for patients classified at baseline as having moderate or high diabetic-foot risk. Patients classified as low risk were recommended routine follow-up after one year according to the clinical care pathway and were not included in the six-month follow-up analysis. No new data were collected, and no patients were contacted by the research team.

Existing data were retrieved, including:

- Thermal images
- Clinical assessments
- Demographics and comorbidities

Screening and risk classification:

The thermal imaging system generated a TFScan patient risk classification for all 105 participants. Documented clinical risk data were complete for 102 participants. The TFScan risk-classification output (N=105) was analyzed separately from the detailed thermal findings (N=102), which included thermal abnormalities, lesion characteristics, and regional temperature-delta parameters.

These were analyzed as:

- Ordinal categories
- Dichotomized (low/high risk)

Outcome measures:

The primary analyses described TFScan-generated patient risk classifications and detailed thermal findings in the study population. Clinical risk characteristics were summarized separately using the available clinical dataset. An exploratory retrospective review additionally described six-month

documented clinical outcomes among patients classified as moderate or high risk at baseline. These analyses were intended to characterize screening findings and risk stratification in routine practice rather than to provide a formal independent diagnostic-accuracy validation.

Statistical analysis:

Statistical analysis was primarily descriptive. Continuous variables were summarized using appropriate measures of central tendency and dispersion where available, while categorical variables were expressed as frequencies and proportions. TFScan-generated patient risk categories, clinical risk characteristics, detailed thermal findings, and six-month documented outcomes were summarized using analysis-specific denominators. Demographic and TFScan-generated patient risk-classification analyses used the full sample of 105 participants, whereas the clinical-risk and detailed thermal findings analyses used 102 participants with complete data for those analyses. The six-month retrospective outcome analysis was restricted to the 25 participants classified as moderate or high risk at baseline.

Chapter Four

Study Results

Demographic Data of Participants:

Table 4. 1 presents the demographic and clinical profile of 105 participants enrolled in the present research on early detection of diabetic foot complications at the Specialized Diabetes Center, King Abdulaziz Hospital, Jeddah First Health Cluster. A total of 105 eligible patients who had undergone TFScan were included in the overall study sample. TFScan-generated patient risk classification was available for all 105 participants, while clinical-risk and detailed thermal findings analyses were based on 102 participants with complete data for those analyses. This provides a clear description of the patient population served by the center during the study period. Regarding age, the largest proportion of participants was aged 46–60 years, accounting for 46 individuals (43.8%). Participants aged 60 years and above constituted the second-largest group, with 27 cases (25.7%). Together, these middle-aged and older groups represent 69.5% of the sample, indicating that diabetic foot-complication screening is particularly relevant among patients in later adulthood. This pattern is clinically important because increasing age is often accompanied by longer diabetes exposure, vascular changes, neuropathy, reduced mobility, and other factors associated with foot ulceration and delayed wound healing. Participants aged 31–45 years represented 20.9%, while only 9.5% were below 30 years. Although younger adults formed a

smaller proportion, their inclusion remains important, particularly for early preventive education and risk assessment (**Table 4.1**).

The sample was predominantly male, with 66 participants (62.8%), compared with 39 females (37.2%). This male predominance may reflect patterns of attendance at the specialized center, differences in health-seeking behavior, or a potentially greater burden of diabetes-related foot risk among male patients. It suggests that prevention and screening activities should remain gender-sensitive while ensuring that female patients are equally reached and supported. Most participants were Saudi nationals, comprising 94.2% of the sample, whereas only 5.8% were non-Saudi. Therefore, the findings are highly representative of the Saudi patient population attending this center. However, the relatively limited number of non-Saudi participants means that conclusions may be less generalizable to the wider expatriate population in Jeddah. Type II diabetes was overwhelmingly predominant, affecting 99 participants (94.2%), while only 6 participants (5.8%) had Type I diabetes. No non-diabetic individuals were included, as expected in a diabetes-

center sample. This distribution is consistent with the greater prevalence of Type II diabetes among adults and reinforces the need to prioritize foot-risk screening within this group. Nearly half of the participants (47.6%) had lived with diabetes for 11 years or more. A further 24.7% had diabetes for 6–10 years, while 28.5% had diabetes for five years or less. The substantial proportion with long-standing diabetes is particularly significant because prolonged disease duration is associated with a higher likelihood of peripheral neuropathy, peripheral arterial disease, foot deformities, and ulcer development. Early detection programs should therefore give particular attention to patients with diabetes duration exceeding 10 years. Finally, the BMI findings show a considerable burden of excess body weight. Obesity was reported among 40.9% of participants, and 35.2% were overweight; thus, 76.1% had a BMI of 25 kg/m² or higher. Only 22.8% had normal BMI, and 0.9% were underweight. This emphasizes the importance of integrating weight-management counseling, glycemic control, physical-activity guidance, and routine foot examinations into diabetic foot prevention services (**Table 4.1**).

Table 4.1: Demographic data of participants (N=105).

No.	Demographic Data	Data	Responses	
			Frequency (N)	Percentage (%)
1	No. of Cases	Received cases	105	100%
2	Age	Less than 30 years	10	9.5%
		31 – 45 years	22	20.9%
		46 – 60 years	46	43.8%
		60 years and more	27	25.7%
3	Gender	Male	66	62.8%
		Female	39	37.2%
4	Nationality	Saudi	99	94.2%
		Non-Saudi	6	5.8%
5	Diabetes	Diabetes Type-I	6	5.8%
		Diabetes Type-II	99	94.2%
		Non-Diabetic	0	0%
6	Diabetes Duration	Less than or 5 years	30	28.5%
		6 – 10 years	26	24.7%
		11 years and more	49	47.6%
7	BMI	Underweight ≤ 18.5	1	0.9%
		Normal 18.5 – 24.9	24	22.8%
		Overweight 25 – 29.9	37	35.2%
		Obese ≥ 30	43	40.9%

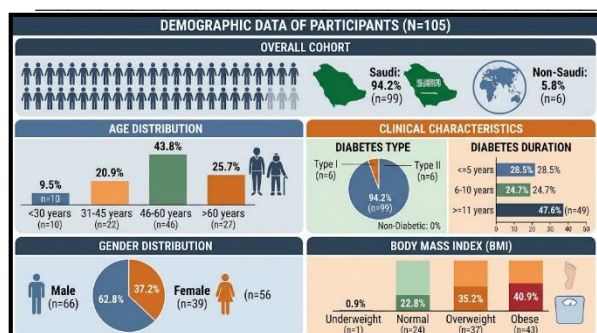


Figure 2: Demographic Characteristics of Participants (n=105).

Clinical Risk Findings:

The clinical-risk data indicate a substantial burden of diabetes-related complications and symptoms suggestive of impaired foot sensation among the study participants. Clinical risk data were available for 102 of the 105 participants; three participants had incomplete clinical data and were therefore excluded from the clinical risk analysis. Retinopathy was the most frequently reported clinical risk factor, affecting 72.5% of patients, followed closely by neuropathy at 67.6%. This is highly relevant to diabetic-foot prevention because neuropathy can reduce protective sensation, allowing minor trauma, pressure injuries, burns, or wounds to progress unnoticed. The high prevalence of retinopathy may also suggest a broader burden of microvascular diabetic complications and potentially reflect prolonged or insufficiently controlled diabetes in this population (**Table 4.2**).

Chronic cardiovascular conditions were reported in 45.1% of participants, representing an important coexisting risk. Cardiovascular disease may be associated with reduced circulation, lower exercise tolerance, and poorer healing capacity, all of which can complicate diabetic foot outcomes. Peripheral arterial disease (PAD) was not quantified in the available dataset and was therefore not included in the prevalence analysis. Symptoms

Table 4.2: Clinical Risks Evaluation (N=102).

Clinical variable	Category	Frequency (N)	Percentage (%)
Clinical risk factors	Peripheral arterial disease (PAD)*	Not reported	Not reported
	Neuropathy	69	67.6
	Retinopathy	74	72.5
	Chronic cardiovascular conditions	46	45.1
	Numbness	74	72.5
	Tingling	59	57.8
Loss of protective sensation symptoms	Pain and tenderness	68	66.7
	Walking unsteadiness	34	33.3
	Optimal ($\leq 6.5\%$)	19	18.6
HbA1c level	Acceptable (6.6–7.5%)	23	22.5

related to loss of protective sensation were also common. Numbness was the most prevalent symptom, reported by 72.5% of patients. Pain and tenderness affected 66.7%, while tingling was reported by 57.8%. Walking unsteadiness was less common but still affected one-third of participants (33.3%). These findings demonstrate that sensory and functional symptoms are widespread in the sample. Numbness and tingling are particularly consistent with peripheral neuropathy, while walking unsteadiness may reflect impaired proprioception, reduced sensation, pain, musculoskeletal limitations, or balance difficulties. Clinically, such symptoms may increase the risk of falls, unnoticed foot trauma, abnormal gait, and repeated pressure on vulnerable foot areas (**Table 4.2**).

The pattern of symptom burden is reinforced by the number of loss-of-protective-sensation symptoms reported per patient. Only 17.6% of participants had no symptoms, meaning that 82.3% experienced at least one symptom. Most notably, 51.0% reported three or more symptoms, indicating a high-risk subgroup requiring comprehensive foot assessment and close follow-up. Patients with multiple symptoms should be prioritized for monofilament testing, vibration perception assessment, pedal-pulse examination, footwear evaluation, skin inspection, and structured self-care education. Glycemic control was also suboptimal for a large proportion of the sample. Poor HbA1c levels ($\geq 8.6\%$) were found in 44.1% of participants, the largest HbA1c category. Only 18.6% achieved optimal control ($\leq 6.5\%$), while 22.5% had acceptable control and 14.7% had elevated HbA1c levels. Poor glycemic control can accelerate neuropathy, retinopathy, vascular damage, infection risk, and impaired wound healing. Overall, the results support the need for intensified early screening and multidisciplinary diabetes management, especially for patients with neuropathy, multiple sensory symptoms, long-standing diabetes, obesity, and poor HbA1c control (**Table 4.2**).

Clinical variable	Category	Frequency (N)	Percentage (%)
	Elevated (7.6–8.5%)	15	14.7
	Poor ($\geq 8.6\%$)	45	44.1
Number of loss-of-protective-sensation symptoms per patient	0 symptoms	18	17.6
	1 symptom	19	18.6
	2 symptoms	13	12.7
	≥ 3 symptoms	52	51.0
	Total	102	100.0

*PAD was not quantified in the available dataset.

Patient Risk Analysis:

The patient-risk summary included all 105 TFScan examinations because the TFScan-generated patient risk classification was available for every participant. This patient-level risk output is distinct from the detailed thermal findings analysis, for which complete thermal parameters were available for 102 participants. Most participants were categorized as having a low risk of diabetic foot complications. Low-risk patients represented the largest group, with 75 participants (71.4%). In addition, 5 participants (4.8%) were classified as very low risk. Together, the low- and very-low-risk groups accounted for 80 patients (76.2%), suggesting that most screened patients did not demonstrate an immediate high-risk profile at the time of assessment. However, 18 patients (17.1%) were classified as having moderate risk, while 7 patients (6.7%) were categorized as high risk. Therefore, 25 participants (23.8%) had moderate-to-high risk and representing the subgroup requiring closer clinical assessment and follow-up according to risk-based care pathways. This proportion is clinically meaningful, as moderate- and high-risk classifications may reflect the presence of one or more concerning findings, such as sensory impairment, thermal asymmetry, foot lesions, poor glycemic control, neuropathy, vascular concerns, or previous foot-related complications. High-risk

Table 4.3: Patient Risk analysis (N=105).

Risk category	Frequency (N)	Percentage (%)
High risk	7	6.7
Moderate risk	18	17.1
Low risk	75	71.4
Very low risk	5	4.8
Total	105	100.0

Note: TFScan-generated patient risk classification was available for all 105 participants; therefore, the denominator for this analysis is N=105.

patients should receive prompt and frequent comprehensive foot assessment. Their care should include detailed examination of skin integrity, pedal circulation, neuropathy, foot deformity, pressure areas, footwear, and signs of infection. They may also require individualized education on daily foot inspection, appropriate footwear, avoiding barefoot walking, glycemic control, and timely reporting of skin color changes, swelling, pain, wounds, or increased foot temperature (**Table 4.3**).

Patients in the moderate-risk group should not be overlooked. Although their immediate risk is lower than that of the high-risk group, they may progress to more serious complications if risk factors are not managed early. Regular follow-up, monitoring of temperature changes, optimization of HbA1c, weight management, and reinforcement of self-care behaviors are appropriate for this group. The predominance of low-risk patients supports the value of early screening within the specialized diabetes center. Identifying risk before ulceration develops creates an opportunity for preventive care and may reduce the future burden of diabetic foot ulcers, infection, hospitalization, and amputation. Nevertheless, approximately one-quarter of participants with moderate or high risk confirm the need for a structured risk-stratification pathway and targeted multidisciplinary follow-up (**Table 4.3**).

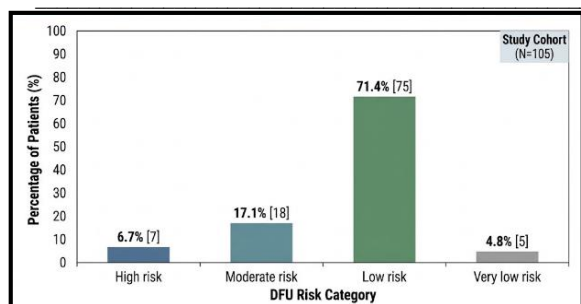


Figure 3: Diabetic Foot Risk Category.

Thermal Findings:

The detailed thermal findings analysis included 102 participants with complete thermal parameters. This denominator differs from the TFScan-generated patient risk classification (N=105), which was available for all scanned participants. Among the 102 participants included in the detailed thermal analysis, overt thermal abnormalities were present in a relatively small but clinically important proportion. Thermal asymmetry was the most common abnormality, occurring in 7 patients (6.9%), followed by hyperthermia in 6 patients (5.9%) and hypothermia in 4 patients (3.9%). These findings are relevant to diabetic foot screening because localized temperature changes may precede visible ulceration. Hyperthermia and asymmetry may indicate inflammation, repetitive pressure, tissue stress, or early infection, whereas hypothermia may suggest reduced blood flow or peripheral vascular compromise. Since these abnormalities may overlap in the same patient, their percentages should not be added together (**Table 4.4**). Most participants had no

Table 4.4: Thermal Findings Evaluation (N=102).

Finding	Category / temperature delta	Frequency (N)	Percentage (%)
Thermal abnormalities	Hyperthermia	6	5.9
	Hypothermia	4	3.9
	Thermal asymmetry	7	6.9
Lesion size	No lesion / small lesion	95	93.1
	Medium lesion	5	4.9
	Large lesion	2	2.0
Metatarsal plantar area (MPA) temperature delta	0	93	91.2
	1	8	7.8
	2	1	1.0
Lateral plantar area (LPA) temperature delta	0	92	90.2
	1	8	7.8
	2	2	2.0
Lateral calcaneal area (LCA) temperature delta	0	71	69.6
	1	29	28.4
	2	1	1.0
	3	1	1.0

lesion or only a small lesion, accounting for 95 patients (93.1%). Medium lesions were observed in 5 patients (4.9%), and large lesions in 2 patients (2.0%). Despite their low frequency, medium and large lesions require urgent attention because lesion severity may increase the risk of infection, delayed healing, hospitalization, and amputation. Temperature-delta measurements showed that most participants had no measurable temperature difference across the assessed foot areas. In the metatarsal plantar area (MPA), 93 patients (91.2%) had a delta of 0; 8 (7.8%) had a delta of 1; and 1 (1.0%) had a delta of 2. Similarly, in the lateral plantar area (LPA), 92 participants (90.2%) had a delta of 0, while 8 (7.8%) and 2 (2.0%) had deltas of 1 and 2, respectively. These findings suggest that mild temperature variation was more common than marked variation (**Table 4.4**).

For the calcaneal areas, the lateral calcaneal area showed greater variation than the medial calcaneal area. In the lateral calcaneal area, 31 patients (30.4%) had a temperature delta of at least 1, compared with 10 patients (9.8%) in the medial calcaneal area. This pattern suggests that the lateral heel may deserve particular attention during thermal screening and clinical foot examination. The overall temperature-delta distribution further supports this conclusion: 95 patients (93.1%) had an overall delta of 0, 5 (4.9%) had a delta of 1, and 2 (2.0%) had a delta of 2. The overall lesion-delta chart recorded four cases, with two patients each showing lesion-delta values of 2 and 3 (**Table 4.4**).

Finding	Category / temperature delta	Frequency (N)	Percentage (%)
Medial calcaneal area (MCA) temperature delta	0	92	90.2
	1	7	6.9
	2	3	2.9
Overall temperature delta	0	95	93.1
	1	5	4.9
	2	2	2.0
Overall lesion delta*	2	2	2.0
	3	2	2.0

Note: Detailed thermal parameters were available for 102 participants; therefore, the detailed thermal findings analysis uses N=102. This is separate from the TFScan-generated patient risk classification, which was available for all 105 participants.

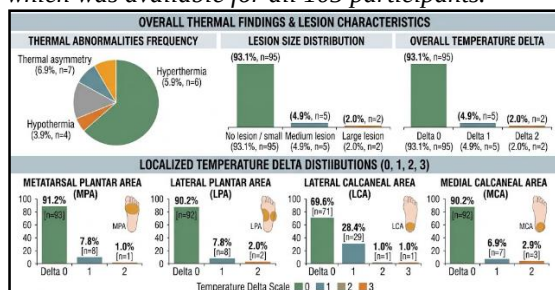


Figure 4: Overall Thermal Findings.

High Risk and Moderate Risk Progression Over 6 months Follow-up:

The six-month retrospective follow-up review included 25 patients with baseline diabetic-foot risk classifications. Most patients had bilateral moderate risk (18 patients, 72.0%), while 5 patients (20.0%) had high risk affecting one or both feet. Two patients had mixed bilateral risk classifications: one had moderate risk in one foot and high risk in the other, while one had high risk in one foot and low risk in the other. Overall, 7 patients (28.0%) had at least one high-risk foot at baseline. At follow-up, 19 patients (76.0%) had documented clinical stability. Three patients (12.0%) had a documented new foot wound or ulcer, and two patients (8.0%) had documented plantar fasciitis. For one patient (4.0%), no documented follow-up outcome was available in the medical record. These findings describe documented outcomes during the retrospective review period and should not be interpreted as evidence of a causal effect of screening or preventive care (Table 4.5 and 4.6).

Nevertheless, three patients (12.0%) developed a new foot wound or ulcer. One patient

Table 4.5: Six-Month Clinical Progression Outcomes (N = 25).

Follow-up outcome	Frequency (N)	Percentage (%)
Clinically stable	19	76.0

with left-foot high risk developed an ulcer; this patient had a markedly elevated HbA1c of 15.1%, was aged 52 years, and had a history of myocardial infarction and left big-toe amputation. The other two wound events occurred in patients categorized as having bilateral moderate risk. Both had important pre-existing risk factors, including neuropathy, retinopathy, cardiovascular disease or hypertension, foot deformity, and/or onychomycosis. These findings demonstrate that a moderate-risk classification should not be considered free of risk, particularly when several complications coexist. Two patients (8.0%) were reported to have plantar fasciitis. Although plantar fasciitis is not necessarily equivalent to diabetic-foot ulceration or progression of neuropathic disease, it may cause pain, reduced mobility, altered gait, and increased mechanical stress on the foot. These patients require clinical follow-up, footwear assessment, and management of plantar pressure (Table 4.5 and 4.6).

Glycemic control was suboptimal in many patients. HbA1c data were available for 24 patients, with a mean HbA1c of approximately 8.3% and values ranging from 5.9% to 15.1%. Nine patients (37.5% of those with available HbA1c values) had HbA1c levels of 8.6% or higher. Poor glycemic control, together with neuropathy, vascular disease, renal disease, retinopathy, foot deformity, and previous amputation, may increase the likelihood of future diabetic-foot complications. The findings should be interpreted cautiously because of the small sample size, mixed date formats, one missing follow-up outcome, and absence of baseline-to-follow-up clinical measurements for each patient. However, the observed wound incidence highlights the importance of intensified follow-up for patients with high-risk feet and for moderate-risk patients with multiple comorbidities (Table 4.5 and 4.6).

Follow-up outcome	Frequency (N)	Percentage (%)
New foot wound / ulcer	3	12.0
Plantar fasciitis	2	8.0
No documented follow-up outcome available	1	4.0
Total	25	100.0

Table 4.6: Baseline Patient Risk Classification (N = 25).

Baseline risk classification	Frequency (N)	Percentage (%)
Bilateral moderate risk	18	72.0
High risk in one or both feet	5	20.0
Mixed moderate-risk and high-risk feet	1	4.0
Mixed high-risk and low-risk feet	1	4.0
Total	25	100.0

Chapter Five

Discussion, Study limitations, Recommendations and Conclusion**Discussion:**

The present study provides a comprehensive profile of patients attending a specialized diabetes center for early assessment of diabetic foot complications. The findings demonstrate a substantial burden of metabolic, neurological, vascular, and thermal risk factors, despite the fact that most patients were classified by the thermal screening system as low or very low risk. This apparent contrast is clinically important: it indicates that diabetic foot risk exists on a continuum and that a low-risk screening result should not replace regular clinical examination, metabolic optimization, and patient education. Instead, thermal screening should be considered an additional risk-stratification method that assists clinicians in identifying subclinical abnormalities and prioritizing patients who require more intensive assessment. The demographic findings showed that the largest proportion of participants was aged 46–60 years (43.8%), followed by those aged 60 years or more (25.7%). Thus, approximately two-thirds of the study population were middle-aged or older adults. This pattern is expected in diabetes services because the cumulative effects of long-standing hyperglycemia, neuropathy, microvascular disease, cardiovascular disease, and reduced mobility become more evident with advancing age. Older age is not an isolated determinant of diabetic foot disease; however, it often coexists with longer diabetes duration, reduced visual acuity, musculoskeletal limitations, and diminished capacity for self-foot inspection. These interacting

factors may delay the recognition of minor trauma or early tissue injury and increase the likelihood that a preventable lesion progresses to ulceration.

Male participants represented 62.8% of the study population, compared with 37.2% females. This predominance may reflect local patterns of clinic utilization, the referral pathway to the specialized center, or a higher accumulated burden of foot-related risk among male attendees. It should not, however, be interpreted as evidence that females are protected from diabetic foot complications. Rather, the result highlights the need for gender-sensitive education and screening strategies that ensure both men and women receive regular foot examinations and culturally appropriate preventive advice. Most participants were Saudi nationals (94.2%), which makes the findings particularly relevant to the Saudi population served by King Abdulaziz Hospital and Jeddah First Health Cluster. At the same time, the relatively small non-Saudi subgroup limits the extent to which the results can be generalized to expatriate populations with potentially different socioeconomic conditions, healthcare access, occupational exposures, and self-care behaviors. Type II diabetes was present in 94.2% of participants, while Type I diabetes accounted for only 5.8%. This distribution is consistent with the adult clinical population commonly seen in diabetes centers and supports prioritizing Type II diabetes within diabetic-foot prevention programs. Furthermore, 47.6% of participants had diabetes for 11 years or more. Prolonged diabetes duration is a relevant clinical marker because it increases cumulative exposure to hyperglycemia and therefore the probability of microvascular and macrovascular complications. The high prevalence of long-standing disease in this sample provides an important context for the

observed burden of neuropathy, retinopathy, poor glycemic control, and sensory symptoms.

Excess body weight was also highly prevalent. Obesity affected 40.9% of participants and overweight affected a further 35.2%, meaning that 76.1% had a body mass index above the normal range. This finding is especially relevant because obesity contributes to insulin resistance and makes glycemic control more difficult. It may also increase plantar pressure, limit mobility, compromise balance, and complicate footwear selection. In a person with neuropathy or impaired sensation, elevated plantar loading can facilitate repetitive unnoticed trauma. Therefore, risk reduction should combine foot examination with weight management, safe physical-activity advice, nutritional counseling, and individualized footwear assessment rather than treating foot risk as an isolated complication. The clinical-risk findings show that diabetic complications were common. Retinopathy was reported in 72.5% of participants, neuropathy in 67.6%, and chronic cardiovascular conditions in 45.1%. The high prevalence of retinopathy and neuropathy suggests considerable cumulative microvascular disease burden. Neuropathy is particularly central to diabetic-foot pathogenesis because loss of protective sensation reduces the patient's ability to detect mechanical trauma, excessive pressure, heat, foreign objects, and early skin damage. Consequently, lesions can develop and progress without the pain that would ordinarily prompt protective behavior or timely clinical presentation. Current standards emphasize that neuropathy, vascular status, skin integrity, structural deformity, footwear, and prior foot history should be assessed together because diabetic-foot risk is multifactorial rather than attributable to a single finding [20].

The high proportion of participants with sensory symptoms supports the neuropathy findings. Numbness was reported by 72.5%, pain and tenderness by 66.7%, tingling by 57.8%, and walking unsteadiness by 33.3%. Only 17.6% of patients reported no loss-of-protective-sensation symptoms, whereas 51.0% reported three or more symptoms. This concentration of multiple symptoms is clinically concerning. Numbness and tingling are compatible with peripheral neuropathy, while pain may represent neuropathic pain, musculoskeletal conditions, inflammation, or tissue stress. Walking unsteadiness may be associated with impaired proprioception, lower-limb weakness, visual impairment, pain, or balance difficulties. Regardless of the underlying mechanism, these symptoms may increase the risk of falls, abnormal gait, increased plantar pressure, and unnoticed trauma. The findings reinforce the need for structured bedside examination using monofilament testing, vibration perception testing, pulse assessment, skin inspection, and evaluation of footwear and foot deformity. Thermographic

assessment can complement, but should not replace, these clinical measures [20,28]. Glycemic control was suboptimal in a considerable proportion of the sample. Poor HbA1c control, defined as HbA1c of 8.6% or higher, was found in 44.1% of participants, while only 18.6% had optimal HbA1c values. This result is important because chronic hyperglycemia contributes to peripheral neuropathy, endothelial dysfunction, immune impairment, reduced collagen synthesis, and delayed wound healing. Poor glycemic control may therefore amplify the effect of other risk factors such as obesity, neuropathy, retinopathy, and cardiovascular disease. The findings support incorporating HbA1c review into diabetic-foot risk management, with referral for diabetes optimization when needed. Nevertheless, HbA1c should be interpreted as one component of risk rather than as a standalone predictor, since ulceration results from the interaction of metabolic control, neuropathy, ischemia, infection, pressure, deformity, self-care, and access to treatment.

The system-based patient-risk classification showed that 71.4% of the 105 TFScan examinations were low risk and 4.8% were very low risk, whereas 17.1% were moderate risk and 6.7% were high risk. Thus, 23.8% of scanned patients were categorized as moderate or high risk. The TFScan-generated patient risk classification was available for the entire sample (N=105), whereas the separate clinical-risk and detailed thermal findings analyses were based on 102 participants with complete data for those analyses. This distinction explains the different denominators and should be considered when interpreting percentages across tables. The observed distribution is less favorable than that reported in a large multicenter Saudi study, in which 90.7% of participants were classified as very low or low risk and 9.3% as moderate or high risk [20]. The higher moderate-to-high-risk proportion in the present study may reflect the specialized nature of the diabetes-center population, differences in referral patterns, a greater burden of diabetes complications, or variation in screening eligibility criteria.

Detailed thermal findings were analyzed in the 102 participants with complete thermal parameters; these findings should therefore be interpreted using N=102 rather than the full TFScan risk-classification denominator of 105. Hyperthermia was detected in 5.9% of these participants, hypothermia in 3.9%, and thermal asymmetry in 6.9%. Although these percentages are relatively low, thermal abnormalities are clinically relevant because localized increases in temperature may indicate inflammation, repetitive mechanical stress, or pre-ulcerative tissue injury, whereas low temperature may suggest impaired perfusion. The biological rationale for this interpretation is well established: autonomic neuropathy may alter microvascular regulation and produce hyperthermia, while peripheral arterial disease can reduce blood flow and

result in hypothermia [22]. The literature review further notes that contralateral temperature asymmetry of approximately 2.2°C may be associated with increased risk of tissue breakdown, although thermal findings must always be interpreted in conjunction with clinical examination and standardized acquisition procedures [22-24]. The lesion-size findings were generally favorable, with 93.1% of participants having no lesion or only a small lesion. Medium lesions were recorded in 4.9% and large lesions in 2.0%. Although the latter categories were uncommon, their clinical significance is high. Even a small number of medium or large lesions may represent patients requiring urgent wound assessment, infection surveillance, vascular evaluation, pressure off-loading, and close multidisciplinary follow-up. The low prevalence of larger lesions may reflect early identification through screening, but it may also be influenced by the study setting, referral processes, and the exclusion of patients with severe active pathology from some assessments. Therefore, the result should be interpreted as a description of the screened population rather than as a direct estimate of lesion prevalence in all people with diabetes.

Regional temperature-delta findings demonstrated that most patients had a delta of zero in the metatarsal plantar area, lateral plantar area, medial calcaneal area, and overall analysis. However, the lateral calcaneal area showed a higher frequency of temperature variation: 30.4% had a temperature delta of one or more, compared with 9.8% in the medial calcaneal area. This difference may indicate that the lateral heel is an area deserving particular attention during clinical inspection and thermal monitoring. Heel tissue is susceptible to pressure-related injury, particularly in people with reduced mobility, gait abnormalities, neuropathy, or poorly fitting footwear. The angiosome-based approach described in the literature review offers a useful framework for interpreting such regional changes because it maps thermal signals to distinct vascular territories, including medial and lateral plantar and calcaneal regions [27]. The ability to detect localized changes may support targeted interventions, such as focused inspection, pressure redistribution, footwear modification, or referral for vascular assessment. The thermal results also demonstrate why thermography should be interpreted cautiously. Most patients showed no overall temperature delta, yet the same population had a high prevalence of neuropathy, retinopathy, sensory symptoms, and poor glycemic control. A normal or low-risk thermal profile does not eliminate the possibility of clinically significant neuropathy, bilateral symmetrical pathology, or future ulceration. The literature review identifies symmetrical pathology as an important limitation of asymmetry-based systems: both feet may be similarly affected and therefore show limited contralateral

difference despite clinically meaningful disease [20]. In addition, thermography may not distinguish infection from non-infectious inflammation without clinical context. For these reasons, thermal imaging should function as a complementary screening tool within a multidisciplinary diabetic-foot pathway rather than as a replacement for comprehensive assessment.

The six-month follow-up findings provide preliminary retrospective longitudinal observations. Among 25 moderate- or high-risk patients, 19 (76.0%) had documented clinical stability, three (12.0%) developed a new wound or ulcer, and two (8.0%) had documented plantar fasciitis. For one patient (4.0%), no documented follow-up outcome was available in the medical record. The predominance of documented clinical stability is encouraging; however, the data do not include a comparison group or detailed information on interventions received, and no causal conclusion can be made regarding the effectiveness of screening or follow-up. The three wound events are nevertheless clinically informative. One occurred in a patient with high-risk left-foot status, HbA1c of 15.1%, previous myocardial infarction, and prior left big-toe amputation. This clinical profile illustrates the compounding effect of severe metabolic dysregulation, previous tissue loss, and cardiovascular disease. The other two wounds occurred in patients classified as moderate risk, both of whom had additional clinical concerns such as neuropathy, retinopathy, cardiovascular disease or hypertension, foot deformity, and onychomycosis. These cases demonstrate that moderate risk should not be considered a benign category. Rather, it represents an opportunity for intensified prevention before progression to ulceration. The two plantar-fasciitis cases should be interpreted separately from ulceration because plantar fasciitis is not itself a diabetic-foot ulcer outcome; however, its associated pain and gait changes may alter pressure distribution and warrant footwear evaluation and follow-up.

The follow-up findings also address an important research gap identified in the literature review. Much of the evidence regarding AI-supported thermography is cross-sectional and focused on concurrent risk stratification rather than prediction of future ulceration [20]. The present six-month observations are limited by the small sample size, variable follow-up documentation, mixed date formats, missing HbA1c data for one patient, and one patient with no documented follow-up outcome available. Nevertheless, they provide preliminary evidence that a subgroup identified as moderate or high risk experienced clinically meaningful adverse outcomes within a relatively short period. Future studies should use a prospective longitudinal design with predefined follow-up intervals, standardized ulcer definitions, serial thermal imaging, clinical

reference assessment, and documentation of interventions. Such a design would allow stronger evaluation of whether baseline thermal abnormalities and automated risk categories predict wound development.

Overall, the findings suggest that AI-assisted plantar thermography may have a supportive role within routine diabetic-foot screening at specialized diabetes centers. Technology may help identify localized thermal changes that are not evident during routine visual inspection and may assist clinicians in directing high-risk patients to more intensive assessment. Previous evidence indicates that AI-supported thermography can provide reproducible risk stratification and may support a triage model in which low-risk patients receive routine surveillance while moderate- and high-risk patients receive prompt podiatric, vascular, and metabolic intervention [20,25,26]. Its practical utility will be greatest when combined with standardized image acquisition, careful interpretation of regional thermal patterns, regular clinical foot examinations, patient education, glycemic management, and multidisciplinary care. This integrated approach is particularly important in a population with substantial obesity, long diabetes duration, neuropathy, retinopathy, sensory symptoms, and poor HbA1c control.

In conclusion, the present results show that early diabetic-foot screening in a specialized Saudi diabetes-center setting identified both a large low-risk population and a subgroup classified as having moderate or high risk. The findings suggest that thermal imaging may have value as an adjunctive tool for identifying thermal abnormalities and supporting risk prioritization. However, its role is best considered within a comprehensive prevention pathway rather than in isolation. Continued longitudinal evaluation is required to determine whether regional temperature changes, thermal asymmetry, and automated risk scores predict future ulceration and improve patient outcomes over time.

Study Limitations

This study has several limitations that should be considered when interpreting the findings. Its retrospective, single-center design limits causal inference and may reduce generalizability to other settings. Although TFScan-generated patient risk classification was available for all 105 participants, complete clinical data and detailed thermal parameters were available for 102 participants, and peripheral arterial disease was not quantified in the available clinical dataset. The six-month outcome review was exploratory and restricted to 25 patients classified as moderate or high risk at baseline; one patient had no documented six-month outcome, and follow-up documentation was not standardized prospectively. In addition, the available retrospective dataset did not permit a complete independent diagnostic-accuracy validation with formal

sensitivity, specificity, and predictive-value estimates for the present cohort. Nevertheless, the study provides real-world evidence on TFScan-supported risk stratification, thermal findings, and documented short-term outcomes in a specialized Saudi diabetes-center setting, and it provides a basis for future prospective validation.

Recommendations:

The findings support the implementation of a structured diabetic-foot prevention pathway at the Specialized Diabetes Center. All patients with diabetes should receive routine annual foot screening; however, patients categorized as moderate or high risk, those with neuropathy, poor glycemic control, long diabetes duration, previous amputation, foot deformity, or thermal abnormalities should undergo more frequent follow-up. A risk-based schedule should be adopted, with high-risk patients reviewed promptly and moderate-risk patients reassessed at predefined intervals. Thermal imaging should be integrated as an adjunct to, rather than a replacement for, comprehensive clinical assessment. The screening protocol should combine thermal findings with monofilament testing, vibration perception, pedal-pulse assessment, skin and nail examination, deformity assessment, footwear evaluation, and HbA1c review. Particular attention should be directed to patients with thermal asymmetry, hyperthermia, hypothermia, or increased temperature deltas in the lateral calcaneal region. Standardized image-acquisition procedures, including appropriate acclimatization and controlled environmental conditions, are essential to ensure reliable thermographic findings [22-24,30]. A multidisciplinary referral pathway should be established for patients with active wounds, large lesions, suspected ischemia, infection, or rapidly changing thermal patterns. This pathway should include diabetes specialists, podiatrists, wound-care nurses, vascular specialists, dietitians, and diabetes educators. Glycemic optimization should be prioritized, especially for patients with HbA1c values of 8.6% or higher, alongside weight-management and cardiovascular-risk interventions. Patient education should focus on daily self-inspection, appropriate footwear, avoidance of barefoot walking, skin moisturization, early reporting of redness or wounds, and adherence to diabetes treatment. Digital thermal images may be used as educational tools to improve engagement with preventive behaviors [31]. Finally, future research should use prospective longitudinal follow-up with standardized outcome definitions to evaluate the ability of thermal abnormalities and automated risk scores to predict ulceration [20].

Conclusion

This study identified a considerable burden of diabetic-foot risk factors among patients attending the specialized diabetes center, including long diabetes

duration, obesity, poor glycemic control, neuropathy, retinopathy, sensory symptoms, and cardiovascular comorbidity. Although most participants were classified as low or very low risk, nearly one-quarter were classified as moderate or high risk. Thermal imaging identified hyperthermia, hypothermia, thermal asymmetry, lesions, and regional temperature variation in a subset of participants. The lateral calcaneal area showed more frequent temperature variation than other assessed regions, suggesting that this site may warrant particular attention during clinical assessment. During six-month follow-up, most moderate- and high-risk patients had documented clinical stability; however, new wounds were documented in three patients, including patients initially classified as moderate risk. Overall, AI-supported thermal screening may support early diabetic-foot risk assessment and risk stratification when combined with standardized clinical assessment, glycemic management, patient education, and multidisciplinary follow-up. Further prospective longitudinal validation is needed before predictive or diagnostic-performance conclusions can be established.

References

1. Sun H, Saeedi P, Karuranga S, et al. IDF Diabetes Atlas global, regional and country-level diabetes prevalence estimates for 2021 and projections for 2045. *Diabetes Res Clin Pract.* 2022;183:109119.
2. Armstrong DG, Boulton AJ, Bus SA. Diabetic foot ulcers and their recurrence. *N Engl J Med.* 2017;376:2367–2375.
3. Sen P, Demirdal T, Emir B. Meta-analysis of risk factors for amputation in diabetic foot infections. *Diabetes Metab Res Rev.* 2019;35:e3165.
4. Armstrong DG, Swerdlow MA, Armstrong AA, et al. Five-year mortality and direct costs of care for people with diabetic foot complications are comparable to cancer. *J Foot Ankle Res.* 2020;13:16.
5. Ilo A, Romsa P, Mäkelä J. Infrared thermography and vascular disorders in diabetic feet. *J Diabetes Sci Technol.* 2020;14:28–36.
6. Dros J, Wewerinke A, Bindels PJ, et al. Accuracy of monofilament testing to diagnose peripheral neuropathy: a systematic review. *Ann Fam Med.* 2009;7:555–558.
7. Wang F, Zhang J, Yu J, et al. Diagnostic accuracy of monofilament tests for detecting diabetic peripheral neuropathy: a systematic review and meta-analysis. *J Diabetes Res.* 2017;2017:8787261.
8. Crawford F, Welch K, Andras A, et al. Ankle-brachial index for the diagnosis of lower-limb peripheral arterial disease. *Cochrane Database Syst Rev.* 2016;9:CD006887.
9. Bhasin N, Scott DJA. Ankle brachial pressure index identifying cardiovascular risk and improving diagnostic accuracy. *J R Soc Med.* 2007;100:4–5.
10. Casey SL, Lanting SM, Chuter VH. The ankle brachial index in people with and without diabetes intra-tester reliability. *J Foot Ankle Res.* 2020;13:42.
11. Eiberg JP, Rasmussen JG, Hansen MA, et al. Duplex ultrasound scanning of peripheral arterial disease of the lower limb. *Eur J Vasc Endovasc Surg.* 2010;40:507–512.
12. Collins R, Cranny G, Burch J, et al. A systematic review of duplex ultrasound, magnetic resonance angiography and computed tomography angiography for the diagnosis and assessment of symptomatic lower limb peripheral arterial disease. *Health Technol Assess.* 2007;11:iii–iv, ix–184.
13. Amin N, Doupis J. Diabetic foot disease from the evaluation of the foot at risk to novel diabetic ulcer treatment modalities. *World J Diabetes.* 2016;7:153–164.
14. American Diabetes Association Professional Practice Committee. Retinopathy, neuropathy, and foot care standards of care in diabetes 2024. *Diabetes Care.* 2024;47:S231–S243.
15. Schaper NC, van Netten JJ, Apelqvist J, et al. Practical guidelines on the prevention and management of diabetes-related foot disease IWGDF 2023 update. *Diabetes Metab Res Rev.* 2024;40:e3657.
16. Campbell JS, Mead MN. Human medical thermography. Boca Raton FL: CRC Press; 2022.
17. Serbu G. Infrared imaging of the diabetic foot. In *Proceedings of the 10th Conference on InfraMation 2009; October 19–22 2009; Las Vegas NV.* Available from <https://degroenezuster.nl/wp-content/uploads/2019/11/Thermography-of-Diabetic-foot.pdf>
18. Lahiri BB, Bagavathiappan S, Jayakumar T, et al. Medical applications of infrared thermography a review. *Infrared Phys Technol.* 2012;55:221–235.
19. Schwartz RG, Brioschi M, Young O, et al. The American Academy of Thermology guidelines for neuro-musculoskeletal 2021 infrared medical thermology and sympathetic skin response studies. *Pan Am J Med Thermol.* 2021;1:1–13.
20. Shara, Khansa et al. “Combining thermography and artificial intelligence in comparison with a diabetic foot nurse for diabetic foot ulcer detection: A diagnostic accuracy study.” *Digital health* vol. 12 20552076261416807. 19 Jan. 2026, doi:10.1177/20552076261416807
21. Waller K, Ogrin R, Ngo QC, Polus B, Hanna S, Tint AN, MacIsaac RJ, Galligan A, Ekinici EI,

-
- Kumar D. Using Textural Analysis of Thermal Imaging to Predict Healing Status of Diabetes-Related Neuropathic Foot Ulcers: Protocol for a Co-Design and Longitudinal Study. *JMIR Research Protocols*. 2026 Feb 26;15(1):e69793.
22. de Deus Passos M, Da Rocha AF. Evaluation of infrared thermography with a portable camera as a diagnostic tool for peripheral arterial disease of the lower limbs compared with color Doppler ultrasonography. *Archives of medical sciences. Atherosclerotic diseases*. 2022 Aug 8;7:e66.
 23. Khandakar, Amith et al. "Thermal Change Index-Based Diabetic Foot Thermogram Image Classification Using Machine Learning Techniques." *Sensors (Basel, Switzerland)* vol. 22,5 1793. 24 Feb. 2022, doi:10.3390/s22051793
 24. Cruz-Vega, Israel et al. "Deep Learning Classification for Diabetic Foot Thermograms." *Sensors (Basel, Switzerland)* vol. 20,6 1762. 22 Mar. 2020, doi:10.3390/s20061762
 25. Wara, S. Amplifai Health's AI Diabetic Foot Scanner Gets SFDA Green Light. 2025. Available online via [Amplifai Health's AI Diabetic Foot Scanner Approved by SFDA](#)
 26. Alwashmi MF, Alghali M, AlMogbel A, Alwabel AA, Alhomod AS, Almaghlouth I, Temsah MH, Jamal A. The use of AI-powered thermography to detect early plantar thermal abnormalities in patients with diabetes: cross-sectional observational study. *JMIR diabetes*. 2025 Jun 13;10:e65209.
 27. Qin Q, Nakagami G, Ohashi Y, Dai M, Sanada H, Oe M. Development of a self-monitoring tool for diabetic foot prevention using smartphone-based thermography: Plantar thermal pattern changes and usability in the home environment. *Drug Discoveries & Therapeutics*. 2022 Aug 31;16(4):169-76.
 28. Hernandez-Contreras DA, Peregrina-Barreto H, de Jesus Rangel-Magdaleno J, Renero-Carrillo FJ. Plantar thermogram database for the study of diabetic foot complications. *Ieee Access*. 2019 Nov 4;7:161296-307.
 29. Wang F, Zhang J, Yu J, Liu S, Zhang R, Ma X, Yang Y, Wang P. Diagnostic accuracy of monofilament tests for detecting diabetic peripheral neuropathy: a systematic review and meta-analysis. *Journal of diabetes research*. 2017;2017(1):8787261.
 30. Getson DO, Govindan S, Uricchio J, Bernton T, Brioschi M, Zhang HY. Guidelines for neuromusculoskeletal infrared thermography sympathetic skin response (SSR) studies. *Pan Am. J. Med. Thermol*. 2015;2:35-43.
- TekScan. Confirming Diabetic Foot Ulcer Treatment with F-Scan. 2025. Available online via [Diabetic Foot Ulcer Treatment | F-Scan Diabetic Foot Scanner | Tekscan](#).
-