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ORIGINAL RESEARCH

Effectiveness of Keeogo Exoskeleton-Assisted Rehabilitation on Functional Mobility in Older Adults with Multimorbidity: A Single-Arm Pilot Study

Shin-Ting Yeh[1,*], Yu-Shan Hsieh[2,*]

[1]Graduate Institute of Artificial Intelligence and Big Data in Healthcare, National Taipei University of Nursing and Health Sciences, Taipei, Taiwan, Republic of China; [2]School of Nursing, National Taipei University of Nursing and Health Sciences, Taipei, Taiwan, Republic of China

*These authors contributed equally to this work

Correspondence: Shin-Ting Yeh, Graduate Institute of Artificial Intelligence and Big Data in Healthcare, National Taipei University of Nursing and Health Sciences, No. 365, Ming-te Road, Peitou Dist, Taipei, 112303, Taiwan, Republic of China, Tel +886-2-2822-7101 ext. 1350 / 1388, Fax +886-2-2821-4668, Email shinting@ntunhs.edu.tw

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Background: Mobility impairment is a common consequence of multimorbidity in older adults, especially among those with diabetes mellitus and hypertension. Although robotic exoskeletons have shown promising results in neurological rehabilitation, evidence regarding their use in non-neurological multimorbid populations remains scarce.

Objective: To evaluate the feasibility and effectiveness of Keeogo exoskeleton-assisted rehabilitation, in combination with conventional therapy, on functional mobility in older adults with multimorbidity.

Patients and Methods: This single-arm pilot study recruited 13 participants aged 51–89 years with at least two physician-diagnosed chronic conditions and lower-limb weakness. Participants completed eight sessions of conventional therapy plus Keeogo-assisted training over a 4-week period. Functional outcomes were assessed pre- and post-intervention using the Short Physical Performance Battery (SPPB), Barthel Index (BI), Timed Up and Go (TUG), and Five-Time Sit-to-Stand Test (FTSST).

Results: Significant improvements were observed in SPPB scores (from 2.23 to 4.15, $p = 0.0019$), BI scores (from 52.69 to 60.00, $p = 0.044$), TUG (from 149.75 to 85.37 seconds, $p = 0.006$), and FTSST (from 65.14 to 33.85 seconds, $p = 0.006$). Subgroup analyses showed greater functional gains among participants with ≥3 chronic conditions, diabetes, or hypertension. No adverse events were reported.

Conclusion: Keeogo exoskeleton-assisted rehabilitation combined with conventional therapy was feasible and associated with short-term gains in functional mobility and independence in older adults with multimorbidity. Further randomized controlled trials with larger cohorts are warranted to confirm efficacy, evaluate long-term outcomes, and determine cost-effectiveness.

Keywords: multimorbidity, exoskeleton device, rehabilitation, functional mobility, geriatric patients, diabetes mellitus, hypertension

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Introduction

The global population is experiencing rapid aging, with adults aged ≥60 years surpassing children under 5 years for the first time in 2020, marking an irreversible demographic shift.[1] This transition is accompanied by a sharp rise in age-related disabilities and healthcare costs. A central contributor to disability in older adults is mobility impairment, which is closely linked to sarcopenia, balance deficits, and reduced endurance, ultimately limiting independence in activities of daily living.[2,3]

The burden of mobility impairment is further compounded by multimorbidity, defined as the coexistence of two or more chronic conditions.[4,5] Chronic diseases such as type 2 diabetes and hypertension are especially prevalent in older adults and are strongly associated with functional decline. Diabetes contributes to muscle dysfunction, neuropathy, and

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metabolic dysregulation,[6,7] while hypertension is associated with vascular alterations and white matter changes that impair motor and cognitive function.[8,9] These mechanisms highlight why older adults with multimorbidity are at particularly high risk of disability and underscore the need for effective rehabilitation strategies.

Wearable robotic exoskeletons have emerged as promising adjuncts in rehabilitation. Studies in neurological populations—including stroke, multiple sclerosis, and spinal cord injury—have demonstrated improvements in gait, balance, and functional independence following exoskeleton-assisted training.[10–12] By enabling high-repetition, task-specific practice with adjustable support, exoskeletons may facilitate motor recovery and compensate for physical limitations that restrict conventional therapy.[13] However, their potential application to non-neurological populations, particularly older adults with multimorbidity-related mobility impairments, remains underexplored.

In Taiwan, diabetes and hypertension rank among the leading causes of disability, contributing substantially to mobility decline and dependence in daily living.[14] Yet, rehabilitation options for this population remain limited. Investigating whether exoskeleton-assisted interventions can improve functional outcomes in older adults with multimorbidity could expand the scope of robotic rehabilitation beyond traditional neurological indications.

The present pilot study evaluates the feasibility and effectiveness of Keeogo exoskeleton-assisted rehabilitation combined with conventional therapy in older adults with multimorbidity. We specifically examined functional outcomes in individuals with multiple chronic conditions, diabetes, or hypertension, aiming to generate preliminary evidence that may inform future randomized controlled trials.

Materials and Methods

Study Design and Participants

This single-group interventional study was conducted at a regional hospital in northern Taiwan between October 2023 and January 2024. The primary aim was to evaluate the effectiveness of Keeogo exoskeleton-assisted rehabilitation among individuals with multimorbidity and lower-limb mobility impairments. Participants were recruited through referrals from hospital rehabilitation clinics and community healthcare providers. Eligibility was determined based on clinical assessment of multimorbidity status and lower-limb functional impairment, as detailed in the inclusion and exclusion criteria. Written informed consent was obtained prior to enrollment, and only aggregated, anonymized data were analyzed and presented in this study.

Inclusion and Exclusion Criteria of Participants

Eligible participants were adults aged 18–90 years with at least two physician-diagnosed chronic conditions, consistent with widely accepted definitions of multimorbidity.[5,15] To ensure the study population reflected the intended focus on older adults, the majority of the sample was recruited from individuals aged 50 years or older; in practice, all enrolled participants were aged 51–89 years. Lower-limb mobility impairment was defined by two complementary criteria. First, participants were required to demonstrate reduced muscular strength with a Manual Muscle Testing (MMT) score below grade 5 in at least one major lower-limb muscle group, such as hip flexors, knee extensors, or ankle dorsiflexors. The MMT grading scale, ranging from 0 (no visible contraction) to 5 (normal strength against maximal resistance), is widely used in rehabilitation practice.[16] Second, participants were required to exhibit functional limitations during transfers, standing, or ambulation, as determined by a licensed therapist during clinical screening. To ensure safe device usage, only individuals with hip flexor strength of grade 3 or higher (antigravity capacity) were included. Exclusion criteria comprised spasticity greater than grade 3 on the Modified Ashworth Scale, severe osteoporosis or recent fractures, lower-limb paralysis, severe cognitive impairment, uncontrolled cardiovascular conditions, or unresolved skin lesions at exoskeleton contact points. In addition, the Keeogo device has specific anthropometric requirements for thigh, shank, and waist dimensions. Based on these manufacturer specifications, participants with height ≤152 cm were excluded to avoid misfitting of the adjustable frame.[16]

Intervention

All participants completed a four-week rehabilitation program consisting of eight sessions in total. Sessions were typically scheduled twice per week, with occasional adjustments to three sessions per week when required by participant availability, ensuring that the total intervention dose remained constant across participants. Each session lasted 60 minutes and was divided into two components: conventional therapy for 30 minutes, followed by exoskeleton-assisted training with Keeogo for 30 minutes. Conventional therapy was conducted without exoskeleton support and included therapist-led warm-up exercises, range-of-motion activities, strengthening of lower-limb muscles, static and dynamic balance training, and gait practice. Exercises consisted of sit-to-stand drills, squats and lunges, step-ups, tandem standing, rhythmic stepping, cone weaving, and over-ground walking with posture and cadence cues. Keeogo-assisted training was conducted after donning and parameter adjustment of the device. This component emphasized high-intensity, repetitive, and task-specific exercises such as sit-to-stand and stand-to-sit transitions, squatting, stepping, over-ground walking, and obstacle negotiation. Intensity was progressed through increased repetitions, shorter rest intervals, and adjustment of device assistance levels via the controller interface. The Keeogo exoskeleton provides powered torque at the hip and knee joints and adapts to user movement, enabling patients with multimorbidity to practice greater volumes of functional tasks while minimizing fatigue.

Outcome Measures

Functional outcomes were assessed at baseline and after the four-week intervention period. All post-intervention assessments were conducted without the Keeogo device to evaluate unassisted performance. The primary outcome was the Short Physical Performance Battery (SPPB), which includes balance tests (side-by-side, semi-tandem, and tandem stance up to 10 seconds), gait speed over 3–4 meters, and a repeated chair-stand test. Each subtest is scored from 0 to 4, with a total possible score of 12, and higher scores indicate better lower-extremity performance.[17] Secondary outcomes included the Barthel Index (BI),[18] the Timed Up and Go (TUG) test,[19] and the Five-Times Sit-to-Stand Test (FTSST).[20] The BI evaluates independence across 10 basic activities of daily living, yielding a score between 0 and 100, with higher scores reflecting greater independence.[21,22] The TUG measures the time required to stand up from a chair, walk 3 meters, turn, return, and sit down; shorter times indicate better functional mobility.[19] The FTSST assesses lower-limb strength and endurance by timing how long participants take to complete five consecutive sit-to-stand transitions without arm support; shorter times reflect better performance.[23] Together, these outcome measures provide a comprehensive assessment of muscular strength, balance, functional mobility, and independence in daily activities.

Statistical Analyses

Data were analyzed using SPSS v22 and MedCalc v20.113. Continuous variables were tested for normality using the Shapiro–Wilk test. Depending on distribution, paired comparisons of baseline and post-intervention scores were conducted using paired t-tests or Wilcoxon signed-rank tests. Repeated-measures ANOVA was used to examine within-group changes for normally distributed data, with effect sizes reported as Cohen's d or partial eta squared. For non-parametric tests, effect size r was calculated. Statistical significance was defined as $p < 0.05$ for all analyses. Subgroup analyses were conducted to explore the differential effects of the intervention among participants with three or more chronic conditions, those with type 2 diabetes, and those with hypertension. These subgroups were chosen due to their high prevalence in the study population and their established association with mobility decline.[24–26] Although stroke was also prevalent, it was not analyzed as a subgroup due to heterogeneity in lesion characteristics and baseline functional severity, which could confound comparisons in this small sample. A complete session-by-session description of both conventional and exoskeleton-assisted therapy, along with safety procedures and progression criteria, is provided in the Supplementary Table to facilitate reproducibility.

Ethical Approval and Informed Consent

The study protocol was approved by the Institutional Review Board of National Yang Ming Chiao Tung University (IRB No. NYCU112189AE), one of the cooperative IRBs designated by the National Taipei University of Nursing and Health Sciences. As NTUNHS does not operate its own IRB, all human studies are submitted through its partner institutions. The research was conducted in accordance with the Declaration of Helsinki and ICMJE recommendations, and written informed consent was obtained from all participants prior to enrollment.

Results

Participant Characteristics

A total of 13 participants (6 women, 7 men; age range: 51–89 years) were enrolled. Common comorbidities included hypertension (HTN), type 2 diabetes mellitus (T2DM), stroke, chronic kidney disease (CKD), coronary artery disease (CAD), gastrointestinal disorders, and dyslipidemia. HTN and stroke were the most prevalent, each affecting eight participants. Several participants presented with multimorbidity, defined as having three or more chronic conditions, particularly those involving cardiovascular and metabolic diseases (Table 1).

Overall Intervention Effects

Post-intervention assessments revealed significant improvements in physical and functional performance. The Short Physical Performance Battery (SPPB) scores increased from 2.23 ± 2.05 to 4.15 ± 2.99 ($p = 0.0019$, Figure 1A), and the Barthel Index (BI) improved from 52.69 ± 18.10 to 60.0 ± 21.02 ($p = 0.044$, Figure 1C). Timed Up and Go (TUG) results decreased from 149.75 ± 105.54 to 85.37 ± 50.01 ($p = 0.006$, Figure 1B), and Five-Time Sit-to-Stand Test (FTSST) times declined from 65.14 ± 35.30 to 33.85 ± 19.65 seconds ($p = 0.006$, Figure 1D), indicating improved mobility.

Subgroup Analyses - Multimorbidity (≥3 vs <3 Conditions)

Participants with ≥3 comorbidities showed significantly greater improvements in SPPB (1.67 ± 0.57 to 3.67 ± 2.08; $p = 0.025$, Figure 2A) and BI (39.0 ± 13.87 to 43.29 ± 16.80; $p = 0.011$, Figure 2C) versus pretest results. However, in participants with < 3 comorbidities was showed only trend of improvement in BI. TUG scores also showed more improvement versus fewer than three comorbidities significantly in post-test (99.82 ± 36.86 v.s 77.11 ± 57.25; $p < 0.001$, Figure 2B). In contrast, participants with <3 comorbidities exhibited smaller changes, FTSST was also not showed significant in groups both pre-test (62.32 ± 37.57 to 75.0 ± 35.53; $p = 0.35$) of post test (29.68 ± 20.31 to 48.50 ± 17.78; $p = 0.11$, Figure 2D).

Subgroup Analyses - Diabetes (T2DM vs Non-T2DM)

Between-group comparison revealed lower post-intervention BI scores in the T2DM group compared to the non-T2DM group (43.00 ± 16.81 vs 70.62 ± 16.13; $p = 0.015$). Within-group analysis showed significant improvements in SPPB (3.00 ± 2.23 to 5.87 ± 2.61;$p = 0.008$, Figure 3A), TUG (160.87 ± 108.48 to 89.25 ± 58.25;$p < 0.001$, Figure 3B), BI (61.25 ± 14.82 to 70.0 1± 17.32; $p = 0.007$, Figure 3C), and FTSST (55.17 ± 33.77 to 31.65± 19.08; $p = 0.034$, Figure 3D) in the T2DM group, suggesting greater relative benefit.

Subgroup Analyses - Hypertension (HTN vs Non-HTN)

Post-intervention BI scores were higher in the HTN group than in the non-HTN group (70.00 ± 17.32 vs 44.00 ± 16.73; $p = 0.031$, Figure 4C). The HTN group also demonstrated significant within-group improvements in SPPB (3.28 ± 2.21 to 6.28 ± 2.28; $p = 0.006$, Figure 4A), TUG (159.90 ± 109.33 to 87.01 ± 59.54;$p < 0.001$, Figure 4B), BI (62.14 ± 15.77 to 74.28 ± 13.36; $p = 0.005$, Figure 4C), and FTSST (62.32 ± 37.53 to 28.67 ± 18.62;$p = 0.007$, Figure 4D), suggesting positive effects of the intervention on functional mobility in this subgroup.

Table 1 Baseline Characteristics of Patients

NO.	Gender	Age	Comorbidity	T2DM	Stroke	HTN	GI Ulcerative Disease	Postate cancer	CKD	CAD	SAH	Vascular Thromboembolic Disease	Dyslipidemia	Polycystic Kidney Disease	Colon Cancer
1	Male	77	3	V			V	V							
2	Male	66	2		V				V						
3	Male	81	4	V		V		V		V					
4	Male	73	1			V					V	V			
5	Female	51	4		V	V							V	V	
6	Female	85	3		V	V							V		
7	Female	74	3		V	V									V
8	Female	89	1	V											
9	Male	53	3	V	V	V									
10	Male	55	1		V										
11	Female	75	2	V		V									
12	Male	63	3		V	V							V		
13	Female	61	1		V										

Abbreviations: T2DM, type 2 diabetes mellitus; HTN, hypertension; GI, gastrointestinal, CKD, chronic kidney disease; CAD, coronary artery disease.

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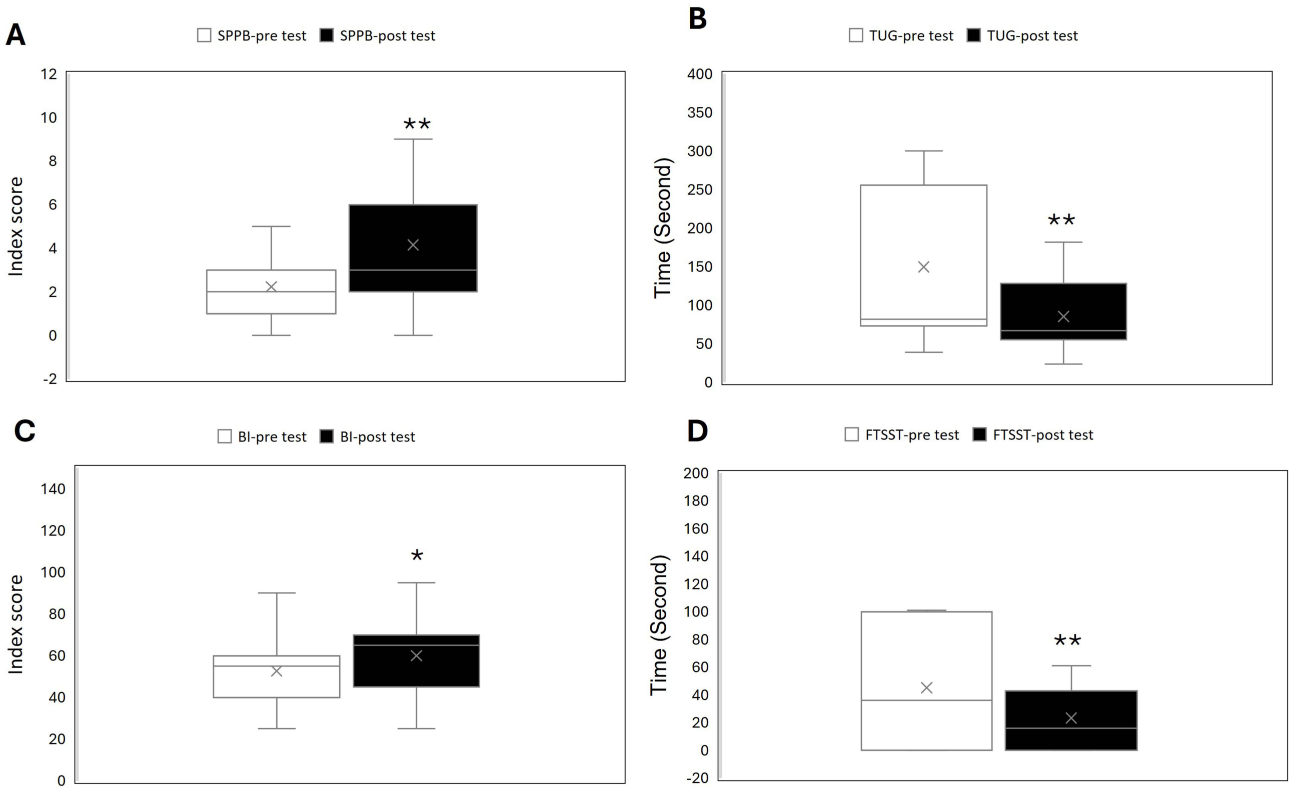

Figure 1 Effects of intervention on (**A**) SPPB scores, (**B**) TUG results, (**C**) BI scores, and (**D**) FTSST results among participants. BI and SPPB results are presented as scores. TUG and FTSST results are presented in terms of time (in seconds). *p < 0.05 versus pretest. **p < 0.01 versus pretest. The lower and upper boxes of the box represent the 25th and 75th percentile values, respectively. The horizontal line in the center of the box represents the median. The cross mark represents the mean.

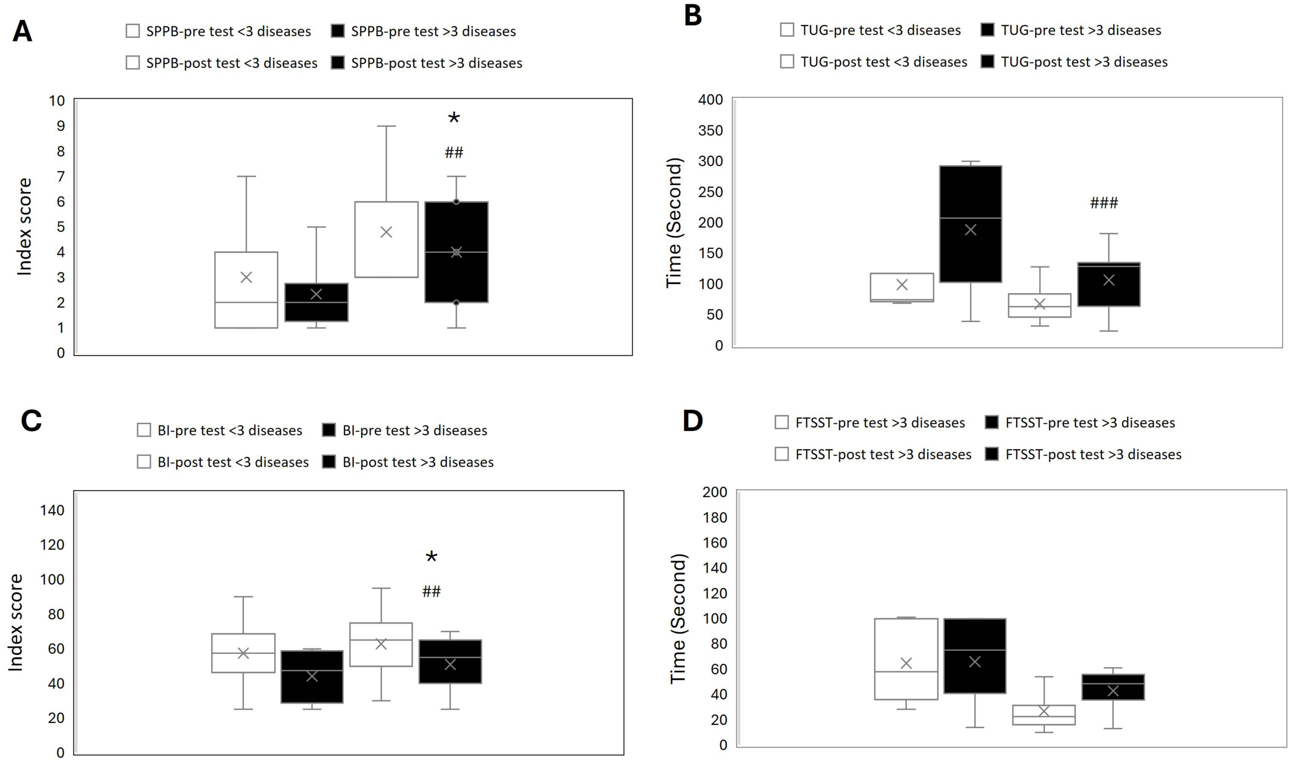

Figure 2 Effect of the intervention in patients with more three comorbidities versus those with fewer than three comorbidities on (**A**) SPPB scores, (**B**) TUG results, (**C**) BI scores, and (**D**) FTSST results. BI and SPPB results are presented as scores. TUG and FTSST results are presented in terms of time (in seconds) (log). *p < 0.05 versus pretest results.; $^{\#\#}$p < 0.01 versus fewer than three comorbidities; $^{\#\#\#}$p < 0.001 versus fewer than three comorbidities The lower and upper boxes of the box represent the 25th and 75th percentile values, respectively. The horizontal line in the center of the box represents the median. The cross mark represents the mean.

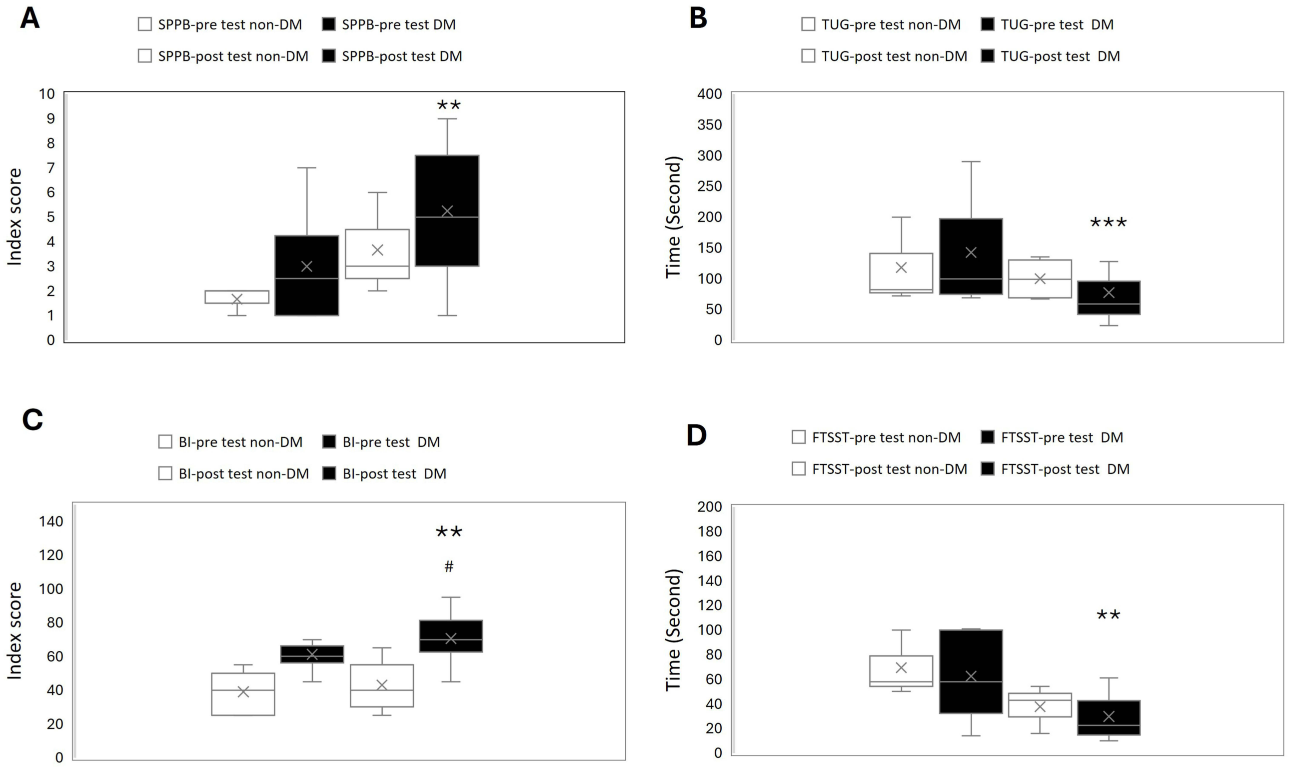

Figure 3 Effects of intervention in patients with or without T2DM. (**A**) SPPB score, (**B**) TUG, (**C**) BI and (**D**) FTSST. BI and SPPB scores are presented in terms of scale scores, TUG and FTSST results are presented in terms of time (in seconds) (log). **p < 0.01 versus pretest results; ***p < 0.001 versus pretest results; $^{\#}p < 0.05$ versus participants with DM. The lower and upper boxes of the box represent the 25th and 75th percentile values, respectively. The horizontal line in the center of the box represents the median. The cross mark represents the mean.

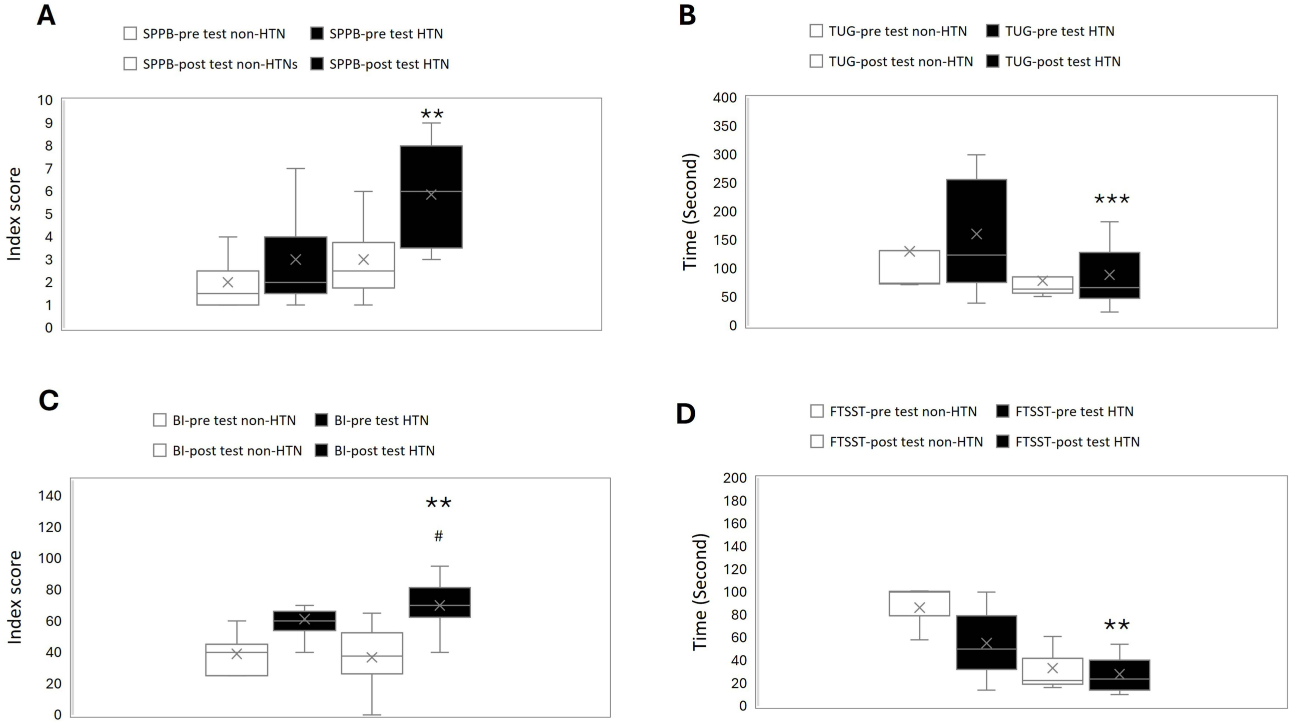

Figure 4 Effects of intervention in patients with or without HTN. (**A**) SPPB scores, (**B**) TUG results, (**C**) BI scores, and (**D**) FTSST results. BI and SPPB results are presented as scores. TUG and FTSST results are presented in terms of time (in seconds) (log). **p < 0.01 versus pretest results; ***p < 0.001 versus pretest results; $^{\#}p < 0.05$ versus participants with HTN. The lower and upper boxes of the box represent the 25th and 75th percentile values, respectively. The horizontal line in the center of the box represents the median. The cross mark represents the mean.

Discussion

Functional Impairments in Multimorbidity, Diabetes, and Hypertension

Our findings indicate that older adults with multimorbidity, particularly those with diabetes and hypertension, experienced significant improvements in mobility and functional independence following a 4-week rehabilitation program that combined conventional therapy with exoskeleton-assisted training. These results align with epidemiological evidence that multimorbidity is strongly associated with accelerated physical decline, including slower gait speed, impaired balance, and reduced muscle strength.[27,28] Diabetes and hypertension are especially important contributors: diabetes is linked to muscle dysfunction, peripheral neuropathy, and metabolic dysregulation that reduce mobility,[6,7,29] while hypertension contributes to vascular and neurological changes that impair lower-limb perfusion and motor control.[8,9,30] These mechanisms provide biological plausibility for the baseline impairments in our participants and support our rationale for targeting these chronic conditions.

Mechanisms Underlying Lower-Limb Dysfunction in Chronic Disease

Chronic disease-related lower-limb dysfunction arises from shared pathways, including inflammation, vascular damage, and sarcopenia.[3] Diabetic neuropathy affects sensory and motor function, increasing fall risk,[29,31] while hypertension-related arterial stiffness and white matter hyperintensities have been linked to mobility and cognitive decline.[9,32] Such mechanisms highlight why individuals with diabetes and hypertension frequently experience mobility loss and underscore the importance of rehabilitation strategies that enhance functional performance.

Comparison with Conventional Rehabilitation Without Exoskeletons

The mobility gains in our cohort are noteworthy when contrasted with studies of conventional exercise programs of comparable duration. Binder et al and Nocera et al demonstrated improvements in gait and chair-stand performance following multicomponent exercise, but the magnitude of gains was modest compared with our 4-week outcomes.[33,34] Similarly, Falck et al reported that exercise training improved mobility and cognition in older adults, though the improvements generally required longer intervention periods.[1] Smith et al in a Cochrane review, concluded that interventions for multimorbid patients improve outcomes, but effect sizes remain small.[4] These comparisons suggest that exoskeleton-assisted training may accelerate functional improvements by enabling more repetitive, higher-intensity practice within the same timeframe. Nonetheless, given our lack of a control group, these observations remain preliminary and require direct testing in randomized trials.

Integration with Prior Exoskeleton Studies

Our results complement prior investigations of exoskeleton-assisted rehabilitation. McGibbon et al reported improved gait endurance and stair climbing in individuals with multiple sclerosis following Keeogo-assisted training,[10] while Jin et al and Huo et al demonstrated enhanced gait recovery and balance in stroke survivors using lower-limb exoskeletons.[12,35] More recently, Gil-Agudo et al and He et al highlighted improved walking independence and neuroplasticity in spinal cord injury patients after exoskeleton training.[11,36] These consistent findings across populations reinforce the potential role of exoskeletons as an adjunct to conventional rehabilitation.

Limitations and Future Directions

This study has limitations. The single-group design precludes causal inference, and improvements cannot be attributed solely to exoskeleton use. Our small sample size limited subgroup analyses, and biological markers such as blood pressure and glycemic control were not assessed, meaning we cannot draw conclusions about metabolic effects. Moreover, the high cost of exoskeletons presents feasibility concerns. Future research should incorporate randomized controlled designs comparing exoskeleton-assisted and conventional rehabilitation of equal duration, alongside biomarker and cost-effectiveness evaluations.

Conclusion

This pilot study demonstrated that Keeogo exoskeleton-assisted rehabilitation, when combined with conventional therapy, was associated with significant improvements in lower-limb function, mobility, and independence among older adults with multimorbidity. Participants with multiple chronic conditions, diabetes, or hypertension appeared to derive particular benefit. The Keeogo device may enhance rehabilitation by enabling repetitive, task-specific, and higher-intensity practice, which are key elements for functional recovery. Nevertheless, these preliminary findings should be interpreted cautiously given the small sample size and single-group design. Future randomized controlled trials with larger cohorts are warranted to validate the efficacy, explore underlying mechanisms, and assess long-term feasibility and cost-effectiveness.

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Disclosure

The authors report no conflicts of interest in this work.

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