International Journal of Innovative Technologies in Social Science

e-ISSN: 2544-9435

Operating Publisher
SciFormat Publishing Inc.
ISNI: 0000 0005 1449 8214

2734 17 Avenue SW,
Calgary, Alberta, T3E0A7,
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ARTICLE TITLE	SMARTPHONE-BASED AND INFRARED THERMOGRAPHY FOR HOME PREVENTION OF DIABETIC FOOT ULCERS: ACCESSIBILITY, ADOPTION, AND HEALTH-EQUITY PERSPECTIVE
DOI	https://doi.org/10.31435/ijitss.3(51).2026.6043
RECEIVED	18 June 2026
ACCEPTED	01 September 2026
PUBLISHED	07 September 2026
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SMARTPHONE-BASED AND INFRARED THERMOGRAPHY FOR HOME PREVENTION OF DIABETIC FOOT ULCERS: ACCESSIBILITY, ADOPTION, AND HEALTH-EQUITY PERSPECTIVE

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ABSTRACT

Home infrared temperature monitoring for diabetic foot ulcer (DFU) prevention is supported by multiple randomized controlled trials demonstrating reductions of roughly 60 to 90% in ulcer recurrence among high-risk patients (IWGDF risk categories 2 to 3) when compared with standard care without thermometry. These findings hold across diverse geographic and resource settings, including low-resource contexts in Indonesia and Peru. Technology platforms range from handheld infrared thermometers costing 30 to 100 US dollars to smartphone-attached thermal cameras, wireless thermometric mats, sensor-embedded socks rated 9 to 10 out of 10 for comfort, and wearable Internet-of-Things devices costing as little as 14.80 US dollars per unit. Adherence rates across technologies generally range from 70% to 88% over study periods of 6 to 24 months, and predictive systems can detect impending ulcers up to 37 days in advance with 97% sensitivity, though at the cost of a 57% false-positive rate at standard thresholds. Despite promising accessibility features, significant barriers remain, including physical limitations such as arthritis and vision loss, incorrect device use in nearly half of participants despite training, and reliance on assistance from others for interpreting results among older, low-income users, all of which disproportionately affect vulnerable populations. Critically, no study formally evaluated differential effectiveness by socioeconomic status, race or ethnicity, education level, or insurance coverage, leaving a substantial gap in the health-equity evidence base. The addition of mHealth reminders to thermometry did not improve adherence or outcomes beyond thermometry alone. While the technological and cost barriers to home thermometry are increasingly surmountable, the absence of equity-stratified analyses means that whether these tools reduce or inadvertently widen disparities in DFU outcomes cannot yet be determined from the available evidence.

KEYWORDS

Diabetic Foot Ulcer, Infrared Thermography, Home Monitoring, Mobile Health, Health Equity, Ulcer Prevention

CITATION

Jerzy Buszko, Michał Dyś, Adrianna Buż, Damian Danilczuk, Marta Bajkowska-Piterak, Monika Szlachta-Gubernat, Nicol Baran, Przemysław Piterak, Wiktor Adamiec. (2026). Smartphone-Based and Infrared Thermography for Home Prevention of Diabetic Foot Ulcers: Accessibility, Adoption, and Health-Equity Perspective. *International Journal of Innovative Technologies in Social Science*. 3(51). doi: 10.31435/ijitss.3(51).2026.6043

1. Introduction

Diabetic foot ulceration is among the most serious and costly complications of diabetes mellitus, frequently preceding lower-extremity amputation and carrying a recurrence rate that exceeds 40% within one year of healing. Because ulcers are typically preceded by localized inflammation that raises skin temperature before any visible breakdown, the contralateral comparison of plantar skin temperature offers a physiologically grounded early-warning signal: a sustained difference of more than 2.2 degrees Celsius between matched sites on the two feet identifies tissue at risk days to weeks before ulceration.

Home temperature monitoring operationalizes this principle by having high-risk patients measure their own plantar temperatures daily and reduce activity or contact their care team when an asymmetry threshold is crossed. The earliest evidence relied on dedicated medical-grade infrared thermometers, but the underlying measurement has since been embedded in a widening range of consumer-accessible platforms, from low-cost handheld thermometers and smartphone-attached thermal cameras to sensor-embedded socks, sole inserts, and passive floor mats. This proliferation raises the prospect of scalable, affordable prevention that could reach populations who bear a disproportionate share of the DFU burden.

Yet accessibility is not determined by device cost alone. Physical limitations, digital literacy, and the need for ongoing training and support shape whether a technology is usable in practice, and these factors fall unevenly across age, income, and educational lines. This review synthesizes the evidence on smartphone-based and infrared thermography for home DFU prevention with three objectives: to characterize the effectiveness of home temperature monitoring against standard care; to map the accessibility, adoption, and adherence profiles of the available technology platforms; and to assess what the evidence does, and does not, reveal about health equity. The central thesis is that home thermography consistently and substantially reduces ulcer recurrence and is increasingly accessible through low-cost platforms, but that the complete absence of equity-stratified analyses leaves the distributional consequences of widespread adoption unknown.

2. Methodology

A structured literature search was performed across the MEDLINE/PubMed, Scopus, and Web of Science databases, supplemented by manual searching of the reference lists of relevant articles and reviews to identify additional studies not captured by the database queries. Search terms combined controlled vocabulary and free-text keywords relating to the population, technology, and outcome of interest, including variants of "diabetic foot ulcer," "infrared thermography," "thermometry," "skin temperature," "smartphone," "home monitoring," and "prevention," linked with the Boolean operators AND and OR. No language restriction was applied at the search stage, and the search covered publications up to 2025.

All retrieved records were screened manually against a common set of eligibility criteria, and a holistic judgment was made for each paper rather than applying the criteria mechanically. The inclusion criteria were:

- Population: adults aged 18 years and older with type 1 or type 2 diabetes mellitus.
- Technology intervention: the study investigates smartphone-based thermography, infrared thermography, or thermal imaging for foot monitoring.
- Setting and monitoring type: the study involves home-based or self-monitoring interventions rather than solely clinic- or hospital-based monitoring.
- Primary outcomes: the study reports outcomes related to DFU prevention, detection, or early identification.
- Secondary outcomes: the study reports on accessibility, usability, adoption, adherence, patient acceptance, or health-equity factors.
- Study design: randomized controlled trial, quasi-experimental, observational, pilot, feasibility study, systematic review, or meta-analysis, focused on prevention rather than solely on treatment, and excluding animal or in-vitro studies, conference abstracts, case reports, and small case series.

Records were excluded when they fell outside the scope of the review on closer reading. After screening, 25 sources were retained for data extraction. Data were extracted manually by the author using a predefined extraction form covering technology description, accessibility features, patient demographics, adoption and adherence, user experience, prevention effectiveness, health equity, and implementation factors. Several sources represented companion or duplicate publications of the same trial and are noted as such where relevant. Owing to substantial heterogeneity in study designs, technologies, comparators, and outcome reporting, a narrative synthesis was undertaken rather than a quantitative meta-analysis.

3. Results

3.1. Characteristics of Included Studies

The 25 included sources span publication dates from 2004 to 2025 and reflect considerable geographic diversity, including studies from the United States, Indonesia, Peru, Saudi Arabia, Turkey, Germany, the United Kingdom, Canada, France, and additional countries represented in reviews. Study designs range from randomized controlled trials, the largest category with at least eight trials, to systematic and integrative reviews, prospective cohort studies, cross-sectional studies, pilot studies, technical development papers, and protocol publications. The technologies under investigation fall into five broad categories that differ markedly in their accessibility profiles, summarized schematically in Figure 1. Sample sizes range from 27 in a pilot study to over 26,000 in a model-validation dataset, with follow-up durations spanning 6 weeks to 24 months across interventional studies.

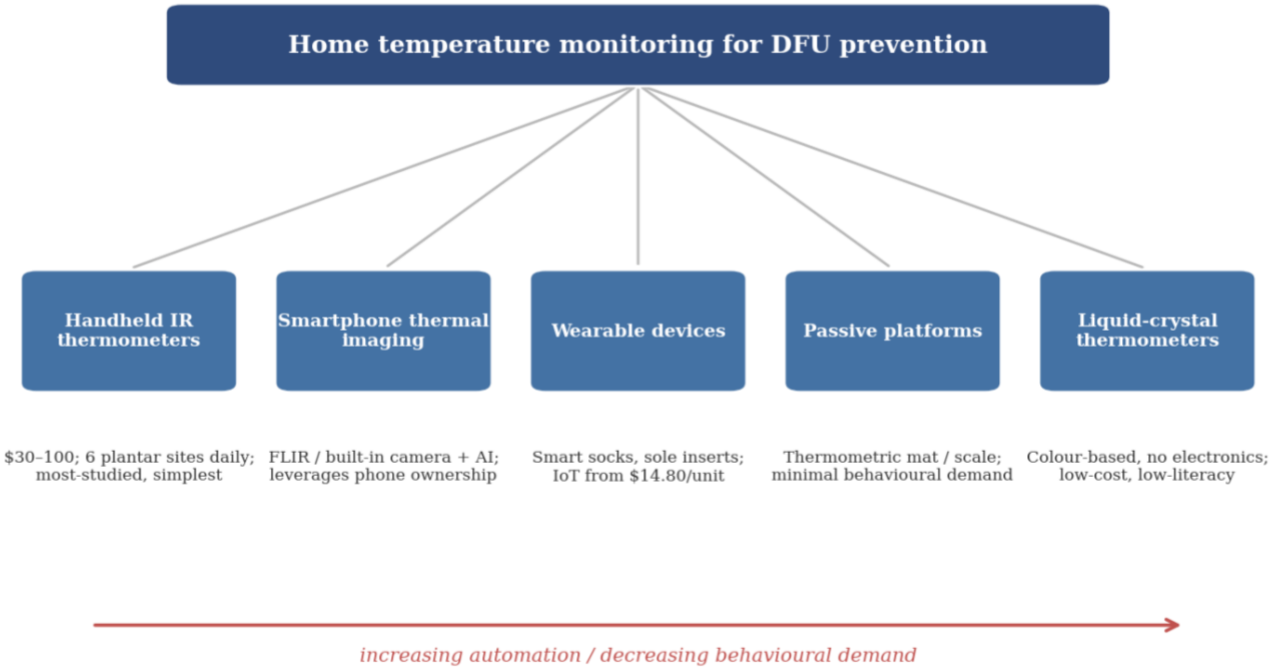

Fig. 1. *Taxonomy of home temperature-monitoring technologies for DFU prevention, ordered by increasing automation and decreasing behavioural demand.*

3.2. Ulcer Prevention Effectiveness

The primary outcome across interventional studies was the incidence or recurrence of DFUs. Three seminal randomized controlled trials, Lavery et al. (2004), Lavery et al. (2007), and Armstrong et al. (2007), consistently demonstrated that home infrared temperature monitoring significantly reduced DFU incidence compared with standard care, with risk reductions ranging from roughly threefold (odds ratio 3.0) to more than tenfold (odds ratio 10.3) depending on the comparator and population. These foundational trials enrolled high-risk patients and used a contralateral temperature-difference threshold of more than 2.2 degrees Celsius to trigger activity reduction and clinical contact. Figure 2 contrasts intervention and control ulcer rates across the principal trials.

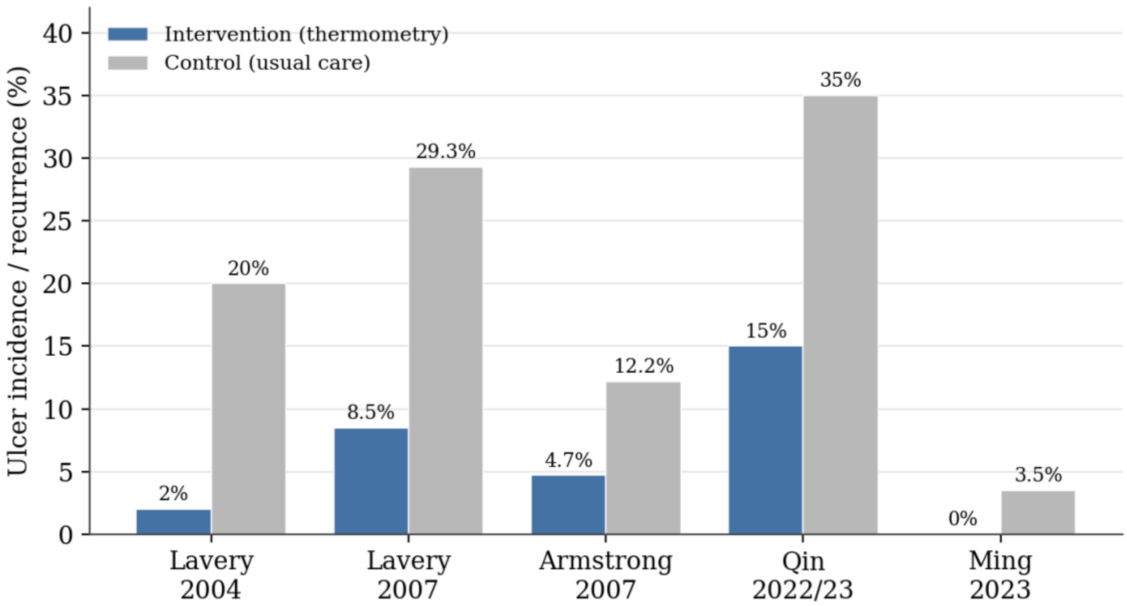

Fig. 2. *Ulcer incidence or recurrence in intervention versus control arms across the principal trials.*

The Qin et al. (2022/2023) trial conducted in Indonesia replicated these findings using smartphone-based thermography in a low-resource setting, demonstrating a 59% reduction in recurrence risk (hazard ratio 0.41), alongside significant improvements in quality of life and foot-care behaviors at six months. Not all studies reached statistical significance. The Smart Prevent Diabetic Feet trial (Ming et al., 2023) found zero ulcerations in the intervention group versus five in the control group over 24 months, but the unexpectedly low overall ulceration rate, likely attributable to the training and regular follow-up provided to all participants and to reduced mobility during the COVID-19 pandemic, left the study underpowered and the hazard ratio non-significant. The Lazo-Porras et al. (2020) trial did not compare thermometry with no thermometry; rather, it compared thermometry plus mHealth reminders with thermometry alone, finding no incremental benefit from the mHealth component, with the higher ulcer incidence in the mHealth arm (24% versus 11%) attributable to baseline imbalances in prior ulcer history.

3.3. Predictive Accuracy and Lead Time

Beyond binary prevention outcomes, several platforms were evaluated for their ability to predict impending ulceration. The thermometric mat demonstrated high sensitivity, 97% at the standard 2.2 degrees Celsius threshold, with an average lead time of 37 days before clinical ulceration, and this predictive capacity was maintained in subgroups with recently healed ulcers or partial amputations. The principal limitation is the false-positive rate, which reached 57% at this threshold and would translate into frequent unnecessary activity restrictions and clinical contacts. Raising the threshold to 3.2 degrees Celsius reduced false positives to 32% while still detecting 70% of ulcers, illustrating a direct trade-off between sensitivity and specificity, shown in Figure 3. A multimodal wearable combining pressure and temperature sensing achieved 94.2% prediction accuracy and reduced false positives by 32% relative to single-modality approaches, though this system remains at an earlier stage of clinical validation.

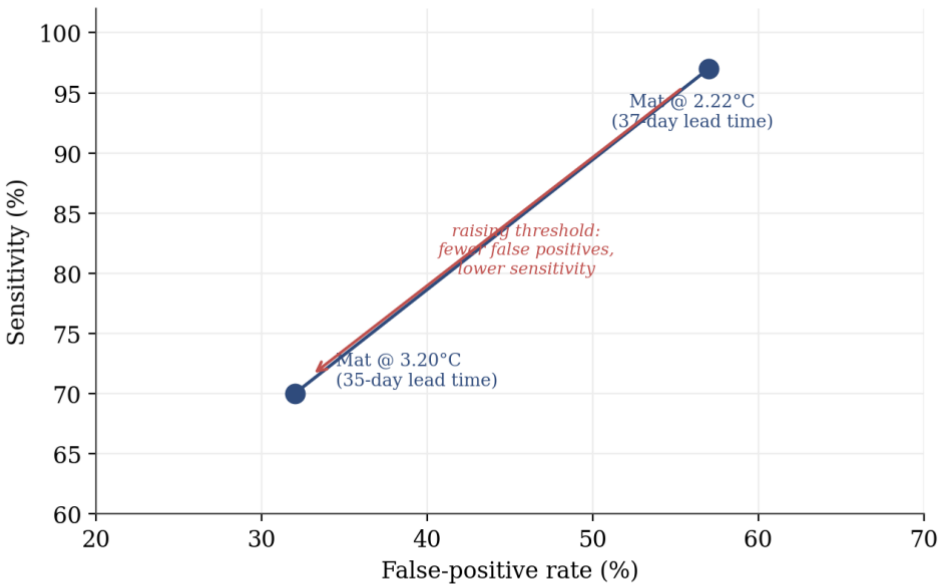

Fig. 3. *Sensitivity versus false-positive rate for the thermometric-mat platform at two temperature thresholds.*

3.4. Adoption and Adherence

Adherence to home monitoring was generally favorable, ranging from roughly 70% to 88% across technologies and study durations, although the metrics used to define adherence varied between studies. Passive and low-demand platforms tended to sit at the higher end of this range, consistent with the intuition that minimizing behavioral demand supports sustained use. Figure 4 consolidates the available adherence data by technology. Notably, the addition of mHealth reminders to thermometry did not improve adherence relative to thermometry alone. Dropout in the Lavery et al. (2007) trial was 10.2%, with participants citing the monitoring protocol as too demanding, and in one pilot 11 of 27 participants were withdrawn early, mostly because of new ulcers or technical issues. While 96.8% of users in one study said they would continue using a commercially available thermometer, 37.9% indicated they would do so only sometimes or rarely, suggesting that sustained daily adherence may be harder to maintain over longer periods.

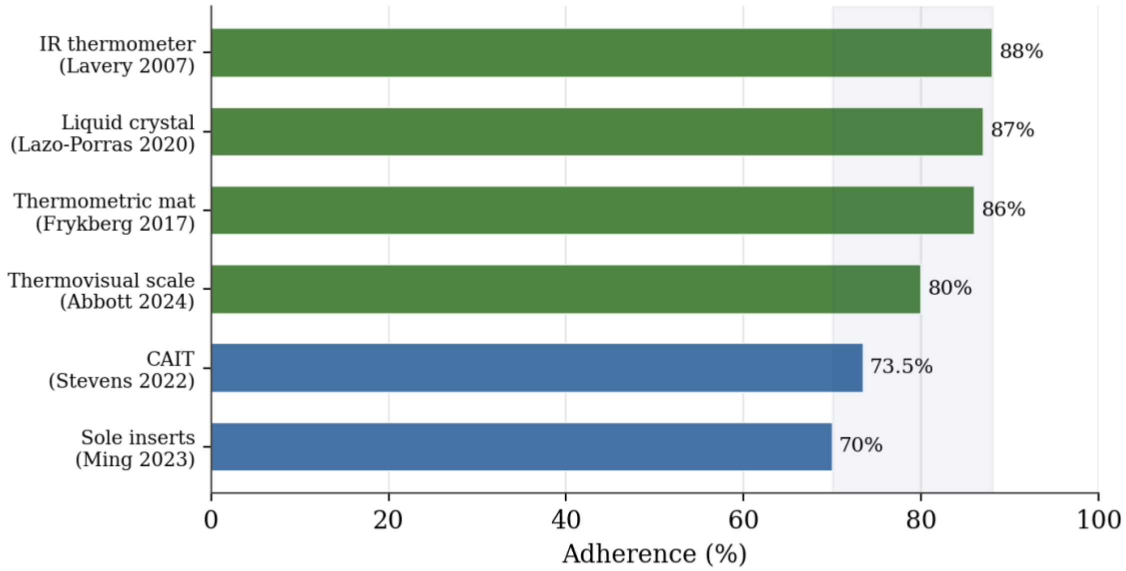

Fig. 4. *Adherence rates by technology platform; shaded band marks the 70 to 88% range observed across studies.*

Qualitative data illuminated the experience factors driving adoption. Participants reported that monitoring engaged them in foot care, prompted action, and provided reassurance, with benefits including more frequent self-assessment, reduced callusing, and easier discussions with clinicians. Barriers included difficulty understanding the purpose of monitoring, misinterpretation of readings, physical challenges such as limited flexibility and vision loss, and uncertainty about when to seek care. Older, low-income participants in Peru preferred voice messages to text because of difficulty reading small screens and sometimes needed assistance from others.

3.5. Health Equity Considerations

Health equity was rarely the primary focus of the included studies, but several contextual features are relevant. The evidence base includes trials from low- and middle-income countries, notably the Indonesian smartphone-thermography trial explicitly designed for low-resource settings and the Peruvian trial enrolling low-income patients over age 60, alongside feasibility work across community health centers in Indonesia and four regions of Saudi Arabia, suggesting that smartphone-based thermography may be implementable in resource-constrained environments. Cost data were sparse but encouraging: commercially available thermometers cost 30 to 100 US dollars, a wearable prototype reported a production cost of 14.80 US dollars per unit, and one analysis suggested digital thermometry may be cost-effective when used broadly. Demographic detail relevant to equity was limited; some trials enrolled racially diverse or predominantly female low-income cohorts, and one found no loss of accuracy in patients with recently healed ulcers or partial amputations, but none reported differential effects by race or ethnicity.

Most importantly, no study formally assessed differential effectiveness by socioeconomic status, insurance coverage, education level, or rural versus urban residence, despite well-documented disparities in DFU incidence and amputation across precisely these dimensions. Figure 5 represents this gap conceptually: across every major equity dimension, the available evidence remains far below the level required to draw equity-stratified conclusions. Reported barriers, including physical limitations, the need for assistance interpreting results, and incorrect device use in nearly half of trained participants, are precisely those that fall most heavily on older and lower-resourced patients, underscoring why the absence of stratified analysis matters.

3.6. Implementation Context

Successful implementation of home thermometry requires integration with clinical workflows and active clinician engagement. The standard model has patients contact a study nurse when temperature asymmetry exceeds the threshold, followed by instructions to reduce activity, often paired with podiatric evaluation and therapeutic footwear. More recent remote-monitoring systems use a cloud server with daily clinician review of transmitted data; in one pilot, abnormal scans prompted remote intervention or continued monitoring in most cases and in-person care in a substantial minority, with clinicians agreeing that the data supported remote assessment and earlier identification of problems, while rating visual data as more useful than temperature data alone. Reviews emphasized that reimbursement and demonstrated cost-effectiveness remain critical barriers to widespread adoption, and that despite guideline recommendations, thermometry is not yet commonly practiced. Figure 6 summarizes the canonical clinical response pathway that links a daily self-measurement to ulcer prevention.

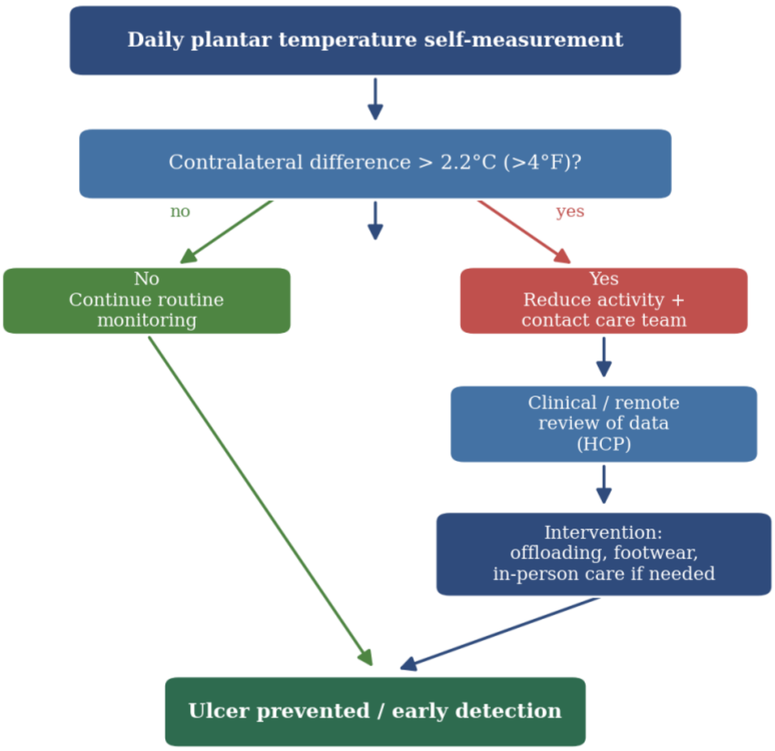

Fig. 5. *Canonical clinical response pathway for home temperature monitoring in DFU prevention.*

4. Discussion

The evidence reveals an apparent tension: while the core efficacy of home temperature monitoring for DFU prevention is supported by multiple randomized controlled trials showing threefold to tenfold reductions in ulcer incidence, adoption in clinical practice remains limited and equity-relevant evidence is sparse. Several factors help explain the heterogeneity in findings and the gap between efficacy and implementation.

The three foundational trials all enrolled high-risk patients in US clinical settings and demonstrated large, statistically significant effects, and the Indonesian smartphone-thermography trial reproduced these findings in a low-resource setting, suggesting that the intervention principle transfers across contexts and technology platforms. The two later trials that did not show significant ulcer reduction do not undermine this conclusion: one was underpowered by an unexpectedly low control-group event rate driven by intensive shared training and pandemic-related immobility, and the other compared two thermometry conditions rather than thermometry against its absence, with baseline imbalance further confounding interpretation.

The variation in effect size across the positive trials, from an odds ratio of 3.0 to 10.3, likely reflects differences in comparator intensity, population risk, and follow-up duration. The smallest effect came from the trial with the most active control group, which included daily structured foot inspection, while the largest came from the earliest and smallest trial comparing thermometry with standard care alone. This pattern is consistent with the interpretation that temperature monitoring adds incremental benefit above usual care, but that much of the preventive effect can also be achieved through structured inspection and education, an important consideration for settings where thermometry devices are unavailable.

Regarding accessibility, the cost barrier appears increasingly surmountable, with commercially available thermometers and wearable prototypes representing substantial reductions from earlier medical-grade devices and smartphone platforms leveraging existing phone ownership to lower the entry point further. Cost alone, however, does not determine accessibility: physical limitations, digital literacy, and the need for ongoing training and support remain persistent barriers that fall disproportionately on older adults and those in under-resourced settings. The false-positive rate is a further implementation concern, since the high sensitivity of passive platforms comes at the price of frequent false alarms, and although multimodal approaches show promise for improving specificity, they remain at earlier validation stages.

The equity dimension is the most underdeveloped aspect of this literature. No study formally compared effectiveness across socioeconomic strata, education levels, or racial or ethnic groups, despite the well-documented disparities in DFU incidence and amputation across these dimensions. The geographic diversity of the evidence provides indirect reassurance of cross-cultural feasibility, but no study reported cultural or linguistic adaptations beyond basic language accommodation, and the reliance on contralateral temperature comparison raises unresolved questions for patients with bilateral pathology or amputations, for whom alternative baseline or population-normed thresholds would be required.

This review has limitations. The synthesis is narrative rather than quantitative owing to heterogeneity in designs, technologies, comparators, and outcomes. These constraints temper the strength of the conclusions and define clear priorities for future research.

5. Conclusions

For high-risk patients with diabetes, home infrared temperature monitoring with a contralateral difference threshold of more than 2.2 degrees Celsius, combined with structured education and a clear clinical response pathway, consistently reduces diabetic foot ulcer recurrence by approximately 60 to 90% over 6 to 18 months when compared with usual care without thermometry. The intervention is feasible across diverse geographic and resource settings, with adherence rates of 70 to 88%, and commercially available and smartphone-based platforms have substantially lowered the cost barrier, although physical and digital-literacy barriers persist for older and lower-resourced patients.

The decisive gap is not efficacy or affordability but equity evidence. No study has formally assessed whether these tools perform differently across socioeconomic, racial, educational, or insurance subgroups, so it cannot yet be determined whether widespread adoption would narrow or inadvertently widen existing disparities in DFU outcomes. Future work should prioritize equity-stratified effectiveness analyses, evaluation of culturally and linguistically adapted designs, strategies to lower false-positive burden through multimodal sensing, and long-term effectiveness data beyond 24 months, so that an intervention with demonstrated efficacy can be deployed in a way that is demonstrably fair.

All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: All data supporting the findings of this study are available in the cited literature included in this review.

Conflicts of Interest: The authors declare no conflict of interest.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process: In preparing this work, the authors used ChatGPT (OpenAI) exclusively for language editing and grammatical correction of the manuscript. Tools were not involved in data collection, analysis, interpretation of results, or the formulation of conclusions. All substantive content was generated, reviewed, and approved by the human authors, who accept full responsibility for the integrity of the publication.

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