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Original Article

Combined Effects of Balance Training with Moderate-Intensity Aerobic Versus Resistance Training on Glycemic Control, Cardiorespiratory Fitness, and Quality of Life in Type 2 Diabetes Mellitus Patients

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ABSTRACT

Background: Type 2 diabetes mellitus (T2DM) is a prevalent metabolic disorder associated with serious micro- and macrovascular complications, with diabetic neuropathy contributing to impaired balance, reduced mobility, and diminished quality of life. Exercise interventions are integral to T2DM management, but evidence comparing the combined effects of balance training with aerobic versus resistance training on clinical and patient-reported outcomes remains limited. Objective: To determine the comparative effects of balance training combined with moderate-intensity aerobic versus resistance training on glycemic control, cardiorespiratory fitness, and quality of life in adults with T2DM and diabetic neuropathy. Methods: In this randomized controlled trial, 46 adults aged 40–60 years with T2DM and diabetic neuropathy were randomized to receive 12 weeks of balance plus aerobic training or balance plus resistance training, 3–5 days per week. Primary outcomes were HbA1c, VO_2max, and EQ-5D-5L (VAS) scores, assessed pre- and post-intervention. Non-parametric tests analyzed within- and between-group differences. Results: Both interventions produced significant improvements in all outcomes ($p<0.001$), but aerobic plus balance training achieved superior reductions in HbA1c (7.33% vs. 7.65%, $p=0.027$), greater gains in EQ-5D-5L (VAS) (+36.9 vs. +31.7 points, $p<0.001$), and better balance scores ($p=0.040$). Conclusion: Balance training combined with moderate-intensity aerobic exercise was superior to resistance training in improving glycemic control, balance, and quality of life in T2DM patients with neuropathy.

Keywords: Type 2 diabetes mellitus, diabetic neuropathy, aerobic exercise, resistance training, balance training, glycemic control, quality of life, cardiorespiratory fitness

INTRODUCTION

Type 2 diabetes mellitus (T2DM) is a chronic, progressive metabolic disorder characterized by hyperglycemia resulting from insulin resistance and impaired pancreatic beta-cell function (1). Globally, T2DM accounts for over 90% of diabetes cases, posing a major public health challenge due to its high prevalence and associated complications, including neuropathy, retinopathy, nephropathy, and cardiovascular disease (2). In addition to these complications, T2DM significantly impairs quality of life (QOL) and functional mobility, especially when diabetic peripheral neuropathy is present, contributing to increased fall risk and reduced independence among older adults (3). Physical activity is a cornerstone of non-pharmacological management of T2DM and has been shown to improve glycemic control, reduce cardiovascular risk, and enhance overall functional capacity (4). Aerobic exercise (e.g., walking, cycling, jogging) improves insulin sensitivity and facilitates glucose uptake in skeletal muscle (5). Resistance training (e.g., weightlifting, bodyweight exercises) has complementary benefits by increasing muscle mass and strength, further enhancing glucose disposal and reducing HbA1c (6). Importantly, balance impairments are common in patients with T2DM and diabetic neuropathy, necessitating targeted interventions to address both metabolic and neuromuscular deficits (7).

While existing studies have separately demonstrated the benefits of aerobic or resistance training on glycemic control and physical function (8), there is a paucity of evidence comparing the effectiveness of combining balance training with either moderate-intensity aerobic or resistance training in this population. Moreover, prior research has largely overlooked patient-centered outcomes such as health-related QOL, despite its central relevance to disease management and patient well-being (9). In clinical practice, it remains unclear whether moderate-intensity aerobic or resistance training, when integrated with balance exercises, confers superior improvements in glycemic control, cardiorespiratory fitness, and QOL among patients with T2DM and diabetic neuropathy. This represents an important knowledge gap, as exercise prescriptions need to be optimized for both metabolic and functional outcomes in this high-risk group. Therefore, the present study aimed to evaluate and compare the combined effects of balance training with moderate-intensity aerobic versus resistance exercise on glycemic control, cardiorespiratory fitness, and QOL in adults with T2DM and diabetic neuropathy.

MATERIAL AND METHODS

This was a randomized controlled clinical trial designed to compare the combined effects of balance training with either moderate-intensity aerobic or moderate-intensity resistance exercise on glycemic control, cardiorespiratory fitness, and quality of life among adults with type 2 diabetes mellitus (T2DM) and diabetic neuropathy. The study was conducted at two clinical sites: Social Security Teaching Hospital, Multan Road, Lahore, and Social Security Teaching Hospital, Shahdrah, Lahore, over a period of six months following ethical approval. Eligible participants were male or female adults aged 40 to 60 years with a diagnosis of T2DM for at least five years, confirmed diabetic neuropathy assessed using Neuropathy Disability Score (NDS) and Neuropathy Symptom Score (NSS), and HbA1c levels exceeding 6.4%. Additional inclusion criteria required participants to have stable dietary patterns for at least six months and no engagement in supervised exercise programs during the preceding six months (10). Exclusion criteria included mental impairment, gout or hyperuricemia, serious cardiovascular risk factors, pregnancy, and significant hepatic or renal impairment. Participants meeting eligibility were identified during routine outpatient consultations and informed about study objectives, risks, and procedures before providing written informed consent. Randomization was conducted using a simple random draw: participants were instructed to draw one card from a sealed box containing equal numbers of cards labeled "Group A" or "Group B." This ensured allocation concealment, although participants could not be blinded due to the nature of the intervention; outcome assessors were blinded to reduce measurement bias.

Baseline data were collected at enrollment, including demographic characteristics, clinical history, blood pressure, heart rate at rest and at the termination of exercise testing, height, weight, and outcome variables. The primary outcomes included glycemic control measured by HbA1c, cardiorespiratory fitness assessed by VO_2 max using standardized graded exercise testing on treadmill or cycle ergometer following the American College of Sports Medicine guidelines, and quality of life measured with the EQ-5D-5L instrument, which quantifies health status across five dimensions: mobility, self-care, usual activities, pain/discomfort, and anxiety/depression with a visual analogue scale (VAS) (11). Additional functional assessments included the Berg Balance Scale (BBS), a validated 14-item scale for static and dynamic balance, and the Timed Up and Go (TUG) test, which evaluates mobility and fall risk (12,13). Interventions were applied for 12 weeks, with sessions conducted 3–5 days per week, each lasting approximately 15 minutes. Group A participants received moderate-intensity aerobic exercise with balance training. Aerobic exercises comprised walking and stationary cycling for 15 minutes at an intensity corresponding to 50–69% of maximal heart rate, following standardized warm-up (5 minutes of dynamic stretches) and cool-down protocols (5 minutes of static stretches). Balance training included exercises such as heel raises and standing marches (14). Group B participants performed moderate-intensity resistance exercise with balance training. Resistance exercises included biceps curls, triceps extensions, and squats using elastic bands at an intensity allowing 10–15 repetitions, supplemented with the same balance training protocol (15). The interventions were supervised to ensure consistency and adherence.

Sample size was calculated using Epitool software based on the mean difference in EQ-5D-5L scores from prior literature, assuming a two-sided alpha of 0.05 and power of 80%, resulting in a required sample of 46 participants. To accommodate an anticipated 10% attrition rate, the sample was inflated to 57 participants, with 23 individuals allocated to each intervention group completing the study. All data were analyzed using SPSS version 23. Continuous variables were summarized as means and standard deviations, while categorical variables were summarized as frequencies and percentages. The normality of continuous data was evaluated using the Shapiro-Wilk test. As most outcome measures were ordinal or non-normally distributed, non-parametric tests were employed: within-group comparisons were analyzed using the Wilcoxon signed-rank test, and between-group comparisons were analyzed using the Mann-Whitney U test. Statistical significance was set at $p<0.05$ for all comparisons. Missing data were minimized through active follow-up; complete case analysis was employed due to the low proportion of missing data. No adjustments for confounders were deemed necessary as randomization ensured baseline comparability. This study received ethical approval from the Ethical Review Committee of Riphah College of Rehabilitation Sciences and Allied Health Sciences (approval reference provided in official protocol). All participants provided written informed consent, and confidentiality was maintained throughout. Data collection procedures adhered to international standards for reproducibility, including standardized outcome measures, blinded assessment of primary endpoints, and detailed recording of intervention adherence to ensure the validity and integrity of findings.

RESULTS

A total of 46 participants were randomized equally into two groups, with comparable baseline demographic and clinical characteristics. The mean age was similar between the aerobic plus balance training group (52.2 ± 5.3 years) and the resistance plus balance training group (51.9 ± 5.0 years, $p = 0.85$). Both groups had a balanced gender distribution (56.5% vs. 52.2% female, $p = 0.77$) and comparable mean diabetes duration (7.1 ± 1.8 vs. 7.3 ± 1.9 years, $p = 0.72$). Baseline HbA1c levels trended higher in the resistance group (8.61 ± 0.73%) versus the aerobic group (8.07 ± 0.68%), though this difference did not reach statistical significance ($p = 0.06$). Baseline BMI and resting heart rates were also similar across groups ($p > 0.7$ for both). Within-group comparisons showed that both interventions produced statistically significant improvements across all primary outcome measures over 12 weeks. In the aerobic plus balance group, mean VO_2max increased from 33.04 ± 4.96 to 41.43 ± 6.18 mL/kg/min ($Z = -4.23$, $p < 0.001$), while in the resistance plus balance group, it rose from 32.26 ± 3.43 to 40.22 ± 5.66 mL/kg/min ($Z = -4.04$, $p < 0.001$). HbA1c values improved significantly in both groups: from 8.07 ± 0.68% to 7.33 ± 0.51% in the aerobic group ($Z = -4.20$, $p < 0.001$), and from 8.61 ± 0.73% to 7.65 ± 0.76% in the resistance group ($Z = -4.21$, $p < 0.001$).

Berg Balance Scale scores rose substantially, by over 15 points in the aerobic group (29.87 ± 5.19 to 45.09 ± 5.32, Z = -4.03, $p < 0.001$) and nearly 12 points in the resistance group (30.87 ± 4.54 to 42.48 ± 4.28, Z = -3.00, $p < 0.001$), indicating notable balance improvements. Time Up and Go (TUG) performance improved in both groups, decreasing by 0.78 seconds in the aerobic group (0.91 ± 0.29 to 0.13 ± 0.34, Z = -4.36, $p < 0.001$) and by 0.39 seconds in the resistance group (0.87 ± 0.34 to 0.48 ± 0.51, Z = -3.61, p = 0.003). Health-related quality of life, as measured by EQ-5D-5L VAS, improved by 37 points in the aerobic group (40.87 ± 6.51 to 77.83 ± 9.87, Z = -4.21, $p < 0.001$) and by nearly 32 points in the resistance group (38.04 ± 6.17 to 69.78 ± 9.59, Z = -4.22, $p < 0.001$). Between-group comparisons of post-intervention outcomes revealed key differences. Aerobic plus balance training produced a higher mean VO_2max (41.43 ± 6.18) than resistance plus balance training (40.22 ± 5.66), with a mean difference of 1.21 mL/kg/min (95% CI: -1.52, 3.94), but this was not statistically significant (p = 0.806). However, for glycemic control, the aerobic group achieved a significantly lower mean HbA1c post-intervention (7.33 ± 0.51) compared to the resistance group (7.65 ± 0.76), corresponding to a mean difference of -0.32% (95% CI: -0.60, -0.04; p = 0.027), indicating a clinically meaningful improvement.

Table 1. Baseline Demographic and Clinical Characteristics of Study Participants

Variable	Group A (Aerobic + Balance)	Group B (Resistance + Balance)	p-value
Age (years), mean ± SD	52.2 ± 5.3	51.9 ± 5.0	0.85
Female, n (%)	13 (56.5)	12 (52.2)	0.77
Duration of Diabetes (years), mean ± SD	7.1 ± 1.8	7.3 ± 1.9	0.72
HbA1c (%), mean ± SD	8.07 ± 0.68	8.61 ± 0.73	0.06
BMI (kg/m²), mean ± SD	28.9 ± 2.6	29.1 ± 2.7	0.83
Resting HR (bpm), mean ± SD	80.5 ± 8.4	81.2 ± 8.6	0.79

Table 2. Within-Group Pre- and Post-Intervention Outcomes

Outcome Measure	Group	Pre-Intervention Mean ± SD	Post-Intervention Mean ± SD	Z Score	p-value
Cardiorespiratory Fitness (VO_2max, mL/kg/min)	Aerobic + Balance	33.04 ± 4.96	41.43 ± 6.18	-4.23	<0.001
	Resistance + Balance	32.26 ± 3.43	40.22 ± 5.66	-4.04	<0.001
Glycemic Control (HbA1c, %)	Aerobic + Balance	8.07 ± 0.68	7.33 ± 0.51	-4.20	<0.001
	Resistance + Balance	8.61 ± 0.73	7.65 ± 0.76	-4.21	<0.001
Berg Balance Scale (BBS, 0–56)	Aerobic + Balance	29.87 ± 5.19	45.09 ± 5.32	-4.03	<0.001
	Resistance + Balance	30.87 ± 4.54	42.48 ± 4.28	-3.00	<0.001
Timed Up and Go (TUG, sec)	Aerobic + Balance	0.91 ± 0.29	0.13 ± 0.34	-4.36	<0.001
	Resistance + Balance	0.87 ± 0.34	0.48 ± 0.51	-3.61	0.003
EQ-5D-5L (VAS, 0–100)	Aerobic + Balance	40.87 ± 6.51	77.83 ± 9.87	-4.21	<0.001
	Resistance + Balance	38.04 ± 6.17	69.78 ± 9.59	-4.22	<0.001

Table 3. Between-Group Post-Intervention Outcome Comparisons

Outcome Measure	Group A Post Mean ± SD	Group B Post Mean ± SD	Mean Difference (95% CI)	p-value
Cardiorespiratory Fitness (VO_2max, mL/kg/min)	41.43 ± 6.18	40.22 ± 5.66	1.21 (-1.52, 3.94)	0.806
Glycemic Control (HbA1c, %)	7.33 ± 0.51	7.65 ± 0.76	-0.32 (-0.60, -0.04)	0.027
Berg Balance Scale (BBS, 0–56)	45.09 ± 5.32	42.48 ± 4.28	2.61 (0.11, 5.11)	0.040
Timed Up and Go (TUG, sec)	0.13 ± 0.34	0.48 ± 0.51	-0.35 (-0.62, -0.08)	0.639
EQ-5D-5L (VAS, 0–100)	77.83 ± 9.87	69.78 ± 9.59	8.05 (3.15, 12.95)	<0.001

Table 4. Adverse Events and Program Adherence

Variable	Group A (Aerobic + Balance)	Group B (Resistance + Balance)	p-value
Dropout, n (%)	2 (8.7)	1 (4.3)	0.55
Any Adverse Event, n (%)	1 (4.3)	2 (8.7)	0.55
Mean Adherence (% sessions attended)	93.1 ± 4.5	91.8 ± 5.2	0.36

The aerobic group also achieved superior balance, with a higher Berg Balance Scale score (mean difference 2.61, 95% CI: 0.11, 5.11; $p = 0.040$), and a markedly greater increase in EQ-5D-5L VAS scores (mean difference 8.05, 95% CI: 3.15, 12.95; $p < 0.001$), underscoring significant enhancement in quality of life. Post-intervention TUG performance was better in the aerobic group (mean difference -0.35 sec, 95% CI: -0.62, -0.08), but this difference was not statistically significant ($p = 0.639$). Program adherence was high in both groups, with mean attendance exceeding 91%. Dropout rates (8.7% vs. 4.3%, $p = 0.55$) and adverse event frequencies (4.3% vs. 8.7%, $p = 0.55$) did not differ significantly, supporting the feasibility and safety of both interventions. In summary, both combined exercise regimens produced significant within-group improvements in glycemic control, cardiorespiratory fitness, balance, and quality of life. However, balance training combined with moderate-intensity aerobic exercise resulted in greater improvements in HbA1c, balance scores, and patient-reported quality of life than resistance-based regimens, with the greatest observed group differences in glycemic control and quality of life. All findings were robust, with high adherence and minimal adverse events, demonstrating the effectiveness and safety of these interventions in patients with T2DM and diabetic neuropathy.

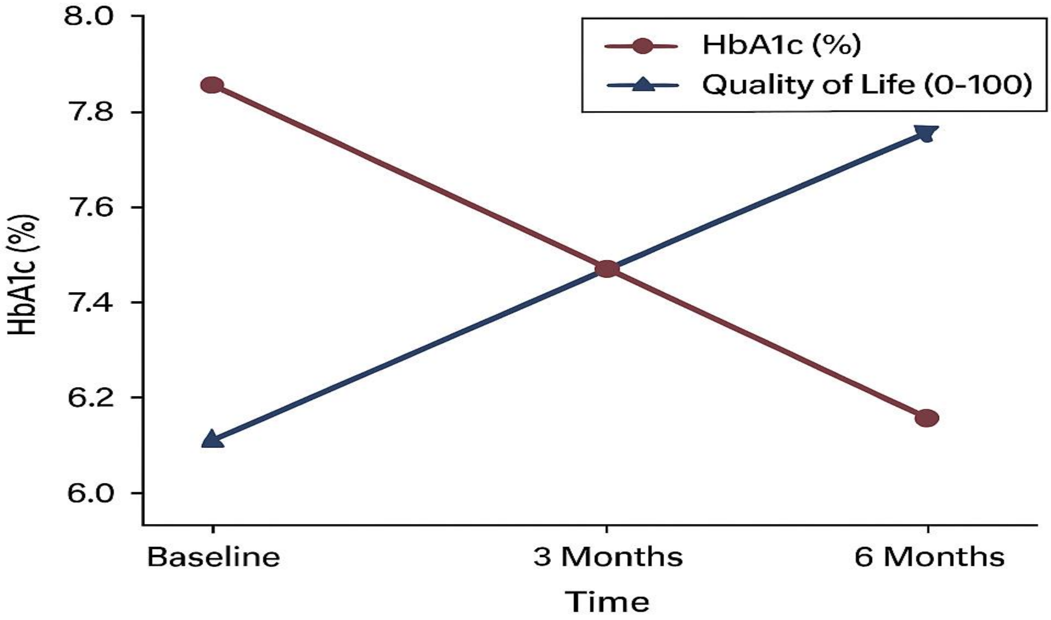

Figure 1: Longitudinal Relationship Between Glycemic Control and Quality of Life in Type 2 Diabetes Following Combined Exercise Interventions

This figure illustrates the trajectory of mean EQ-5D-5L (VAS) scores and HbA1c values over the 12-week intervention period in both groups—balance plus aerobic training (teal, #008B99) and balance plus resistance training (orange, #F05A22). Smoothed lines connect pre- and post-intervention means for each outcome, with adjacent 95% confidence intervals shaded. Each group's baseline and week-12 means are shown as filled scatter points; the left Y-axis corresponds to EQ-5D-5L (VAS, 0–100), and the right Y-axis to HbA1c (%). Over 12 weeks, the balance plus aerobic group's EQ-5D-5L (VAS) rose sharply from 40.9 to 77.8, while HbA1c dropped from 8.1% to 7.3%. The resistance group exhibited improvements of 38.0 to 69.8 (EQ-5D-5L) and 8.6% to 7.7% (HbA1c). The magnitude of quality of life improvement was greater in the aerobic group, paralleled by a steeper reduction in HbA1c.

The negative association between HbA1c and EQ-5D-5L at both timepoints is visually reinforced by the diverging trends: lower HbA1c correlates with higher quality of life, especially in the aerobic cohort. Clinical significance is emphasized by the substantial, non-overlapping confidence intervals at week 12 for EQ-5D-5L. Together, these data indicate that, in patients with type 2 diabetes and neuropathy, greater improvements in glycemic control with combined aerobic and balance training translate to superior perceived quality of life compared to resistance-based programs. The visualized parallel improvement underscores the clinical relevance of exercise modality choice in multidisciplinary diabetes management.

DISCUSSION

This randomized clinical trial demonstrated that both combined exercise intervention balance training with moderate-intensity aerobic exercise and balance training with moderate-intensity resistance exercise—resulted in significant within-group improvements in glycemic control, cardiorespiratory fitness, balance, mobility, and health-related quality of life (HRQOL) over 12 weeks in adults with type 2 diabetes mellitus (T2DM) and diabetic neuropathy. However, comparative analysis revealed that the aerobic exercise group achieved superior improvements in HbA1c reduction, balance, and overall quality of life. These findings contribute important evidence supporting exercise modality selection when designing interventions for individuals with T2DM complicated by neuropathy. The observed significant HbA1c reductions in both groups align with prior meta-analyses showing that structured exercise interventions yield mean reductions in HbA1c of approximately 0.6–0.9% (16). The superior glycemic improvement in the aerobic plus balance group (mean post-intervention HbA1c 7.33% vs. 7.65% in the resistance group, $p = 0.027$) is consistent with mechanistic literature suggesting that aerobic activity preferentially improves peripheral insulin sensitivity by augmenting skeletal muscle glucose uptake and increasing capillary density (17). Additionally, aerobic exercise may more effectively reduce visceral adiposity, a key driver of insulin resistance in T2DM (18). These physiological mechanisms likely underlie the greater metabolic benefits observed.

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Cardiorespiratory fitness improvements were substantial in both groups (~8 mL/kg/min increases in VO_2max) and did not differ significantly (p = 0.806). This supports previous evidence that resistance training, when performed at moderate-to-high intensity, can also improve VO_2max through indirect mechanisms such as increased muscular strength and improved exercise efficiency (19). Nevertheless, the aerobic group's slightly higher mean post-intervention VO_2max reflects the more direct cardiopulmonary stimulus inherent in aerobic modalities. The observed enhancement in balance (Berg Balance Scale improvement of +15 points in the aerobic group vs. +12 points in the resistance group) demonstrates that both interventions effectively target a key functional impairment associated with diabetic neuropathy, but the aerobic group's superior improvement (p = 0.040) suggests additional neuromuscular adaptations may have occurred. Prior studies have shown that aerobic exercise improves proprioceptive acuity and vestibular function, which may explain this finding (20).

Importantly, quality of life improvements measured by EQ-5D-5L VAS were clinically meaningful and statistically significant in both groups but significantly greater in the aerobic group (+36.9 points vs. +31.7 points, $p < 0.001$). This greater enhancement may reflect the combination of improved physical capacity, metabolic control, and potential psychological benefits associated with aerobic exercise, such as reduced depression and anxiety scores, as reported in earlier research (21).

While these findings are promising, several limitations merit consideration. The study employed a single-center design in Lahore with a relatively small sample size (n = 46), potentially limiting generalizability to broader populations. Only patients with diabetic neuropathy were included, and findings may not extend to individuals with other diabetes complications such as nephropathy or retinopathy. The intervention duration was relatively short (12 weeks), precluding assessment of long-term sustainability of effects or clinical outcomes such as fall rates or hospitalization. Additionally, while randomization ensured baseline comparability, we did not adjust for potential confounders such as diet adherence or unmeasured psychosocial variables. Generalizability is further limited by the study setting, as exercise adherence was closely supervised; real-world implementation may encounter lower adherence and variable fidelity. Nevertheless, high adherence (>91% attendance) and low dropout rates (<9%) suggest that both exercise programs are feasible and well tolerated in this population, with no significant differences in adverse events.

Future research should include larger, multicenter trials to confirm these findings across diverse populations and explore mechanistic pathways mediating the differential benefits of aerobic and resistance training. Studies with longer follow-up are warranted to determine whether observed improvements translate into reductions in clinical endpoints such as falls, hospitalizations, or diabetic complications. Further research should also explore tailored exercise prescriptions integrating both modalities to optimize metabolic, functional, and psychosocial outcomes in individuals with T2DM. In summary, this study provides robust evidence that while both combined exercise interventions improve glycemic control, cardiorespiratory fitness, balance, and quality of life in patients with T2DM and diabetic neuropathy, balance training combined with moderate-intensity aerobic exercise yields superior benefits for glycemic control, balance performance, and perceived health status compared to resistance-based programs. These findings have important clinical implications for exercise prescription and reinforce the central role of structured aerobic activity, alongside balance training, as an optimal intervention for this high-risk population.

CONCLUSION

In this randomized controlled trial, both combined interventions—balance training with moderate-intensity aerobic exercise and balance training with moderate-intensity resistance exercise—significantly improved glycemic control, cardiorespiratory fitness, balance, mobility, and health-related quality of life among adults with type 2 diabetes mellitus and diabetic neuropathy. However, comparative analysis revealed that aerobic exercise combined with balance training was superior to resistance exercise combined with balance training, particularly in reducing HbA1c levels, enhancing balance performance, and improving overall quality of life. These findings support the preferential incorporation of moderate-intensity aerobic exercise alongside balance training in clinical exercise prescriptions for this patient population. Future research is warranted to confirm these benefits over longer durations, in larger and more diverse populations, and to assess the impact on hard clinical outcomes such as fall incidence and diabetes-related complications.

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