International Journal of General Medicine

Dovepress
Taylor & Francis Group

Open Access Full Text Article

ORIGINAL RESEARCH

Static Balance in Prediabetic Subjects: Correlation Study Involving Glucose Indicators, Insulin Resistance and Postural Stability Indices

Zhishan Wang[1,2], Yihang Chen[3], Weijun Yang[3], Yuanya Xie[4], Miaoyun Li[5], Jingran Liang[6], Xingyu Li[3], LingJing Gao[3], Dehong Pan[3], Xiaoling Wang[1,6], Shujiao Chen[1–3]

[1]Department of Preventive Treatment of Disease, The Third Affiliated People's Hospital of Fujian University of Traditional Chinese Medicine, Fuzhou, 350108, People's Republic of China; [2]Clinical Research Center for TCM Clinical Medicine in Diabetes and Lipid Disorders of Fujian Province, Fuzhou, 350108, People's Republic of China; [3]College of Traditional Chinese Medicine, Fujian University of Traditional Chinese Medicine, Fuzhou, 350122, People's Republic of China; [4]College of Acupuncture and Tuina, Fujian University of Traditional Chinese Medicine, Fuzhou, 350122, People's Republic of China; [5]Department of Preventive Treatment of Disease, Affiliated People's Hospital of Fujian University of Traditional Chinese Medicine, Fuzhou, 350004, People's Republic of China; [6]College of Rehabilitation Medicine, Fujian University of Traditional Chinese Medicine, Fuzhou, 350122, People's Republic of China

Correspondence: Xiaoling Wang, College of Rehabilitation Medicine, Fujian University of Traditional Chinese Medicine, Fuzhou, 350122, People's Republic of China, Tel +86 15705960213, Email 2013004@fjtcm.edu.cn; Shujiao Chen, Department of Preventive Treatment of Disease, The Third Affiliated People's Hospital of Fujian University of Traditional Chinese Medicine, Fuzhou, 350108, People's Republic of China, Tel +86 15880449869, Email fjcsj12@163.com

Objective: To investigate the relationship between different glycemic parameters and static balance function in prediabetic patients.

Patients and Methods: A total of 92 prediabetic patients who attended The Third Affiliated Hospital of Fujian University of Traditional Chinese Medicine from October 2023 to February 2024 were enrolled in this observational study. All patients underwent assessments of glucose parameters, insulin resistance, and static balance function parameters. Spearman rank correlation test was used to analyze the correlations between these indices.

Results: Among the 92 participants, age, gender, height, weight, BMI, FIns, 2hPG, HOMA-IR, and HbA1c were correlated with static balance function. Specifically, age was negatively correlated with visual and vestibular function; height and weight were negatively correlated with proprioception; and BMI was negatively correlated with proprioception, vision, and vestibular function. 2hPG and HbA1c were negatively correlated with vestibular function and proprioception, respectively, while HOMA-IR and FIns were negatively correlated with vestibular function and vision. For patients with poorly controlled 2hPG or HbA1c, emphasis is recommended on coronal plane postural control training; for those with poorly controlled HOMA-IR or FIns, priority should be given to sagittal plane postural control training.

Conclusion: Through multi-indicator correlation analysis, this study preliminarily identifies the potential mechanisms underlying the association between abnormal glucose metabolism and static balance dysfunction in prediabetic patients. These findings provide a reference for further exploration of clinical research on combined "glycemic control-balance training" interventions.

Keywords: prediabetes, static balance function, blood glucose, correlation

Introduction

Diabetes mellitus (DM) is a chronic metabolic disease involving the cochlea, vestibular and balance systems. Type 2 diabetes mellitus (T2DM) is the most common form of diabetes mellitus.[1] Because T2DM can lead to nervous system damage, somatosensory impairment, visual impairment and vestibular damage, and then cause abnormal balance function, can lead to the development of sensory complications such as diabetic peripheral neuropathy, diabetic retinopathy, and diabetic vestibulopathy,[2,3] and can severely affect patients' postural control and reduce their ability to balance, often leads to impaired mobility and an increased risk of falls.[3–7] The occurrence of falls is related to many factors, but the most important is impaired balance.[8] Balance refers to the ability of multiple physiological systems to

Received: 15 June 2025
Accepted: 28 August 2025
Published: 9 September 2025

sense, process and integrate to maintain or restore body stability. It is often divided into static balance and Dynamic equilibrium. It is the most basic factor in preventing falls. Evidence suggests that DM complications have a direct impact on the vestibular system,[9] and at the same time, patients with DM damage the sensory systems (vision, proprioception, and vestibular) that are required for balance due to their complications, suggesting that DM complications may have a direct impact on the vestibular system, their fall risk is significantly higher than the general population.[8] Long-term glucose metabolic disorders, varying degrees of impairment of DM-related sensory functions (somatosensory, visual, and vestibular nerves) and motor control, followed by impairment of their balance functions,[10,11] affect their social participation and quality of life.

Prediabetes (Pre-DM) is a transitional stage before the onset of DM, an intermediate hyperglycemic state between normoglycemia and DM. According to the 11th edition of the IDF Diabetes Atlas, the global 2024 of adults aged 20–79 with DM is 589 million, of whom 635 million have impaired glucose tolerance and 488 million have impaired fasting glucose (https://diabetesatlas.org/). DM is one of the fastest-growing challenges in global public health in the 21st century, and early intervention of pre-DM can delay or even block T2DM progression, thus understanding, evaluating the balance function status of pre-DM patients, and improving the management of pre-DM patients are important, helps to maintain or improve balance through functional exercise to reduce the risk of falls. Studies have shown that patients with impaired glucose regulation have a reduced ability to balance and maintain postural stability when their proprioception is disturbed, the ability of the vestibular system to maintain postural balance was lower than that of normal subjects.[12] However, there are few studies on the static balance function of Pre-DM patients, and the internal relationship has not been further explored. In recent years, digital instruments have been used to quantitatively assess balance function, the main principle being that the characteristics of the body's center of gravity swing during the test can be recorded through a force platform, which can quantitatively study the postural stability of the subject.[13,14] Therefore, this study aimed to apply the Italian Tecnobody Pro-kin252 type balance test system for open/closed eyes and with/without cushion conditions, and to provide a reference for the design of the eye balance test system, to quantitatively evaluate the independent and integrated effects of proprioceptive, visual, and vestibular systems in balance function in Pre-DM patients, to explore the association between blood glucose levels and static balance function in Pre-DM patients, and to provide a theoretical basis for the study of the role of the proprioceptive, visual, and vestibular systems in balance function in Pre-DM patients, developing postural control strategies for Pre-DM patients to reduce fall risk and improve social participation and quality of life in Pre-DM patients.

Material and Methods

Study Design and Patient Selection

This was an observational study of 92 Pre-DM patients 2023 from a Fujian University of Traditional Chinese Medicine Third People's Hospital between October and February 2024.

We recruited patients according to the following inclusion and exclusion criteria. Inclusion criteria: (1) adult patients over 18 years of age; and (2) those meeting the Impaired Fasting Glucose (IFG) and/or Impaired Glucose Tolerance (IGT) diagnosis in the Chinese guidelines for Type 2 diabetes prevention and control (2020 edition):[15] IFG: 6.1 mmol/L≤Fasting Blood Glucose (FBG) < 7.0 mmol/L, with 2-Hour Postprandial Blood Glucose (2hPG) < 7.8 mmol/L; IGT (Impaired Glucose Tolerance): FBG<7.0 mmol/L, with 7.8 mmol/L≤2hPG<11.1 mmol/L. (3) those who voluntarily participate in the project and sign the informed consent form.

Exclusion criteria were (1) those with missing case data, unable to cooperate with the research process or who dropped out of the study; (2) persons with endocrine disease other than T2DM; (3) due to drugs, poisoning and other exogenous factors lead to balance dysfunction; (4) patients with hip, knee and ankle diseases, limb defects, or serious musculoskeletal disorders (such as severe kyphosis, severe scoliosis, etc) affecting postural stability; (5) those with severe mental disorders (eg, major depression, mania) or severe cognitive impairment who are unable to complete the assessment; (6) presence of central nervous system disease (eg, Parkinson's disease) or vestibular or auditory nerve related diseases (eg, vestibular neuritis, acoustic neuroma); (7) persons with sensory/perceptual abnormalities such as Vision/visual field impairment or lateral neglect that affect balance function assessment.

The study was reviewed and approved by the Institutional Review Board (Medical Ethics Committee of The Third People's Hospital Affiliated to Fujian University of Traditional Chinese Medicine (Approval No.2023KS-85-1)) and complied with the principles of the Declaration of Helsinki. Written informed consent was obtained from all participants.

Data Acquisition

Laboratory Parameters

All subjects were Fujian University of Traditional Chinese Medicine for blood biochemical tests at the laboratory department of the Third People's Hospital. FBG, Fasting Insulin (FIns), 2hPG, Glycated Hemoglobin A1C (HbA1c), homeostatic Model Assessment for Insulin Resistance (HOMA-IR). Fast for 8 to 10 hours before blood collection.

Functional Assessment of Static Balance

The static balance index of the subjects in standing position was tested by the static balance assessment module of the balance feedback training instrument (Italian TECNO-BODY company, model: PK-254 Pro-Kin). Adjust the resistance buffer to 10 gears in advance (static, the ramp does not move). Before the test, the balance panel was reset, and the parameters were adjusted to "Open eyes/close eyes" to evaluate the balance function of the subjects under 4 standing conditions. The order was as follows: T1 Mode: Eyes Open and upright on the rigid balance board, sensory input mainly depends on the combined effect of vision, proprioception and vestibular sense; T2 mode: eyes closed and upright on the rigid balance board, the sensory input mainly depends on proprioception and vestibular sense; T3 mode: Eyes Open and upright on the balance plate with sponge pad, sensory input mainly depends on visual and vestibular sense; T4 Mode: Standing upright with eyes closed on a balance board equipped with a foam pad, where sensory input primarily relies on the vestibular sense. The test is conducted in a quiet, well-lit environment, with detailed instructions for the patient and his or her family.

The test indicators are as follows: ①X-axis mean Center of Pressure (C.o.P): Trajectory of pressure center movement in the coronal plane. C.o.P refers to the mean distance of pressure center movement; the larger the absolute value of C.o. P, the poorer the balance stability. ②Y-axis C.o.P: Trajectory of pressure center movement in the sagittal plane. ③Area of Movement Ellipse: The area enclosed by the trajectory of body's center of gravity sway, reflecting the amplitude of center of gravity oscillation. It represents the area of the pressure center movement trajectory; the larger the value, the poorer the balance stability. ④Romberg Ratio: The ratio of trajectory area under upright standing conditions with eyes closed versus eyes open. It reflects the compensatory capacity of vestibular and proprioceptive senses when maintaining posture with visual input removed, as well as the impact of visual feedback on patients' balance function.

Statistical Analysis

In order to carry out our analysis, various methods were used according to the nature of the data: SPSS 26.0 statistical software was used for processing, and the measurement data were expressed as ($\bar{x} \pm s$) if they conformed to a normal distribution; those who did not conform to a normal distribution, and those who did not conform to a normal distribution, presented as M (IQR). If variables are ordinal or rankable data, meet the requirements of independence and monotonic correlation under study, and are not normally distributed, Spearman's rank test was used for correlation analysis, and $P < 0.05$ was considered to be statistically significant.

Results

Demographics and Disease Characteristics

A total of 92 patients were included in this study. Patient Demographics and disease characteristics are summarized in Table 1. The age was 55.01±9.84 years, of which 30 were male and 62 were female. Body Mass Index (BMI) was 23.35±3.27.

Table 1 Clinical Features and Biochemical Parameters of Patients

Pre-DM	**Variabels**	**Total**
General demographic characteristics		
	Male/Female	30/62
	Age (yrs)	55.01±9.84
	Height (m)	1.62±0.08
	Weight (kg)	61.52±11.69
	BMI	23.35±3.27
Glycemic index		
	FBG (mmol/L)	5.86 (1.2)
	2 hPG (mmol/L)	7.62 (3.71)
	HbA1c (%)	6.42±0.64
	FIns (μIU/mL)	12.03±5.96
	HOMA-IR	3.24±1.93

Correlation Between General Population Characteristics and Static Equilibrium Index

Age showed a positive correlation with the area of movement ellipse under conditions T3 and T4, respectively ($P<0.01$, $P<0.05$). Gender was negatively correlated with Y-axis C.o.P under condition T2 ($P<0.05$). Height exhibited a positive correlation with Y-axis mean C.o.P and the area of movement ellipse under conditions T1 and T2 ($P<0.01$). Weight showed a positive correlation with the area of movement ellipse under conditions T1 and T2, respectively ($P<0.01$, $P<0.05$); BMI was positively correlated with the area of movement ellipse under condition T2 ($P<0.05$) and negatively correlated with Y-axis mean C.o.P under condition T3 ($P<0.01$). See Table 2 for details.

Correlations Between Glucose Indices, Insulin Resistance, and Static Balance Indices

HbA1c showed a positive correlation with X-axis Center of Pressure (C.o.P) under conditions T1 and T2 ($P<0.05$). FIns and HOMA-IR showed a negative correlation with Y-axis C.o.P under condition T3 ($P<0.05$). No correlation was observed between FBG levels and the aforementioned static balance parameters ($P>0.05$).2hPG showed a negative correlation with the Romberg ratio for T2/T1 and T4/T3, respectively ($P<0.01$); it also showed a positive correlation with X-axis C.o.P and the area of the movement ellipse under condition T4 ($P<0.01$). See Table 3 for details.

Discussion

Static balance is the ability of the body to maintain postural stability while at rest.[16] The maintenance of postural balance relies on the central nervous system integration of proprioceptive, visual, and vestibular afferent information and the control of effectors.[17] Proprioception is formed by the integration of afferent signals from muscles, tendons, joint capsules, ligaments, meniscus, articular cartilage, and cutaneous receptors located around the joint, which are processed in different central nervous systems, efferent activity through reflex responses and tone regulation circuits is clinically important in stabilizing joints, correcting posture, and maintaining balance.[18] Vision is the environmental information obtained by processing visual information, so as to know the body's environment and the specific location of the surrounding objects. The vestibular sense, by perceiving head position and movement, enables the body skeletal muscles to respond and coordinate head movements for adjustments to maintain postural balance.[19,20] The Pro-kin252 balance tester mainly uses the electronic moving inclined plate to sense the change of the center of gravity of the human body,

Table 2 Correlation Between General Demographic Characteristics and Static Equilibrium Index

Variabels	T1						T2						T2/T1	
	X-C.o.P		Y-C.o.P		Movement Ellipse Area		X-C.o.P		Y-C.o.P		Movement Ellipse Area		Romberg ratio	
	ρ value	*P*-value	ρ value	*P*-value	ρ value	*P*-value	ρ value	*P*-value	ρ value	*P*-value	ρ value	*P*-value	ρ value	*P*-value
Age	−0.068	0.518	−0.042	0.69	−0.006	0.958	−0.103	0.326	−0.11	0.297	−0.031	0.77	−0.042	0.688
Gender	0.076	0.471	−0.144	0.172	−0.149	0.157	0.071	0.503	−0.241	0.021	−0.171	0.103	0.062	0.557
Height	−0.046	0.664	0.251	0.016	0.225	0.031	−0.033	0.754	0.223	0.032	0.266	0.01	0.082	0.435
Weight	0.117	0.267	0.04	0.704	0.216	0.039	0.105	0.317	0.093	0.376	0.352	0.001	0.114	0.277
BMI	0.197	0.059	−0.142	0.176	0.13	0.216	0.175	0.096	−0.051	0.627	0.327	0.001	0.116	0.271
Variabels	**T3**						**T4**						**T4/T3**	
	X-C.o.P		**Y-C.o.P**		**Movement Ellipse Area**		**X-C.o.P**		**Y-C.o.P**		**Movement Ellipse Area**		**Romberg ratio**	
	ρ value	*P*-value	ρ value	*P*-value	ρ value	*P*-value	ρ value	*P*-value	ρ value	*P*-value	ρ value	*P*-value	ρ value	*P*-value
Age	0.084	0.424	−0.012	0.912	0.288	0.005	0.113	0.285	0.04	0.706	0.207	0.047	−0.081	0.442
Gender	−0.007	0.944	0.076	0.472	−0.126	0.232	−0.107	0.312	0.077	0.466	−0.19	0.07	0.077	0.464
Height	0.138	0.191	−0.13	0.217	0.152	0.147	0.081	0.441	−0.04	0.704	0.101	0.336	−0.005	0.962
Weight	0.113	0.285	−0.2	0.055	0.109	0.301	−0.023	0.83	−0.08	0.45	0.083	0.431	−0.044	0.675
BMI	0.09	0.392	−0.220	0.035	0.068	0.517	−0.081	0.441	−0.091	0.386	0.058	0.582	−0.088	0.407

https://doi.org/10.2147/IJGM.S547267

https://doi.org/10.2147/IJGM.S547267

Table 3 Correlation of Glucose Indicators and Insulin Resistance with Static Balance Indicators

Variabels	T1						T2						T2/T1	
	X-C.o.P		Y-C.o.P		Movement Ellipse Area		X-C.o.P		Y-C.o.P		Movement Ellipse Area		Romberg ratio	
	ρ value	*P*-value	ρ value	*P*-value	ρ value	*P*-value	ρ value	*P*-value	ρ value	*P*-value	ρ value	*P*-value	ρ value	*P*-value
HbA1c	0.266	0.01	−0.015	0.885	0.084	0.424	0.262	0.012	0.037	0.724	0.091	0.389	−0.147	0.163
FIns	0.029	0.785	−0.18	0.087	−0.06	0.567	−0.036	0.73	−0.15	0.154	−0.073	0.488	−0.111	0.293
HOMA-IR	0.019	0.854	−0.142	0.176	−0.042	0.69	−0.037	0.729	−0.104	0.325	−0.043	0.681	−0.141	0.18
FBG	0.045	0.673	0.105	0.32	0.069	0.513	0.057	0.592	0.129	0.221	0.122	0.245	−0.124	0.237
2 hPG	0.121	0.249	0.089	0.4	−0.03	0.774	0.134	0.204	0.125	0.234	−0.095	0.368	−0.306	0.003
Variabels	**T3**						**T4**						**T4/T3**	
	X-C.o.P		**Y-C.o.P**		**Movement Ellipse Area**		**X-C.o.P**		**Y-C.o.P**		**Movement Ellipse Area**		**Romberg ratio**	
	ρ value	*P*-value	ρ value	*P*-value	ρ value	*P*-value	ρ value	*P*-value	ρ value	*P*-value	ρ value	*P*-value	ρ value	*P*-value
HbA1c	0.194	0.064	−0.015	0.884	0.065	0.537	0.12	0.253	0.006	0.958	0.153	0.145	−0.127	0.229
FIns	−0.005	0.962	−0.239	0.022	−0.035	0.741	−0.081	0.444	−0.036	0.735	−0.023	0.825	−0.118	0.261
HOMA-IR	−0.01	0.923	−0.238	0.023	0.002	0.987	−0.032	0.76	−0.05	0.636	0.007	0.947	−0.136	0.195
FBG	−0.013	0.904	−0.004	0.972	0.114	0.28	0.163	0.12	−0.034	0.746	0.139	0.188	−0.11	0.295
2 hPG	0.189	0.072	0.039	0.715	−0.012	0.91	0.310	0.003	−0.026	0.802	0.312	0.002	−0.382	<0.001

and converts the signal into data for quantitative evaluation of human balance function. Therefore, the static balance ability of Pre-DM patients was studied by balance tester.

There were differences in sensory input to maintain balance in T1, T2, T3 and T4. In T1 condition, the balance was maintained by both vision and proprioception; in T2 condition, the balance was maintained by proprioception and vestibular sense; in T3 condition, the balance was maintained by vision and vestibular sense T4 blocks visual input, interferes with proprioception, and maintains balance mainly by vestibular sense. This study assessed the role of proprioception, vision, and vestibular perception in static balance in Pre-DM patients, respectively, by changing the input conditions of vision or proprioception with and without open and closed eyes and with and without cushions, analysis of the three senses in the static balance of the independent role and relationship.[21] Falls are the most common accidental injury in elderly patients with DM in our country, and the decline in static balance is one of the main risk factors for falls in the elderly.[22] Studies have shown that older adults with T2DM are 2.73 times more likely to have multiple falls than non-T2DM older adults and are more prone to serious events including reduced mobility, restricted mobility, hospitalization, and death.[9,23,24] Balance disorders in patients with DM are mainly related to peripheral neuropathy impairment of proprioceptive function.[25,26] Patients with Pre-DM have decreased balance and postural stability in the presence of proprioception interference[12.]Based on the above research background, this paper is the first to explore the correlation between different blood glucose values and static balance function in Pre-DM patients, it provides clues and data support for the follow-up development of postural management strategies and hypoglycemic exercise programs according to patients' different blood glucose status.

In this study, the correlation analysis of general population characteristics and static balance index showed that age was positively correlated with the area of motor ellipse under T3 and T4 conditions, indicating that age is related to vestibular sensation, age was associated with decreased equilibrium stability. Studies have shown that the vestibular system degenerates with age, and older adults are prone to chronic imbalance, decreased mobility, and gait changes.[27,28] The older the patient, the worse the reactive balance control, that is, the balance stability also decreased.[10] This is consistent with the results of this study. In addition, studies have shown that gender and age can affect balance function, and the range of normal values of each index varies by gender and age of patients[29,30,] and this study also found a correlation between gender and static balance. Height was positively correlated with the average Y-axis C.o.P and the area of the movement ellipse under both T1 and T2 conditions. This suggests that height appears to be associated with proprioception. The results indicate that taller patients exhibit poorer balance stability, which may necessitate enhanced postural control in the sagittal plane to prevent falls. The findings of this study reveal that body weight was positively correlated with the area of the movement ellipse under T1 and T2 conditions, implying that body weight has a closer association with proprioception. Specifically, individuals with greater body weight demonstrated poorer balance stability. Research has identified body weight as one of the internal factors influencing human balance ability, with body weight showing an inverse relationship with human balance ability, and balance index being inversely proportional to BMI.[31,32] Due to the fact that obese individuals often lack exercise and have increased weight burden, this adversely affects both dynamic and static balance functions, thereby impacting fall efficacy.[33] BMI was positively correlated with the area of the movement ellipse under T2 conditions and negatively correlated with the Y-axis C.o.P under T3 conditions. This indicates that BMI is associated with proprioception, vision, and vestibular sense, and that higher BMI values correspond to poorer stability, particularly in terms of postural control in the sagittal plane.

As a more stable indicator of blood glucose control, HbA1c can reflect the average blood glucose level in patients with Pre-DM over the past 2–3 months. Since it is not affected by short-term diet or exercise, it serves to evaluate and monitor long-term blood glucose control. This study found that HbA1c in Pre-DM patients was positively correlated with the X-axis C.o.P under both T1 and T2 conditions, indicating that HbA1c may have a closer association with proprioception. Research has revealed that in patients with DM, the incidence of abnormal balance function increases significantly due to complications such as concurrent neuropathy, retinopathy, and muscle atrophy.[34] Among DM patients, the incidence of vestibular function impairment is as high as 70%, while the prevalence of diabetic retinopathy ranges from 24% to 37%;[35,36] these conditions impair visual input and ultimately lead to balance dysfunction. Decreased balance ability in patients with type T2DM is characterized primarily by significant declines in vestibular sense and vision.[37] Furthermore, the findings of this study also showed that HbA1c in Pre-DM patients was positively correlated

 https://doi.org/10.2147/IJGM.S547267

with the X-axis C.o.P under T1 and T2 conditions, suggesting an association between HbA1c and postural control ability in the coronal plane. It may thus be possible to reduce the incidence of falls by enhancing coronal plane exercise training in Pre-DM patients.

FIns, which measures insulin levels in the fasting state, is used to evaluate pancreatic β-cell function and insulin resistance. HOMA-IR, by incorporating both blood glucose and insulin levels, more accurately reflects insulin resistance status and is well suited for assessing long-term insulin sensitivity. At present, there are few studies on FIns, HOMA-IR and static balance in patients with Pre-DM. However, the findings of this study revealed that HOMA-IR and FIns were negatively correlated with the Y-axis C.o.P under T3 conditions. This suggests that in patients at the Pre-DM stage, their vestibular system and visual function may still be in a compensatory phase, allowing them to maintain body balance through adjustments and adaptations—hence the observed negative correlation. Studies have indicated that human activities primarily occur in the anteroposterior direction, and the range of stability limits in this direction is significantly associated with the muscle strength of the ankle plantar flexor muscles. Therefore, incorporating strength training for plantar flexors into balance training for DM patients may help prevent falls.[37,38] The results of this study further suggest that HOMA-IR and FIns may be associated with postural control ability in the sagittal plane. Thus, enhancing sagittal plane exercise training in Pre-DM patients could potentially reduce the incidence of falls.

2hPG is measured during the Oral Glucose Tolerance Test as the blood glucose level 2 hours after oral glucose administration. It is used to assess the body's glucose metabolism and insulin secretion, and more comprehensively reflects pancreatic β-cell function and insulin sensitivity, and aids in identifying DM and Pre-DM. 2hPG was positively correlated with the X-axis C.o.P and the area of the movement ellipse under T4 conditions, while negatively correlated with the Romberg ratio. This indicates that in Pre-DM patients, 2hPG is associated with vestibular sense, with minimal dependence on vision. This may be attributed to damage to the nerves and blood vessels of the vestibular system caused by fluctuations in insulin levels and blood glucose, leading to vestibular system dysfunction and subsequent impairment of balance function in patients.[37] Thus,we speculate that enhancing blood glucose management and implementing targeted exercises for proprioception, vision, and vestibular sense in Pre-DM patients may help improve their static balance function, thereby reducing the risk of falls in this population. Specifically, if HbA1c is poorly controlled in Pre-DM patients, emphasis should be placed on strengthening proprioception and vestibular sense exercises; if there is abnormal FIns secretion in Pre-DM patients, exercises targeting vestibular sense and vision can be reinforced; and for patients with poorly controlled 2hPG, vestibular sense training should be prioritized. Regarding exercise training for Pre-DM patients, since HbA1c and 2hPG in Pre-DM patients are associated with postural control ability in the coronal plane, enhancing coronal plane exercise training is recommended. Additionally, as HOMA-IR and FIns in Pre-DM patients are correlated with postural control ability in the sagittal plane, it is advisable to increase sagittal plane exercise training. Such targeted interventions may be beneficial for improving blood glucose levels and static balance function in Pre-DM patients.

Conclusion

The main innovation of our study lies in systematically investigating the relationship between different glycemic parameters and static balance function in Pre-DM patients, further exploring evidence of the association between the two, and thus providing a new perspective for research in this field. The results showed that age was negatively correlated with vision and vestibular sense; height and weight were negatively correlated with proprioception; and BMI was negatively correlated with proprioception, vision, and vestibular sense. Specifically, 2hPG and HbA1c were negatively correlated with vestibular sense and proprioception, respectively; HOMA-IR and FIns were negatively correlated with vestibular sense and vision; while no correlation was observed between FBG and static balance. Proprioception, vestibular sense, and vision play crucial roles in maintaining static balance in Pre-DM patients, providing preliminary clues for further exploration of optimized directions in clinical practice.

Accordingly, we propose the following: For Pre-DM patients, those with poorly controlled 2hPG or HbA1c may be advised to enhance coronal plane postural control training; those with poorly controlled HOMA-IR or FIns may be recommended to strengthen sagittal plane postural control training. Based on the glycemic control status of Pre-DM patients, formulating appropriate and rational glucose-lowering regimens and conducting targeted training for vestibular sense, proprioception, and vision may, on the one hand, benefit their glycemic levels and static balance ability, help prevent falls, and reduce the incidence of fall-related adverse events. On the other hand, enhancing static balance training may stabilize blood glucose levels in Pre-DM patients and delay disease progression.

Although this study obtained preliminary findings through cross-sectional analysis, it has limitations: the current conclusions are based solely on correlation analysis, and causal relationships have not yet been verified. In future studies, we plan to expand the sample size, broaden research dimensions, and further systematically investigate the association patterns between different glycemic levels and balance function in Pre-DM patients. Meanwhile, through interventional or prospective experimental designs, we will conduct standardized exploration of the potential impact of balance function training on glycemic management, aiming to provide more valuable preliminary research evidence for fall prevention. Its clinical practical value remains to be verified in subsequent studies.

Acknowledgments

We thank the nurses and doctors who assisted in this study. We thank the Third People's Hospital affiliated to the Fujian University of Traditional Chinese Medicine for the clinical data.

Funding

This study was National Administration of Traditional Chinese Medicine (NATCM) Fifth Batch National Clinical Excellence Talent Cultivation Program (No. [2022]1); National Administration of Traditional Chinese Medicine (NATCM) High-Level Key Discipline Construction Project in Traditional Chinese Medicine (Document No. [2023] 85); National Traditional Chinese Medicine Advantageous Specialties Construction Project (Document No.Guozhongyiyi Zheng Han [2024] No.90); Fujian Provincial Traditional Chinese Medicine Clinical Medical Research Center for Glucose and Lipid Metabolism Disorders (No. FJSSK [2023]3); Project supported by the Natural Science Foundation of Fujian Province, China (No. 2025J01955); Fujian Provincial Traditional Chinese Medicine Science and Technology Project Funding Program (No. 2025YBA033); Joint Open Research Project between the Discipline of TCM Health Management of Fujian University of Traditional Chinese Medicine and the Key Specialty of Its Affiliated Third People's Hospital (under the High-Level Key Discipline of Traditional Chinese Medicine-TCM Health Management) (No. XJG2023001). Funding agencies had no role in the design and conduct of the study, the collection, management, analysis, and interpretation of the data, the preparation, review, and approval of the manuscript, and the decision to submit the manuscript for publication.

Disclosure

The authors state that there is no competing interest in this work.

References

1. Enayati Z, Cacace AT. Vestibular and balance considerations in type 2 diabetes: a tutorial on pertinent areas and issues. *Am J Audiol*. 2024;33 (4):1092–1103. doi:10.1044/2024_AJA-24-00075
2. Li J, Xie Y, Zhao MM, et al. Research progress on balance function in patients with type 2 diabetes mellitus. *Chinese Journal of Contemporary Medicine*. 2021;28(12):42–46.
3. Lopatin T, Sakyi K, Kendall B, et al. Standing balance impairment in persons with type 2 diabetes is predicted by peripheral neuropathy and vestibulopathy. *Prim Care Diabetes*. 2025;19(1):35–39. doi:10.1016/j.pcd.2024.12.003
4. Bonnet C, Turvey MT, Turvey MT. Diabetes and postural stability: review and hypotheses. *J Mot Behav*. 2009;41(2):172–190. doi:10.3200/ JMBR.41.2.172-192
5. Lopatin T, Ko M, Brown E, et al. Balance testing for patients with type 2 diabetes. *J Diabetes Sci Technol*. 2022;16(6):1582–1583. doi:10.1177/ 19322968221121679
6. Komalasari DR, Vongsirinavararat M, Hiengkaew V, et al. Balance performance, falls-efficacy and social participation in patients with type 2 diabetes mellitus with and without vestibular dysfunction. *PeerJ*. 2024;12:e17287. doi:10.7717/peerj.17287
7. Li J, Jiang J, Zhang Y, et al. Impairment of vestibular function and balance control in patients with type 2 diabetes. *Audiol Neurootol*. 2019;24 (3):154–160. doi:10.1159/000501291
8. Zhou Y, Liu B. Mechanism of balance dysfunction in diabetic patients. *Chinese Journal of Otology*. 2011;9(4):365–368.
9. Piker EG, Romero DJ. Diabetes and the vestibular system. *Semin Hear*. 2019;40(4):300–307. doi:10.1055/s-0039-1697032
10. Lee PY, Tsai YJ, Liao YT, et al. Reactive balance control in older adults with diabetes. *Gait Posture*. 2018;61:67–72. doi:10.1016/j. gaitpost.2017.12.030
11. Hewston P, Deshpande N. Falls and balance impairments in older adults with type 2 diabetes: thinking beyond diabetic peripheral neuropathy. *Can J Diabetes*. 2016;40(1):6–9. doi:10.1016/j.jcjd.2015.08.005

12. Yan Q. *Research on Balance Function in Patients with Impaired Glucose Regulation[D]*. Beijing: Capital Medical University; 2017.
13. Clark RA, Mentiplay BF, Pua YH, et al. Reliability and validity of the Wii Balance Board for assessment of standing balance: a systematic review. *Gait Posture*. 2018;61:40–54. doi:10.1016/j.gaitpost.2017.12.022
14. Dixon CJ, Knight T, Binns E, et al. Clinical measures of balance in people with type two diabetes: a systematic literature review. *Gait Posture*. 2017;58:325–332. doi:10.1016/j.gaitpost.2017.08.022
15. Prevention, Diabetes, and Treatment of Clinical Guidelines Writing Group. Guidelines for the Prevention and Treatment of Type 2 Diabetes in China (2020 Edition) (Part 1). *Chinese Journal of Practical Internal Medicine*. 2021;41(8):668–695. doi:10.19538/j.nk2021080106
16. Zhuang CH, Wang YF, He SJ, et al. Effects of functional ankle instability on balance ability and lower limb explosive strength. *Chinese Journal of Rehabilitation Theory and Practice*. 2024;30(9):1107–1116.
17. Liu C, Ren LF, Shi JW, et al. Evaluation system of human balance ability. *Chinese Journal of Tissue Engineering Research and Clinical Rehabilitation*. 2009;2009(2):363–367.
18. Salamanna F, Caravelli S, Marchese L, et al. Proprioception and mechanoreceptors in osteoarthritis: a systematic literature review. *J Clin Med*. 2023;12(20):6623. doi:10.3390/jcm12206623
19. Shen Y, Yin ZF, Meng DH, et al. Clinical practice guidelines for rehabilitation: standing balance impairment in stroke patients. *Journal of Rehabilitation Medicine*. 2024;34(3):195–210. doi:10.3724/SP.J.1329.2024.03001
20. J LX, Du Y, Wang Y, et al. Stabilizing body balance: learning from the perspective of clinical vestibular examination techniques. *Chinese Scientific Journal of Hearing and Speech Rehabilitation*. 2023;21(5):557–560.
21. Zhang L, Weng CS, Wang QH, et al. Analysis of factors influencing fall risk in the elderly: roles of vestibular, proprioceptive, and visual functions. *Chinese Journal of Rehabilitation Theory and Practice*. 2010;16(1):16–18.
22. Pizzigalli L, Micheletti Cremasco M, Mulasso A, et al. The contribution of postural balance analysis in older adult fallers: a narrative review. *J Bodyw Mov Ther*. 2016;20(2):409–417. doi:10.1016/j.jbmt.2015.12.008
23. Maurer MS, Burcham J, Cheng H. Diabetes mellitus is associated with an increased risk of falls in elderly residents of a long-term care facility. *J Gerontol a Biol Sci Med Sci*. 2005;60(9):1157–1162. doi:10.1093/gerona/60.9.1157
24. Janghorbani M, Van Dam RM, Willett WC, et al. Systematic review of type 1 and type 2 diabetes mellitus and risk of fracture. *Am J Epidemiol*. 2007;166(5):495–505. doi:10.1093/aje/kwm106
25. Riandini T, Wee HL, Khoo EYH, et al. Functional status mediates the association between peripheral neuropathy and health-related quality of life in individuals with diabetes. *Acta Diabetol*. 2018;55(2):155–164. doi:10.1007/s00592-017-1077-8
26. Crews RT, Yalla SV, Fleischer AE, et al. A growing troubling triad: diabetes, aging, and falls. *J Aging Res*. 2013;2013:342650. doi:10.1155/2013/342650
27. Harun A, Li C, Bridges JFP, et al. Understanding the experience of age-related vestibular loss in older individuals: a qualitative study. *Patient*. 2016;9(4):303–309. doi:10.1007/s40271-015-0156-6
28. Agrawal Y, Davalos-Bichara M, Zuniga MG, et al. Head impulse test abnormalities and influence on gait speed and falls in older individuals. *Otol Neurotol*. 2013;34(9):1729–1735. doi:10.1097/MAO.0b013e318295313c
29. Zhang PD, Peng XW, Pi ZK, et al. Series studies on human balance function assessment (1): quantitative evaluation of static postural balance in normal adults and differences by gender and age. *Chinese Journal of Rehabilitation Theory and Practice*. 2004;2004(7):34–37.
30. Xu BH, Xie B, Huang YX. Study on influencing factors of static balance posture graph in normal adults. *Chinese Journal of Physical Medicine and Rehabilitation*. 2003;2003(6):22–25.
31. Yuan MZ. Effects of obesity on balance ability in young adults. *Journal of Military Physical Education and Sports College*. 2011;30(4):106–108.
32. Huang SQ, Xu YH, Yin LH. Analysis of differences in balance ability and body mass index among men and women of different ages: a study of 414 cases. *Shandong Sports Science & Technology*. 2016;38(2):52–55.
33. Zhang Y, Wang ZH, Shao MN, et al. Research on the effects of overweight and obesity on static and dynamic balance ability in middle-aged and elderly adults[A]//Sports Biomechanics Branch of Chinese Sports Science Society. Abstracts of the 20th National Academic Conference on Sports Biomechanics[C]. Beijing: Sports Biomechanics Branch of Chinese Sports Science Society, 2018: 2.
34. Brown SJ, Handsaker JC, Bowling FL, et al. Diabetic peripheral neuropathy compromises balance during daily activities. *Diabetes Care*. 2015;38(6):1116–1122. doi:10.2337/dc14-1982
35. Agrawal Y, Carey JP, Della Santina CC, et al. Disorders of balance and vestibular function in US adults: data from the national health and nutrition examination survey, 2001-2004. *Arch Intern Med*. 2009;169(10):938. doi:10.1001/archinternmed.2009.66
36. Diabetes Prevention Program Research Group. The prevalence of retinopathy in impaired glucose tolerance and recent-onset diabetes in the Diabetes Prevention Program. *Diabet Med*. 2007;24(2):137–144. doi:10.1111/j.1464-5491.2007.02043.x
37. Huang XB, Liu B, Sun JW, et al. Analysis and evaluation of balance function in patients with type 2 diabetes mellitus. *Journal of Clinical Otorhinolaryngology Head and Neck Surgery*. 2016;2016(1):27–30.
38. Melzer I, Benjuya N, Kaplanski J, et al. Association between ankle muscle strength and limit of stability in older adults. *Age Ageing*. 2009;38(1):119–123. doi:10.1093/ageing/afn249