

A novel half-squat position approach for improved balance assessment for Type 2 Diabetes Mellitus patients

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Abstract

Aim. Falls among the elderly, particularly those with type 2 diabetes mellitus (T2DM), often occur during dynamic activities rather than static standing. Traditional balance assessments, such as the Romberg test, do not fully capture real-life fall risks. This study proposes a novel half-squat position for balance assessment, reflecting functional movements like stair climbing and sitting. We hypothesized that the risk of falling in the half-squat position would be comparable to that observed on soft surfaces. Methods. A total of 102 T2DM patients from rural Cluj County, Romania, were evaluated using the BTS P-WALK baropodometric platform. Measurements of the body's center of mass (Area, Speed, and Length) were taken under various conditions (hard vs. soft surfaces, eyes open vs. closed, half-squat). Statistical analyses involved the Shapiro-Wilk test and the Wilcoxon signed-rank test. Significant differences ($p < .000$) were observed in most variables, except for length and speed when comparing hard eyes-closed (EC) and half-squat (H-Sqt) conditions. Both the barycenter area and sway speed increased. On a hard surface, path length and speed showed little change between the H-Sqt and EC positions. The H-Sqt position revealed balance impairments that were not apparent during static tests, such as increased reliance on vision and impaired proprioception. Growing evidence supports that dynamic and functional assessments are more effective in predicting the real-life fall risk of patients with type 2 diabetes mellitus (T2DM). This suggests that the required stability levels were similar. The data show that the H-Sqt imposes postural control demands comparable to those of a soft surface, highlighting its importance in balance assessments. Integrating the H-Sqt into balance evaluation protocols could improve fall risk prediction for elderly T2DM patients, especially those with diabetic neuropathy. Future studies should apply this method to larger populations and explore variations such as the EC H-Sqt to further improve balance assessment strategies.

Keyword: fall risk; half-squat position; balance assessment; type 2 diabetes; stabilometric platform

Introduction

Diabetes mellitus (DM) is a chronic condition affecting millions globally, with type 2 diabetes mellitus (T2DM) accounting for most cases. Recent data estimate that over 537 million adults worldwide have diabetes, numbers projected to increase to 643 million by 2030 (Magliano & Boyko, 2021). The impact of diabetes extends beyond blood sugar management, involving serious complications such as cardiovascular disease, neuropathy, and a higher risk of falls, especially in older adults. Those with diabetic issues: mainly face peripheral artery disease (PAD) and diabetic neuropathy. Reduced blood flow is a key factor in the development and worsening of diabetic foot ulcers (DFUs). Diabetic neuropathy results from metabolic disruptions caused by chronic high blood glucose levels (Wardani et al., 2025).

One of the less frequently addressed but important consequences of T2DM is postural instability. Van Dieën et al. (2017) emphasize that postural instability receives less research attention in diabetes compared to complications such as neuropathy and retinopathy. They attribute this gap to the complexity of accurately evaluating postural stability, which is influenced by multiple factors and often requires specialized assessment tools and techniques. Citing this study offers up-to-date evidence of the relative underrepresentation of postural

instability in diabetes research. Peripheral neuropathy, a common complication of T2DM, impairs proprioception, and makes maintaining balance difficult. Research indicates that individuals with T2DM face a 1.7 times greater risk of falls than non-diabetic individuals (Freire et al., 2024). Reduced muscle strength, delayed reaction times, and altered sensory feedback further contribute to the increased risk of falls.

Traditionally, clinical balance assessments rely on tests such as the Romberg test and the Berg Balance Scale (BBS). While these tools provide valuable insight into postural control, they mainly assess static balance and do not adequately capture the dynamic stability necessary for everyday activities. Proprioceptive training alone may not substantially improve postural stability in patients without clinical signs of diabetic neuropathy; however, combining it with other exercise modalities can produce beneficial effects. Although static balance tests provide useful information their limitation lies in not evaluating dynamic stability, which is essential for functional mobility and fall prevention. Recent research indicates that static measures, such as the Functional Reach Test, often fail to capture the complexity of daily movements, while dynamic assessments such as the Timed Up and Go (TUG) and Four Square Step Test (FSST), are more effective. For example, Sibley et al. (2015) showed that dynamic tests, such as the TUG and FSST, were better at detecting balance impairments in individuals with neurological disorders than static methods. They noted that dynamic assessments better simulated of daily activities, such as walking, turning, and changing direction, that static tests fail to measure adequately. These findings highlight the importance of integrating static assessments with dynamic tests to achieve a more comprehensive understanding of postural stability in real-world scenarios.

The TUG test includes a mobility component but does not replicate real-life functional movements such as stair climbing or squatting.

Given the limitations of traditional assessments, this study investigates the half-squat (H-Sqt) position as an alternative balance measure. The H-Sqt reflects movements commonly performed in daily life, making it a functional tool for assessment. By assessing balance in this posture, this study offers a more practical and accurate evaluation of fall risk in patients with T2DM.

The H-Sqt, while not a natural static stance, is highly valuable for assessing postural control and fall risk, especially in individuals with T2DM. It replicates key transitional movements, such as sitting and standing up, which are often difficult for T2DM patients owing to muscle weakness, proprioceptive deficits, and impaired balance. Holding the H-Sqt requires considerably lower limb strength, core stability, and proprioceptive input, making it an effective method to evaluate dynamic balance under controlled stress conditions. Unlike static tests, the H-Sqt more accurately reflects real life challenges, by revealing compensatory strategies such as uneven weight distribution or reliance on visual cues, which may indicate underlying balance issues. For individuals with T2DM, who often experience complications such as neuropathy and reduced joint mobility, this assessment helps identify functional limitations and guides targeted interventions, including strength and proprioceptive training. Research indicates that transitional movements, such as sit-to-stand tasks, strongly predict of fall risk in older adults and those with chronic conditions such as T2DM (Pijnappels et al., 2010). As a controlled simulation of these transitions, the H-Sqt serves as a practical and informative assessment tool in clinical settings.

Literature Review

T2DM-related balance impairments result from multiple physiological factors, including neuropathy, retinopathy, and muscle weakness. Neuropathy impairs proprioception by reducing sensory input from the feet, while retinopathy compromises visual stability. Together, these factors weaken postural control, and increase fall risk (Rivera-Chavez et al., 2020).

Most traditional balance assessment tools such as the BBS and Romberg test, focus on static postures and standing stability but lack evaluation of dynamic movement. Recent studies recommend incorporating functional movement-based, assessments such as stair climbing, tandem walking, or squatting to better capture real-world balance challenges (Zhuang et al., 2023).

Standard rating scales are widely used in rehabilitation to assess balance in patients with neurological disorders and musculoskeletal injuries. However, these scales offer limited insight into the underlying causes of balance dysfunction, highlighting the need for more quantitative assessment tools. Advanced balance platforms provide objective measurements of subtle changes in postural control allowing for accurate identification of root causes and enabling more targeted therapeutic interventions (Demirchyan et al., 2025).

Recent research underscores the importance of dynamic stability. Studies indicate that including the H-Sqt in assessments provides valuable information about postural control. Lin et al. (2024) found a strong correlation between balance responses in the H-Sqt and real-life fall risk, reinforcing its usefulness as an effective evaluation tool. Despite advancements in assessment methodologies, a gap remains in integrating functional balance tests specifically designed for T2DM patients. Traditional balance assessments, such as the BBS and Romberg test, often fail to fully capture the unique postural control deficits experienced by this population, especially under dynamic conditions (Kahn, 2023). Research by Santamaria-Garcia et al. (2023) suggests that incorporating functional movement evaluations, such as the H-Sqt, provides a more comprehensive assessment of fall risk. By focusing on the H-Sqt, this study adds to the growing evidence supporting dynamic postural assessments more effective tools for predicting fall susceptibility in individuals with T2DM.

Materials and methods

Subjects

We assessed 102 patients diagnosed with T2DM in rural Cluj County. Evaluations were performed in a specialized diabetologist's office, where patients had previously been screened for neuropathy and foot ulcers. The study was approved by the research ethics committee under UBB approval number 6652/24.06.2021.

Owing to physical limitations, eight patients (four males and four females) were excluded from the H-Sqt balance assessment, because they had gonarthrosis and could not maintain the H-Sqt for 30 s.

This study was coordinated and managed by the Center for Interdisciplinary Research in Physical Education and Sport (CIRPES) at Babes-Bolyai University, Faculty of Physical Education and Sport.

Evaluation protocols

The evaluation was performed once for each of the following 30-s protocols. The subject stood in a bipodal orthostatic position with feet shoulder width apart. The protocols were:

- Standing on a baropodometric plate (H) with eyes closed (EC).
- Standing on an H with eyes open (EO).
- H-Sqt on the H with arms extended forward and EO.
- Standing on an H covered with a 1.5 cm thick sponge (S), with EC.
- Standing on an H covered with a 1.5 cm S, with EO.

This sequence allowed the subject to gradually adjust to different orthostatic positions. The H-Sqt was held for 30 s outside the orthostatic balance zone, allowing assessment of aerobic capacity while maintaining safety.

Data analysis was performed using SPSS 17.0b and MS Office Suite-Excel 10. Normality was assessed with the Shapiro-Wilk test, and non-parametric comparisons were performed using the Wilcoxon test.

The Romberg test, usually performed with EO and EC on a hard surface (H), was expanded to include additional conditions: testing on a soft surface (S) and in H-Sqt. Various parameters were evaluated under these conditions:

- Soft Surface (S): EC and EO measurements of barycenter area, length, and speed for the left foot, right foot, and whole body.
- Hard Surface (H): EC and EO measurements for barycenter area, length, and speed for the left foot, right foot, and whole body, assessed in both H-Sqt and standing positions.

The assessments were performed using the BTS P-WALK baropodometric platform, consisting of a 675 mm x 540 mm x 5 mm plate equipped with 2,304 resistive sensors (each 1x1 cm). It has a pressure range of 30-400 kPa, a sampling frequency of 100 Hz, and is powered by an AC/USB adapter, with a total weight of approximately 7 kg.

Results

The results showed that the assessment protocols significantly influenced postural control. The H-Sqt condition imposed balance demands comparable to those experienced on S. However, specific comparisons showed that not all parameters were affected. To the same extent.

Statistical analyses for each condition.

Are presented below. The Shapiro-Wilk test was used to evaluate data distribution. Revealing that the data were not normally distributed. Therefore, the nonparametric Wilcoxon test was used to assess differences between parameters, ensuring the statistical methods were appropriate for the dataset.

Table 1. Descriptive statistics of the collected data

	Mean	SD	Minimum	Maximum
S_EC_Area_L, mm ²	60.65	±51.47	3.12	282.18
S_EC_Area_B, mm ²	297.51	±267.29	15.53	1680.95
S_EC_Area_R, mm ²	51.80	±65.35	1.62	451.73
S_EC_L, mm	254.33	±175.33	102.60	1669.90
S_EC_Speed, mm/s	8.48	±5.85	3.40	55.70
S_EO_Area_L, mm ²	18.09	±25.01	1.12	174.38
S_EO_Area_B, mm ²	75.42	±129.21	4.42	1093.19
S_EO_Area_R, mm ²	13.37	±18.93	0.99	138.06
S_EO_L, mm	133.53	±45.44	80.00	356.90
S_EO_Speed, mm/s	4.45	±1.51	2.70	11.90
H_EO_Area_L_HalfSquat, mm ²	64.92	±106.52	3.07	728.11
H_EO_Area_B_HalfSquat, mm ²	169.74	±179.18	11.66	1268.22
H_EO_Area_R_HalfSquat, mm ²	57.65	±68.69	1.33	367.65
H_EO_L_HalfSquat, mm	183.45	±87.55	90.60	767.40
H_EO_Speed_HalfSquat, mm/s	6.12	±2.92	3.00	25.60

H_EC_Area_L, mm ²	38.17	±64.41	1.17	538.00
H_EC_Area_B, mm ²	120.39	±206.93	7.81	1833.33
H_EC_Area_R, mm ²	24.35	±37.38	1.61	331.53
H_EC_L, mm	198.23	±133.05	91.40	1241.90
H_EC_Speed, mm/s	6.61	±4.44	3.00	41.40
H_EO_Area_L, mm ²	9.57	±12.17	0.40	69.37
H_EO_Area_B, mm ²	32.73	±64.63	2.91	588.11
H_EO_Area_R, mm ²	6.90	±8.60	0.53	52.77
H_EO_L, mm	119.40	±43.35	63.60	432.30
H_EO_Speed, mm/s	3.98	±1.45	2.10	14.40

mm² = square millimeter; mm/s = millimeters per second; SD = standard deviation; Soft surface Eyes Closed Area Left (S_EC_Area_L, mm²); Soft surface Eyes Closed Area Body (S_EC_Area_B, mm²); Soft surface Eyes Closed Area Right (S_EC_Area_R, mm²); Soft surface Eyes Closed Length (S_EC_L, mm); Soft surface Eyes Closed Speed (S_EC_Speed, mm/s); Soft surface Eyes Open Area Left (S_EO_Area_L, mm²); Soft surface Eyes Open Area Body (S_EO_Area_B, mm²); Soft surface Eyes Open Area Right (S_EO_Area_R, mm²); Soft surface Eyes Open Length (S_EO_L, mm); Soft surface Eyes Open Speed (S_EO_Speed, mm/s); Hard surface Eyes Open Area Left Half Squat position (H_EO_Area_L_HalfSquat, mm²); Hard surface Eyes Open Area Body Half Squat position (H_EO_Area_B_HalfSquat, mm²); Hard surface Eyes Open Area Right Half Squat position (H_EO_Area_R_HalfSquat, mm²); Hard surface Eyes Open Length Half Squat position (H_EO_L_HalfSquat, mm);

Hard surface Eyes Open Speed Half Squat position (H_EO_Speed_HalfSquat, mm/s); Hard surface Eyes Close Area Left (H_EC_Area_L, mm²); Hard surface Eyes Close Area Body (H_EC_Area_B, mm²); Hard surface Eyes Close Area Right (H_EC_Area_R, mm²); Hard surface Eyes Close Length (H_EC_L, mm); Hard surface Eyes Close Speed (H_EC_Speed, mm/s); Hard surface Eyes Open Area Left (H_EO_Area_L, mm²); Hard surface Eyes Open Area Body (H_EO_Area_B, mm²); Hard surface Eyes Open Area Right (H_EO_Area_R, mm²); Hard surface Eyes Open Length (H_EO_L, mm); Hard surface Eyes Open Speed (H_EO_Speed, mm/s)

The mean body barycenter area (unit: mm²) across different evaluation protocols. Is shown in Table 1. Protocol 2 (H_EO_Aria_B) exhibited a mean barycenter area 2.3 times smaller than Protocol 5 (S_EO_Aria_B). Visual input with EO caused a 2.47-fold increase in mean barycenter area in Protocol 4 (S_EC_Aria_B) compared to Protocol 1 (H_EC_Aria_B). Additionally, the H-Sqt resulted in a 1.4-fold increase in mean barycenter area compared to Protocol 1 (H_EC_Aria_B) and a 1.75-fold increase compared to Protocol 5 (S_EO_Aria_B).

Table 2. Results for all parameter values based on the Wilcoxon test

	Z	p
H_EC_Area_L - S_EC_Area_L	-5.353	.000
H_EC_Area_B - S_EC_Area_B	-7.179	.000
H_EC_Area_R - S_EC_Area_R	-5.698	.000
H_EC_L - S_EC_L	-5.420	.000
H_EC_Speed - S_EC_Speed	-5.411	.000
H_EO_Area_L - S_EO_Area_L	-4.922	.000
H_EO_Area_L - H_EO_Area_L_HalfSquat	-8.424	.000
H_EO_Area_B - S_EO_Area_B	-6.615	.000
H_EO_Area_B - H_EO_Area_B_HalfSquat	-8.424	.000
H_EO_Area_R - S_EO_Area_R	-5.186	.000
H_EO_Area_R - H_EO_Area_R_HalfSquat	-8.751	.000
H_EO_L - S_EO_L	-4.490	.000
H_EO_L - H_EO_L_HalfSquat	-7.943	.000
H_EO_Speed - S_EO_Speed	-4.438	.000
H_EO_Speed - H_EO_Speed_HalfSquat	-7.930	.000
H_EC_Area_L - H_EO_Area_L_HalfSquat	-3.916	.000
H_EC_Area_B - H_EO_Area_B_HalfSquat	-4.124	.000
H_EC_Area_R - H_EO_Area_R_HalfSquat	-6.000	.000
H_EC_L - H_EO_L_HalfSquat	-1.314	.189
H_EC_Speed - H_EO_Speed_HalfSquat	-1.297	.195

Significant at $p < 0.05$ Hard surface Eyes Closed Area Left- Soft surface Eyes Closed Area Left (H_EC_Area_L-S_EC_Area_L, mm²); Hard surface Eyes Closed Area Body- Soft surface Eyes Closed Area

Body (H_EC_Area_B-S_EC_Area_B, mm²); Hard surface Eyes Closed Area Right- Soft surface Eyes Closed Area Right (H_EC_Area_R-S_EC_Area_R, mm²); Hard surface Eyes Closed Length- Soft surface Eyes Closed Length (H_EC_L-S_EC_L, mm); Hard surface Eyes Closed Speed - Soft surface Eyes Closed Speed (H_EC_Speed-S_EC_Speed, mm/s); Hard surface Eyes Open Area Left- Soft surface Eyes Open Area Left (H_EO_Area_L-S_EO_Area_L, mm²); Hard surface Eyes Open Area Left- Hard surface Eyes Open Area Left Half Squat (H_EO_Area_L-H_EO_Area_L_Half Squat, mm²); Hard surface Eyes Open Area Body- Soft surface Eyes Open Area Body (H_EO_Area_B-S_EO_Area_B, mm²); Hard surface Eyes Open Area Body- Hard surface Eyes Open Area Body Half Squat (H_EO_Area_B-H_EO_Area_B_Half Squat, mm²); Hard surface Eyes Open Area Right- Soft surface Eyes Open Area Right (H_EO_Area_R-S_EO_Area_R, mm²); Hard surface Eyes Open Area Right-Hard surface Eyes Open Area Right Half Squat (H_EO_Area_R-H_EO_Area_R_Half Squat, mm²); Hard surface Eyes Open Length- Soft surface Eyes Open Length (H_EO_L-S_EO_L, mm); Hard surface Eyes Open Length- Hard surface Eyes Open Length Half Squat (H_EO_L-H_EO_L_Half Squat, mm); Hard surface Eyes Open Speed - Soft surface Eyes Open Speed (H_EO_Speed-S_EO_Speed, mm/s); Hard surface Eyes Open Speed - Hard surface Eyes Open Speed Half Squat (H_EO_Speed-H_EO_Speed_Half Squat, mm/s); Hard surface Eyes Close Area Left- Hard surface Eyes Open Area Left Half Squat (H_EC_Area_L-H_EO_Area_L_Half Squat, mm²); Hard surface Eyes Closed Area Body- Hard surface Eyes Open Area Body Half Squat (H_EC_Area_B-H_EO_Area_B_Half Squat, mm²); Hard surface Eyes Closed Area Right- Hard surface Eyes Open Area Right Half Squat (H_EC_Area_R-H_EO_Area_R_Half Squat, mm²); Not statistically significant: Hard surface Eyes Closed Length- Hard surface Eyes Open Length Half Squat (H_EC_L-H_EO_L_Half Squat, mm); $p=0.189$ Hard surface Eyes Close Speed- Hard surface Eyes Open Speed Half Squat (H_EC_L-H_EO_L_Half Squat, mm/s) at $p=0.195$;

Wilcoxon signed-rank test results, presented in Table 2, show significant differences across all variables when comparing EO and EC conditions ($p < .000$). This indicates that visual input is essential for maintaining postural stability, particularly in T2DM patients, who often have impaired proprioception owing to diabetic neuropathy. Table 2, also shows that changes in the center of gravity area, length, and speed confirm a significant reduction in balance control without vision emphasizing the importance of multisensory integration in fall prevention.

Discussion

The results highlight considerable balance challenges in T2DM patients, especially under dynamic conditions. The H-Sqt produced postural responses comparable to those on S, validating its use as a functional assessment tool. This aligns with Qin et al., (2021) who emphasize the importance of dynamic postural evaluations in fall risk assessment. Alahmari & Reddy (2024) also reported impaired proprioceptive control in T2DM patients during dynamic tasks, reinforcing the relevance of functional balance tests such as the H-Sqt. Additionally Ong et al. (2022) found a strong correlation between balance responses in the H-Sqt and fall risk in older adults, which suggests that static tests may underestimate fall susceptibility. Together these findings, support incorporating dynamic postural assessments in clinical practice for T2DM patients to better evaluate and manage fall risk.

By incorporating functional assessments into standard balance evaluations, healthcare providers can more effectively identify individuals who are at risk of falls and tailor interventions accordingly. The H-Sqt test is promising for use in both diagnostic and rehabilitative contexts. Previous studies have emphasized the importance of functional movement assessments, such as the Functional Gait Assessment and the Four Square Step Test, in predicting the likelihood of falls (de Aquino et al., 2022). While these tests include dynamic movements, yet they do not specifically evaluate balance in sustained postures that require isometric contraction. In contrast, studies by Sato (2020) have shown that lower extremity muscle activation during the H-Sqt is directly correlated with balance impairments in diabetic patients. This highlights the importance of incorporating such assessments into clinical practice to improve patient outcomes and reduce risk of falls. Additionally, comparative studies between the BBS and new dynamic tests indicate that traditional static assessments may underestimate the likelihood of falls in elderly populations (Pavlikova et al., 2020).

Conclusions

This study investigated how different evaluation protocols affected the body's barycenter area, the distance traveled, and speed in individuals with T2DM, emphasizing the considerable effect of dynamic postural conditions. The results show that both the H-Sqt and visual input EO vs. EC had a significant influence on the body's barycenter area and speed. This confirms the importance of including functional postural assessments when evaluating balance and fall risk. Although there were no significant differences in the distance traveled by the body's barycenter between the H-Sqt and EC conditions, the overall data indicate that dynamic testing offers valuable insights beyond what traditional static balance assessments provide. These findings are consistent with previous studies on patients with T2DM, underscoring, the necessity of dynamic postural assessments for more accurate fall risk prediction and intervention planning. The H-Sqt test shows promise as a valuable tool for balance assessment in both diagnostic and rehabilitative contexts. However, further research needed to investigate additional functional postural conditions, wider populations, and real-life mobility tasks. This will help to improve the applicability of these findings and to refine balance evaluation strategies even further.

Study Limitations and Future Directions

The study has limitations, such as the lack of an EC H-Sqt condition and the rural setting, which may limit the generalizability of the findings. Future research should focus on performing balance assessments across various populations and include real-world mobility tasks.

Conflicts of interest

The authors do not have any conflicts of interest to declare.

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