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A multi-domain fall risk model in diabetes: From screening to prevention

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Abstract

Falls are a common and serious complication among individuals with diabetes mellitus (DM), particularly those with diabetic peripheral neuropathy (D-PN). Multiple impairments in neuromuscular, sensory, and cognitive systems may contribute to increased fall risk in this population. The study aimed to identify key risk factors for falls among older adults with diabetes and to develop a multi-domain fall risk model that integrates screening and explanatory variables for clinical application.

A prospective cohort study was conducted among community-dwelling adults aged 50-70 years with DM for over 5 years, and participants were followed for 6 months to record fall incidence. Group comparisons and multivariate analyses were carried out to identify significant screening and explanatory predictors.

Participants with D-PN demonstrated significantly poorer muscle strength, reaction time, balance, and sensory function compared with non-neuropathic and control groups. Female gender and a history of previous falls were the strongest predictors for screening. Quadriceps strength and tandem balance emerged as key explanatory factors. The final model, comprising five risk variables: diagnosed neuropathy, poor contrast vision, reduced knee strength, impaired balance, and slow walking speed, showed a graded increase in fall incidence from 0% (≥1 factor) to 83% (five factors).

A simple, multi-domain fall risk model can effectively identify individuals with diabetes at high risk of falling, supporting targeted screening and preventive interventions in clinical practice.

Key words: diabetes mellitus, falls, neuropathy, balance, fall risk assessment, older adults

Introduction

Diabetes mellitus (DM) is now a worldwide pandemic, with two-thirds of the global diabetes population living in developing countries.[1] In Sri Lanka, the prevalence of DM has increased dramatically over the past 15 years in both urban and rural areas, with significant impacts on sufferers and the health care system, and it's reported as 23.0% which is higher than current global estimates for any other Asian country.[2]

Falls represent one of the significant health care issues for people with DM. Approximately 39% of people with DM fall one or more times within a year.[3] Falls can result in injuries ranging from lacerations, bruises, and abrasions, through to dislocations, sprains, fractures, and traumatic brain injury.[4] Falls can also lead to decreased functioning in daily life, social isolation, fear of falling, loss of independent living, and reduced quality of life.[5-9]

Previous studies have found that, in addition to poor diabetes control,[10] diabetic complications,[10] advanced disease status,[11] sensory loss,[12] muscle weakness,[13] increased postural sway,[14] gait and mobility impairments,[15,16] foot and body pain,[17] pharmacological complications,[17] and fear of falling[18] increase fall risk in people with DM. In addition, although it does not provide insight into why future falls occur, "past falls" is a valuable screening variable for fall risk.[19]

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However, previous studies have used only a limited range of tests to assess potential risk factors for falls, and some have utilised expensive, high-tech equipment that is unavailable in most clinical settings worldwide. Furthermore, a simple, low-cost fall risk screen has yet to be developed for people with DM.

In this study, we assessed specific impairments across DM specific, cognitive, sensorimotor, balance, and functional mobility domains to identify risk factors for falls in a community-living sample of people with DM. We aimed to derive (1) a simple screening tool and (2) an explanatory assessment that elucidates the pathophysiology of falls in people with DM to guide intervention strategies for fall prevention.

Methods

This study employed a prospective cohort design with a six-month follow-up on falls. All participants underwent baseline assessments. Ethics approval was obtained from the Ethics Review Committee of the Faculty of Medicine, University of Colombo, and from the National Hospital of Sri Lanka (NHSL). Informed verbal and written consent were obtained from all participants before they participated in the study.

Participants were recruited from endocrinology clinics at the NHSL. Inclusion criteria included having diabetes for more than 5 years, aged 50-70 years, living in the community, able to understand the instructions necessary for the assessments, and able to ambulate household distances without an assistive device. Participants with significant central nervous system dysfunction, musculoskeletal deformity, or lower-limb pathologies that affect balance were excluded. The sample size was chosen to allow up to 3 predictors in multivariate models, with at least 10 outcome cases per predictor variable.[20]

Baseline assessments

Demographics, health status, and fear of falling

Participants completed a questionnaire that included questions about demographics, falls in the previous year, diabetes-related factors, and medication use. Peripheral neuropathy was defined as the presence of three of the following: a) Diabetic Neuropathy Symptom (DNS) score >1,[21] b) Diabetic Neuropathy Examination (DNE) score>4,[21] c) a nerve conduction time (tibial nerve velocity) < 40m/s[21] and d) a vibration perception threshold > 25V.[21] Additionally, we tested HbA1c to assess glycaemic control. Fear of falls was assessed using the Iconographical Falls Efficacy Scale (Icon-FES).[22]

Neuropathy and lower limb sensation

Diabetic Neuropathy Symptom[21] and Diabetic Neuropathy Examination[21] scores were used to diagnose diabetic polyneuropathy (D-PN). Each symptom is scored as 1 point, with a score of 1 being sufficient to indicate D-PN. The DNE score consists of two items related to muscle strength, one item related to reflexes, and five items related to sensation. Each item is scored from 0 (normal) to 2 (2 severely disturbed). The maximum score is 16 points, and a score of more than 3 points is indicative of D-PN.

Nerve conduction studies of tibial and sural nerve velocity, amplitude and latency values were assessed using a Natus Xltek nerve conduction device (Koll Centre Parkway, Suite, Pleasanton, CA, USA).[21] Vibration perception thresholds of the big toe were measured using a Biothesiometer (Bio Medical Instrument Co., Ohio, USA).[21]

Tactile sensitivity was assessed using a Semmes-Weinstein pressure aesthesiometer, which comprises 20 nylon filaments of equal length with varying diameters.[21] The filaments were applied to the centre of the lateral malleolus, and pressure measurements were expressed as logarithms of the bending force in milligrams. Lower limb proprioception was assessed using a lower limb matching task with participants sitting and eyes closed. Errors in matching the great toes were recorded using a protractor inscribed on a vertical, clear acrylic sheet (60x60x1cm) placed between the legs.[22]

Fall risk

Fall risk was estimated using the Physiological Profile Assessment (PPA),[22] which comprises five physical tests evaluating key functions of the human balance system: lower limb proprioception, visual contrast sensitivity, knee extension strength, simple reaction time and postural sway when standing on a foam surface.[21,22] The five PPA components were weighted to compute a composite PPA fall risk score expressed in standard (z-score) units, with high scores indicating poorer physical performance. In multivariate models, weighted contributions from these five variables provide a fall risk score that can predict community-dwelling older Caucasian people at risk of multiple falls over 12 months with 75% accuracy.[26]

Cognition and neuropsychological functioning

The Montreal Cognitive Assessment Test (MOCA)[23] was used to assess general cognition. Cognitive motor speed and task switching ability, aspects of executive function, were assessed using the Trail Making Test (TMT).[24] Part A requires

participants to draw lines connecting numbers (e.g., 1-2-3), and Part B requires participants to draw lines connecting alternating letters and numbers (e.g., 1-A-2-B). The difference between the two parts was calculated to remove the speed element from the test evaluation.

Vision and reaction time

High and low contrast visual acuity were tested with a LogMAR letter chart,[26] positioned 3m in front of participants and measured under binocular conditions with participants wearing their distance correction glasses if applicable. Visual contrast sensitivity was assessed using the Melbourne Edge Test (MET),[25] which presents 20 circular patches containing edges with decreasing contrast. Correct identification of the orientation of the edge on the patches provides a measure of contrast sensitivity in decibel units, where 1 dB = 10 log 10 contrast.

Simple reaction time, measured in milliseconds, was assessed using a light as the stimulus and a button press as the response.[22]

Muscle strength, balance, gait and mobility

Maximal isometric quadriceps strength was measured in the dominant leg while participants were seated in a high chair, with their hips and knees flexed to 90 degrees.[25] A strain gauge was fixed horizontally with straps on the lower shin, 10 cm above the ankle. Afterwards, the participant was given three attempts with the dominant leg to push against the strap as forcefully as possible. In addition, the five-time sit-to-stand test was administered.[27] Participants were given a practice trial, and then the second trial was taken as the test result.

Postural sway was assessed using a sway meter that measured displacements of the body at the waist.[28] Testing was performed with participants standing on the floor and on a foam rubber mat (40×40×15cm thick) with eyes open and closed. Sway path (number of mm squares traversed by the sway meter pen) for each 30 s test was recorded. Two measures of leaning balance were administered: the maximal balance range test,[29] which measures maximal fore-aft lean and the coordinated stability test,[29] which assesses participants' ability to adjust body position in a steady and coordinated way while placing them at or near the limits of their base of support. Standing balance was also assessed by measuring the time participants could stand on one leg[30] and in different positions[28,31] (i.e., tandem and near-tandem standing for 30 seconds).

Gait was assessed using the Gait-Up gait analysis system (Physilog5®, GaitUp; Lausanne, Switzerland)[32] that contains wearable sensors attached to the participant's left and right shoes or footwear, which they usually wear. Participants walked at their usual pace for 25m along a corridor at the assessment site. During the analysis, two steps were discarded from the initiation and termination phases. Gait velocity, gait variability, double support time, stance time, swing time, swing width, stride length and cadence were recorded.

Functional mobility was assessed with the Timed Up and Go Test (TUG).[33] Participants were asked to rise from a chair, walk forward 3 meters as fast as they could, turn 180 degrees, walk back to the chair and sit down. In TUGcog, participants were asked to walk, while counting backwards in threes from a randomly chosen start number between 60 and 100.

Falls

Falls were defined as "unexpected events which resulted in the participant unintentionally coming to the ground, floor or other lower level".[34] Participants were given six calendars at the baseline assessment and asked to record falls on them each month and return them in prepaid envelopes to the research centre. Participants who did not return calendars were telephoned by a research assistant to obtain the information.

Results

Anthropometric, demographic and medical measures

The D-PN (diabetic neuropathy), D-noPN (diabetes without neuropathy) and HC (healthy controls) groups were well-matched for age, height and weight. The D-PN group had longer disease duration than the D-noPN group, and both diabetes groups were taking significantly more medications than the HC.

Lower limb sensation

There were significant differences among the three groups for all four lower limb sensation tests: tibial nerve conduction velocity ($p<0.001$), vibration perceptual thresholds ($p<0.001$), tactile sensitivity ($p<0.001$) and proprioception ($p<0.001$). Post-hoc comparisons indicated both diabetes groups had significantly poorer scores in all tests compared to the HC group, and that the D-PN group had poorer scores than the D-noPN group in the vibration perceptual threshold and tactile sensitivity tests. D-noPN group also has significantly poorer scores than HC in tibial nerve velocity, vibration perception threshold, proprioception, and tactile sensitivity.

Table 1. Demographic, medication, diabetes mellitus and fall-related measures for non-faller, single faller and multiple faller groups (mean+SD unless stated)

Variable	*No falls (n=66)*	*One fall (n=11)*	*Two plus falls (n=26)*	*IRR (95% CI)*
Demographic				
Age	61.4±5.6	64.0±5.5	60.8±7.2	0.99 (0.94-1.05)
Female, n (%)	40 (60.6)	6 (54.5)	22 (84.6)	3.60 (1.50-8.65)
Height (cm)	157.6±8.0	156.9±8.0	153.83±6.7	0.95 (0.89-1.00)
Weight (kg)	63.09±9.20	60.72±9.79	58.76±9.49	0.96 (0.92-1.002)
BMI	25.4 (3.3)	24.6 (3.2)	24.8 (2.9)	0.95 (0.83-1.08)
Medications				
Number of medications	6.7±2.6	6.4±1.6	7.4±2.9	1.14 (0.99-1.31)
Insulin dependent, n (%)	18 (27.3)	1 (9.1)	12 (46.1)	2.23 (1.00-5.00)
Diabetes-related measures				
HbA1c (%)	8.1±1.5	7.1±1.2	8.9±2.3	1.23 (1.00-1.5)
Symptom score	1.2±1.3	1.1±1.2	2.0±1.4	1.54 (1.19-2.00)
Examination score	3.1±3.1	1.7±2.2	4.0±3.3	1.13 (1.00-1.27)
Diagnosed neuropathy, n (%)	29 (43.9)	3 (27.3)	19 (73.1)	2.52 (1.17-5.41)
Lower limb sensation				
Tibial nerve velocity[#] (ms^{-1})	40.5±+5.7	40.7±3.7	39.7±6.5	0.99 (0.92-1.06)
VPT (mV)	27.6±14.1	23.9±13.5	30.9±15.7	1.01 (0.99-1.04)
Tactile sensitivity ($_{lg}$10 mg force)	4.13±0.76	4.11±0.90	4.12±0.93	1.24 (0.80-1.90)
Proprioception (degrees)	2.5±1.3	2.3±0.9	2.1±1.2	0.77 (0.56-1.07)
Fall-related measures				
1+ fall in previous year, n (%)	15 (22.7)	7 (63.6)	17 (65.4)	5.47 (2.72-11.01)
Fear of falling	26.6±7.6	25.4±7.7	30.2±6.6	1.07 (1.01-1.13)

[#]n; no falls = 59, one fall = 11, two plus falls = 21 (tibial nerve velocity was not detected in the remainder of participants).

Muscle strength, balance, gait and reaction time

There were significant differences among the three groups for the simple reaction time (p=0.001), knee extension strength (p<0.001), five-time sit-to-stand (p<0.001), one-leg stand (p<0.001), timed up and go (p<0.001), and sway on foam eyes open and eyes closed tests. Post-hoc comparisons indicated both diabetes groups had significantly slower five-time sit-to-stand times compared to the HC group, and that the D-PN group had poorer scores than both the D-noPN and HC groups in the simple reaction time, knee extension strength, one-leg stand, timed up and go, and sway on foam eyes open and eyes closed tests.

Falls, physiological fall risk and fear of falling

Thirty-four D-PN participants (66.7%), 19 D-noPN participants (36.5%) and 7 HC (14.0%) reported one or more falls in the past three months; Chi2 test for trend =28.1, df=2, p<0.001).

Compared with the HC group, the D-noPN and D-PN groups had markedly increased odds of being a faller: 3.54 and 12.3, respectively. Mean PPA and Icon-FES scores differed significantly among the groups in the ANOVA, and post hoc analyses revealed that the D-PN group had higher PPA scores than both the HC and D-noPN groups, and that Icon-FES scores differed significantly among groups.

Falls data for the complete 6-month follow-up period were available for all participants; 66 participants (64.1%) had no fall, 11 (10.7%) fell only once, and 26 participants (25.2%) fell on two or more occasions during follow-up. Twelve participants (32.4%) suffered one or more fall-related injuries.

Demographic, medication, and DM-specific measures for the non-faller, single-faller and multiple-faller groups were analysed. Of these measures, female gender, a history of falls and greater fear of falling were identified as predictors of falls. Of the DM-specific factors, Neuropathy Symptom and Neuropathy Examination scores, HbA1c levels, insulin dependence and diagnosed neuropathy were significantly associated with falling. In contrast, increased age, reduced lower limb sensation, increased weight, higher BMI and greater medication use were not significantly associated with falls.

Cognitive functions, vision, strength, gait, and mobility measures for the non-faller, single-faller, and multiple-faller groups were analysed. Several measures were significantly associated with falls: poor contrast vision, reduced knee extension strength, increased postural sway, decreased ability to tandem stand, slow walking speed, short stride length and slow TUG times (with and without a cognitive task). Notably, no cognitive measures were associated with falls.

The binomial regression multivariate model for the identification of screening measures revealed past falls and female gender as significant and independent predictors of falls (likelihood-ratio Chi-square = 48.91, p<0.001). A history of one or more falls in the past year and female gender increased fall rates by factors of 4.62 (95% CI = 2.31 to 9.27) and 2.40 (95% CI = 1.04 to 5.54), respectively. The multivariate negative binomial regression model for the identification of explanatory measures comprised two significant and independent variables influencing falls: quadriceps strength and tandem balance ability (likelihood ratio Chi square = 12.43, p=0.002). For each 1kg increase in quadriceps strength, fall rates decreased by 6% (IRR = 0.94 95% CI = 0.89 to 0.99) and the inability to undertake the tandem balance increased fall rates by a factor of 2.49 (95% CI = 1.07 to 5.77).

The variables selected from the five explanatory domains for inclusion in a fall risk assessment tool comprised diagnosed neuropathy, poor contrast vision, reduced knee extension strength, poor balance and slow walking speed. Figure 1 shows the proportion of participants who suffered multiple falls in the follow-up period with respect the number of these risk factors present. The absolute risk of multiple falls ranged from 0% in those with 0 or 1 risk factor to 83% in those with all 5 risk factors.

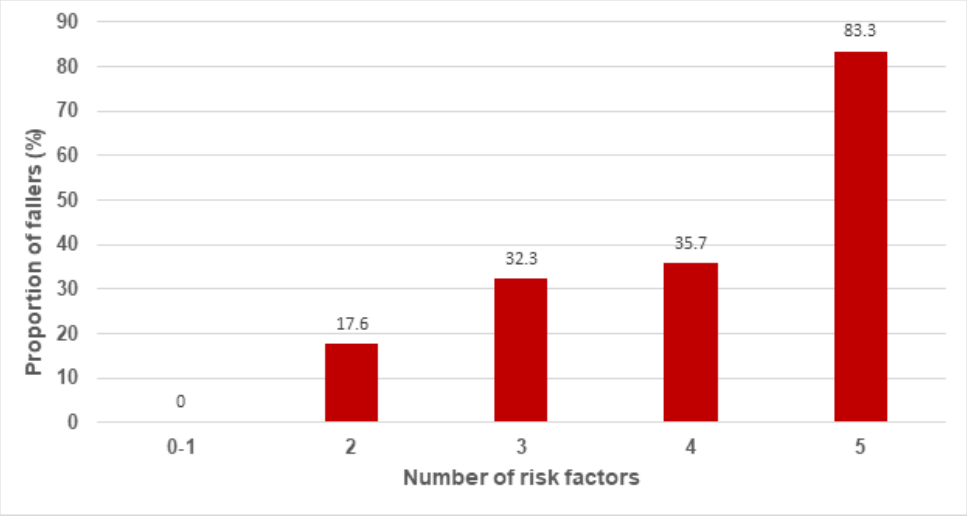

Figure 1. Proportion of falls in relation to the number of fall risk factors.

Table 2. Cognition, vision, strength, gait and mobility measures for the non-faller, single faller and multiple faller groups (mean+SD unless stated)

Variable	*No falls (n=66)*	*One fall (n=11)*	*Two plus falls (n=26)*	*IRR (95% CI)*
Cognition				
MOCA(score)	23.3±2.7	22.6±3.5	22.3±3.0	0.90 (0.78-1.04)
Simple reaction time(ms)	254±48	257±45	266±50	1.003 (0.99-1.01)
Trails A(s)	65.0±27.3	65.8±8.7	67.9±25.6	1.00 (0.98-1.01)
Trails B(s)	164.7±79.5	174.6±85.0	190.1±109.2	1.00 (0.99-1.00)
Trails B-A(s)	97.2±62.0	97.3±54.4	123.6±94.2	1.00 (0.99-1.00)
Vision				
Contrast sensitivity(dB)	20.8±2.4	19.4±1.9	19.5±2.6	0.82 (0.69-0.97)
High contrast visual acuity(MAR)	1.66±1.00	1.74±1.10	1.59±0.68	1.16 (0.72-1.86)
Low contrast visual acuity(MAR)	4.46±3.66	5.21±4.69	4.54±3.48	1.03 (0.92-1.16)
Strength				
Knee extension strength(kg)	23.7±8.0	23.3±7.8	20.1±5.6	0.92 (0.87-0.97)
Five time sit to stand time(s)	13.0±2.4	13.8±2.5	13.1±2.2	1.10 (0.93-1.31)
Balance				
Sway-EO-on floor(cm)	6.7±2.7	7.2±1.9	8.4±4.5	1.09 (0.99-1.21)
Sway-EC-on foam(cm)	8.8±35	9.7±55	10.8±5.2	1.10 (1.02-1.19)
Sway-EO-on floor(cm)	19.5±91	19.9±100	21.8±9.7	1.04 (1.00-1.08)
Sway-EC-on foam(cm)	45.5±18.3	38.1±12.2	48.5±18.7	1.01 (0.99-1.03)
Maximum balance range(cm)	13.5±2.3	13.1±3.6	13.3±2.6	0.89 (0.77-1.02)
Coordinated stability (error score)	10.4±8.7	11.0±7.7	12.9±8.7	1.04 (0.99-1.08)
Unipedal stance time(s)	21.7±10.1	25.5±5.1	18.9±10.0	0.96 (0.92-1.00)
Inability to maintain tandem standing for 30sec, n(%)	10 (15.2)	5 (45.5)	8 (30.8)	3.35 (1.47-7.72)
Gait and mobility measures				
Gait velocity(m/s)	1.40+0.24	1.45±0.24	1.30±0.18	0.19 (0.03-1.16)
Stride length/height	0.86±0.09	0.88±0.09	0.82±0.07	0.009 (0.0001-0.829)
Cadence (steps/min)	121.3±10.2	124.9±10.1	120.4±8.2	1.00 (0.96-1.05)
Gait variability(%)	2.79±1.24	2.43±1.01	2.88±1.02	1.21 (0.83-1.76)
TUG(s)	7.6±1.9	7.7±1.3	8.2±1.9	1.29 (1.03-1.62)
TUG cognitive(s)	11.7±3.6	11.5±2.8	14.1±5.0	1.13 (1.02-1.24)

Discussion

This study demonstrated that sensorimotor, balance, and functional mobility measures were significantly impaired in older adults with DM, particularly among those with D-PN. Participants with D-PN exhibited poorer knee extension strength, delayed reaction time, impaired standing balance, slower mobility, and marked lower-limb sensory loss. These multisystem deficits explain the elevated risk of falls observed in older individuals with diabetes.

As expected, participants with D-PN showed significant impairments across all sensory domains – tibial nerve conduction velocity, vibration perception, tactile sensitivity, and proprioception – indicating substantial sensory degradation. Interestingly, even participants without clinically diagnosed neuropathy (D-noPN) showed measurable sensory loss compared with healthy controls, suggesting that subclinical neuropathic changes are common in diabetes and may predispose individuals to postural instability and falls. These findings support previous literature highlighting the role of impaired proprioception and sensory feedback in poor postural control,[28,29] and increased sway during perturbations.[30] People with D-PN also tend to adopt a rigid postural control strategy as a compensatory response, further compromising stability.

Previous research has reported that individuals with type 2 DM have reduced muscle mass,[31-33] impaired strength, balance deficits, and altered gait characteristics.[34] Increased postural sway,[35-37] especially under eyes-closed conditions,[28,38] is well documented in D-PN populations. This study similarly found significant impairments in muscle strength, reaction time, and balance, with mobility limitations likely arising from cumulative deficits across these domains. The findings reinforce that the Timed Up and Go (TUG) test, a widely used functional mobility assessment, is influenced by multiple physiological factors, including strength and postural control.[40]

Consistent with earlier studies,[12,13,41] the D-PN group demonstrated a significantly higher risk of falls than both the D-noPN and control groups. Fall risk was accompanied by greater concern about falling and higher physiological fall risk scores. Physiological Profile Assessment (PPA) data indicated that D-noPN participants performed comparably to older, non-diabetic reference groups, while the D-PN group showed even poorer performance, confirming reduced functional capacity. The composite PPA score of 1.68 for the D-PN group indicates a markedly elevated fall risk based on population norms[42].

Fall incidence was significantly associated with several factors, including a history of previous falls, female gender, neuropathy severity, elevated HbA1c levels, poor contrast sensitivity, weak quadriceps strength, increased postural sway, shorter stride length, and poor tandem balance and TUG performance. A multivariable fall risk model incorporating five key predictors-diagnosed neuropathy, poor contrast vision, reduced knee strength, impaired balance, and slow walking speed-demonstrated a graded increase in fall probability from 0% (≤1 risk factor) to 83% (five factors). Among these, previous falls and female gender emerged as the strongest screening predictors, consistent with earlier studies in both diabetes[19, 35,36] and the general older populations.[37-39] Consequently, these two factors warrant inclusion in fall-risk screening protocols, supplemented by tandem balance and quadriceps strength tests to form a simple four-item screening tool.

Many explanatory factors were identified here, including neuropathy,[11] glycaemic control (HbA1c),[40] insulin use,[41] vision deficits,[10] muscle weakness,[13] balance impairment,[42] and reduced gait speed,[42] are modifiable and have been recognised in previous literature. Among them, diabetic neuropathy plays a central role, affecting nearly half of older adults with DM and influencing most other risk domains. Poor glycaemic control and insulin dependence may elevate fall risk through hypoglycaemia-related confusion, dizziness, or transient loss of consciousness.

Although some prior research has linked cognitive decline to falls in individuals with diabetes, this study did not find significant associations between falls and either global cognition (as measured by the MOCA) or executive function (as assessed by the Trail Making Tests). Similarly, dual-task TUG performance was less predictive of falls than the standard TUG, possibly indicating that cognitive deficits were subtle or yet to be manifest in this relatively young diabetic cohort.

Clinically, these findings highlight the importance of conducting early, multidimensional fall-risk assessment in older adults with diabetes. The five key variables identified – neuropathy, vision impairment, reduced strength, balance deficit, and slow walking speed – can form a practical, low-cost screening model suitable for routine clinical use. Because these risk factors are modifiable, interventions focusing on exercise-based strength and balance training, visual optimisation, and improved diabetic control through education and lifestyle management are recommended to reduce fall risk and enhance overall safety and independence among older adults with diabetes.

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Conflict of Interests

None.

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