Review Article
DOI: https://doi.org/10.70749/ijbr.v3i6.1586

INDUS JOURNAL OF BIOSCIENCE RESEARCH
https://induspublishers.com/IJBR
ISSN: 2960-2793/ 2960-2807

Association Between Diabetic Peripheral Neuropathy and Risk of Falls in Adults with Type 2 Diabetes: A Narrative Review

Faisal Wali Ahmed[1], Aakash Mahato[2], Jawad Mahmood[3], Mahnoor Akram[4], Abdullah Amir Basra[5], Fatima Tuz Zahra[6], Muhammad Usairam Cheema[7], Neelesh Taticherala[8], Maleeha Rehman[9], Zohaib Hassan[10]

[1]Department of Critical Care Medicine, King Saud Medical City, Riyadh, Saudi Arabia.
[2]Mirbat Hospital, Ministry of Health, Mirbat, Oman.
[3]Central Park Medical College, Lahore, Punjab, Pakistan.
[4]Islamabad Medical and Dental College, Islamabad, Pakistan.
[5]Akhtar Saeed Medical and Dental College, Lahore, Punjab, Pakistan.
[6]Combined Institute of Medical Sciences, CMH, Multan, Punjab, Pakistan.
[7]Department of General Medicine, Services Institute of Medical Sciences, Lahore, Punjab, Pakistan.
[8]Medical College of Xiamen University, Xiamen, China.
[9]Rashid Latif Khan University Medical College, Lahore, Punjab, Pakistan.
[10]Department of Cardiology, Sundas Foundation, Gujranwala, Punjab, Pakistan.

ARTICLE INFO

Keywords: Diabetic Peripheral Neuropathy, Type 2 Diabetes, Falls, Balance Impairment.

Correspondence to: Zohaib Hassan
Department of Cardiology, Sundas Foundation, Gujranwala, Punjab, Pakistan.
Email: drzohaibhassan197@gmail.com

Declaration
Authors' Contribution
All authors equally contributed to the study and approved the final manuscript

Conflict of Interest: No conflict of interest.

Funding: No funding received by the authors.

Article History
Received: 28-03-2025 Revised: 23-05-2025
Accepted: 09-05-2025 Published: 17-06-2025

ABSTRACT

Background: Diabetic peripheral neuropathy (DPN) is a prevalent and debilitating complication of type 2 diabetes mellitus (T2DM), characterized by progressive sensory and motor deficits. These impairments significantly increase the risk of falls, which are a major cause of injury, disability, and reduced quality of life in this population. **Objective:** This narrative review aims to synthesize current clinical evidence on the association between DPN and fall risk, identify key mechanisms contributing to instability, and highlight tools and strategies for fall prevention. **Key Findings:** DPN contributes to falls through multiple pathways, including sensory loss, proprioceptive dysfunction, gait abnormalities, postural instability, and neuropathic pain. Clinical studies confirm a significantly higher fall incidence in individuals with DPN compared to diabetic patients without neuropathy. Validated tools such as the monofilament test, vibration perception threshold, and Timed Up and Go (TUG) test are effective in assessing fall risk. Preventive strategies including glycemic control, balance training, foot care, and assistive devices show promise but are underutilized. Limitations in current literature include reliance on cross-sectional designs, inconsistent definitions, and lack of inclusive or long-term data. **Conclusion:** DPN is a critical yet under-addressed risk factor for falls in adults with T2DM. Routine fall risk screening and comprehensive, multidisciplinary management approaches should be integrated into diabetic care to reduce fall-related morbidity and improve functional outcomes.

INTRODUCTION

Type 2 diabetes mellitus (T2DM) is a rapidly growing global health concern affecting over 537 million adults worldwide, with projections indicating a rise to 643 million by 2030 [1]. Among its many complications, diabetic peripheral neuropathy (DPN) is one of the most common and debilitating, affecting nearly 50% of individuals with long-standing diabetes [2]. DPN primarily involves sensory nerve damage, which disrupts proprioception and balance, significantly elevating the risk of falls—especially in older adults [3].

Falls represent a major source of injury, disability, and hospitalization among individuals with diabetes. Compared to non-diabetic counterparts, adults with diabetes are at a twofold higher risk of falling, with DPN playing a key mediating role [4]. As T2DM progresses, chronic hyperglycemia leads to microvascular damage and metabolic disturbances that impair nerve function. The resulting sensory loss, muscle weakness, and postural instability contribute directly to impaired balance and increased fall susceptibility [5].

DPN is often insidious in onset, with many patients unaware of the progressive sensory deficits affecting their feet and lower limbs. Reduced vibratory and pressure sensation, as well as delayed reaction times, compromise gait and increase the likelihood of stumbling on uneven surfaces [6]. Moreover, patients with DPN often exhibit altered gait patterns, including shorter steps, slower speed, and widened base of support, which are compensatory adaptations to maintain stability [7]. These

biomechanical changes, while protective in some contexts, can paradoxically predispose individuals to falls under certain environmental or physiological stressors.

In addition to physical impairments, cognitive decline, polypharmacy, and comorbidities such as visual disturbances and vestibular dysfunction further amplify the fall risk in diabetic populations [8]. The psychosocial consequences of falling—including fear of falling again, reduced mobility, and social withdrawal—can severely impact the quality of life and functional independence of patients with T2DM [9].

Despite the high prevalence and clinical significance of falls in diabetic patients, the specific contribution of DPN to fall risk remains under-recognized in routine care. Current diabetes management guidelines emphasize glycemic control and cardiovascular risk reduction, often overlooking fall risk assessments and preventive strategies in patients with neuropathy [10]. Early identification of DPN and implementation of fall-prevention interventions—such as balance training, foot care education, and assistive devices—can play a crucial role in minimizing disability and improving patient outcomes.

This narrative review aims to explore the association between diabetic peripheral neuropathy and the risk of falls in adults with type 2 diabetes. By synthesizing current evidence on the pathophysiological mechanisms, clinical features, and risk factors contributing to falls in this population, the review emphasizes the need for integrated screening and intervention approaches in diabetes care.

Pathophysiology of Diabetic Peripheral Neuropathy

Diabetic peripheral neuropathy (DPN) is one of the most common and debilitating microvascular complications of type 2 diabetes mellitus (T2DM), characterized by a progressive loss of nerve fiber function. The pathophysiological mechanisms underlying DPN are multifactorial and complex, involving metabolic, vascular, and inflammatory processes that collectively lead to nerve injury [11].

The development of DPN begins with chronic hyperglycemia, which induces metabolic disturbances such as increased formation of advanced glycation end products (AGEs), activation of the polyol pathway, and enhanced oxidative stress. These metabolic alterations lead to intracellular accumulation of sorbitol, depletion of myo-inositol, and impaired Na+/K±ATPase activity in neurons [12]. Oxidative stress, in particular, plays a critical role by generating reactive oxygen species (ROS) that damage cellular structures, including DNA, proteins, and lipids [13].

In addition to metabolic injury, hyperglycemia contributes to microvascular dysfunction by impairing endothelial nitric oxide production, increasing vascular permeability, and promoting capillary basement membrane thickening. This leads to reduced blood flow and oxygen delivery to peripheral nerves, a phenomenon termed endoneurial hypoxia [14]. Chronic ischemia and reduced neurotrophic support result in demyelination and axonal degeneration, particularly affecting the longest nerves first—typically those innervating the feet and lower limbs [15].

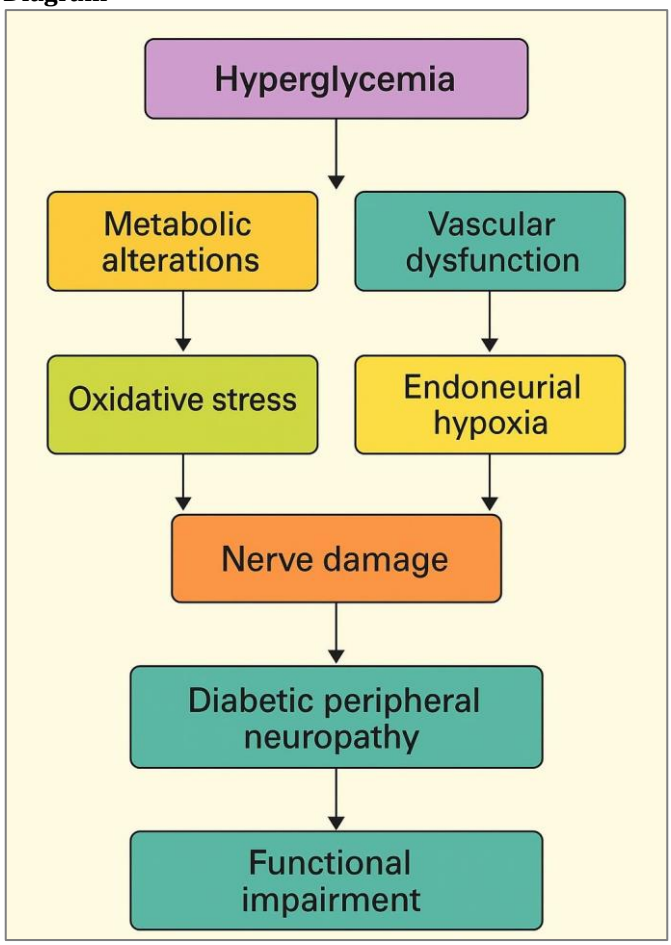
The immune-inflammatory axis is also implicated in DPN pathogenesis. Hyperglycemia triggers systemic low-grade inflammation characterized by increased levels of pro-inflammatory cytokines such as TNF-α, IL-6, and CRP. These mediators enhance vascular damage and sensitize nociceptors, contributing to neuropathic pain in many patients [16]. Moreover, dysfunction in mitochondrial energy metabolism and impaired calcium homeostasis further aggravate neuronal apoptosis and degeneration [17].

DPN predominantly affects sensory neurons but may also involve motor and autonomic fibers. Sensory damage is most common, leading to impaired detection of vibration, pressure, and temperature. As large-fiber neuropathy progresses, proprioception declines, compromising balance and coordination. Small-fiber involvement leads to burning pain, tingling, and altered thermal perception [18]. Motor nerve damage, although less frequent, results in distal muscle weakness and atrophy, contributing further to gait instability [19].

These pathological changes manifest clinically in the "stocking-glove" distribution of symptoms, typically beginning in the toes and progressing proximally. The combination of sensory loss, altered proprioception, and muscular imbalance creates a high-risk environment for falls, particularly in older adults with T2DM [20].

The diagram below summarizes the cascade of events from hyperglycemia to nerve damage and functional impairment:

Diagram



Understanding the multifactorial nature of DPN is critical for clinicians, as it not only guides therapeutic interventions but also highlights the importance of early detection and comprehensive management strategies. Despite advances in glycemic control and pharmacological therapies, prevention of DPN progression remains challenging, reinforcing the need for ongoing research and patient education.

Mechanisms Linking Diabetic Peripheral Neuropathy to Falls

Diabetic peripheral neuropathy (DPN) contributes to falls through multiple physiological and biomechanical mechanisms. The interplay of sensory deficits, motor impairments, and autonomic dysfunction results in compromised balance, delayed protective responses, and altered gait patterns—all of which elevate the risk of falling in adults with type 2 diabetes [21].

Sensory Impairment and Proprioceptive Loss

One of the primary mechanisms is large fiber sensory loss, particularly involving proprioception. Proprioceptive input from mechanoreceptors in the lower limbs helps maintain balance during movement and while standing. In DPN, damage to these fibers blunts the ability to perceive foot placement, joint angles, and surface irregularities, increasing instability [22]. As patients lose the capacity to detect ground contact and adjust posture accordingly, the likelihood of stumbling and losing balance rises significantly [23].

Gait Abnormalities and Muscle Weakness

DPN leads to changes in gait, such as reduced step length, slower walking speed, and a wider base of support. These alterations are often compensatory but reflect an underlying loss of coordination and confidence [24]. Weakness in the intrinsic muscles of the foot and distal leg muscles due to motor nerve involvement further diminishes push-off power and reduces balance during transitions like turning or stepping up [25].

Muscle atrophy—especially in the anterior tibialis and peroneal groups—leads to "foot drop" and increases the chance of tripping. These biomechanical impairments disrupt the smooth execution of walking and make patients more reliant on vision or external support for maintaining balance [26].

Altered Postural Reflexes

Postural control is an integrated function involving input from the visual, vestibular, and somatosensory systems. DPN disrupts the somatosensory pathway, and patients often develop delayed or ineffective postural responses to perturbations, especially during dual-task situations or in the presence of environmental hazards [27].

Clinical studies using tools like the Timed Up and Go (TUG) test and posturography platforms show significantly reduced stability and greater sway in patients with DPN compared to those without neuropathy [28].

Pain and Fear of Falling

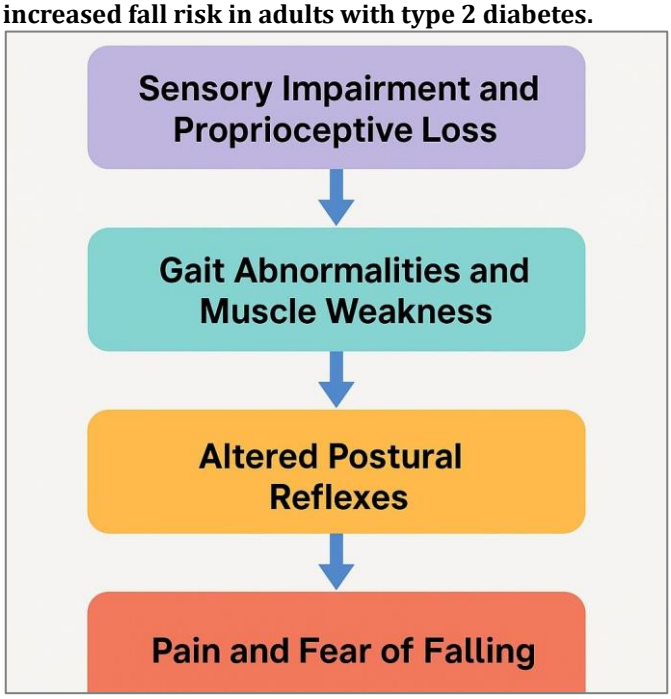
Neuropathic pain, a common symptom in DPN, can interfere with concentration and walking efficiency. It may cause individuals to adopt protective, but unsteady, postures. Additionally, fear of falling can lead to reduced mobility, deconditioning, and further loss of strength and balance—creating a vicious cycle [29].

Autonomic Dysfunction

Autonomic nerve damage in DPN may result in orthostatic hypotension, leading to dizziness and an increased likelihood of falling, particularly upon standing. Sudden drops in blood pressure can impair cerebral perfusion and compromise alertness and balance in elderly patients [30].

Together, these mechanisms create a multidimensional risk profile for falls in patients with DPN. Understanding these underlying physiological disruptions can help clinicians tailor effective prevention strategies, including balance training, strength rehabilitation, and gait assistance technologies.

Visual summary of major mechanisms by which diabetic peripheral neuropathy contributes to increased fall risk in adults with type 2 diabetes.



Evidence from Clinical Studies

Several clinical studies have examined the relationship between diabetic peripheral neuropathy (DPN) and increased risk of falls in adults with type 2 diabetes mellitus (T2DM). Evidence from both cross-sectional and longitudinal research consistently demonstrates that DPN significantly contributes to postural instability, gait abnormalities, and ultimately, falls.

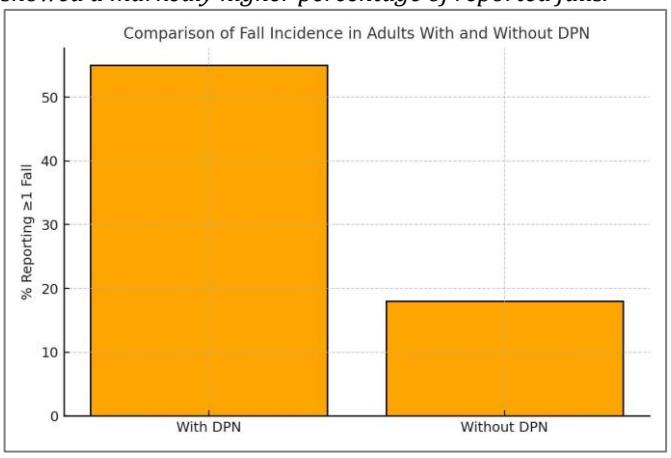
In a large prospective study by Allet et al. Involving over 100 patients with T2DM, individuals with DPN exhibited significantly lower balance scores and greater postural sway compared to diabetic patients without neuropathy [31]. These findings were consistent across both static and dynamic postural assessments, emphasizing the central role of sensory deficits in fall risk.

Another cross-sectional study by Richardson et al. Showed that over 50% of patients with DPN had a history of at least one fall within the past year, compared to just 18% in non-neuropathic diabetic patients [32]. The presence of impaired vibration perception and monofilament test failure were strongly associated with

increased fall episodes. These sensory testing tools have thus become standard in fall-risk screening for diabetic patients.

Figure 1

Comparison of fall incidence in adults with and without diabetic peripheral neuropathy.Individuals with DPN showed a markedly higher percentage of reported falls.



Furthermore, the Fremantle Diabetes Study, a longitudinal observational cohort, found that patients with moderate to severe neuropathy had a more than twofold increased risk of recurrent falls over a 2-year follow-up period [33]. Importantly, the study also highlighted that DPN severity—measured using the Michigan Neuropathy Screening Instrument (MNSI)—was an independent predictor of fall frequency, even after adjusting for age, comorbidities, and vision impairment.

Functional performance tests such as the Timed Up and Go (TUG), Berg Balance Scale, and gait velocity measurements have been widely utilized in clinical trials to objectively quantify fall risk in patients with DPN. One randomized controlled trial conducted by Menz et al. Assessed the effect of neuropathic symptoms on balance confidence and walking ability. It found that DPN was associated with increased double-support time and reduced swing phase during walking, which are known predictors of instability [34].

In addition to balance and gait issues, several studies have linked neuropathic pain to impaired physical function. A study by Vinik et al. Observed that patients experiencing painful DPN reported significantly reduced quality of life and were more likely to limit movement, which inadvertently increased their fall risk due to muscular deconditioning and joint stiffness [35].

Another recent systematic review pooled data from 11 studies and concluded that adults with DPN were approximately 1.9 times more likely to fall than those without DPN. Moreover, interventions targeting proprioception and strength training showed promising results in fall prevention among this high-risk population [36].

Together, these studies provide robust evidence that DPN is not just a sensory complication of diabetes but a critical risk factor for falls. The consistent association observed across diverse populations and assessment methods underscores the need for routine DPN screening in diabetic care to proactively address fall risk.

Table 1

Summary of Key Clinical Studies Examining DPN and Fall Risk

Author	Year	Sample Size	Design	DPN Measure	Fall Outcome	Key Findings
Allet et al.	2010	102	RCT	Balance test + TUG	Postural sway	DPN = ↓balance
Richardson et al.	1995	80	Cross-sectional	VPT + Monofilament	Fall history	DPN = ↑ falls
Bruce et al.	2005	945	Longitudinal	MNSI	Recurrent falls	DPN severity = fall predictor

Fall Risk Assessment Tools in Diabetic Peripheral Neuropathy

Effective assessment of fall risk in individuals with diabetic peripheral neuropathy (DPN) is crucial for timely intervention and prevention. Various clinical tools and objective tests are used to identify balance deficits, sensory impairment, and functional limitations in this population. These tools aid in both risk stratification and in monitoring responses to interventions.

Michigan Neuropathy Screening Instrument (MNSI)

The MNSI is a widely validated screening tool that includes both a questionnaire and physical examination. It evaluates symptoms like numbness, tingling, and pain, and checks for ankle reflexes, vibration sensation, and monofilament sensitivity. MNSI scores correlate with the severity of DPN and are predictive of gait instability and increased fall risk [37].

10g Semmes-Weinstein Monofilament Test

This tool is a standard bedside method for detecting loss of protective sensation. A 10-gram monofilament is applied to several points on the foot; inability to feel the pressure at specific sites is indicative of significant sensory neuropathy. Patients failing this test have been shown to have a 1.7–2.1 times greater fall risk [38].

Vibration Perception Threshold (VPT)

Using a biothesiometer or tuning fork, vibration perception is tested on bony prominences like the hallux or malleolus. Higher VPT values are associated with greater sensory loss. Studies have demonstrated a strong association between elevated VPT and impaired balance, as well as increased fall frequency in DPN patients [39].

Timed Up and Go (TUG) Test

The TUG is a functional mobility test in which a person rises from a chair, walks 3 meters, turns around, returns, and sits down. A time greater than 13.5 seconds indicates increased fall risk. TUG is particularly useful in DPN populations, as it reflects lower limb strength, gait coordination, and postural control [40].

Berg Balance Scale (BBS)

The BBS is a 14-item scale assessing static and dynamic balance tasks such as standing, reaching, and turning. Scores below 45 out of 56 suggest elevated fall risk. BBS has been shown to reliably detect balance deficits in older adults with DPN and is used frequently in clinical rehabilitation settings [41].

Dynamic Gait Index (DGI) and Functional Gait Assessment (FGA)

These tools assess gait under various conditions (e.g., changing speed, stepping over obstacles). Both scales are sensitive in detecting subtle gait abnormalities caused by neuropathy and are often used in diabetic foot care and fall prevention programs [42].

Computerized Posturography

Although more costly and typically used in research settings, this tool quantifies postural sway, center of pressure displacement, and sensory integration. Patients with DPN show greater sway and less adaptive postural strategies under altered sensory conditions, making this method highly sensitive for fall-risk evaluation [43].

Table 2

Summary of Key Clinical Studies Examining DPN and Fall Risk

Tool	Measures	Scoring	Fall-Risk Cutoff	Strength
Monofilament	Tactile sensation	Felt/Not felt	>2 sites = risk	Simple and fast
TUG	Functional mobility	Time (sec)	>13.5 sec	Validated, quick
BBS	Balance tasks	0–56	<45 = risk	Comprehensive
VPT	Vibration sense	Voltage threshold	>25V = risk	Objective measure
MNSI	Symptoms + signs	Score (0–8)	≥2 = abnormal	Widely used

Preventive and Management Strategies

Preventing falls in individuals with diabetic peripheral neuropathy (DPN) involves a multidimensional approach targeting glycemic control, physical function, footwear, pain management, and education. These strategies aim to mitigate the underlying neurological deficits and improve stability.

Glycemic Control

Maintaining optimal blood glucose levels helps prevent the progression of DPN and its complications. The DCCT and UKPDS studies demonstrated that tight glycemic control significantly reduces the incidence of neuropathy and related functional impairments [44], [45].

Balance and Strength Training

Exercise programs that include lower limb strengthening, balance exercises, and proprioceptive retraining are effective in improving gait and reducing fall risk in patients with DPN. Allet et al. Found that such interventions led to significant improvements in gait speed and balance among patients with moderate neuropathy [46].

Footwear and Foot Care

Protective footwear and regular foot assessments are essential components of fall prevention. Proper shoes reduce pain, improve balance, and prevent skin breakdown that could alter gait. Diabetic foot care guidelines recommend regular foot examinations and patient education for self-inspection [47].

Pain Management

Neuropathic pain can reduce mobility and increase fall risk. First-line agents such as duloxetine and pregabalin not only alleviate pain but also improve sleep and quality of life, which supports greater physical engagement and reduces fear of falling [48].

Education and Environmental Modification

Educating patients on fall risk and modifying home environments (e.g., removing loose rugs, using grab bars) are low-cost but effective measures. These interventions help reduce situational hazards, especially for patients with impaired sensation and balance.

Limitations in Existing Literature

Although numerous studies highlight the association between diabetic peripheral neuropathy (DPN) and increased fall risk, several limitations in the current literature restrict the generalizability and strength of conclusions.

First, many studies use cross-sectional designs, which limit causal inference. While associations between neuropathy severity and fall incidence are well-documented, the directionality and temporality of this relationship are often unclear [49]. Longitudinal studies are relatively few, and those available are limited by short follow-up periods and small sample sizes.

Second, variability in diagnostic criteria for DPN and inconsistent use of fall definitions across studies creates challenges in comparing results. Some studies rely solely on symptom questionnaires, while others use nerve conduction studies or objective sensory testing. Similarly, fall events are often self-reported, which may introduce recall bias and underestimation [50].

Third, many trials fail to control for confounding variables such as visual impairment, cognitive decline, polypharmacy, and depression—factors known to independently affect fall risk [51]. Without proper adjustment, it is difficult to isolate the specific contribution of DPN.

Fourth, most research has been conducted in older, high-income populations, which limits the applicability to younger adults with T2DM or individuals in low-resource settings. There is a need for more ethnically and geographically diverse studies to reflect real-world heterogeneity in diabetes care and outcomes [52].

Finally, relatively few studies have evaluated interventions specifically targeting fall prevention in DPN. While balance training and foot care have shown promise, rigorous randomized controlled trials (RCTs) with standardized outcomes are still lacking.

Future Directions

Future research should prioritize long-term, multicenter studies that use standardized diagnostic criteria for diabetic peripheral neuropathy (DPN) and consistent methods to assess falls. Current research often lacks uniformity in how DPN is measured and how falls are reported, making cross-study comparison difficult.

There is also a need for early screening models that are practical and quick to use in clinical settings. Tools that combine functional mobility testing, simple sensory evaluations, and balance assessments should be validated specifically for DPN populations.

Additionally, new interventions should be tested in controlled trials. While balance training and foot care are

widely recommended, there is limited high-quality evidence on comprehensive, multidisciplinary programs that also address psychological components like fear of falling.

Emerging technologies — such as wearable sensors, smart insoles, and vibration-based feedback devices — show promise in improving balance and gait stability, but they require further validation in diverse populations.

Lastly, future studies must be more inclusive of younger adults with T2DM, underserved populations, and low-resource settings. Community-level fall prevention programs that are affordable, culturally sensitive, and scalable should be explored to broaden the global impact of DPN management.

CONCLUSION

Diabetic peripheral neuropathy (DPN) is a common yet often under-recognized complication of type 2 diabetes that significantly increases the risk of falls in affected individuals. The interplay of sensory loss, motor dysfunction, and altered postural control contributes to gait instability and impaired balance, making fall prevention a critical aspect of diabetic care.

Clinical evidence consistently shows that individuals with DPN are more likely to experience recurrent falls, with sensory impairment and delayed protective reflexes being the primary contributors. Despite this well-established link, fall risk assessment is not routinely integrated into standard diabetic evaluations. Tools such as the monofilament test, vibration perception threshold, and functional mobility assessments can offer early insights into fall risk and should be more widely adopted in clinical practice.

Preventive strategies, including tight glycemic control, structured exercise programs, protective footwear, and pain management, have shown promising outcomes in reducing falls and improving functional independence. However, there remains a gap in translating these interventions into consistent, long-term care plans—particularly in under-resourced settings.

Addressing fall risk in patients with DPN requires a proactive, multidisciplinary approach. Physicians, physical therapists, podiatrists, and diabetes educators must work collaboratively to implement individualized fall prevention strategies tailored to each patient's needs and severity of neuropathy.

In conclusion, the relationship between DPN and falls is well-documented, but clinical translation remains limited. There is an urgent need for healthcare systems to prioritize fall risk assessment and management as integral components of diabetes care. By doing so, we can reduce injuries, preserve mobility, and ultimately improve the quality of life for millions of individuals living with diabetic neuropathy.

REFERENCES

1. International Diabetes Federation. (2021). IDF Diabetes Atlas (10th ed.). https://diabetesatlas.org/
2. Tesfaye, S., Boulton, A. J. M., Dyck, P. J., Freeman, R., Horowitz, M., Kempler, P., Lauria, G., Malik, R. A., Spallone, V., Vinik, A., Bernardi, L., Valensi, P., & Toronto Diabetic Neuropathy Expert Group. (2010). Diabetic neuropathies: update on definitions, diagnostic criteria, estimation of severity, and treatments. Diabetes Care, 33(10), 2285–2293. https://doi.org/10.2337/dc10-1303
3. Hicks, C. W., & Selvin, E. (2019). Epidemiology of peripheral neuropathy and lower extremity complications in diabetes. Current Diabetes Reports, 19(10), 86. https://doi.org/10.1007/s11892-019-1212-8
4. Schwartz, A. V., Vittinghoff, E., Sellmeyer, D. E., Feingold, K. R., de Rekeneire, N., Strotmeyer, E. S., Resnick, H. E., Harris, T. B., Nevitt, M. C., & Tylavsky, F. A. (2008). Diabetes-related complications, glycemic control, and falls in older adults. Diabetes Care, 31(3), 391–396. https://doi.org/10.2337/dc07-1152
5. Callaghan, B. C., Cheng, H. T., Stables, C. L., Smith, A. L., & Feldman, E. L. (2012). Diabetic neuropathy: Clinical manifestations and current treatments. The Lancet Neurology, 11(6), 521–534. https://doi.org/10.1016/S1474-4422(12)70065-0
6. Allet, L., Armand, S., Golay, A., Monnin, D., de Bie, R. A., & de Bruin, E. D. (2008). Gait characteristics of diabetic patients: A systematic review. Diabetes/Metabolism Research and Reviews, 24(3), 173–191. https://doi.org/10.1002/dmrr.809
7. Courtemanche, R., Teasdale, N., Boucher, P., Fleury, M., Lajoie, Y., & Bard, C. (1996). Gait problems in diabetic neuropathic patients. Archives of Physical Medicine and Rehabilitation, 77(9), 849–855. https://doi.org/10.1016/S0003-9993(96)90031-9
8. Volpato, S., Leveille, S. G., Blaum, C., Fried, L. P., Guralnik, J. M., & Women's Health and Aging Study. (2005). Risk factors for falls in older disabled women with diabetes: The Women's Health and Aging Study. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 60(12), 1539–1545. https://doi.org/10.1093/gerona/60.12.1539
9. Tinetti, M. E., Speechley, M., & Ginter, S. F. (1988). Risk factors for falls among elderly persons living in the community. New England Journal of Medicine, 319(26), 1701–1707. https://doi.org/10.1056/NEJM198812293192604
10. American Diabetes Association. (2023). 2. Classification and diagnosis of diabetes: Standards of Medical Care in Diabetes—2023. Diabetes Care, 46(Suppl. 1), S19–S40. https://doi.org/10.2337/dc23-S002
11. Feldman, E. L., Callaghan, B. C., Pop-Busui, R., Zochodne, D. W., Wright, D. E., Bennett, D. L., Bril, V., Russell, J. W., & Viswanathan, V. (2019). Diabetic neuropathy. Nature Reviews Disease Primers, 5(1), 41. https://doi.org/10.1038/s41572-019-0092-1
12. Obrosova, I. G. (2009). Diabetic painful and insensate neuropathy: pathogenesis and potential treatments. Neurotherapeutics, 6(4), 638–647. https://doi.org/10.1016/j.nurt.2009.07.003
13. Vincent, A. M., Russell, J. W., Low, P., & Feldman, E. L. (2004). Oxidative stress in the pathogenesis of diabetic neuropathy. Endocrine Reviews, 25(4), 612–628. https://doi.org/10.1210/er.2003-0019
14. Cameron, N. E., & Cotter, M. A. (1997). Metabolic and vascular factors in the pathogenesis of diabetic neuropathy. Diabetes, 46(S2), S31–S37.

https://doi.org/10.2337/diab.46.2.S31
15. Malik, R. A. (1997). Pathology of human diabetic neuropathy. Handbook of Clinical Neurology, 126, 249–259. https://doi.org/10.1016/B978-0-444-53480-4.00019-7
16. Liu, Y., Guo, Y., Xu, L., Wei, T., & Zhang, D. (2020). The role of inflammation in diabetic peripheral neuropathy. Frontiers in Pharmacology, 11, 622448. https://doi.org/10.3389/fphar.2020.622448
17. Chowdhury, S. K. R., Smith, D. R., & Fernyhough, P. (2003). The role of aberrant mitochondrial bioenergetics in diabetic neuropathy. Neurobiology of Disease, 13(1), 1–14. https://doi.org/10.1016/S0969-9961(03)00043-5
18. Tesfaye, S., & Selvarajah, D. (2012). Advances in the epidemiology, pathogenesis and management of diabetic peripheral neuropathy. Diabetes/Metabolism Research and Reviews, 28(S1), 8–14. https://doi.org/10.1002/dmrr.2239
19. Andersen, H. (2012). Motor dysfunction in diabetes. Diabetes/Metabolism Research and Reviews, 28(S1), 89–92. https://doi.org/10.1002/dmrr.2244
20. Petrofsky, J. S., Lee, S., & Bweir, S. (2005). Gait characteristics in people with type 2 diabetes mellitus. European Journal of Applied Physiology, 93(5-6), 640–647. https://doi.org/10.1007/s00421-004-1264-1
21. Allet, L., Armand, S., de Bie, R. A., Golay, A., Monnin, D., Aminian, K., & de Bruin, E. D. (2010). The gait and balance of patients with diabetes can be improved: A randomised controlled trial. Diabetologia, 53(3), 458–466. https://doi.org/10.1007/s00125-009-1607-1
22. Simoneau, G. G., Ulbrecht, J. S., Derr, J. A., Becker, M. B., & Cavanagh, P. R. (1994). Postural instability in patients with diabetic sensory neuropathy. Diabetes Care, 17(12), 1411–1421. https://doi.org/10.2337/diacare.17.12.1411
23. Menz, H. B., Lord, S. R., & St George, R. (2004). The effect of standard and modified insoles on balance and gait in older people. Archives of Physical Medicine and Rehabilitation, 85(10), 1706–1712. https://doi.org/10.1016/j.apmr.2004.01.031
24. Cavanagh, P. R., Derr, J. A., Ulbrecht, J. S., Maser, R. E., & Orchard, T. J. (1992). Problems with gait and posture in neuropathic patients with insulin-dependent diabetes mellitus. Diabetes Medicine, 9(5), 469–474. https://doi.org/10.1111/j.1464-5491.1992.tb01817.x
25. Andersen, H., Nielsen, S., Mogensen, C. E., & Jakobsen, J. (2004). Muscle strength in type 2 diabetes. Diabetes, 53(6), 1543–1548. https://doi.org/10.2337/diabetes.53.6.1543
26. Mueller, M. J., Minor, S. D., Sahrmann, S. A., Schaaf, J. A., & Strube, M. J. (1994). Differences in the gait characteristics of patients with diabetes and peripheral neuropathy compared with age-matched controls. Physical Therapy, 74(4), 299–308. https://doi.org/10.1093/ptj/74.4.299
27. Menz, H. B., Morris, M. E., & Lord, S. R. (2006). Foot and ankle risk factors for falls in older people: A prospective study. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 61(8), 866–870. https://doi.org/10.1093/gerona/61.8.866
28. Boucher, P., Teasdale, N., Courtemanche, R., Bard, C., & Fleury, M. (1995). Postural stability in diabetic polyneuropathy. Diabetes Care, 18(5), 638–645. https://doi.org/10.2337/diacare.18.5.638
29. Delbaere, K., Close, J. C., Mikolaizak, A. S., Sachdev, P. S., Brodaty, H., & Lord, S. R. (2010). The Falls Efficacy Scale International (FES-I). Age and Ageing, 39(2), 210–215. https://doi.org/10.1093/ageing/afp225
30. Freeman, R. (2005). Diabetic autonomic neuropathy. Handbook of Clinical Neurology, 126, 63–79. https://doi.org/10.1016/B978-0-444-53480-4.00004-5
31. Allet, L., Armand, S., Aminian, K., Pataky, Z., Golay, A., & de Bie, R. A. (2009). An exercise intervention to improve balance in diabetic patients with peripheral neuropathy: A randomized controlled trial. Clinical Rehabilitation, 24(1), 26–36. https://doi.org/10.1177/0269215509343249
32. Richardson, J. K., Hurvitz, E. A., & Schultz, J. S. (1995). Relationship between electromyographic activity, balance, and falls in patients with diabetic neuropathy. Archives of Physical Medicine and Rehabilitation, 76(10), 916–920. https://doi.org/10.1016/S0003-9993(95)80074-4
33. Bruce, D. G., Davis, W. A., Casey, G. P., & Davis, T. M. (2005). Predictors of falls and fractures in older people with diabetes. Diabetes Care, 28(5), 1174–1179. https://doi.org/10.2337/diacare.28.5.1174
34. Menz, H. B., Lord, S. R., & Fitzpatrick, R. C. (2003). Acceleration patterns of the head and pelvis when walking on level and irregular surfaces. Gait & Posture, 18(1), 35–46. https://doi.org/10.1016/S0966-6362(02)00159-5
35. Vinik, A. I., Nevoret, M. L., Casellini, C., & Parson, H. (2013). Diabetic neuropathy. Endocrinology and Metabolism Clinics, 42(4), 747–787. https://doi.org/10.1016/j.ecl.2013.06.001
36. Hijmans, J. M., Geertzen, J. H., Schokker, B., Postema, K., & Zijlstra, W. (2007). Effects of vibrating insoles on standing balance in diabetic neuropathy. Journal of Rehabilitation Research and Development, 44(5), 787–794. https://doi.org/10.1682/JRRD.2006.10.0138
37. Feldman, E. L., Stevens, M. J., Thomas, P. K., Brown, M. B., Canal, N., & Greene, D. A. (1994). A practical two-step quantitative clinical and electrophysiological assessment for the diagnosis and staging of diabetic neuropathy. Diabetes Care, 17(11), 1281–1289. https://doi.org/10.2337/diacare.17.11.1281
38. Perkins, B. A., Olaleye, D., Bril, V. (2002). Carpal tunnel syndrome in patients with diabetic polyneuropathy. Diabetes Care, 25(3), 565–569. https://doi.org/10.2337/diacare.25.3.565
39. Young, M. J., Breddy, J. L., Veves, A., & Boulton, A. J. (1994). The prediction of diabetic neuropathic foot ulceration using vibration perception thresholds: A prospective study. Diabetes Care, 17(6), 557–560. https://doi.org/10.2337/diacare.17.6.557
40. Podsiadlo, D., & Richardson, S. (1991). The Timed "Up & Go": A test of basic functional mobility for frail elderly persons. Journal of the American Geriatrics Society, 39(2), 142–148. https://doi.org/10.1111/j.1532-5415.1991.tb01616.x
41. Berg, K. O., Wood-Dauphinee, S. L., Williams, J. I., & Maki, B. (1992). Measuring balance in the elderly: Validation of an instrument. Canadian Journal of Public Health, 83(S2), S7–S11. https://doi.org/10.24095/hpcdp.83.Suppl.2.04
42. Wrisley, D. M., Marchetti, G. F., Kuharsky, D. K., & Whitney, S. L. (2004). Reliability, internal consistency, and validity of data obtained with the functional gait assessment. Physical Therapy, 84(10), 906–918. https://doi.org/10.1093/ptj/84.10.906
43. Hinman, M. R. (2000). Comparison of static balance in fallers and nonfallers in an assisted-living community. Journal of Geriatric Physical Therapy, 23(1), 3–6. https://doi.org/10.1519/00139143-200023010-00003
44. The Diabetes Control and Complications Trial Research Group. (1993). The effect of intensive treatment of diabetes on complications. NEJM, 329(14), 977–986. https://doi.org/10.1056/NEJM199309303291401
45. UKPDS Group. (1998). Intensive blood-glucose control in type 2 diabetes. The Lancet, 352(9131), 837–853. https://doi.org/10.1016/S0140-6736(98)07019-6

46. Allet, L., et al. (2010). An exercise intervention to improve balance in diabetic patients with peripheral neuropathy. Clinical Rehabilitation, 24(1), 26–36. https://doi.org/10.1177/0269215509343249
47. Boulton, A. J., et al. (2008). Comprehensive foot examination and risk assessment. Diabetes Care, 31(8), 1679–1685. https://doi.org/10.2337/dc08-9021
48. Pop-Busui, R., et al. (2017). Diabetic neuropathy: A position statement by the ADA. Diabetes Care, 40(1), 136–154. https://doi.org/10.2337/dc16-2042
49. Bruce, D. G., et al. (2005). Predictors of falls and fractures in older people with diabetes. Diabetes Care, 28(5), 1174–1179. https://doi.org/10.2337/diacare.28.5.1174
50. Richardson, J. K., et al. (1995). Relationship between balance and falls in diabetic neuropathy. Archives of Physical Medicine and Rehabilitation, 76(10), 916–920. https://doi.org/10.1016/S0003-9993(95)80074-4
51. Tinetti, M. E., et al. (1988). Risk factors for falls among elderly persons. NEJM, 319(26), 1701–1707. https://doi.org/10.1056/NEJM198812293192604
52. Hicks, C. W., & Selvin, E. (2019). Epidemiology of peripheral neuropathy and lower extremity complications. Current Diabetes Reports, 19(10), 86. https://doi.org/10.1007/s11892-019-1212-8