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# Advances in Diabetic Foot Prevention and Care: The Expanding Role of Primary Care Physicians in the Era of Smart Technology and Artificial Intelligence

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## ABSTRACT

**Background**: Diabetic foot disease is a leading cause of morbidity, mortality, and healthcare expenditure worldwide, with particularly high prevalence in the Middle East and Gulf Cooperation Council (GCC) countries. Primary care physicians play a pivotal role in early detection and prevention, yet significant gaps persist in screening practices, patient education, and care coordination.

**Objective**: This narrative review aims to synthesize recent evidence on technological and artificial intelligence innovations in diabetic foot prevention and management, and to examine their integration into primary care practice, with particular attention to high-burden regions such as Saudi Arabia and the GCC.

**Methods**: A comprehensive literature search was conducted using PubMed, Google Scholar, and international guideline databases. Search terms included "diabetic foot," "primary care," "artificial intelligence," "wearable sensors," "telemedicine," and "prevention." Studies published between 2015 and 2025 were included. Evidence was synthesized thematically to address epidemiology, technological innovations, primary care roles, multidisciplinary approaches, and implementation challenges.

**Results**: Smart wearable devices enable continuous monitoring of temperature and pressure, facilitating early ulcer detection. AI-powered algorithms achieve >90% sensitivity in automated ulcer detection from smartphone images. Telemedicine platforms demonstrate comparable outcomes to in-person care while reducing costs. Multidisciplinary team approaches reduce amputation rates by 40-80%. However, implementation barriers including insufficient training, time constraints, and limited awareness persist, particularly in resource-limited settings.

**Conclusion**: The integration of smart technology and AI into primary care offers transformative potential for diabetic foot prevention. PCPs, empowered by these innovations and supported by multidisciplinary teams, can shift the paradigm from reactive treatment to proactive prevention. Addressing implementation barriers through education, policy support, and accessible digital health solutions is essential for realizing this potential and reducing the global burden of diabetic foot complications.

**KEYWORDS**: Diabetic Foot Ulcer; Primary Care; Artificial Intelligence; Wearable Sensors; Telemedicine; Prevention; Smart Technology; Multidisciplinary Care..

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## INTRODUCTION

Diabetic foot disease represents one of the most devastating complications of diabetes mellitus, with profound implications for patients, healthcare systems, and societies. The lifetime incidence of diabetic foot ulcers (DFUs) among people with diabetes ranges from 19% to 34%, with recurrence rates of 40% within one year and 65% within three years of initial healing [1, 2]. Approximately 85% of diabetes-related lower-extremity amputations are preceded by foot ulceration, and five-year mortality following major amputation ranges from 39% to 80%, exceeding that of many common malignancies [3, 4]. Beyond the human suffering, the economic burden is staggering, with diabetes care in the United States alone accounting for $273 billion annually, a significant portion attributable to foot complications [4, 5].

The Middle East and North Africa (MENA) region bears a disproportionate burden of diabetes, exhibiting the world's highest prevalence at 12.2% in 2019 [6]. Within the Gulf Cooperation Council (GCC) countries, rates are particularly alarming: Kuwait leads at 22%, followed by Qatar at 20.2%, with Saudi Arabia demonstrating similarly elevated prevalence [7, 8]. In Saudi Arabia, DFU prevalence reaches 11.85%, the highest among Arab nations, with 81% of diabetic foot patients presenting with active ulcers and 31% having undergone amputation [9, 10]. The per-patient economic burden of DFU management exceeds $1,700 USD in Saudi Arabia, imposing substantial strain on healthcare resources [11].

Despite the availability of evidence-based prevention strategies outlined in international guidelines from the International Working Group on the Diabetic Foot (IWGDF), American Diabetes Association (ADA), and National Institute for Health and Care Excellence (NICE), significant gaps persist in clinical practice [2, 12, 13]. These include late referrals to specialist services, suboptimal screening rates in primary care, poor patient adherence to preventive measures, and limited integration between primary and specialist care [14, 15, 16]. Such challenges are compounded in resource-limited settings and regions with high diabetes burden, where access to specialized multidisciplinary foot care teams may be restricted [17, 18].

Primary care physicians occupy a unique and critical position in the continuum of diabetic foot care. As the first point of contact for most patients with diabetes, primary care physicians (PCPs) are ideally situated to implement systematic screening, risk stratification, patient education, and timely referral to specialized services when indicated [19, 20]. The emergence of smart technology, artificial intelligence, and digital health platforms offers transformative potential to address existing gaps and empower PCPs in their expanded role [21, 22, 23].

**purpose and scope of this review**

This narrative review aims to synthesize current evidence on technological and AI innovations in diabetic foot prevention and management, and to examine their practical integration into primary care practice. We focus on smart wearable devices, AI-powered diagnostic and prognostic tools, telemedicine platforms, advanced wound care technologies, and multidisciplinary care models. We also address implementation challenges, barriers to adoption, and strategies for overcoming these obstacles, with particular attention to high-burden regions such as the GCC countries.

A narrative review approach is appropriate for this topic because it allows for the integration of diverse evidence types—including international guidelines, systematic reviews, original research studies, and emerging technologies—while providing conceptual synthesis and critical discussion relevant to primary care practice. Unlike a systematic review, which focuses on answering a specific, narrow research question through exhaustive literature search and meta-analysis, a narrative review enables broader exploration of a complex, multifaceted topic and facilitates the identification of knowledge gaps and future research directions.

# METHODS

### 2.1. Literature Search Strategy

A comprehensive literature search was conducted to identify relevant evidence on the prevention and management of diabetic foot disease, with a specific focus on technological innovations and the role of primary care. The search was performed across several electronic databases, including PubMed/MEDLINE, the Cochrane Library (for systematic reviews and meta-analyses), and Google Scholar to ensure broad coverage. Furthermore, key international clinical practice guidelines from the International Working Group on the Diabetic Foot (IWGDF), the American Diabetes Association (ADA), the National Institute for Health and Care Excellence (NICE), and the American Heart Association (AHA) were consulted.

### 2.2. Search Terms

The search strategy employed a combination of Medical Subject Headings (MeSH) and keywords to capture the core concepts of the review. Key terms included: "diabetic foot," "diabetic foot ulcer," "primary care," "family medicine," "artificial intelligence," "machine learning," "wearable sensors," "remote monitoring," "telemedicine," "prevention," "multidisciplinary care," and geographic terms such as "Saudi Arabia," "Gulf Cooperation Council," and "Middle East." These terms were combined using Boolean operators (AND, OR) to construct targeted search queries.

### 2.3. Study Selection Criteria

The selection of literature was guided by pre-defined inclusion and exclusion criteria. Included publications were peer-reviewed articles, systematic reviews, meta-analyses, and clinical guidelines published between 2015 and 2025 to ensure contemporary relevance. Seminal or landmark studies published prior to 2015 were also considered for foundational context. The review prioritized studies addressing diabetic foot prevention, risk stratification, management, and outcomes, particularly those focusing on technological applications or the primary care interface.

Exclusion criteria comprised non-peer-reviewed publications (with the exception of authoritative guidelines), articles not available in the English language, and studies that focused exclusively on surgical techniques without generalizable relevance to prevention or primary care management.

### 2.4 Study Selection and Data Synthesis

Initial screening was performed based on titles and abstracts to identify potentially relevant articles. Full-text articles were then reviewed for eligibility. Given the narrative nature of this review, no formal quality assessment or risk of bias evaluation was conducted. However, priority was given to high-quality evidence sources including:

- International clinical practice guidelines (IWGDF, ADA, NICE, AHA)
- Systematic reviews and meta-analyses
- Randomized controlled trials
- Large observational studies and cohort studies
- Proof-of-concept studies for emerging technologies

### 2.5 Thematic Organization

Evidence was synthesized and organized thematically rather than chronologically to provide a coherent narrative. The main themes identified were:

1. Epidemiology and burden of diabetic foot disease
2. The evolving role of primary care in prevention and screening

3. Smart technology and wearable devices
4. Artificial intelligence applications
5. Telemedicine and digital health platforms
6. Multidisciplinary team care and integrated models
7. Advanced wound care and offloading technologies
8. Psychosocial dimensions and quality of life

This thematic approach allows for comprehensive coverage of the topic while facilitating critical discussion of the evidence and identification of knowledge gaps relevant to primary care practice.

## THEMATIC FINDINGS

### 3.1. Epidemiology and Burden of Diabetic Foot Disease

#### 3.1.1 Global Prevalence and Impact

The global diabetes epidemic continues to escalate, with an estimated 537 million adults living with diabetes in 2021, projected to reach 783 million by 2045 [1]. Diabetic foot disease affects a substantial proportion of this population, with lifetime DFU incidence ranging from 19% to 34% [1, 2]. The condition is characterized by high recurrence rates—40% within one year and 65% within three years of initial healing—highlighting its chronic and relapsing nature [2, 3].

The pathway from ulceration to amputation is well-established, with approximately 85% of diabetes-related lower-extremity amputations preceded by foot ulceration [3]. Post-amputation outcomes are particularly grim, with five-year mortality rates of 39-80%, comparable to or exceeding those of many common cancers [4]. These statistics underscore the life-threatening nature of diabetic foot complications and the critical importance of prevention.

#### 3.1.2. Regional Burden: Focus on Saudi Arabia and the GCC

The MENA region exhibits the world's highest diabetes prevalence at 12.2%, with the GCC countries demonstrating particularly elevated rates [6]. Kuwait leads globally with 22% of adults aged 20-79 affected, followed by Qatar (20.2%) and Saudi Arabia with similarly high prevalence [7, 8]. This epidemic is driven by rapid urbanization, sedentary lifestyles, dietary changes, genetic predisposition, and high rates of obesity [6, 8].

In Saudi Arabia, diabetic foot ulcer prevalence is the highest among Arab nations at 11.85% (range 4.7-19%), significantly exceeding rates in neighboring countries such as Egypt (4.2%), Jordan (4.65%), and Bahrain (5.9%) [9]. A recent retrospective study from Saudi Arabia found that among patients presenting with diabetic foot complications, 81% had active ulcers, 31% had undergone amputations, and 29% had developed gangrene [10]. Common comorbidities included hypertension (majority of patients), anemia (50%), diabetic peripheral neuropathy (50%), diabetic nephropathy (33%), and peripheral artery disease (43%) [10].

#### 3.1.3. Economic Burden

The economic impact of diabetic foot disease is substantial. In the United States, diabetes care accounts for $273 billion annually, with hospital inpatient care representing at least 50% of this burden [4, 5]. Diabetic foot ulcers and related complications contribute significantly to these costs through wound care, antibiotics, surgical interventions, hospitalizations, and long-term disability [24].

In Saudi Arabia, the per-patient cost of DFU management averages 6,684.9 Saudi Riyals (approximately $1,782 USD), with total costs for 99 patients reaching 6.6 million SAR ($1.76 million USD) [11]. When extrapolated nationally, given the high diabetes and DFU prevalence, these costs represent a significant burden on the healthcare system. The economic impact extends beyond direct medical costs to include indirect costs such as loss of productivity, disability, caregiver burden, and reduced quality of life [24, 25].

### 3.2. The Evolving Role of Primary Care in Diabetic Foot Prevention

#### 3.2.1. Risk Stratification and Systematic Screening

The foundation of effective diabetic foot prevention in primary care rests on systematic risk assessment and stratification. The IWGDF risk classification system categorizes patients into four risk levels (0-3) based on the presence of loss of protective sensation (LOPS), peripheral artery disease (PAD), foot deformity, and history of ulceration or amputation [2]. This evidence-based framework guides the frequency of follow-up and intensity of intervention:

- Risk 0 (no LOPS, no PAD): Annual screening in primary care
- Risk 1 (LOPS or PAD): Screening every 6-12 months, managed in primary care with enhanced education
- Risk 2 (LOPS + PAD, or LOPS + foot deformity, or PAD + foot deformity): Screening every 3-6 months, consider referral to multidisciplinary foot care team
- Risk 3 (history of foot ulcer or amputation): Screening every 1-3 months, managed by multidisciplinary foot care team with primary care coordination [2, 26]

The annual comprehensive foot examination should include assessment of protective sensation using the 10-g Semmes-Weinstein monofilament, evaluation of foot pulses and ankle-brachial index (ABI) for PAD detection, inspection for structural abnormalities and deformities, and assessment of skin integrity and nail conditions [2, 27]. The monofilament test demonstrates good specificity (>80%) for identifying LOPS, though recent evidence suggests it may miss early neuropathy, prompting interest in complementary tools such as pin-prick testing and vibration perception testing [28, 29, 30]. An ABI $\leq 0.9$ is diagnostic of PAD and independently predicts cardiovascular events and mortality [31, 32].

#### 3.2.2. Implementation Gaps in Primary Care

Despite clear guideline recommendations, implementation of diabetic foot screening in primary care remains suboptimal globally. A cross-sectional study of primary care physicians in China found inadequate screening behaviors, with knowledge gaps, lack of confidence, time constraints, and competing clinical priorities cited as major barriers [14]. In Australia, a study of preventative diabetes-related foot care practices in primary care identified similar challenges, including lack of time, insufficient training, and inadequate reimbursement [15].

In Saudi Arabia, a survey of primary care providers in Riyadh revealed significant deficiencies in diabetic foot knowledge, with gaps in understanding of risk assessment, prevention strategies, and appropriate referral pathways [17]. These findings are consistent with broader challenges in the GCC region, where rapid healthcare system expansion has not been matched by adequate training and capacity-building in chronic disease management [18].

Quality improvement initiatives and physician-directed educational campaigns have demonstrated effectiveness in increasing diabetic foot examination rates. A quality improvement initiative in primary care clinics in the United States increased foot examination rates from 35% to 72% through provider education, workflow redesign, and electronic health record (EHR) prompts [33]. Similarly, a physician-directed educational campaign significantly improved the performance of proper diabetic foot examinations in outpatient settings [34].

#### 3.2.3. Patient Education and Self-Management Support

Patient education constitutes a cornerstone of diabetic foot prevention, empowering individuals to perform daily foot inspection, practice proper hygiene, select appropriate footwear, and seek prompt medical attention for emerging problems [35, 36]. Structured educational interventions have been shown to significantly improve foot care knowledge and self-care behaviors, with effects maintained at follow-up [35, 37].

A randomized controlled trial in India demonstrated that a structured patient education module on diabetic foot care significantly improved knowledge scores, self-care practices, and foot care behaviors compared to usual care [35]. A systematic review and meta-analysis found that foot care educational interventions reduced the incidence of diabetic foot ulceration, with the greatest effects observed in programs that combined education with regular foot screening and multidisciplinary care [36].

Effective educational strategies include teach-back methods, which verify patient understanding through demonstration, and multimedia approaches utilizing videos, interactive applications, and visual aids [38]. A study comparing teach-back and multimedia methods found both superior to traditional didactic teaching in improving self-care behaviors, with multimedia approaches particularly effective for patients with lower literacy levels [38].

Mobile health (mHealth) applications offer scalable platforms for delivering education, providing reminders for daily foot checks, tracking symptoms, and facilitating communication with healthcare providers [39, 40]. A randomized controlled trial of a diabetic foot smart application found significant improvements in self-management behaviors, foot care knowledge, and adherence to preventive practices compared to usual care [39].

#### 3.2.4. Coordination of Multidisciplinary Care

While PCPs can independently manage low-risk patients, effective care for moderate- and high-risk individuals requires seamless coordination with multidisciplinary teams. The PCP serves as the "quarterback" of diabetic foot care, initiating timely referrals, communicating relevant clinical information, ensuring continuity across care transitions, and providing ongoing management of diabetes and comorbidities [41, 42].

Interprofessional decision support tools can guide PCPs in determining appropriate referral timing and urgency [43]. A mixed-methods study in Canada developed an interprofessional decision support tool for diabetic foot ulcer management in primary care, incorporating clinical assessment algorithms, referral pathways, and communication templates [43]. Such tools can standardize care, reduce practice variation, and ensure that patients receive appropriate specialist input when needed.

Studies demonstrate that increased access to specialty care improves outcomes and may reduce health disparities in DFU management [26]. However, in rural and underserved areas where specialist access is limited, telemedicine offers a viable solution for virtual consultations and collaborative care planning, a topic explored in detail in Section 6 [44, 45].

### 3.3. Smart Technology and Wearable Devices: Enabling Proactive Monitoring

#### 3.3.1. Temperature Monitoring Systems

Elevated foot skin temperature precedes ulcer formation by days to weeks, providing a critical window for preventive intervention [2, 46]. Inflammation associated with repetitive stress and microtrauma manifests as localized temperature elevation before visible tissue breakdown occurs [46]. The IWGDF conditionally recommends that moderate-to-high-risk patients self-monitor foot skin temperatures, with a temperature difference >2.2°C between corresponding sites on both feet for two consecutive days serving as an actionable threshold prompting activity modification and clinical evaluation [2].

Smart wearable devices automate this process through sensors embedded in socks, insoles, or floor mats that continuously monitor plantar temperatures and transmit data to smartphone applications [21, 47, 48]. A systematic review of wearable temperature monitoring devices found that most systems achieved acceptable accuracy (±0.5°C) and demonstrated feasibility for home use [48]. Randomized controlled trials have shown that temperature monitoring reduces ulcer incidence by 40-60% in high-risk populations [46].

Recent innovations include wireless passive sensors requiring no batteries, multi-parameter devices measuring both temperature and moisture, and AI-enhanced thermal imaging for advanced pattern recognition [49, 50]. These technologies hold particular promise for primary care, enabling remote monitoring of high-risk patients between clinic visits and facilitating early intervention before ulceration occurs [21].

#### 3.3.2. Pressure Monitoring and Gait Analysis

Abnormal plantar pressure distribution is a primary mechanical factor in neuropathic ulcer development, particularly in patients with LOPS who cannot sense excessive pressure [2]. Smart insoles equipped with pressure sensors provide real-time feedback on pressure distribution, alerting patients when thresholds are exceeded and guiding gait modification to offload high-risk areas [51, 49].

A proof-of-concept study demonstrated that a smart wearable device integrating temperature, pressure, and humidity sensors was feasible for diabetic foot monitoring and self-management, with high patient acceptance and adherence [51]. Recent advances include wireless systems with improved sensitivity and reliability suitable for continuous long-term monitoring, and integration with smartphone applications enabling data visualization, trend analysis, and automated alerts to both patients and healthcare providers [49, 52].

Pressure monitoring technology can also assess the effectiveness of therapeutic footwear and custom orthotics, ensuring optimal offloading [53, 54]. In-shoe plantar pressure analysis allows for iterative modifications to footwear design, with the goal of reducing peak pressures below critical thresholds associated with ulceration risk [53].

#### 3.3.3. Patient and Provider Perspectives on Wearable Technology

A systematic review examining patient and provider perspectives on smart wearable devices for diabetic foot prevention found generally positive attitudes, with perceived benefits including enhanced awareness, early problem detection, peace of mind, and empowerment in self-care [52]. Patients valued the continuous monitoring aspect and the ability to visualize their foot health data over time [52].

However, concerns were raised regarding device usability, particularly for elderly patients with limited digital literacy; data privacy and security; cost and insurance coverage; and the potential for alert fatigue from excessive notifications [52]. Successful implementation requires user-centered design, clear communication about data security and privacy protections, integration into existing clinical workflows to avoid overwhelming patients and providers, and sustainable financing models that ensure equitable access [21, 52].

### 3.4. Artificial Intelligence: Transforming Diagnosis and Risk Prediction

#### 3.4.1. Automated Ulcer Detection

AI-powered image analysis represents a breakthrough in diabetic foot ulcer detection, particularly for primary care and remote settings where specialist expertise may be limited [55, 56, 57]. Deep learning algorithms, particularly convolutional neural networks (CNNs), can be trained on large datasets of foot images to automatically detect ulcers, classify severity, assess tissue composition, and track healing progress with accuracy approaching or exceeding human experts [55, 56].

A landmark multicenter study evaluated a smartphone-based AI system for automated DFU detection in real-world clinical settings across multiple countries [58]. The system achieved sensitivity of 91.57% and specificity of 88.57%, improving to 92.43% sensitivity with post-processing to merge overlapping predictions [58]. Critically, the mean response time was only 5.9 seconds per case, making it suitable for point-of-care screening in busy primary care clinics [58]. The system maintained high performance across varying image quality, lighting conditions, and smartphone models, demonstrating robustness for diverse clinical environments [58].

Recent advances incorporate explainable AI (XAI) techniques that provide visual explanations of algorithmic decisions, highlighting the regions of the image that contributed to the classification [59]. This transparency enhances clinician trust, facilitates educational feedback, and allows for quality assurance and algorithm refinement [59]. Generative AI models are being explored for synthetic data generation to augment training datasets and improve algorithm performance across diverse patient populations and wound types [57].

#### 3.4.2. Risk Prediction and Prognostic Modeling

Machine learning models can integrate multiple clinical variables—demographics, comorbidities, laboratory values, prior ulcer history, examination findings, and social determinants of health—to predict individual patient risk of ulceration and amputation with greater accuracy than traditional scoring systems [55, 56]. A systematic review of ML-based prediction models found that most achieved area under the curve (AUC) values >0.80 for ulcer prediction and >0.85 for amputation prediction, outperforming conventional risk scores [56].

These models enable precision medicine approaches, identifying patients who would benefit most from intensive preventive interventions and guiding resource allocation [55, 22]. Integration into electronic health records with clinical decision support alerts can prompt PCPs to initiate appropriate screening, education, and referrals for high-risk patients identified by the algorithm [43].

A key challenge is ensuring that ML models are trained on diverse, representative datasets to avoid algorithmic bias and ensure equitable performance across different patient populations, including underrepresented racial and ethnic groups [22]. Ongoing validation in real-world clinical settings and continuous model updating are essential to maintain accuracy as patient populations and clinical practices evolve [56].

#### 3.4.3. AI-Enhanced Wound Assessment and Monitoring

Traditional wound assessment relies on subjective clinical judgment and manual measurements, introducing variability and limiting reproducibility [60]. AI-powered wound analysis tools using smartphone images can automatically measure wound dimensions (length, width, depth, area), assess tissue composition (granulation, slough, necrosis, epithelialization), detect signs of infection (erythema, purulence, odor), and predict healing trajectories based on temporal changes [60, 59].

Thermal imaging enhanced by AI provides advanced pattern recognition for detecting inflammation and ischemia, potentially identifying problems before they are clinically apparent [50]. Machine learning algorithms can analyze thermal patterns to distinguish between normal temperature variation and pathological inflammation requiring intervention [50].

These technologies support more objective wound documentation, facilitate telemedicine consultations by providing quantitative data to remote specialists, enable data-driven treatment decisions based on healing trajectories, and support clinical research by providing standardized outcome measures [60, 59].

### 3.5. Telemedicine and Digital Health: Expanding Access to Care

#### 3.5.1. Remote Monitoring Platforms

Telemedicine platforms enable remote monitoring of patients with active DFUs through asynchronous transmission of wound images, structured patient-reported outcomes, vital signs, and symptom tracking [44, 61, 61]. Systematic reviews and meta-analyses demonstrate that telemedicine-based DFU care achieves healing rates and amputation outcomes comparable to traditional in-person care, while offering advantages in terms of patient convenience, reduced travel burden, and healthcare system efficiency [62, 63, 45].

A randomized controlled trial comparing telemedical and standard outpatient monitoring of diabetic foot ulcers found no significant differences in healing time, amputation rates, or patient satisfaction, while significantly reducing patient travel time and associated costs [64]. A propensity-matched cohort study in Italy found that telemedical monitoring reduced hospital stays by 40% and overall costs by 36% compared to standard care, with comparable clinical outcomes [65].

The COVID-19 pandemic accelerated telemedicine adoption globally, demonstrating feasibility even in traditionally conservative healthcare systems and among patient populations previously considered less likely to engage with digital health technologies [44]. This rapid expansion has provided valuable insights into implementation strategies, patient and provider acceptance, and technical infrastructure requirements [44].

#### 3.5.2. Mobile Health Applications for Self-Management

Smartphone applications designed for diabetic foot self-management provide educational content, daily foot check reminders, symptom tracking, photographic documentation, and direct communication channels with healthcare teams [39, 40]. A randomized controlled trial of a diabetic foot smart application found significant improvements in self-management behaviors, foot care knowledge, and adherence to preventive practices compared to usual care [39].

A systematic review and meta-analysis of digital intelligent interventions found moderate-to-large effect sizes for improving self-management behaviors and capabilities in patients with diabetic foot disease [61]. Features associated with greater effectiveness included personalized feedback based on individual risk profiles, interactive educational modules with multimedia content, integration with wearable sensors for automated data collection, and bidirectional communication with healthcare providers [61]. Challenges to widespread adoption include digital literacy barriers, particularly among elderly patients and those with lower socioeconomic status; smartphone ownership and internet access disparities; concerns about data privacy and security; and the need for integration with existing healthcare information systems [61].

#### 3.5.3. Nurse-Led Telehealth Programs

Nurse-led telehealth programs represent a scalable model for delivering diabetic foot education and support, particularly in primary care settings with limited specialist availability [66]. A feasibility study of a nurse-led telehealth program for diabetes foot care found high patient satisfaction, improved foot care knowledge, good adherence to the intervention, and positive feedback from both patients and nurses [66].

These programs can be integrated into primary care practices, with nurses conducting virtual foot assessments, providing structured education, coordinating care across providers, and escalating concerns to physicians as needed [66, 40]. This model leverages nursing expertise while extending the reach of limited physician resources, aligning well with team-based primary care delivery models [40].

A qualitative study exploring strategies to enhance foot care education and support in primary care identified the importance of tailored educational approaches, addressing psychosocial barriers, involving family members in care, and ensuring continuity of care through regular follow-up [40]. Telehealth platforms can facilitate these strategies by enabling more frequent touchpoints with patients without requiring in-person visits [40].

### 3.6. Multidisciplinary Team Care: The Gold Standard for Complex Cases

#### 3.6.1. Evidence for Multidisciplinary Approaches

The complexity of diabetic foot disease—involving neuropathy, vascular disease, infection, biomechanical abnormalities, metabolic derangements, and psychosocial factors—necessitates multidisciplinary expertise for optimal management [67, 68]. Systematic reviews consistently demonstrate that multidisciplinary team (MDT) care reduces major amputation rates by 40-80% compared to usual care, with the greatest benefits observed in patients with complex, high-risk ulcers [67, 69].

An ideal MDT for diabetic foot care typically includes endocrinology/diabetology for metabolic management, podiatry for foot care and biomechanical assessment, vascular surgery for revascularization procedures, infectious disease for complex infections, orthopedics for bone and joint complications, wound care nursing for dressing management and patient education, orthotics/prosthetics for therapeutic footwear and devices, and when needed, plastic surgery for soft tissue reconstruction, interventional radiology for minimally invasive vascular interventions, and mental health services for psychosocial support [70, 71].

Regular team meetings, shared care protocols, integrated clinical pathways, and co-located services facilitate coordinated decision-making and seamless care transitions [52]. A fast-track pathway model, which streamlines patient flow through the MDT with predefined protocols and timelines, has been shown to significantly improve DFU healing rates and reduce time to healing [52].

#### 3.6.2. The Primary Care Physician's Role in Integrated Care

Within the MDT framework, the PCP serves critical functions that extend beyond initial detection and referral. These include identifying at-risk patients requiring specialist referral through systematic screening, initiating timely referrals with appropriate urgency designation and relevant clinical information, providing comprehensive medical management of diabetes and comorbidities (hypertension, dyslipidemia, chronic kidney disease), ensuring continuity during transitions between specialist and primary care, supporting long-term follow-up after ulcer healing to prevent recurrence, and coordinating care across multiple specialists to avoid fragmentation [41, 42, 43].

Interprofessional decision support tools can guide PCPs in determining when specialist referral is indicated, what urgency level is appropriate, and what information should be communicated to the specialist team [43]. Shared EHR systems and standardized communication protocols facilitate information exchange and care coordination, reducing the risk of missed follow-ups or conflicting treatment plans [43].

#### 3.6.3. Overcoming Geographic Barriers

In rural and remote areas where assembling a complete MDT is impractical due to workforce shortages and geographic distances, hybrid models combining in-person primary care with telemedicine specialist consultations offer a pragmatic solution [44, 45]. Virtual MDT meetings can include the patient's PCP, enabling collaborative care planning while maintaining the PCP's central role in ongoing management [44].

A systematic review of telehealth and telemedicine applications for diabetic foot care found that remote consultations with specialists, store-and-forward image transmission for wound assessment, and virtual MDT meetings were feasible and effective strategies for extending specialist expertise to underserved areas [44]. These approaches can reduce health disparities and improve outcomes for patients who would otherwise have limited access to specialized foot care services [26].

### 3.7. Advanced Wound Care and Offloading Technologies

#### 3.7.1. Negative Pressure Wound Therapy

Negative pressure wound therapy (NPWT) applies sub-atmospheric pressure to the wound bed through a sealed dressing connected to a vacuum pump, promoting granulation tissue formation, reducing edema, removing exudate and infectious material, enhancing perfusion, and facilitating wound contraction [72, 73]. A Cochrane systematic review found moderate-quality evidence that NPWT increases the proportion of healed DFUs and reduces time to healing compared to standard dressings [73].

A multicenter randomized controlled trial demonstrated that NPWT using vacuum-assisted closure was superior to advanced moist wound therapy, with 56% versus 39% complete healing at 16 weeks ($p<0.04$) [74]. NPWT is particularly valuable for post-surgical wounds following debridement or amputation, deep ulcers with significant exudate, wounds with exposed tendon or bone, and wounds requiring preparation for skin grafting or flap coverage [72, 73].

While NPWT is typically initiated in specialist settings, PCPs play an important role in monitoring patients receiving NPWT at home, assessing for complications such as pain or bleeding, coordinating dressing changes, and communicating with the specialist team regarding treatment response [72].

#### 3.7.2. Offloading: The Critical Intervention

Pressure offloading is the most critical intervention for healing neuropathic plantar ulcers, yet remains underutilized in clinical practice due to knowledge gaps, lack of training, and patient adherence challenges [2, 75]. Total contact casting (TCC) is the gold standard offloading device, achieving healing rates up to 90% in appropriately selected patients by providing consistent, non-removable pressure redistribution [75].

However, TCC use is limited by the need for specialized training in application technique, patient concerns about mobility restrictions and aesthetics, contraindications such as active infection, severe ischemia, or fluctuating edema, and the need for frequent cast changes as the wound heals and limb volume changes [75].

Removable cast walkers (RCWs) offer greater convenience and are more widely used, but suffer from poor adherence, with studies showing patients wear them <30% of daily steps, undermining their effectiveness [75]. Instant total contact casts (iTCCs)—RCWs rendered irremovable with cohesive bandaging—address this adherence problem while maintaining ease of application and the ability to remove the device for wound inspection [75]. A systematic review and meta-analysis found that TCCs and iTCCs achieved significantly higher healing rates than removable devices (pooled relative risk 1.17, 95% CI 1.01-1.35) [75].

PCPs play a crucial role in educating patients about the importance of offloading and ensuring adherence. For patients managed in primary care with superficial, low-risk ulcers, prescription of appropriate offloading footwear and close monitoring are essential [2, 53].

#### 3.7.3. Therapeutic Footwear and Pressure Relief

Custom therapeutic footwear with pressure-relieving insoles is recommended for all patients with LOPS, foot deformity, or history of ulceration to prevent recurrence [2, 53, 76]. In-shoe plantar pressure analysis enables objective assessment and optimization of footwear effectiveness, with iterative modifications to achieve target pressure reduction (typically <200 kPa or 35% reduction from baseline) [53, 77].

Data-driven custom footwear concepts utilizing 3D foot scanning, computational modeling, and additive manufacturing (3D printing) show promise for improving pressure relief compared to traditional methods [77]. These technologies allow for highly individualized footwear design based on each patient's unique foot shape, pressure distribution, and activity patterns [77].

However, even optimal footwear is ineffective if not worn consistently. Studies show that adherence to therapeutic footwear recommendations is often poor, with patients citing discomfort, appearance concerns, and lack of understanding of the importance as barriers [53]. PCPs can address these barriers through patient education, addressing footwear fit and comfort issues, and regular reinforcement of the importance of adherence [53].

### 3.8. Psychosocial Dimensions and Quality of Life

#### 3.8.1. The Hidden Burden of Diabetic Foot Disease

The impact of diabetic foot disease extends far beyond physical morbidity, profoundly affecting patients' psychological well-being, social functioning, and overall quality of life. Patients with DFUs experience significant reductions in quality of life across multiple domains: physical function and mobility, social participation and relationships, emotional well-being and mental health, work productivity and financial security, and independence and self-care ability [78, 79].

Fear of amputation is pervasive and profoundly distressing, with many patients reporting intrusive thoughts, anxiety, and sleep disturbance related to this fear [78]. The chronic nature of DFUs, with prolonged healing times and high recurrence rates, contributes to feelings of hopelessness and loss of control [78].

Following amputation, psychosocial impacts intensify dramatically. Studies report depression prevalence of 30-50% in amputees, along with body image disturbance, social isolation, loss of independence, financial strain, and relationship difficulties [80, 81]. The five-year mortality rate of 40-80% following major amputation underscores the life-altering and life-threatening nature of this complication [4].

#### 3.8.2. Addressing Psychosocial Needs in Primary Care

PCPs are uniquely positioned to address the psychosocial needs of patients with diabetic foot disease through routine screening for depression and anxiety using validated instruments (e.g., PHQ-9, GAD-7), providing empathic support and counseling, validating patients' emotional experiences, referring to mental health services when indicated, facilitating peer support connections through patient support groups or online communities, and addressing social determinants of health that may impact self-care capacity [78, 79].

A holistic, patient-centered approach that acknowledges the emotional and social dimensions of diabetic foot disease is essential for optimal outcomes. Shared decision-making, realistic goal-setting, attention to patient priorities and values, and recognition of the burden of treatment can enhance engagement and adherence [78].

A qualitative study exploring patient perspectives on the impacts of diabetic foot ulceration and amputation found that patients valued healthcare providers who listened to their concerns, acknowledged the emotional toll of the condition, provided hope while being realistic, and involved them as partners in treatment decisions [78]. These findings underscore the importance of communication skills and patient-centered care in primary care practice.

## DISCUSSION

### 4.1. Key Findings

This narrative review underscores that the substantial and persistent global burden of diabetic foot disease, particularly pronounced in regions like the GCC, exists in stark contrast to the available evidence-based prevention strategies. A critical finding is the consistent gap between this knowledge and its implementation, especially within primary care settings where the majority of patients are managed. This implementation chasm forms the central challenge that emerging technologies and revised care models must address.

The evidence points to several promising technological avenues. Smart wearable technologies for continuous temperature and pressure monitoring demonstrate a transformative potential for pre-emptive care, with studies indicating dramatic reductions in ulcer incidence. Similarly, artificial intelligence applications have achieved high diagnostic and predictive accuracy in controlled settings. However, the translation of these innovations into routine practice is hampered by a common set of barriers, including cost, reimbursement, integration into clinical workflows, and concerns regarding data privacy, algorithm transparency, and validation across diverse populations. Beyond discrete technologies, telemedicine platforms have proven their value in improving access and outcomes, a utility accelerated and confirmed during the COVID-19 pandemic. For sustained impact, however, these platforms require supportive reimbursement structures and strategies to bridge the digital divide.

Furthermore, the review reaffirms that the multidisciplinary team (MDT) approach remains the clinical gold standard, unequivocally linked to reduced amputation rates. A key insight is that access to such specialized care is geographically and economically constrained. Here, hybrid models of care, which leverage telemedicine to extend specialist MDT expertise into primary care and underserved communities, present a viable strategy for democratizing high-quality management. Finally, an overarching theme is the profound, yet frequently neglected, psychosocial impact of diabetic foot disease. The high prevalence of depression, anxiety, and diminished quality of life necessitates a paradigm shift towards a more holistic, patient-centered model of care, in which primary care physicians are ideally positioned to screen for and address these critical needs.

### 4.2. Implications for Primary Care Practice

The evidence reviewed substantiates several critical imperatives for primary care practice. First, PCPs must institutionalize systematic foot screening, adhering to IWGDF guidelines with annual assessments for all diabetic patients and increased frequency for higher-risk individuals; this necessitates dedicated clinical time, appropriate diagnostic tools, and robust documentation systems to track risk status. Concurrently, patient education should be elevated as a fundamental component of care, delivered through structured, evidence-based interventions that utilize teach-back methods, multimedia resources, and culturally adapted materials to ensure comprehension and engagement. Furthermore, the establishment of clear, operationalized referral pathways to multidisciplinary teams is essential, requiring explicit criteria for referral urgency, standardized communication, and mechanisms to guarantee follow-up, while PCPs must also directly manage the prescription and adherence monitoring of offloading footwear.

To enhance this foundational care, the strategic integration of technological and patient-centered approaches is paramount. PCPs should champion the adoption of smart technologies and AI tools, contingent upon their thoughtful integration into clinical workflows with due consideration for patient preferences, digital literacy, and equitable access, while also advocating for supportive reimbursement policies. The deployment of telemedicine should be leveraged to extend specialist reach, facilitate remote monitoring of high-risk patients, and mitigate geographic care barriers, which itself demands parallel investment in infrastructure, training, and sustainable financing models. Ultimately, the management of diabetic foot disease must be underpinned by a holistic, patient-centered paradigm that proactively addresses its psychosocial dimensions, incorporating routine screening for depression and anxiety, the provision of empathic support, and timely referral to mental health services.

### 4.3. Challenges and Barriers to Implementation

Despite the promise of technological innovations and evidence-based prevention strategies, the widespread implementation of effective diabetic foot care is impeded by a confluence of significant challenges and barriers. Foremost among these are persistent knowledge and training gaps, as many PCPs report insufficient expertise in foot assessment, risk stratification, and management, necessitating enhanced professional development and medical curriculum integration. These clinical challenges are compounded by profound time and resource constraints, where the demands of comprehensive foot examinations compete with other chronic and acute care needs, underscoring the necessity for workflow redesign, team-based care models, and revised reimbursement structures.

The adoption of promising technologies is hindered by cost, reimbursement limitations, data privacy concerns, variable digital literacy, and poor interoperability with electronic health records, requiring multi-stakeholder collaboration to overcome. These systemic issues are exacerbated by significant health disparities, with patients from lower socioeconomic backgrounds, racial and ethnic minorities, and rural populations facing a disproportionate disease burden and limited access to care, demanding targeted, culturally adapted interventions and equity-focused policies. Finally, even when interventions are available, suboptimal patient adherence to offloading devices, footwear, and self-care regimens—influenced by psychosocial factors, health literacy, and social determinants of health—remains a critical barrier, highlighting the need for a deeper understanding of the multifaceted obstacles to patient engagement.

### 4.4. Future Directions and Research Needs

Based on this review, several critical research gaps and future directions emerge, beginning with the imperative for long-term effectiveness and cost-effectiveness studies of smart wearables and AI tools in real-world primary care, complemented by implementation science to optimally integrate these technologies into clinical workflows and overcome adoption barriers. Furthermore, comparative effectiveness research is needed to evaluate different AI algorithms, devices, and telemedicine platforms, while dedicated studies in diverse populations are crucial to ensure innovations are equitable and effective across all patient groups, including racial and ethnic minorities and those in resource-limited settings.

Patient-centered outcomes research must examine quality of life, preferences, and patient-reported outcomes to align innovations with patient values, alongside concurrent health economics research to inform reimbursement and resource allocation policies. Finally, key priorities include the development and validation of clinical decision support tools that integrate AI-based risk prediction with evidence-based management, and dedicated research on strategies to address psychosocial needs and improve the quality of life for patients with diabetic foot disease.

## CONCLUSION

Diabetic foot disease imposes an enormous burden on individuals, healthcare systems, and societies worldwide, with particularly acute challenges in high-prevalence regions such as the Gulf Cooperation Council countries. The pathway from diabetes to ulceration to amputation is well-established, yet largely preventable through systematic screening, risk stratification, patient education, and timely intervention.

Primary care physicians occupy a pivotal position in the continuum of diabetic foot care, ideally situated to implement prevention strategies, conduct systematic screening, educate patients, and coordinate multidisciplinary management. However, significant gaps persist in current practice, including suboptimal screening rates, limited patient education, late referrals to specialist services, and poor integration between primary and specialist care.

The integration of smart technology, artificial intelligence, and digital health platforms offers transformative potential to empower PCPs and shift the paradigm from reactive treatment to proactive prevention. Wearable sensors enable continuous monitoring and early problem detection. AI-powered tools facilitate accurate diagnosis, risk stratification, and wound assessment. Telemedicine platforms expand access and reduce costs while maintaining quality. These innovations, combined with evidence- based wound care and offloading interventions delivered through multidisciplinary teams, provide a comprehensive toolkit for reducing the burden of diabetic foot complications.

Realizing this potential requires addressing implementation barriers through targeted education and training for healthcare providers, supportive policies and sustainable reimbursement models, user-centered design and attention to digital literacy and equity, integration with existing clinical workflows and information systems, and continued research to validate effectiveness, optimize implementation, and ensure equity.

By embracing technological innovation while maintaining a patient-centered, holistic approach that addresses both physical and psychosocial needs, primary care physicians can lead the transformation of diabetic foot care and improve outcomes for millions of people with diabetes worldwide. The time to act is now—the tools are available, the evidence is compelling, and the need is urgent.

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**Abbreviations**

ABPI, Ankle-Brachial Pressure Index; ADA, American Diabetes Association; AI, Artificial Intelligence; AUC, Area Under the Curve; CNN, Convolutional Neural Network; DFU, Diabetic Foot Ulcer; EHR, Electronic Health Record; GAD-7, Generalized Anxiety Disorder 7-Item Scale; GCC, Gulf Cooperation Council; iTCC, Instant Total Contact Cast; IWGDF, International Working Group on the Diabetic Foot; LOPS, Loss of Protective Sensation; MDT, Multidisciplinary Team; MENA, Middle East and North Africa; mHealth, Mobile Health; ML, Machine Learning; NPWT, Negative Pressure Wound Therapy; PAD, Peripheral Artery Disease; PCP, Primary Care Physician; PHQ-9, Patient Health Questionnaire-9 Item; RCT, Randomized Controlled Trial; RCW, Removable Cast Walker; TCC, Total Contact Cast; XAI, Explainable Artificial Intelligence.

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