

Emerging Trends in Pressure Sensor-Integrated Smart Footwear for Fall Prevention in Diabetic Peripheral Neuropathy- A Comprehensive Review

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BACKGROUND

Diabetes mellitus (DM) is one of the most prevalent non-communicable diseases worldwide and continues to pose a major public health challenge because of its increasing prevalence and associated long-term complications. The World Health Organization (WHO) defines diabetes as a chronic metabolic disorder characterized by elevated blood glucose levels resulting from defects in insulin secretion, insulin action, or both. Persistent hyperglycaemia causes progressive damage to multiple organ systems, particularly the cardiovascular system, kidneys, eyes, peripheral nerves, and blood vessels, leading to considerable morbidity, disability, and mortality. According to the International Diabetes Federation (IDF), approximately 537 million adults aged 20–79 years were living with diabetes globally in 2021, and this number is projected to increase to 643 million by 2030 and 783 million by 2045. India has one of the largest populations affected by diabetes, with approximately 74.2 million adults living with the disease. Rapid urbanization, sedentary lifestyles, obesity, unhealthy dietary habits, population ageing, and genetic susceptibility have contributed significantly to the increasing burden of diabetes. Consequently, diabetes imposes substantial clinical, social, and economic burdens through chronic complications, reduced quality of life, and increased healthcare expenditure.^{1,3}

Diabetic peripheral neuropathy (DPN) is the most common microvascular complication of diabetes and is a leading cause of functional impairment among individuals with the disease. The Toronto Consensus defines DPN as the presence of symptoms and/or signs of peripheral nerve dysfunction in individuals with diabetes after excluding other possible causes of neuropathy. Chronic hyperglycaemia initiates a series of metabolic and vascular changes, including oxidative stress, inflammation, and microvascular dysfunction, resulting in progressive

peripheral nerve damage. Clinically, DPN is characterized by numbness, tingling, burning pain, muscle weakness, impaired vibration sense, diminished proprioception, and loss of protective sensation, particularly in the feet and lower limbs. These impairments adversely affect gait, balance, postural stability, and functional mobility, increasing the risk of falls and foot-related complications.

The prevalence of diabetic peripheral neuropathy is estimated to range from 30% to 50% among individuals with diabetes, depending on the diagnostic criteria and study population. Furthermore, approximately one-third of individuals with diabetic neuropathy develop foot ulcers during their lifetime, which significantly increases the risk of infection, hospitalization, and lower-limb amputation. Impaired plantar sensation, delayed reaction time, muscle weakness, and altered biomechanics contribute to abnormal gait patterns and poor balance, making falls a frequent and clinically important consequence of DPN. Falls in this population often result in fractures, fear of falling, reduced mobility, loss of independence, and deterioration in quality of life. Therefore, interventions that improve balance, gait stability, and plantar pressure distribution are essential components of comprehensive diabetic rehabilitation.^{3,6}

Conventional management of diabetic peripheral neuropathy includes strict glycemic control, pharmacological management of neuropathic pain, therapeutic footwear, patient education, exercise therapy, balance training, gait retraining, and routine foot care.

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Recent advances in wearable healthcare technology have led to the development of pressure-sensor footwear, providing clinicians with objective and continuous assessment of plantar loading and functional mobility. Pressure-sensor footwear is an emerging wearable technology designed to monitor plantar pressure distribution continuously during standing and walking. These intelligent footwear systems incorporate pressure sensors within the insole or shoe that detect excessive plantar loading, gait asymmetry, and abnormal walking patterns in real time. The collected information can be transmitted through smartphone applications or wireless systems and may provide immediate feedback using vibration, visual, or auditory signals. Such feedback enables individuals to modify their gait pattern, redistribute body weight, and reduce excessive pressure on vulnerable areas of the foot. In individuals with diabetic peripheral neuropathy, where plantar sensation is diminished, this external sensory feedback may compensate for sensory deficits, improve postural awareness, promote symmetrical gait, and reduce the risk of falls while simultaneously contributing to diabetic foot ulcer prevention. Continuous monitoring also enables clinicians to identify high-risk plantar pressure areas and develop individualized rehabilitation programs.^{7,9}

Recent studies indicate that pressure-sensor footwear and smart in-shoe monitoring systems can improve plantar pressure distribution, gait, balance, and postural control in individuals with diabetic peripheral neuropathy. While most studies have focused on preventing diabetic foot ulcers, growing evidence suggests that these devices may also help reduce fall risk by improving mobility and stability, making them a useful addition to physiotherapy. However, the available evidence is still inconsistent because of differences in study design, patient characteristics, sensor technology, interventions, and outcome measures. Therefore, this literature review aims to critically evaluate the current evidence on the effectiveness of pressure-sensor footwear in reducing fall risk among individuals with diabetic peripheral neuropathy and to provide guidance for clinical practice while identifying areas for future research.⁷

METHODS

A scoping review was undertaken to comprehensively evaluate the current evidence regarding the effectiveness of pressure-sensor footwear in reducing fall risk among individuals with diabetic peripheral neuropathy (DPN). The review was conducted in accordance with the

Table 1: *Summary of the articles based on level of evidence*

Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) guidelines to ensure a transparent and systematic approach to study identification, selection, and reporting.

A comprehensive electronic literature search was performed across six databases, PubMed, Google Scholar, ScienceDirect, MDPI, SAGE Journals, and ResearchGate, to identify relevant studies published between 2021 to 2026. The search strategy incorporated Medical Subject Headings (MeSH) terms and keywords combined using Boolean operators (AND/OR). The principal search terms included diabetic peripheral neuropathy, pressure-sensor footwear, smart footwear, intelligent insoles, wearable sensor technology, plantar pressure monitoring, gait analysis, balance assessment, postural stability, functional mobility, and fall risk. The studies were considered eligible if they investigated the clinical effectiveness of pressure-sensor footwear or intelligent in-shoe monitoring systems in adults with diabetic peripheral neuropathy. Randomized controlled trials, observational studies, case-control studies, prospective cohort studies, and systematic reviews with meta-analyses published in English were included.

The study selection process followed a structured PRISMA flow with 30 potentially relevant articles were identified through database searching. Scrutinizing the duplicate publications, 22 articles underwent title and abstract screening based on predefined inclusion and exclusion criteria. Full-text assessment was subsequently performed, resulting in 8 studies meeting the eligibility criteria for qualitative synthesis.

The methodological quality of the included studies was critically appraised using the Critical Appraisal Skills Programme (CASP) checklist with the score greater than 9 that were considered to have high methodological quality and were part of final qualitative analysis. Data extracted from the selected studies included study characteristics, participant demographics, intervention details, outcome measures, and key findings related to plantar pressure redistribution, gait performance, balance, postural stability, functional mobility, and fall risk. The findings were synthesized narratively to provide a comprehensive evaluation of the available evidence and to identify current knowledge gaps and future research priorities.

LITERATURE REVIEW

Author & Year & Title	Study Design	Key Findings	Conclusion
Wang et al. (2026) "Multi-modal Sensor Fusion in Smart Footwear to Capture Altered Gait Dynamics in Patients with Diabetic Peripheral Neuropathy."	Observational study	Smart "Lab-in-Shoe" accurately assessed gait and plantar pressure, classifying DPN severity with 86.7% accuracy.	Smart footwear is a reliable tool for early detection of gait abnormalities, fall risk, and foot ulcer risk in DPN.
Savelieff et al. (2025) "The Global and Regional Burden of Diabetic Peripheral Neuropathy."	Systematic Literature review	DPN affects up to 50% of people with diabetes and increases risk of gait impairment, falls, and foot complications.	Early diagnosis and preventive strategies are essential to reduce disability and healthcare burden.
Hatton et al. (2024) "The Effects of Vibrating Shoe Insoles on Standing Balance, Walking, and Ankle-Foot Muscle Activity in Adults with Diabetic Peripheral Neuropathy."	Randomized crossover study	Reduced postural sway and ankle muscle activity, indicating improved balance through enhanced sensory feedback.	Vibrating insoles show promise as a rehabilitation strategy for improving balance in DPN.
Zwaferink et al. (2024) "In-Shoe Pressure Measurements in Diabetic Footwear Practice: Success Rate and Facilitators of and Barriers to Implementation."	Observational study	In-shoe pressure measurement was feasible in clinical practice, with cost and technical issues as barriers.	In-shoe pressure measurement is feasible in clinical practice, when implementation barriers are addressed
Castro-Martins et al. (2024) "In-Shoe Plantar Pressure Measurement Technologies for the Diabetic Foot."	Systematic review	Resistive sensor insoles were the most commonly used and effective for plantar pressure monitoring	Reliable plantar pressure monitoring supports individualized diabetic foot management and ulcer prevention.
Pan Q et al., (2023)."Application of Wearable Technologies in Fall Risk Assessment and Improvement in Patients with Peripheral Neuropathy."	Systematic review	Eight studies showed wearable sensors (mainly accelerometers) improved gait, balance, and reduced fall risk in peripheral neuropathy.	Wearable technologies are promising for fall risk assessment and rehabilitation in peripheral neuropathy.
Khan&Andersen et al.(2022)"The Impact of Diabetic Neuropathy on Activities of Daily Living, Postural Balance and Risk of Falls."	Systematic review	Diabetic neuropathy impaired balance and gait, increasing fall risk.	Early management is needed to reduce falls and improve function.
Chatwin et al. (2021) "An Intelligent Insole System with Personalized Digital Feedback Reduces Foot Pressures During Daily Life."	Randomized controlled trial	Intelligent pressure-sensing insoles reduced high plantar pressure episodes.	Intelligent insoles effectively reduce plantar loading and may help prevent recurrent diabetic foot ulcers in high-risk patients.

RESULTS

The 30 articles were identified through electronic database search and undergone the process of screening for duplicate records, full text articles, English language, relevant titles and abstracts. A qualitative analysis of 8 articles included four systematic reviews (37.5%) that supported the use of wearable sensor technologies and in-shoe plantar pressure monitoring for improving gait assessment, balance evaluation, and fall risk detection. Two observational studies (25%) demonstrated that smart footwear effectively detected gait abnormalities, plantar pressure changes, and the severity of diabetic peripheral neuropathy. One randomized controlled trial (12.5%) showed that personalized pressure-feedback insoles significantly reduced high plantar pressure episodes during daily activities. One randomized crossover study (12.5%) reported significant improvements in standing balance and ankle-foot muscle activity with vibrating insoles.

Several studies reported improvements in gait

characteristics, balance performance, and postural stability following the use of wearable sensor technologies. Vibrating shoe insoles enhanced standing balance and neuromuscular control by providing additional sensory feedback to the plantar surface of the foot. Intelligent pressure-sensing insoles reduced the duration and frequency of prolonged high-pressure episodes, suggesting improved pressure off-loading behavior and greater protection against diabetic foot complications. The findings demonstrated that pressure-sensor footwear and intelligent in-shoe pressure monitoring systems effectively identified areas of excessive plantar pressure during standing and walking. Continuous plantar pressure monitoring enabled early detection of abnormal pressure distribution and gait abnormalities, allowing timely intervention to improve weight redistribution and reduce mechanical stress on the foot. Smart footwear systems also provided real-time visual, auditory, or vibratory feedback, encouraging users to modify their walking pattern and improve plantar loading during daily activities.

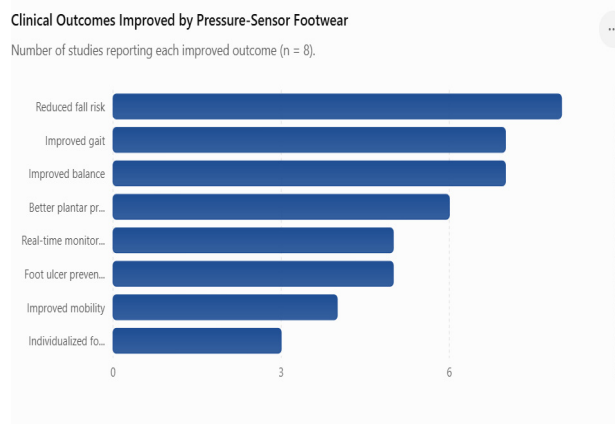


Fig1: Clinical outcomes improve by pressure – sensor footwear (n=8)

DISCUSSION

Pressure-sensor footwear and wearable sensors show promise in reducing fall risk and improving foot health in individuals with diabetic peripheral neuropathy (DPN). These technologies enable continuous plantar pressure monitoring, real-time feedback, and objective gait and balance assessment. However, their widespread use is limited by cost, accessibility, calibration needs, and patient adherence. Current evidence is also constrained by small sample sizes and short follow-up periods. Larger, long-term randomized controlled trials are needed to confirm their effectiveness and establish standardized clinical protocols.

CONCLUSION

The comprehensive review of the literature highlights that Pressure-sensor footwear represents a promising

intervention. Based on current evidences the components that effects by pressure sensor foot wear are fall risk reduction, improvement in gait and balance, better plantar pressure distribution, real-time monitoring , foot ulcer prevention, improved mobility and individualized intervention. Hence these findings indicate that pressure sensor footwear is an effective tool for reducing fall risk and improving quality of life among patients with Diabetic Peripheral Neuropathy. Overall, the reviewed evidence indicated that pressure-sensor footwear is a promising technology for improving plantar pressure distribution, gait performance, balance, and postural stability in individuals with diabetic peripheral neuropathy. The findings also suggested that integrating wearable pressure-monitoring systems into rehabilitation programs may contribute to safer mobility, improved foot protection, and a reduction in factors associated with fall risk.

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