Electronic Journal of General Medicine
2026, 23(4), em745
e-ISSN: 2516-3507
https://www.ejgm.co.uk/

MODESTUM

Review Article

OPEN ACCESS

Smart digital technologies for prevention of diabetic foot ulcers: A scoping review

Okti Sri Purwanti [1,2], Nursalam [3*], Andri Setiya Wahyudi [3]

[1] Faculty of Nursing, Universitas Airlangga, Surabaya, INDONESIA
[2] Department of Nursing, Faculty of Health Science, Universitas Muhammadiyah Surakarta, Surakarta, INDONESIA
[3] Department of Advanced Nursing, Faculty of Nursing, Universitas Airlangga, Surabaya, INDONESIA
***Corresponding Author:** nursalam@fkp.unair.ac.id

Citation: Purwanti OS, Nursalam, Wahyudi AS. Smart digital technologies for prevention of diabetic foot ulcers: A scoping review. Electron J Gen Med. 2026;23(4):em745. https://doi.org/10.29333/ejgm/19003

ARTICLE INFO

Received: 27 Feb. 2026

Accepted: 14 Jul. 2026

ABSTRACT

The risk of diabetic foot ulcers (DFUs) increases with tissue damage in the foot due to neuropathy, ischemia, or infection. DFU prevention through early diabetic ulcer detection with digital innovation. The aim of this research is to classify digital instrument innovations used in prevention of diabetic ulcer. Scoping review study design, Scopus database data search, Web of Science, EBSCO CINAHL, Pubmed, ProQuest, with a combination of Boolean words “diabetic foot ulcer” OR “diabetes mellitus” AND “prevention” AND “method” OR “Device” AND “Technology” articles released between 2020-2025. We filtered articles that talk about smart technology usages in the prevention of diabetic ulcers. Among smart technology usages in the prevention of diabetic ulcers, articles used in our research, there are 25 of them. All articles used has Joanna Briggs Institute assessment score above 75%, which shows their eligibility. The instrument classification used in this research are smart socks, smart insoles, medical applications, machine learning, and artificial intelligence. There are digital innovations developed to help electrophysical therapy and vibration therapy that improve blood flow and increases sensitivity of diabetes mellitus patients’ feet.

Keywords: digital, diabetic foot ulcers, review, prevention, smart technology

INTRODUCTION

Diabetes mellitus is a chronic metabolic disease whose prevalences increases significantly, both in developed and developing countries [1]. In diabetes mellitus patients, one of the most common serious complications is diabetic foot ulcers (DFUs) [2, 3]. The risk of DFUs increases with tissue damage in the feet due to neuropathy, ischemia, or infection. The World Health Organization reported that around 15-25% of diabetic patients are at risk of ulcers throughout their life [4]. The risk significantly increases treatment cost, morbidity, and mortality because untreated diabetic ulcers may develop serious complications that requires intensive treatments or even amputation. This condition also increases health facilities load because of high treatment demands, length of treatments, and high medical resource usages. Furthermore, DFUs has serious negative impacts on patients’ life quality, which includes limited mobility, increased pain, and disrupted daily activities [5, 6].

DFUs are generally caused by neuropathy-induced sensory sensitivity decrease. Delayed detection and wound treatment are main factors of complications because diabetic ulcers are repeatable, infected, and develops into chronic wounds [7]. Therefore, early detection of physiological changes in diabetic patients’ feet is a very crucial aspect in the prevention of DFUs [8]. On the other hand, wound management challenges faced by nurses are solved with effective education and continuous collaboration with patients’ families [9]. Family plays an important role in preventing ulcers with their involvement in daily treatments such as checking and maintaining foot hygiene [10, 11].

Conventional DFU prevention has limitations that affect its effectiveness in early detection and risk monitoring. Periodic manual foot check are done by health workers, but they are unable to observe dynamic physiological changes between health facility visits, therefore pre-ulcer potential development is rarely identified at the right time [12]. Furthermore, foot treatment education effectivity still depends on patients’ compliance, while limited medical literacy, patients’ behavior variation, and lack of monitoring cause daily treatment practice to be inconsistent [13]. Conventional methods also don’t show data such as pressure, temperature, or activity pattern that contributes to ulcer risk [14]. On the other side, early prevention potential is also affected by consistency of follow-up visits and periodical physical examination that might be prevented by service accessibility, waiting time, or health workers’ workload. Those limitations and constraints show there’s a need for technologies that are able to do objective and continuous real-time observation to increases the effectiveness of diabetic ulcer prevention.

Advances in medical technology has created several development of smart devices designed to monitor the condition of diabetic patients’ feet in real-time. Technologies such as smart sock, smart shoe soles, machine learning, and Internet of things (IoT)-based monitoring system enables continuous measurement of temperature change, pressure, humidity, and feet mass distribution that functions as indicator of early detection of diabetic ulcer's risk. Continuous monitoring of those indicators is a very important tool for early detection before clinical symptoms develops. It opens chance of faster and efficient intervention of diabetic feet ulcer.

Besides hardware developments, artificial intelligence (AI) applications and machine learning algorithm has been used to analyze feet physiological data and predict ulcer risk at even more personal level. This technology is able to create early warning system that helps health workers to prevent ulcer more accurately. AI-based analytical system device integration is an innovative approach to decrease DFU incidence [15]. Along with this advancement, more studies start to evaluate various digital innovation usages in prevention of DFU. This shows there's a shift to a more proactive and precise technology-based monitoring strategies.

Despite the abundance of studies that develop various digital technologies to prevent DFU, available proofs are still scattered and unorganized. Many studies only evaluate technical aspects or preliminary tests, with large variation in technological types, research methods, and reported results; therefore, it's hard to draw a comprehensive conclusion [16]. Also, specialized reviews that study how those technologies are used in prevention, including in the context of application, work mechanism, and challenges in implementation for medical services, are still scarce [17]. This situation shows that there's a knowledge gap that needs to be filled through a more structured and comprehensive evidence mapping.

The concept of prevention in public health divides prevention into three levels: primary prevention, secondary prevention, and tertiary prevention [18]. In the context of DFU prevention, prevention is not limited to efforts before an ulcer occurs but also includes early detection and efforts to prevent progression, recurrence, and further complications. Therefore, a preventive approach to chronic diseases such as diabetes is continuous and integrated with clinical management [19].

Based on this background, a comprehensive scientific study is needed to analyze various technological innovation in preventing DFU. This study's purpose is to map available tools and scientific evidence regarding smart technology developed in prevention of DFUs as well as to answer what digital technology that have been used. This include characteristics, function, and mechanism to detect and prevent wound risk. We hope that the result of this study will be able to contribute to the development of technology-based DFU prevention strategy that's more effective and continuous.

METHODS

Study Design

This study use scoping review to identify, evaluate, and synthesize available scientific evidences regarding smart technologies in DFU prevention. This study seeks to answer several questions such as types of device or technology that's been developed and used in DFU prevention; their characteristics, their function, and their mechanism. This study is currently in the official protocol registration process in the open science framework (OSF) platform, no. 10.17605/OSF.IO/237K4. Detailed information can be accessed through official OSF website https://archive.org/details/osf-registrations-237k4-v1

Search Strategy

Scoping review search was conducted in electronic databases such as PubMed, Scopus, EBSCO CINAHL, Web of Science, and ProQuest using a combination of keywords "Diabetic foot ulcer" OR "diabetic foot wound" AND "prevention" AND "diabetes mellitus" AND "method" OR "tool" AND "Technology". The year range was limited to between 2020 and 2025 to ensure the relevance and recency of the data. The article screening process in this study used Rayyan.AI.

Variable Definition, Inclusion Criteria, and Exclusion Criteria

This review's research concept draws on the public health prevention model, which divides prevention efforts into three levels: primary, secondary, and tertiary prevention. Primary prevention focuses on promotive and preventive efforts to prevent disease onset; secondary prevention emphasizes early detection and early treatment to prevent disease progression, while tertiary prevention aims to reduce complications and disability and improve quality of life through rehabilitation and ongoing care. This framework was used in the review to identify, categorize, and analyze various forms of relevant prevention interventions.

The inclusion and exclusion criteria in this study were determined based on the population-concept-contexts (PCC) framework. The included population was studies involving adult patients with diabetes mellitus; the primary concept focused on intelligent digital technologies contributing to DFU prevention; and they were conducted in various contexts such as clinical services, home-based monitoring, remote monitoring, mobile health, or AI-based systems. Articles excluded in this study were those with the use of conventional instruments, with children and toddlers as the target population, studies were animal or laboratory tests, we also excluded articles in the form of editorials, opinion pieces, review articles, or incomplete articles.

Data Analysis and Extractions

In this study, data extraction process included information about references, main author, year, study design, instrument population, and main results of the study. Extracted data for this study are presented in tabular form. Data were analyzed using narrative synthesis due to heterogeneity in the types of interventions and reported outcomes. Narrative synthesis was performed by grouping the results based on the type of smart technology used and its effectiveness in preventing DFU.

Study Selection and Data Processing

Data selection was done through several systematic steps. Duplicate identification and deletion were performed by Rayyan.AI platform, so that identical articles detected and eliminated automatically. Next, screening was performed based on the title and abstract to evaluate initial compliance with the inclusion criteria. Eligible articles then underwent full-text review in order to ensure their relevance and completeness, according to the PCC framework. The overall results of the process are presented in a PRISMA diagram as an overview of the identification flow, screening, and selection process.

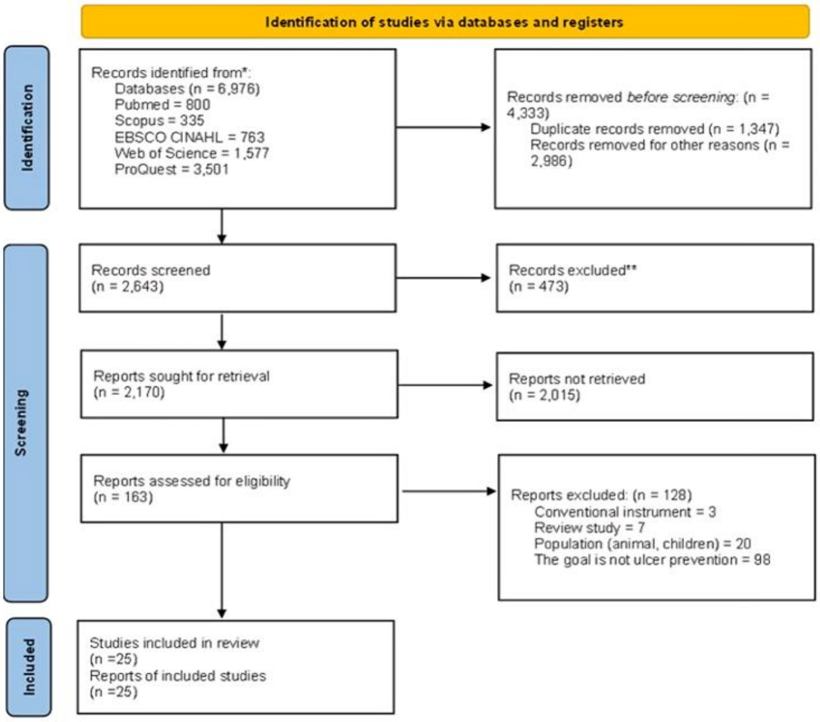

Figure 1. PRISMA flow chart (created by the authors based on the PRISMA 2020 statement [20])

Critical Appraisal Tests

The quality of articles in this review was assessed using the Joanna Briggs Institute (JBI) critical appraisal tool, which consists of nine items covering aspects of research methodology, appropriateness of study design, sample selection, instrument validity and reliability, data analysis, and clarity of research findings. Although JBI does not establish a standard numerical threshold, this study used a pragmatic threshold of ≥ 75% (≥ 7 of 9 items) as the minimum inclusion criterion. Previous studies generally use a score of ≥ 50% for article eligibility, with studies scoring < 50% excluded [21]. Each item in the JBI checklist was scored 1 for "yes" and 0 for "no," "unclear," or "not applicable," and then summed and combined into a percentage.

RESULTS

Selection Process

A total of 6,976 records were identified from multiple databases, including PubMed, Scopus, EBSCO CINAHL, Web of Science, and ProQuest. After removing 4,333 records prior to screening (1,347 duplicates and 2,986 for other reasons), 2,643 records remained for screening. Of these, 473 records were excluded based on title and abstract screening, resulting in 2,170 reports sought for retrieval. However, 2,015 reports were not retrieved, leaving 163 full-text articles assessed for eligibility. Subsequently, 128 articles were excluded due to reasons such as use of manual instruments, focus on diabetes management, review study design, and non-diabetic patient populations. Finally, 25 studies were included in the review (**Figure 1**).

Critical Appraisal Tests

All articles in this study used an experimental research design. Therefore, we used the JBI feasibility assessment of experimental research articles. The results of the feasibility assessment of experimental research designs are shown in **Table 1**.

Table 1. JBI critical appraisal of experimental studies

S	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Total
[22]	+	-	+	+	+	+	+	+	+	8
[23]	+	-	+	+	+	+	+	+	+	8
[24]	+	-	+	+	+	+	+	+	+	8
[25]	+	-	+	+	+	+	+	+	+	8
[26]	+	-	+	+	+	+	+	+	+	8
[27]	+	-	+	+	+	+	+	+	+	8
[28]	+	+	+	+	+	+	+	+	+	9
[29]	+	+	+	+	+	+	+	+	+	9
[30]	+	+	+	+	-	-	+	+	+	7
[31]	+	+	+	+	+	+	+	+	+	9
[32]	+	-	+	+	+	+	+	+	+	8
[33]	+	+	+	+	+	+	+	+	+	9
[34]	+	+	+	+	-	-	+	+	+	7
[35]	+	-	+	-	+	+	+	+	+	7
[36]	+	-	+	-	+	+	+	+	+	7
[37]	+	-	+	-	+	+	+	+	+	7
[38]	+	+	+	+	+	-	+	+	+	8
[39]	+	+	+	+	+	+	+	+	+	9
[40]	+	+	+	+	+	+	+	+	+	9
[41]	+	-	+	+	+	+	+	+	+	8
[42]	+	-	+	+	+	+	+	+	+	8
[43]	+	-	+	+	-	+	+	+	+	7
[44]	+	+	+	+	+	+	+	+	+	9
[45]	+	-	+	+	+	+	+	-	+	7
[46]	+	+	+	+	+	+	+	+	+	9

Note. S: Study

Table 2. Characteristics of included studies

S	Year	Study design	Population	SS	Group
[22]	2020	Experimental study	Diabetes mellitus patients	4	Single group
[23]	2024	Experimental study	Elderly patient with DFU history	138	Single group
[24]	2022	Experimental study	Diabetes mellitus patients	10	Single group
[25]	2023	Experimental study	Diabetes mellitus patients	13	Single group
[26]	2024	Experimental study	Diabetes mellitus patients	4	Single group
[27]	2024	Experimental study	DFU patients	200	Single group
[28]	2024	Experimental study	Diabetes mellitus patients with DFU risk	20	Single group
[29]	2024	Experimental study	Diabetes mellitus patients and healthy patients	150	Control group: 75 & intervention group: 75
[30]	2024	Experimental study	Diabetes mellitus patients and healthy patients	200	Single group
[31]	2025	Experimental study	Diabetes mellitus patients	107	Single group
[32]	2023	Experimental study	DFU patients	20	Single group
[33]	2021	Experimental study	Diabetes mellitus patients	93	Control group: 49 & intervention group: 44
[34]	2024	Experimental study	Diabetic neuropathy patients	22	Single group
[35]	2024	Experimental study	Diabetes mellitus patients	62	Single group
[36]	2023	Experimental study	Diabetes mellitus patients	6	Single group
[37]	2022	Experimental study	Patients with DFU history	197	Single group
[38]	2023	Experimental study	Elderly type 2 diabetes mellitus patients	100	Control group: 50 & intervention group: 50
[39]	2023	Experimental study	Elderly diabetes mellitus patients	120	Control group: 60 & intervention group: 60
[40]	2023	Experimental study	DFU patients and diabetic neuropathy patients	80	Control group: 40 & intervention group: 40
[41]	2021	Experimental study	Diabetes mellitus patients	6	Single group
[42]	2021	Experimental study	Adult patients with diabetes melitus	12	Single group
[43]	2022	Experimental study	Diabetes mellitus patients	22	Single group
[44]	2023	Experimental study	Diabetes mellitus patients	64	Control group: 32 & intervention group: 32
[45]	2025	Experimental study	Health workers wound care specialty in diabetes mellitus	106	Single group
[46]	2024	Experimental study	Diabetic neuropathy patients	29	Single group

Note. S. Study & SS: Sample size

Characteristics of Included Studies

As many as 25 articles included in this study discussed usage of smart technology in preventing DFU. Various technology included in the review were mobile apps, wearable device, smart sensor, and remote monitoring system focused on early risk detection, foot condition monitoring, patient education, and self-care reminder. Description of study result is shown in **Table 2**.

Technology Classification

Various digital instruments such as smart sock, smart insole, and plantar pressure sensor have been used in research on DFU prevention. These instruments can be classified based on their function: biomechanical monitoring devices, physiological monitoring devices, digital-based applications, and therapeutic devices. This classification presents the results of grouping articles based on the type of instrument used in DFU prevention as shown in **Table 3**.

Smart socks

Research conducted in [28, 33] used smart socks that utilize digital technology for early detection of DFU. Digital technology usage includes the development of smart socks by implementing a device system that can detect pressure and temperature in the feet of diabetic patients such as the study conducted in [28], which implemented a compression sensor system to detect pressure and temperature that indicate the risk of DFU. Research in [33], used smart shocks that implemented an infrared system to detect temperature changes in the feet. Both innovations demonstrate that the development of digital systems can be used to routinely monitor foot temperature and pressure in diabetic patients to prevent DFU.

Smart soles

Smart insoles equipped with plantar pressure and temperature sensors can classify healthy feet from those at risk of developing DFU [31]. This innovation also implements an IoT system to connect with other devices for ease of use and enable real-time data transfer [25]. Based on our findings, there are smart insoles that implement a blood oxygenation level measurement system (SpO2) so that they can identify disorders in peripheral circulation [32].

Research on smart insoles made from PORON Medical 4708 has been shown to produce lower mean peak pressure and pressure-time integral compared to rigid insoles such as LunaLight Afresh and Pe-Lite. This shows that the choice of insole material also affects the usefulness of the smart insole. The use of soft materials has been shown to be effective in reducing plantar pressure and reducing the risk of DFU [42]. Smart insoles that integrate machine learning can identify areas with excessive load or abnormal plantar pressure so that they can identify tissue damage that leads to the risk of DFU [29, 38, 41, 47]. Apart from being an instrument for detecting early neuropathy, there is an innovation in smart insoles for therapy for 30 minutes every day for 1 month which increases sensitivity in the feet of diabetes mellitus patients [34].

Remote temperature monitoring

Remote foot temperature monitoring instruments utilize the latest technology, such as infrared, to identify the patient's foot temperature and connect to a device that can display the results in real time. Infrared thermography can identify significant changes in plantar temperature in the foot to detect abnormalities that indicate the risk of DFU. Patients can perform remote temperature monitoring without having to visit a healthcare facility. This technology is useful for early detection of DFU, saves time, and minimizes the cost of foot care for patients with diabetes mellitus [22, 25, 26].

Table 3. Technology classification

IC	S	Primary category	Technology	Ulcer prevention role
Smart sock	[28]	Early detection sensitivities	Smart compression sock (pressure and temperature)	Detect high-ris pressure and temperature
	[33]	Early detection sensitivities	Smart sock with an infrared sensor	Detect localized temperature increase
Smart insole	[29]	Early detection sensitivities	Smart insole + machine learning	Predicts ulcer risk early
	[30]	Early detection sensitivities	Graphene smart insole for plantar temperature	Monitor plantar temperature chances
	[31]	Early detection sensitivities	Temperature-sensing insole	Identifies plantar thermal patterns
	[32]	Early detection sensitivities	Smart oximeter insole	Monitors tissue oxygenation
	[34]	Early detection sensitivities	Vibration insole	Improves sensory function and circulation
	[43]	Early detection sensitivities	Pedar Insole Sensor System	Assesses plantar pressure distribution
In-shoe pressure sensor	[36]	Early detection sensitivities	Insole pressure	Detect high-ris plantar pressure
	[41]	Early detection sensitivities	smart insole	Monitors pressure and temperature
	[42]	Early detection sensitivities	Wearable plantar pressure sensor	Tracks pressure continuously
	[46]	Foot therapy	3D-printed rocker midsoles and self-adjusting insoles	Redistributes plantar pressure
Remote temperature monitoring	[22]	Early detection sensitivities	Remote temperature monitoring device	Tracks temperature remotely
	[25]	Early detection sensitivities	Infrared thermography	Detect thermal assessment
	[26]	Early detection sensitivities	Smart shoes (IoT)	Provides real-time pressure monitoring
	[41]	Early detection sensitivities	Smart insoles	Detection abnormal pressure loading
	[45]	Early detection sensitivities	Thermography imaging protocol	Thermal assessment
Digital applications/ mHealth	[35]	Foot therapy	Web exercise program	Enhances circulation and mobility
	[37]	Education	mHealth App: wound photos, temperature, digital forms	Supports monitoring and self-care
	[38]	Education and monitoring	Digital foot management app	Improves self-care adherence
Machine learning/AI	[23]	Early detection sensitivities	Machine learning algorithm	Identifies risk patterns
	[27]	Early detection sensitivities	Deep learning	Improves risk prediction accuracy
Electrophysical therapy	[39]	Foot therapy	Electrophysical therapy module (electrical stimulation device)	Enhances blood flow
Vibration therapy	[40]	Foot therapy	Vibration therapy	Stimulates nerves and circulation

Note. IC: Instrumental category & S: Study

Digital applications and m-health

Currently, there are many digital applications being developed, including self-monitoring and remote intervention for DFU. Based on research conducted in [37], there is an mHealth application with features for taking pictures of foot wounds, monitoring foot temperature, and filling out questionnaire forms in 1 application. In addition, this mHealth application is useful for improving communication between patients and health workers through automatic data transmission [6. In addition to monitoring applications, there are also applications used to educate diabetes mellitus patients in order to prevent increasingly severe complications, the contents of this education include foot care methods and daily reminders [33]. Latest innovations in web-based foot exercise interventions that have been developed include remote monitoring and can be carried out independently by patients so that time and costs are more efficient [35].

Machine learning and artificial intelligence

Machine learning is used to prevent DFU by utilizing physiological data to identify plantar temperature. The data in this instrument includes various aspects such as DFU history, plantar pressure data, and plantar temperature. Early detection of DFU risk can significantly reduce diagnostic delays and increases patient motivation to seek treatment tailored to each individual's condition [27, 48-50]. The use of AI embedded in wearable devices is equipped with an early warning system regarding ulcer risk test result [26].

Preventive therapy for diabetic foot ulcer

Electrophysical therapy and vibration therapy are potential supportive interventions in the prevention of DFU. Electrophysical therapy was performed by attaching electrodes to the feet for 20-30 minutes per day for approximately 4 weeks. This procedure increases peripheral blood flow and prevents ischemia. There is also vibration therapy (RelaWave), which applies vibrations at a frequency of 47 Hz to the feet area. This therapy is beneficial to increases foot sensitivity in patients with diabetes mellitus [40].

DISCUSSION AND CONCLUSIONS

Elderly patients, those with decreased kidney function, and long-standing diabetic patients are at high risk of developing chronic complications, one of which is cardiovascular autonomic neuropathy [51, 52]. This condition is usually accompanied by peripheral neuropathy, microcirculatory disorders, and decreased sensory function, which increases vulnerability to trauma and worsens the wound healing process in the lower extremities [53]. This combination of factors directly contributes to the increases of the risk of DFU, supporting the urgency of the implementation of smart technologies such as pressure sensors, skin temperature monitoring, and blood flow detection systems for early detection and prevention of complications in high-risk diabetic patients' feet [54].

Based on the review of articles included in this study, the concept of prevention is not limited to conditions before the disease occurs but also encompasses early detection, risk factor control, progression prevention, and recurrence prevention. The prevention approach classifies prevention into three levels: primary, secondary, and tertiary. Within this framework, prevention is not limited to conditions before the disease occurs but also encompasses early detection, risk control, and prevention of progression and recurrence. Primary prevention includes interventions to reduce risk factors before an ulcer occurs. Interventions at this stage focus on increasing patient knowledge, behavioral change, and self-management skills. The technology used at this stage typically takes the form of digital-based education and self-monitoring tools, such as mobile diabetes self-management apps with features including foot care education and daily reminders. Additionally, wearable devices such as smart insoles can be used to connect foot pressure in diabetic patients and monitor physical activity.

Secondary prevention focuses on early detection of early signs of diabetic foot complications before they develop into ulcer. At this stage, technology is designed to identify physiological changes quickly and objectively. Examples of currently widely used devices include vibration-based neuropathy screening devices or sensor-based vibration devices to detect decreased sensation, infrared-based foot temperature sensors, and mobile applications with machine learning-based image analysis features to detect changes in skin color and structure.

Tertiary prevention encompasses efforts to prevent wound progression, recurrence (re-ulceration), and further complications in patients who have already experienced ulcer. Technology plays a role in ongoing monitoring and remote management. Devices used in this prevention process include digital wound monitoring systems utilizing machine learning (digital wounds imaging) for regular wound monitoring and remote monitoring by healthcare professionals. Based on these three prevention classifications, the integration of various technologies at each level of prevention demonstrates that a digital-based approach not only supports early detection but also strengthens continuity of care and patient empowerment.

Early detection of decreased sensitivity in the feet is key to preventing diabetic ulcer. Early detection can identify and categorize patients into high-risk categories before irreversible tissue damage occurs. Through routine screening, patients and healthcare providers can identify gradual decreased sensation and thus determine further interventions for early prevention. Early detection plays a crucial role in slowing the progression of neuropathy through regular monitoring and tailoring interventions. Early detection serves not only as a diagnostic tool but also as a preventive component to reduce the incidence of diabetic ulcer [55].

Integrating early detection and physiological intervention is a crucial strategy in preventing complications of diabetic ulcer. Sensory stimuli, such as vibration therapy, play a crucial role in preventive interventions. Rhythmic mechanical stimulation can improve peripheral circulation through vascular vasodilation and increased microvascular blood flow, which can improve oxygen supply and nourish nerve tissue [32]. Vibration therapy works through mechanoreceptors, namely Pacinian corpuscles, which are sensitive to high-frequency vibration stimulation. This can activate receptors, triggering afferent impulses to the central nervous system and enhancing peripheral neuromuscular responses [56]. Mechanical stimulation can also increases nitric oxide, which plays a role in vasodilation and improving endothelial function [40]. In the digital era, various digital innovations are currently available for diabetic ulcer prevention.

This study systematically reviewed various smart technology innovations used in the prevention of DFU. Based on the 25 articles analyzed, the feasibility assessment showed that all articles met the criteria, evaluated with the JBI experimental study checklist with a score higher than 75%. The results shows that usage of smart technology-based devices plays a crucial role in the early detection and monitoring of diabetic foot conditions. Currently, available technology to monitor DFU allows routine monitoring and faster healing [16].

In recent years, development of DFU prevention tools has shown a paradigm shift from conventional approaches to digital technology approaches. Tools that previously relied on manual evaluation are now developed in the form of devices, digital applications, web-based systems, and smart technologies integrated with electronic medical records. This transformation's purpose is to increases the accuracy of risk identification, improve the efficiency of the monitoring process, and support the care of diabetes patients [50]. Various devices have been designed to measure physiological parameters directly related to the risk of ulcer development, namely skin surface temperature, pressure distribution over the soles of the feet, humidity, and skin color characteristics change. By monitoring these parameters, these devices function as screening tools capable of identifying early changes before the ulcer becomes clinically obvious [57].

One of the device type that has been widely developed is a temperature and pressure sensor that's integrated into shoes or smart insoles. Devices with such specifications can monitor pressure patterns and local temperature increases in specific areas of the foot, which are acknowledged as early indicators of inflammation and high risk ulcer development. Data results are objective and continuous, allowing health workers to identify high-risk areas of the foot more accurately compared to conventional methods [58].

Developments in imaging technology and optical sensors have also been used in the development of devices for DFU prevention. Some devices implement thermal cameras or optical scanning technology to detect changes in tissue such as temperature and blood flow in the feet of diabetic patients. This approach is non-invasive and allows a more comprehensive assessment of foot conditions, whether in healthcare facilities or by patients themselves at home [26].

By integrating digital systems and mobile applications in DFU prevention devices, their role as clinical tools are further expanded. Data from these devices can be automatically transmitted to health information systems or applications used by patients and health workers. This integration supports remote monitoring, early warning systems, and real-time data-driven clinical decision-making, which enables faster and more accurate preventive interventions [28].

Despite its big potential, the implementation of devices as DFU prevention tools still faces numerous challenges. Factors such as user comfort, device procurement cost, sensor accuracy and stability, and patient acceptance are critical aspects that affects the success of the implementation [58]. Comprehensive clinical validation and reliability assessment are also necessary to ensure that the resulting data can be used safely, and effectively as the basis for decision making in medical and nursing practice.

Digital technology in DFU prevention plays a crucial role in improving early detection of changes in foot condition that are often missed during routine examinations. Clinically, the use of plantar temperature and foot pressure sensors allows identification of at-risk areas before tissue damage occurs, particularly in patients with peripheral neuropathy who experience decreased protective sensation. Furthermore, stimulation-based interventions, such as vibration therapy, are beginning to show potential in improving sensory function. Mechanical vibration works by stimulating mechanoreceptors in the skin, specifically Pacinian and Meissner's corpuscles, which play a role in the perception of pressure and vibration. This stimulation can improve peripheral nerve conduction through the activation of A-beta nerve fibers and facilitate neuroplasticity, contributing to increased sensory sensitivity [56].

Based on a pathophysiological perspective, diabetic neuropathy causes decreased perception of pain and pressure, making patients unaware of repeated trauma to the foot, ultimately leading to ulcer formation. Regular vibration stimulation can raise the threshold of sensory perception, enhance proprioception, and increases peripheral blood flow through local vasodilation [59]. This increased tissue perfusion contributes to better oxygen and nutrient supply, thus supporting tissue integrity and reducing the risk of skin damage. Thus, vibration-based interventions not only play a role in improving sensory function but also have clinical significance in breaking the chain of pathogenesis of DFU.

Overall, it's crucial to increases the quality of device development for diabetic foot ucer prevention strategies in order to improve the quality of diabetic foot complication prevention efforts. Devices capable of detecting risks early, integrated with digital systems, and easy to use are potential support to patient-safety oriented and technology-based nursing practice. Therefore, development and implementation of these devices must be done continuously, with clinical, technological, and user aspects in mind.

Limitations

This scoping review has a major limitation related to the limited number of studies available, given that digital innovation in the prevention of DFU is a relatively new and evolving field. This condition limits the breadth of evidence that can be mapped, so that the variety of instruments and findings collected cannot fully describe the overall potential of the technology.

Author contributions: OSP: conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, software, supervision, validation, visualization, writing – original draft, writing – review & editing; **N:** conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, resources, software, supervision, validation, visualization, writing – original draft, writing – review & editing; **ASW:** conceptualization, formal analysis, methodology, project administration, software, validation, visualization, writing – original draft, writing – review & editing. All authors have agreed with the results and conclusions.

Funding: This study was supported by the Direktorat Penelitian dan Pengabdian Kepada Masyarakat, Direktorat Jenderal Riset dan Pengembangan, Ministry of Higher Education, Science and Technology, Indonesia Decree number 0419/C3/DT.05.00/2025, and contract agreement number 059/C3/DT.05.00/PL/2025; 2396/B/UN3.LPPM/PT.01.03/2025.

Acknowledgments: The authors would like to thank the Direktorat Penelitian dan Pengabdian Kepada Masyarakat, Direktorat Jenderal Riset dan Pengembangan, Ministry of Higher Education, Science and Technology, Indonesia for its financial support, which made this research possible. The author also thanks to Universitas Airlangga and Universitas Muhammadiyah Surakarta for facilitating the research process.

Ethical statement: As this study is a scoping review based exclusively on secondary data from previously published scientific literature, ethical approval and informed consent were not required.

AI statement: Generative AI was used solely to assist with language editing. The entire manuscript, including research design, literature search, article selection, data extraction, analysis, interpretation of results, and preparation of the final manuscript, was conducted and verified by the authors.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

1. Crawford F, Nicolson DJ, Amanna AE, et al. Preventing foot ulceration in diabetes: Systematic review and meta-analyses of RCT data. Diabetologia. 2020;63(1):49-64. https://doi.org/10.1007/s00125-019-05020-7 PMid: 31773194 PMCid:PMC6890632
2. Pradipta RO, Wahyuni SD, Zulkarnain H, Efendi F, Chong MC. "I no longer feel that diabetes is the end of everything, but rather the beginning of a healthier lifestyle": Experience of type 2 diabetes mellitus patient to achieve glycemic control. Electron J Gen Med. 2025;22(6):em705. https://doi.org/10.29333/ejgm/17498
3. Zaki MG, Imaduddin H. Early classification of diabetes risk in productive age groups using machine learning. J Sci Technol Res. 2026;2(1 SE-Articles):75-90. https://doi.org/10.23917/saintek.v2i1.16430
4. Cahyono TD, Purwanti OS. Hubungan lama menderita diabetes melitus dengan nilai ankle brachial index [The relationship between the duration of diabetes mellitus and the ankle brachial index value]. J Nurs Sci News. 2019;12(2):65-71. https://doi.org/10.23917/bik.v12i2.9803
5. Dewi GAPK, Faozi E. An overview: Quality of life of diabetes mellitus type 2 patients who participate in the prolanis program in Sukoharjo Regency. J Nurs Sci News. 2023;16(1 SE-Articles):29-38. https://doi.org/10.23917/bik.v16i1.762
6. Ismail MH, Yulian V. Pengaruh dukungan kelompok terhadap kualitas hidup penderita diabetes melitus [The influence of group support on the quality of life of diabetes mellitus sufferers]. J Nurs Sci News. 2019;12(2):51-8. https://doi.org/10.23917/bik.v12i2.9806
7. Ahmed A, Alvi SA, Aftab IB, Akhtar F. Bacterial diversity with emerging antimicrobial resistance of diabetic foot ulceration and current detection techniques: A review. Electron J Gen Med. 2021;18(6):em323. https://doi.org/10.29333/ejgm/11303
8. Purwanti OS, Nursalam, Pandin MGR. Early detection of diabetic neuropathy based on health belief model: A scoping review. Front Endocrinol. 2024;15. https://doi.org/10.3389/fendo.2024.1369699 PMid:38721145 PMCid: PMC11076868
9. Purwihantoro Sudarmaji W, Nursalam, Wulandari S. Identification of nursing problems in hospitalized patients with diabetes mellitus. J Nurs. 2020;15(1Sp SE-Original Article):480-5. https://doi.org/10.20473/jn.v15i1Sp.20516

10. Rondhianto R, Nursalam, Kusnanto K, Melaniani S, Ahsan A. Analysis of the sociodemographic and psychological factors of the family caregivers' self-management capabilities for type 2 diabetes mellitus. J Nurs. 2020;14(2 SE-Original Article):215-23. https://doi.org/10.20473/jn.v14i2.16592
11. Aisyah R, Bestari RS. Peningkatan pengetahuan masyarakat tentang prevalensi dan faktor risiko diabetes melitus serta upaya pencegahannya melalui edukasi [Increasing public knowledge about the prevalence and risk factors of diabetes mellitus and prevention efforts through education]. J Med Commun Serv. 2023;3(1 SE-Articles):35-40. https://doi.org/10.23917/jpmmedika.v3i1.1587
12. Glover K, Stratakos AC, Varadi A, Lamprou DA. 3D scaffolds in the treatment of diabetic foot ulcers: New trends vs conventional approaches. Int J Pharm. 2021;599:120423. https://doi.org/10.1016/j.ijpharm.2021.120423 PMid:33647412
13. Vossen LE, van Netten JJ, Bakker CD, et al. An integrated personalized assistive devices approach to reduce the risk of foot ulcer recurrence in diabetes (DIASSIST): Study protocol for a multicenter randomized controlled trial. Trials. 2023;24:663. https://doi.org/10.1186/s13063-023-07635-z PMid:37828618 PMCid:PMC10568814
14. Luo B, Cai Y, Chen D, et al. Effects of special therapeutic footwear on the prevention of diabetic foot ulcers: A systematic review and meta-analysis of randomized controlled trials. J Diabetes Res. 2022;2022:9742665. https://doi.org/10.1155/2022/9742665 PMid:36204487 PMCid:PMC9530919
15. Beach C, Cooper G, Weightman A, Hodson-Tole EF, Reeves ND, Casson AJ. Monitoring of dynamic plantar foot temperatures in diabetes with personalised 3D-printed wearables. Sensors (Basel). 2021;21(5):1717. https://doi.org/10.3390/s21051717 PMid:33801346 PMCid:PMC7958320
16. Obilor HN, Achore M, Woo K. Use of information communication technology tools in diabetic foot ulcer prevention programs: A scoping review. Can J Diabetes. 2022;46(5):535-48.e5. https://doi.org/10.1016/j.jcjd.2021.11.009 PMid:35739048
17. Lazarou I, Fiska V, Mpaltadoros L, et al. Stepping forward: A scoping systematic literature review on the health outcomes of smart sensor technologies for diabetic foot ulcers. Sensors (Basel). 2024;24(6):2009. https://doi.org/10.3390/s24062009 PMid:38544271 PMCid:PMC10975978
18. Baumann LC, Ylinen A. Prevention: Primary, secondary, tertiary BT – Encyclopedia of behavioral medicine. New York, NY: Springer; 2017. https://doi.org/10.1007/978-1-4614-6439-6_135-2
19. Bus SA, Sacco ICN, Monteiro-Soares M, et al. Guidelines on the prevention of foot ulcers in persons with diabetes (IWGDF 2023 update). Diabetes Metab Res Rev. 2023;40(3):e3651. https://doi.org/10.1002/dmrr.3651 PMid:37302121
20. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ. 2021;372:n71. https://doi.org/10.1136/bmj.n71 PMid:33782057 PMCid:PMC8005924
21. Peters MDJ, Marnie C, Tricco AC, et al. Updated methodological guidance for the conduct of scoping reviews. JBI Evid Synth. 2020;18(10):2119-26. https://doi.org/10.11124/JBIES-20-00167 PMid:33038124
22. Killeen AL, Brock KM, Dancho JF, Walters JL. Remote temperature monitoring in patients with visual impairment due to diabetes mellitus: A proposed improvement to current standard of care for prevention of diabetic foot ulcers. J Diabetes Sci Technol. 2020;14(1):37-45. https://doi.org/10.1177/1932296819848769 PMid:31122064 PMCid:PMC7189171
23. Hong S, Chen Y, Lin Y, et al. Personalized prediction of diabetic foot ulcer recurrence in elderly individuals using machine learning paradigms. Technol Health Care. 2024;32(S1):265-76. https://doi.org/10.3233/THC-248023 PMid:38759055 PMCid:PMC11191519
24. 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 Discov Ther. 2022;16(4):169-76. https://doi.org/10.5582/ddt.2022.01050 PMid:36002308
25. Kurkela O, Lahtela J, Arffman M, Forma L. Infrared thermography compared to standard care in the prevention and care of diabetic foot: A cost analysis utilizing real-world data and an expert panel. Clinicoecon Outcomes Res. 2023;15:111-23. https://doi.org/10.2147/CEOR.S396137 PMid:36855751 PMCid:PMC9968423
26. Ghazi RF, Chiad JS, Abdulghani FM. Design and manufacturing a smart shoe for diabetic foot ulcer monitoring and prediction system using internet-of-things technology. J Braz Soc Mech Sci Eng. 2024;46(2):83. https://doi.org/10.1007/s40430-023-04591-2
27. Fadhel MA, Alzubaidi L, Gu Y, Santamaría J, Duan Y. Real-time diabetic foot ulcer classification based on deep learning & parallel hardware computational tools. Multimed Tools Appl. 2024;83(27):70369-94. https://doi.org/10.1007/s11042-024-18304-x
28. Billings J, Gee J, Ghulam Z, Abdullah HA. Smart compression sock for early detection of diabetic foot ulcers. Sensors (Basel). 2024;24(21):6928. https://doi.org/10.3390/s24216928 PMid:39517824 PMCid:PMC11548053
29. Agrawal DK, Jongpinit W, Pojprapai S, et al. Smart insole-based plantar pressure analysis for healthy and diabetic feet classification: Statistical vs. machine learning approaches. Technologies. 2024;12(11):231. https://doi.org/10.3390/technologies12110231
30. Khandakar A, Faisal AA, Chowdhury MEH, et al. Laser-induced graphene-based smart insole to measure plantar temperature. IEEE Sens J. 2024;24(2):1190-9. https://doi.org/10.1109/JSEN.2023.3317768
31. Burokiene N, Guzaitis J, Boulton AJM, et al. Foot temperature measurement in people with diabetes: Validation of a non-contact thermal device. J Diabetes Sci Technol. 2025. https://doi.org/10.1177/19322968251398863 PMid:41368767 PMCid:PMC12695588
32. Panahi M, Masihi S, Hanson AJ, et al. Development of a flexible smart wearable oximeter insole for monitoring SpO_2 levels of diabetics' foot ulcer. IEEE J Flex Electron. 2022;2(2):61-70. https://doi.org/10.1109/JFLEX.2022.3232465
33. Torreblanca González J, Gómez-Martín B, Hernández Encinas A, Martín-Vaquero J, Queiruga-Dios A, Martínez-Nova A. The use of infrared thermography to develop and assess a wearable sock and monitor foot temperature in diabetic subjects. Sensors (Basel). 2021;21(5):1821. https://doi.org/10.3390/s21051821 PMid:33807804 PMCid:PMC7961733

34. Ennion L, Hijmans JM. Retention of improved plantar sensation in patients with type II diabetes mellitus and sensory peripheral neuropathy after one month of vibrating insole therapy: A pilot study. Sensors (Basel). 2024;24(10):3131. https://doi.org/10.3390/s24103131 PMid:38793985 PMCid:PMC11125190
35. Cruvinel-Júnior RH, Ferreira JSSP, Veríssimo JL, et al. Affordable web-based foot-ankle exercise program proves effective for diabetic foot care in a randomized controlled trial with economic evaluation. Sci Rep. 2024;14:16094. https://doi.org/10.1038/s41598-024-67176-6 PMid: 38997439 PMCid:PMC11245594
36. Tang J, Bader DL, Moser D, et al. A wearable insole system to measure plantar pressure and shear for people with diabetes. Sensors (Basel). 2023;23(6):3126. https://doi.org/10.3390/s23063126 PMid:36991838 PMCid:PMC10056665
37. Haycocks S, Cameron R, Edge M, Budd J, Chadwick P. Implementation of a novel mHealth application for the management of people with diabetes and recently healed foot ulceration: A feasibility study. Digit Health. 2022;8:20552076221142104. https://doi.org/10.1177/20552076221142103 PMid:36506489 PMCid:PMC9732796
38. Chen S-M, Jo Wu C-J. Investigating the effects of digital foot self-management program on enhancing self-efficacy and self-care behavior among community-dwelling older adults with type 2 diabetes: A randomized controlled trial. Digit Health. 2023;9:20552076231220790. https://doi.org/10.1177/20552076231220791 PMid:38107978 PMCid: PMC10722916
39. Dewi Astuti A, Utama NR, Aridamayanti BG. Diabetic ulcers prevention in the elderly for improving blood circulation of lower extremities with combination foot exercise therapy and electrophysical therapy. Bali Med J. 2023;12(1):737-43. https://doi.org/10.15562/bmj.v12i1.4099
40. Syabariyah S, Nurachmah E, Widjojo BD, et al. The effect of vibration on the acceleration of wound healing of diabetic neuropathic foot ulcer: A prospective experimental study on human patients. Healthcare (Basel). 2023;11(2):191. https://doi.org/10.3390/healthcare11020191 PMid: 36673559 PMCid:PMC9859045
41. De Pascali C, Francioso L, Giampetruzzi L, et al. Modeling, fabrication and integration of wearable smart sensors in a monitoring platform for diabetic patients. Sensors (Basel). 2021;21(5):1847. https://doi.org/10.3390/s21051847 PMid: 33800949 PMCid:PMC7962045
42. Chen H-C, Sunardi, Liau B-Y, et al. Estimation of various walking intensities based on wearable plantar pressure sensors using artificial neural networks. Sensors (Basel). 2021;21(19):6513. https://doi.org/10.3390/s21196513 PMid:34640838 PMCid:PMC8512589
43. Shi QQ, Li PL, Yick K-L, Li N-W, Jiao J. Effects of contoured insoles with different materials on plantar pressure offloading in diabetic elderly during gait. Sci Rep. 2022;12:15395. https://doi.org/10.1038/s41598-022-19814-0 PMid:36100637 PMCid:PMC9470545
44. Jais S, Pratama K, Pradika J, Haryanto H. The validity and efficacy of a preventative intervention model for reducing ulcer recurrence in diabetic patients in Indonesia. SAGE Open Nurs. 2023;9:23779608231179548. https://doi.org/10.1177/23779608231179549 PMid:37334064 PMCid: PMC10272669
45. Aminuddin M, Sukarni, Haryanto, et al. Effectiveness of online education on thermography-based diabetic foot ulcer prevention for wound care specialists: A single-group quasi-experimental study. Diabetol Int. 2025;16(2):356-64. https://doi.org/10.1007/s13340-025-00791-4 PMid: 40166452 PMCid:PMC11954768
46. Malki A, Baltasar Badaya M, Dekker R, Verkerke GJ, Hijmans JM. Effects of individually optimized rocker midsoles and self-adjusting insoles on dynamic stability in persons with diabetes mellitus and neuropathy. Gait Posture. 2024;112:154-8. https://doi.org/10.1016/j.gaitpost.2024.05.011 PMid:38795476
47. Reyzelman AM, Shih C-D, Tovmassian G, et al. An evaluation of real-world smart sock–based temperature monitoring data as a physiological indicator of early diabetic foot injury: Case-control study. JMIR Form Res. 2022;6(4):e31870. https://doi.org/10.2196/31870 PMid: 35363148 PMCid:PMC9015780
48. Anisuzzaman D, Patel Y, Rostami B, Niezgoda J, Gopalakrishnan S, Yu Z. Multi-modal wound classification using wound image and location by deep neural network. Sci Rep. 2021;12:20057. https://doi.org/10.1038/s41598-022-21813-0 PMid:36414660 PMCid:PMC9681740
49. Mousa K, Mousa F, Mohamed HS, Elsawy M. Prediction of foot ulcers using artificial intelligence for diabetic patients at Cairo University Hospital, Egypt. SAGE Open Nurs. 2023;9:23779608231185873. https://doi.org/10.1177/23779608231185873 PMid:37435577 PMCid:PMC10331222
50. Tulloch J, Zamani R, Akrami M. Machine learning in the prevention, diagnosis and management of diabetic foot ulcers: A systematic review. IEEE Access. 2020;8:198977-9000. https://doi.org/10.1109/ACCESS.2020.3035327
51. Muhalla HI, Nursalam, Yusuf A, et al. Effectiveness of a health education program in managing diabetes mellitus and preventing renal complications. Iran J War Public Health. 2025;17(1):37-42. https://doi.org/10.58209/ijwph.17.1.37
52. Kanbay M, Copur S, Topçu AU, et al. An update review of post-transplant diabetes mellitus: Concept, risk factors, clinical implications and management. Diabetes Obes Metab. 2024;26(7):2531-45. https://doi.org/10.1111/dom.15575 PMid:38558257
53. Everett B, Liden B, Bray E. Novel plantar sensory insoles providing physiologic data and remote patient monitoring to prevent foot ulcer recurrence and guide treatment plans in patients with diabetic peripheral neuropathy. Can J Diabetes. 2022;46(7):S12. https://doi.org/10.1016/j.jcjd.2022.09.033
54. Fournier C, Singbo N, Morissette N, Thibeault M-M. Outcomes of diabetic foot ulcers in a tertiary referral interdisciplinary clinic: A retrospective Canadian study. Can J Diabetes. 2021;45(3):255-60. https://doi.org/10.1016/j.jcjd.2020.09.004 PMid:33160884
55. Ming A, Walter I, Alhajjar A, Leuckert M, Mertens PR. Study protocol for a randomized controlled trial to test for preventive effects of diabetic foot ulceration by telemedicine that includes sensor-equipped insoles combined with photo documentation. Trials. 2019;20(1):521. https://doi.org/10.1186/s13063-019-3623-x PMid:31439007 PMCid:PMC6704693
56. Purwanti OS, Nursalam, Wahyudi AS. Vibration perception threshold as tool to detect neuropathy diabetic: A scoping review. J Liaquat Univ Med Health Sci. 2025:15-21. https://doi.org/10.22442/JLUMHS.2025.01252

57. Doulamis A, Doulamis N, Angeli A, et al. A non-invasive photonics-based device for monitoring of diabetic foot ulcers: Architectural/Sensorial components & technical specifications. Inventions. 2021;6(2):27. https://doi.org/10.3390/inventions6020027
58. Kosaji D, Awad M, Katmah R, et al. Diabetic foot prevention, assessment, and management using innovative smart wearable technology: A systematic review. J Neuroeng Rehabil. 2025;22(1):168. https://doi.org/10.1186/s12984-025-01695-9 PMid:40682082 PMCid:PMC12273060
59. Deepshidha V, Agrawal VK. Transient receptor potential vanilloid 1 (TRPV1) receptor stimulation by topical capsaicin for the functional assessment of diabetic neuropathy leading to diabetic foot disease. Indian J Physiol Pharmacol. 2022;66(4):286-92. https://doi.org/10.25259/IJPP_468_2022