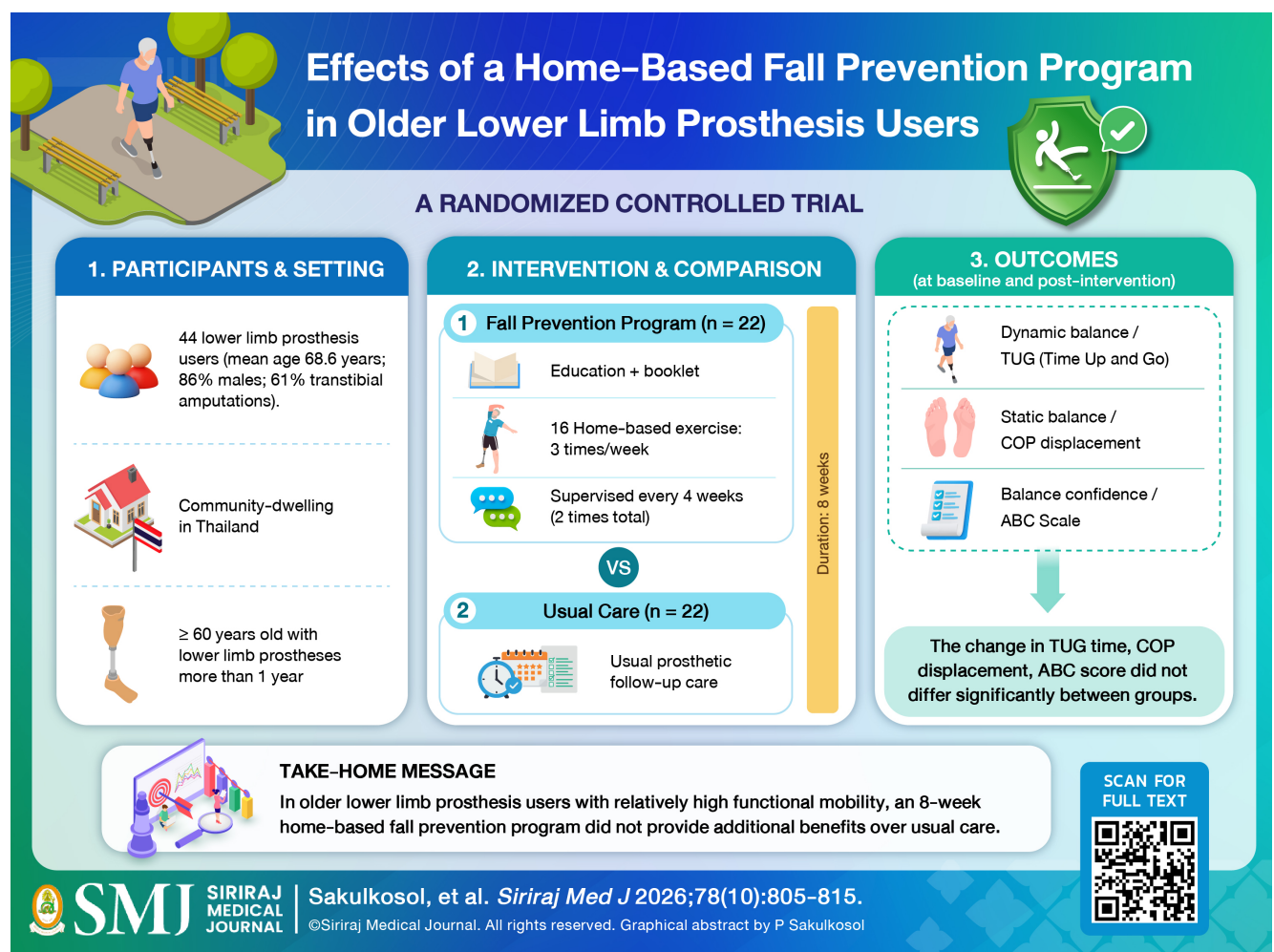


Effects of a Home-Based Fall Prevention Program in Older Lower Limb Prosthesis Users: A Randomized Controlled Trial

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Received 20 July 2026 Revised 20 August 2026 Accepted 3 September 2026

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<https://doi.org/10.33192/smj.v78i10.283047>



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ABSTRACT

Objective: To analyze the effects of a home-based fall prevention program on dynamic and static balance and balance confidence in older lower limb prosthesis (LLP) users.

Materials and Methods: In this randomized controlled trial, 44 older LLP users were randomly assigned to either a control group receiving usual care or an intervention group receiving a fall prevention program consisting of education and 16 home-based exercises performed three times per week for eight weeks. Dynamic balance was measured using the Timed Up and Go (TUG) test, static balance using center of pressure displacement, and balance confidence using the Activities-specific Balance Confidence scale. Outcomes were assessed at baseline and post-intervention.

Results: Forty-one of 44 randomized participants completed the study. Among the 44 randomized participants, the mean age was 68.6 ± 6.7 years; 86% were male; 61% had transtibial amputations; 66% had traumatic amputation. The change in TUG time did not differ significantly between groups (median (inter-quartile range) change: -0.6 ($-1.5, 0.4$) seconds in the intervention group and -0.4 ($-1.2, 0.3$) seconds in the control group; $p = 0.584$, $r = 0.09$). No significant between-group differences were observed in static balance or balance confidence. No falls were reported during the study.

Conclusion: A combined fall prevention education and eight-week home-based exercise program did not result in significantly greater improvements than usual care in dynamic balance, static balance, or balance confidence among older LLP users with relatively high functional mobility. The findings should be interpreted with consideration of the unblinded outcome assessment.

Keywords: Fall prevention; older adult; amputee; lower limb; prosthesis (Siriraj Med J 2026;78(10):805-815)

INTRODUCTION

Following a lower limb amputation (LLA), individuals have a reduced ability to correct balance disturbances due to the loss of proprioceptive information from the amputated limb.¹ As a result, balance in both the anteroposterior and mediolateral directions is significantly reduced.² When people with LLA age, their ability to correct balance declines further, thereby increasing their risk of falling.³ Falls in this population are common, and approximately 40 to 60% of those who fall sustain fall-related injuries.⁴ Such falls often lead to severe injuries, including fractures,⁵ brain injury,⁶ and residual limb injuries,⁷ leading to hospitalization and increased healthcare costs.⁸ Beyond their physical consequences, falls are associated with decreased balance confidence and increased fear of falling,^{9,10} which may contribute to activity restriction and reduced social participation among individuals with LLA.^{9,10}

Fall risk among older lower limb prosthesis (LLP) users is multifactorial, resulting from a combination of age-related and amputation-specific factors.⁴ Although exercise-based fall prevention interventions have shown improvements in physical performance among individuals with LLA, most have adapted established fall prevention models developed for older adult population and have focused on supervised, high-intensity, or task-specific training in relatively younger or mixed-age cohorts.¹¹ A recent meta-analysis demonstrated significant improvements

in gait speed, 2-minute walk test performance, and Timed Up and Go (TUG) test performance in favor of exercise interventions compared with usual care.¹² Additionally, randomized controlled trials have demonstrated reduction in fall incidence and improvements in gait speed following individualized training.³ Nevertheless, current evidence specifically targeting fall prevention exercise programs for older LLP users, particularly those delivered through a home-based approach, remains limited.

Fall prevention education is an important component of multifactorial fall prevention programs for older adults. Previous systematic reviews have shown that educational interventions improve fall-related knowledge and preventive behaviors, particularly when combined with exercise.¹³ However, the effectiveness of such educational approaches in older LLP users has not yet been established.

Although previous studies have implemented exercise-based fall prevention interventions for LLP users, these programs have mainly focused on physical training components, with limited incorporation of educational elements.³ According to the World Health Organization's Falls Prevention for Active Aging model, effective fall prevention strategies should integrate education to increase awareness of fall risk, promote safe behaviors, and enhance adherence to exercise.¹⁴ Moreover, home-based interventions extend rehabilitation support into the home environment and offer advantages in accessibility, feasibility, cost-effectiveness, and long-term sustainability.

These programs are particularly suitable for individuals who are unable to attend supervised sessions.¹⁵ Therefore, developing a program that integrates education with strength and balance exercises tailored to the functional demands of older LLP users may provide a practical approach to fall prevention in this population. However, evidence regarding the combined effects of fall prevention education and home-based exercise on balance outcomes specifically in older LLP users remains limited.

Therefore, the aim of this randomized controlled trial was to analyze the effects of a home-based program combining fall prevention education and exercise on dynamic and static balance and balance confidence in older LLP users. It was hypothesized that participants receiving the combined fall prevention education and home-based exercise program would demonstrate greater improvements in dynamic balance, static balance, and balance confidence than those receiving usual care.

MATERIALS AND METHODS

This study was conducted at the clinic of the Sirindhorn School of Prosthetics and Orthotics (SSPO) after receiving approval from the Institutional Review Board of the Faculty of Medicine Siriraj Hospital (COA no. Si 776/2024) (Thai Clinical Registry, ID no. TCTR20250525005, on May 25th, 2025).

Participants

The inclusion criteria were LLP users aged at least 60 years who had used a prosthesis for more than one year, were able to walk daily with the prosthesis for at least eight hours a day without pain,¹⁶ and were able to speak and read Thai. The exclusion criteria were cognitive impairment, a history of severe depression, or other mental disorders. Cognitive impairment was screened using the Montreal Cognitive Assessment (MoCA), and participants with a score below 26 were not included.¹⁷ During the recruitment interview participants were asked if they had a history of a diagnosed psychiatric disorder, including severe depression.

Procedure

Data collection was conducted between June and October 2025. The participants were recruited through an invitation poster distributed by the researcher (PS). Individuals who expressed interest contacted the researcher and underwent eligibility screening. Eligible participants received a detailed explanation of the study procedures using a participant information sheet before providing written informed consent.

Participants were randomly assigned to either the

intervention group or the control group, which received usual care, in a 1:1 ratio. The allocation sequence was generated by a statistician using block randomization with mixed block sizes. Sequentially numbered, sealed opaque envelopes containing the allocation were prepared by the researcher according to the allocation sequence. After enrollment, the envelope was provided to the participant sequentially and opened to reveal the group allocation. One researcher conducted participant recruitment, intervention delivery, follow-up, and outcome assessments and was therefore not blinded to group allocation.

Baseline assessments were performed before the intervention, and all outcome measures were reassessed after the 8-week intervention period.

Intervention group: Fall prevention education and exercise program

The conceptual framework of this study was adapted from the World Health Organization's Falls Prevention for Active Aging model at the individual level and comprised of education to raise awareness of fall prevention, pre-post assessment of fall risk (dynamic and static balance and perceived balance confidence), as well as an evidence-based exercise program.¹⁴

Participants in the intervention group attended a 1-hour face-to-face education session delivered by the researcher. Additionally, they received a fall prevention booklet¹⁸ specifically developed for older LLP users. The education session included verbal instruction on falls and their consequences, risk factors for falls, fall prevention strategies, environmental safety, the benefits of exercise, exercise principles and precautions and guidance on the home-based strength and balance exercise program. Participants were also given a demonstration of the exercises and practiced them during the session to ensure correct and safe performance.

The home-based exercise program was adapted from the Otago Exercise Program.¹⁹ It consisted of 16 exercises: five strengthening exercises (knee extensor, knee flexor, hip abductor, calf raises, and toe raises) and 11 balance retraining exercises (knee bends, backwards walking, walking and turning around, sideways walking, tandem stance, tandem walking, heel walking, toe walking, backward heel-toe walking, sit-to-stand, and stair walking). Participants were instructed to follow the sequence presented in the booklet.¹⁸ Although no structured progression of exercise intensity or resistance was used, upper-limb support during balance exercises was reduced according to the ability of the participants. Walking was not prescribed as a separate aerobic exercise component of the program. Participants were instructed to perform the exercises

three times per week for eight weeks.¹⁹ Each exercise session lasted approximately 30 minutes and could be divided into three 10-minute sessions throughout the day. Participants recorded exercise completion in a logbook. To support adherence, participants received weekly telephone follow-up calls throughout the study period²⁰ and visited the clinic at week 4 to review exercise performance. During this visit, participants practiced the exercises under the researcher's supervision to ensure correct and safe performance. Exercise compliance was assessed only in the intervention group using participant-completed logbooks and was calculated as the mean number of prescribed exercise sessions completed during the eight-week program.

Control group:

Usual prosthetic care at the clinic includes a routine follow-up visit approximately one month after prosthesis delivery. During this visit, participants received standard verbal instructions regarding residual limb care, care of the remaining limb, prosthesis maintenance, and general safety instructions. They were also provided with a pamphlet on self-care and prosthesis maintenance. During the 8-week study period, control-group participants continued their usual prosthetic care and received no structured exercise training or additional follow-up calls.

To minimize contamination between groups, appointments for intervention and control groups were scheduled at different times, and all clinicians at the clinic were informed about this study to avoid contamination. Fall occurrence was assessed by participant self-report in both groups at weeks 4 and 8. At the end of the study, control-group participants were asked whether they had engaged in any exercise during the study period.

Outcome measures

Primary outcome: Dynamic balance

Dynamic balance was assessed using an inertial sensor (G-Walk, BTS Bioengineering, Milan, Italy) during the TUG test.²¹ Prior to the TUG test, the G-Walk inertial measurement unit (IMU) sensor was placed at the lower back at waist level. Participants were instructed to stand up from a chair, walk three meters at a self-selected comfortable walking speed, turn around, walk back to the chair, and sit down. One practice trial was performed before data collection.²² The TUG test was then performed three times, and the mean time (in seconds) of the three trials was used for analysis. In older adults, a TUG time of ≥ 13.5 seconds is associated with an increased risk of falling,²³ whereas in people with a LLA, a TUG time of ≥ 19.0 seconds is associated with an increased risk of multiple falls.²⁴

Secondary outcome: Static balance and balance confidence

Static balance was assessed by measuring GRAIL-derived center of pressure (COP) displacement as an exploratory measure while standing on an instrumented split-belt treadmill (GRAIL, Motek Medical B.V., Houten, Netherlands). COP signals were sampled at 100 Hz. Participants stood with their hands at their sides and adopted a self-selected comfortable base of support on the GRAIL. All assessments were performed using the participants' usual prosthesis alignment and footwear. Measurements were obtained under two conditions: eyes open (three trials, 30 seconds each) and eyes closed (three trials, 30 seconds each).²⁵ During the eyes-open condition, participants were instructed to focus on a black wall at a distance of 1.5 meters at eye level to minimize external disturbances during testing.²⁶ The COP outcomes included mean COP displacement, maximal sway amplitude in the anteroposterior and mediolateral directions, and sway velocity. COP variables were recorded for each trial, and the mean of the three trials was used for analysis. For each trial, the first 100 frames (1 s) were excluded, and the subsequent 3,000 frames (30 s) were used for analysis. No additional filtering was applied to the exported COP data. COP displacement between consecutive samples was calculated as the Euclidean distance, $d_i = \sqrt{(Cx_i - Cx_{i-1})^2 + (Cy_i - Cy_{i-1})^2}$, where Cx and Cy represent the mediolateral and anteroposterior COP coordinates, respectively. Total sway path was calculated as the sum of consecutive COP displacements, and mean distance was calculated as the mean of these displacements. Maximum sway amplitudes in the mediolateral and anteroposterior directions were calculated as the difference between the maximum and minimum Cx and Cy coordinates, respectively. Sway velocity was calculated by dividing the total sway path by the 30-second analysis duration. Trials in which participants stepped or were unable to complete the assessment were excluded and repeated. Greater mean distance, sway amplitude, and sway velocity indicated poorer static balance.

Balance confidence was assessed using the Activities-specific Balance Confidence Scale (ABC scale), which measures fall-related self-efficacy and perceived confidence in performing daily activities without losing balance.²⁷ Participants rated their balance confidence in performing 16 activities on a scale from 0 (no confidence) to 100 (complete confidence). In the original study, older adults with high mobility demonstrated a mean ABC score of approximately 80%.²⁸ Previous studies in community-dwelling older adults have suggested that ABC scores below 67% are associated with an increased risk of falling.²⁷

Sample size calculation

The sample size was calculated using nQuery Advisor based on an independent-samples *t*-test. Because no previous intervention studies in older LLP users reporting TUG outcomes were available at the time of study planning, the sample size calculation was based on data of a study considering most similar in older adults using a 12-week Otago exercise program.²⁹ The expected post-intervention TUG times at 8 weeks for the intervention and control groups were 9.0 and 10.9 seconds, respectively, corresponding to an expected between-group difference of 1.9 seconds, with an assumed standard deviation of 2.0 seconds.²⁹ With a two-sided significance level of 0.05 and 80% power, 19 participants per group were required. A 15% dropout was added, resulting in 22 participants in each group.

Data analysis

Statistical analyses were performed using SPSS Statistics (version 31) (IBM, Armonk, NY, USA). Descriptive statistics were used to summarize participant characteristics at baseline. Continuous variables were presented as mean and standard deviation (SD) or median and inter-quartile range, depending on data distribution, which was assessed using the P-P plots and the Shapiro–Wilk test. Categorical variables were reported as frequencies and percentages.

For all outcome measures, change scores were calculated as the difference between post-intervention and baseline values. Because the dynamic and static balance outcomes were non-normally distributed, between-group comparisons were conducted using the Mann–Whitney U test and are presented as median (inter-quartile range). Effect sizes were calculated as $r = Z/\sqrt{N}$. Balance confidence, which met normality assumptions, was analyzed using the independent-samples *t*-test. Both per-protocol and an intention-to-treat analyses were performed for the primary outcome (TUG). Secondary outcomes were analyzed using a per-protocol approach. For participants with missing post-intervention TUG data, the baseline TUG value was carried forward as the post-intervention value using the last observation carried forward method, resulting in a change score of zero. All randomized participants were included in the intention-to-treat analysis. All statistical tests were two-tailed, and statistical significance was set at $p \leq 0.05$.

RESULTS

A total of 69 individuals were assessed for eligibility, and 44 participants were randomized. Three participants were lost to follow-up, two in the intervention group and one in the control group, because they were unable to attend the second appointment (Fig 1).

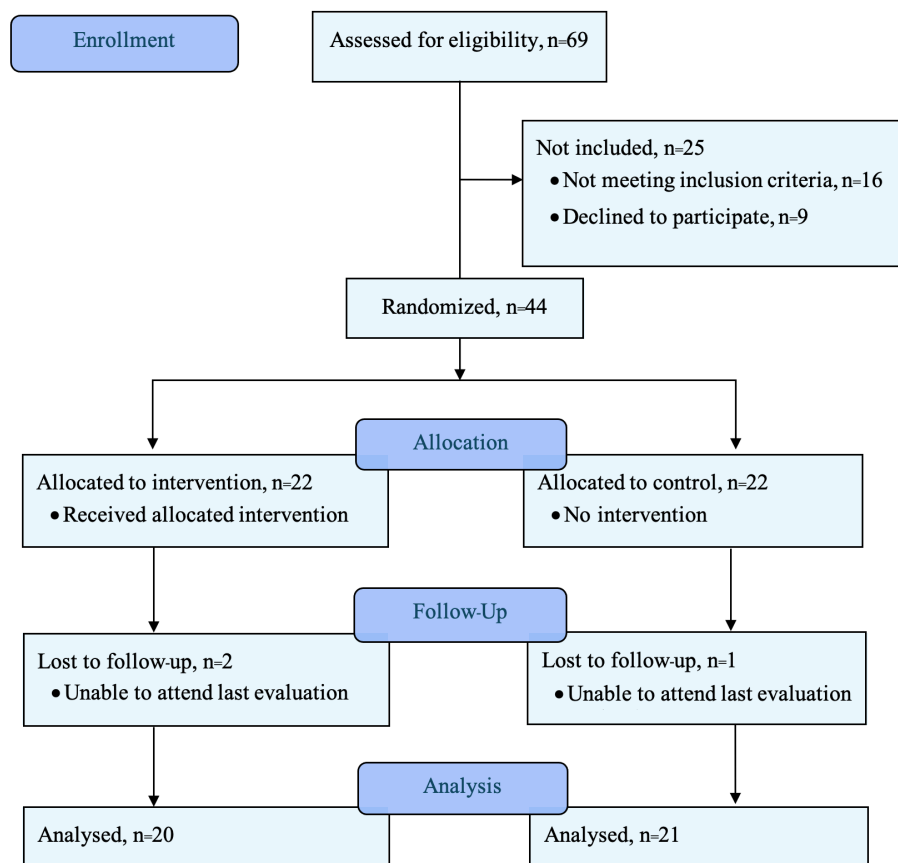


Fig 1. Flow diagram of the randomized controlled trial

Baseline and clinical characteristics were similar between the groups (Table 1). In the intervention group, the median (inter-quartile range) exercise compliance was 24 (12, 24) of the prescribed 24 sessions. No participants in the control group reported engaging in additional exercise during the study period, apart from their usual daily walking activities.

The per-protocol analysis revealed no significant between-group difference in the change in TUG time (Table 2). The intention-to-treat analysis yielded similar nonsignificant results (Mann–Whitney U test, $p = 0.606$ ($r = 0.08$)).

Changes in COP mean distance, maximal sway amplitude in both directions, and sway velocity under

TABLE 1. Participant characteristics ($n=44$).

	Total ($n = 44$)	Intervention group ($n = 22$)	Control group ($n = 22$)	p -value
Age (years), mean (SD)	68.6 (6.7)	69.2 (7.2)	68.0 (6.3)	0.572 ^a
Gender (male), n (%)	38 (86)	20 (91)	18 (82)	0.664 ^b
Weight (kilograms), mean (SD)	62.9 (11.0)	63.6 (10.7)	62.1 (11.5)	0.657 ^c
Height (centimeters), mean (SD)	164.0 (7.6)	164.8 (6.0)	163.2 (9.0)	0.507 ^c
Level of amputation, n (%) *				0.391 ^d
PF	1 (2)	1 (5)	-	
AD	2 (5)	-	2 (9)	
TT	27 (61)	14 (64)	13 (59)	
KD	1 (2)	-	1 (5)	
TF	13 (30)	7 (32)	6 (27)	
Cause of amputation, n (%) *				0.570 ^d
Traumatic	29 (66)	13 (59)	16 (73)	
Diabetes	4 (9)	2 (9)	2 (9)	
Infected wound	5 (11)	4 (18)	1 (5)	
Other	6 (14)	3 (14)	3 (14)	
Type of prosthetic foot, n (%) *				0.391 ^d
SACH foot	27 (61)	14 (64)	13 (59)	
Single-axis foot	13 (30)	6 (27)	7 (32)	
Dynamic-response foot	1 (2)	1 (5)	0 (0)	
Pirogoff foot	2 (5)	0 (0)	2 (9)	
Custom-made foot	1 (2)	1 (5)	0 (0)	
Education, n (%)				0.318 ^d
No education	1 (2)	-	1 (5)	
Primary	20 (45)	9 (41)	11 (50)	
Secondary	13 (30)	9 (41)	4 (18)	
College level or higher	10 (23)	4 (18)	6 (27)	
Number of falls in the previous year, median (IQR)	0 (0;1)	1 (0;2)	0 (0;1)	0.079 ^a
Number of falls during the study period, median (IQR)	0 (0;0)	0 (0;0)	0 (0;0)	NA
Completed exercise sessions (out of 24), median (IQR)	-	24 (12;24)	-	

* The sum of percentages isn't equal to 100 because of rounding.

Exercise compliance was applicable to the intervention group only.

The total number of falls reported during the previous year was 29 in the intervention group and 16 in the control group.

Abbreviations: SD = standard deviation, IQR = inter-quartile range, PF = partial foot, AD = ankle disarticulation, TT = transtibial, KD = knee disarticulation, TF = transfemoral.

^aMann–Whitney U, ^bFisher's Exact Test, ^cIndependent Sample T-Test, ^dPearson Chi-square.

NA = not applicable because no participant experienced a fall during the study period.

TABLE 2. Dynamic and static balance outcomes at two time points, and between-group comparisons of change scores with effect sizes (per-protocol analysis).

Outcome	Pre (n=22)	Intervention Post (n=20)	Change (n=20)	Pre (n=22)	Control Post (n=21)	Change (n=21)	p-value	Effect size
Dynamic balance (TUG)								
Total time (s)	14.2 (13.1;16.3)	14.3 (12.3;16.4)	-0.6 (-1.5;0.4)	14.9 (14.7;17.2)	16.1 (14.4;18.2)	-0.4 (-1.2;0.3)	0.584	$r = 0.09$
Static balance (COP displacement)								
Eyes-opened								
Mean distance (mm)	3.4 (2.8;4.2)	3.9 (2.9;4.3)	0.3 (-0.7;1.1)	3.8 (3.1;4.5)	3.0 (2.7;4.6)	-0.2 (-0.9;0.5)	0.355	$r = 0.15$
Sway maximal amplitude (mm)								
Anteroposterior	33.4 (26;38.6)	33.5 (26.8;39.9)	1.1 (-1.9;4.8)	27.9 (25.0;33.8)	29.2 (27.1;34.4)	-1.3 (-3.2;2.4)	0.461	$r = 0.12$
Mediolateral	17.6 (14.9;22.5)	18.7 (16.3;24.5)	1.5 (-0.9;4.1)	16.4 (13.0;22.2)	16.9 (14.7;18.5)	0.2 (-2.3;3.8)	0.495	$r = 0.11$
Sway velocity (mm/s)	337.7 (281.9;415.5)	394.6 (287.6;428.2)	30.6 (-65.7;110.4)	380.1 (309.2;447.1)	296.2 (265.4;463.1)	-22.3 (-90.6;43.5)	0.383	$r = 0.14$
Eyes-closed								
Mean distance (mm)	3.2 (2.8;4.5)	3.7 (2.5;4.4)	-0.4 (-1.1;1.1)	3.8 (3.1;4.6)	3.6 (2.5;4.7)	-0.3 (-0.6;0.5)	0.938	$r = -0.02$
Sway maximal amplitude (mm)								
Anteroposterior	37.4 (33.4;45.0)	40.7 (35.6;47.3)	0.4 (-2.1;5.7)	41.7 (31.8;44.9)	37.0 (32.1;45.1)	2.2 (-6.3;9.0)	0.729	$r = 0.06$
Mediolateral	22.1 (18.0;26.0)	22.7 (17.3;25.5)	0.2 (-4.1;2.8)	24.2 (16.2;27.6)	20.8 (17.5;24.7)	-2.2 (-3.4;2.4)	0.863	$r = -0.03$
Sway velocity (mm/s)	321.7 (287.7;455.5)	388.6 (265.5;442.5)	-31.4 (-91.5;100.9)	390.9 (311.4;459.4)	399.1 (249.2;500.0)	-30.5 (-59.3;53.2)	0.840	$r = -0.04$
Balance confidence (ABC)	81.4 (12.0)	83.8 (12.3)	2.4 (9.4)	79.8 (14.8)	83.1 (13.4)	3.3 (8.1)	0.750	$d = 0.10$

Values are presented as median (inter-quartile range), except for balance confidence (ABC), which is presented as mean (SD).

Change scores were calculated for each participant as the post-intervention value minus the baseline value and included only participants with data available at both time points.

Effect sizes are reported as r for Mann-Whitney U tests and Cohen's d for the independent-samples t -test.

Abbreviations: TUG = Timed-up-and-go, COP = center of pressure, ABC = Activities-specific Balance Confidence, mm = millimeter, mm/s = millimeter/second.

eyes-open and eyes-closed conditions did not differ significantly between the intervention and control groups (all p values > 0.05 , r ranged from -0.04 to 0.15 , Table 2).

Balance confidence, measured using the ABC Scale, also did not differ significantly between groups (Table 2). The between-group mean difference in change was -0.9% (95% CI = -6.46 to 4.66 ; independent samples t -test, $p = 0.750$; Cohen's $d = 0.10$). Analyses of the ABC scale were based on complete-case data. No falls were reported during the training period in the intervention group or the control group (Table 1).

DISCUSSION

No significant between-group differences were observed in dynamic balance (TUG), static balance (COP displacement under eyes-open and eyes-closed conditions), or balance confidence (ABC scale) following the eight-week intervention. Although TUG time showed a slight reduction in the intervention group, baseline TUG values were well below the established fall-risk threshold for individuals with LLA (≥ 19 s).²⁴ Our participants had relatively high functional mobility, as reflected by their baseline TUG performance, low fall incidence, and moderate-to-high balance confidence ($\sim 80\%$). The sample was also composed predominantly of individuals with transtibial amputations (mean age 68.6 ± 6.7 years; predominantly transtibial amputees). Given that a transtibial amputation is generally associated with better mobility outcomes than more proximal levels,³⁰ these characteristics may have limited the potential for improvement with a short-term exercise intervention. Greater effects may require a more individualized and progressively challenging training approach.

Multicomponent exercise, incorporating different exercise modalities such as balance, functional, and resistance training, is recommended for fall prevention in older adults. Exercise intensity and progression should be individualized according to functional capacity and comorbidities.³¹ Systematic reviews have shown that structured exercise programs can improve physical performance in individuals with LLA.^{12,32} In a meta-analysis a significant pooled improvement in TUG time was found (weighted mean difference = -2.01 s, 95% CI = -3.90 to -0.13) in favor of exercise interventions.¹² However, many of the included studies enrolled relatively younger participants (often in their 50s to early 60s) and individuals with mixed amputation levels compared to participants in the current study.^{3,12,33} These differences in participant characteristics may partly explain the smaller treatment effects observed in our

study, as older LLP users with relatively high functional mobility may require more intensive, longer-duration, or progressively challenging interventions to achieve measurable balance adaptations.¹² Previous studies have incorporated supervised progressive resistance training, treadmill-based perturbation training, task-specific gait training, and structured progression of exercise intensity or complexity.¹¹ Given the relatively high functional mobility of participants in the present study, a greater emphasis on progressive resistance and progressively challenging balance exercises may have provided a more appropriate training stimulus. In contrast, the present program was primarily home-based, included only two supervised sessions, and did not incorporate structured progression, progressive overload, or perturbation-based components. Furthermore, walking was not prescribed as a separate aerobic exercise component. Although several exercises involved walking tasks, these were designed primarily as balance exercises rather than aerobic training. Considering the relatively high functional mobility of the participants, the intervention focused primarily on strength and balance exercises; however, the absence of a structured aerobic component may have limited the overall training stimulus. The intervention intensity was intentionally designed to be moderate and feasible for older LLP users to ensure safety and promote adherence. However, this conservative approach may have limited the magnitude of balance improvements observed. Although exercise adherence was acceptable, with a median (inter-quartile range) of 24 (12, 24) completed sessions, variability in completion of specific exercises was observed. In particular, some participants did not perform the stair-ascending and stair-descending task due to environmental constraints (e.g., absence of stairs at home) or fear of stair negotiation. Because stair ambulation represents a higher-level, task-specific balance challenge, reduced exposure to this component may have attenuated the overall training stimulus and limited potential functional gains.

Additionally, structural and prosthetic factors, including socket fit, prosthetic alignment, and prosthetic foot characteristics, are known to influence center of pressure displacement and postural steadiness during quiet standing.^{34,35} As these biomechanical determinants were not modified or controlled in the present study, changes in static balance measures may have been limited despite participation in the exercise program. Balance confidence may also be less responsive to short-term physical training alone because psychosocial factors contribute substantially to self-perceived stability.^{36,37}

Taken together, the small effect sizes across all outcomes indicate that the intervention did not produce measurable benefits beyond usual care.

These findings suggest that an eight-week program consisting primarily of fall prevention education and home-based exercise program did not result in statistically significant improvements in older LLP users with relatively high functional mobility. More intensive, longer-duration, or task-specific interventions may be required to elicit clinically meaningful improvements.

Limitations

Several limitations should be considered when interpreting the results of this study. Although exercise adherence was generally acceptable, variability in session completion may have influenced individual responses to the intervention. In addition, exercise adherence was assessed using self-reported logbooks, which may have introduced information bias due to inaccurate or incomplete recording.

Although exercise completion was monitored using participant logbooks and weekly follow-up calls, actual exercise performance and quality of execution could not be objectively verified. Therefore, variability in adherence to the prescribed exercises may have influenced the effectiveness of the intervention. However, the consistency between the complete-case and intention-to-treat sensitivity analyses suggests that the study findings were not substantially influenced by the small number of dropouts.

Furthermore, the relatively high functional mobility of the participants may limit generalizability of the findings to individuals with lower baseline mobility, or a higher risk of falls. In addition, the predominantly male composition of the sample should be considered when interpreting the applicability of these findings to female older LLP users.

Moreover, participant recruitment, intervention delivery, follow-up, and outcome assessments were conducted by the same unblinded researcher, which may have introduced performance and detection bias, particularly for timed and self-reported outcomes. The intervention group also received more frequent contact through weekly telephone calls and a supervised visit at week 4, whereas the control group did not receive matched attention. This differential contact represents a potential co-intervention and may have influenced participant engagement and self-reported outcomes. Adverse events were not systematically collected, which limited the assessment of potential intervention-related harms.

Future research should consider stratifying participants according to baseline functional level or fall history to better target individuals at higher risk of falls, as well as examining whether amputation level and prosthetic characteristics influence intervention outcomes. Studies should also investigate the effects of progressive, task-specific balance challenges and extended interventions and follow-up periods.

CONCLUSIONS

A fall prevention education and exercise program consisting of verbal instruction on fall prevention supported by a booklet and an eight-week program of 16 strength and balance exercises did not result in significantly greater improvements than usual care in dynamic balance, static balance, or balance confidence in older LLP users with relatively high functional mobility. These findings suggest that a longer duration of training or a higher-intensity, progressively challenging exercise program may be required to produce meaningful changes in balance performance in this population.

Data Availability Statement

The data that support the findings of this study are available from the first author upon reasonable request.

ACKNOWLEDGEMENTS

The authors would like to thank the participants for their contributions to this study. The authors also thank Dr. Udomporn Manupibul for her help with the static balance data cleaning.

DECLARATIONS

Grants and Funding Information

This work was supported by the Faculty of Medicine, Siriraj Hospital, Mahidol University under Grant number (IO) R016832005; and Siriraj Research Development Fund, Faculty of Medicine Siriraj Hospital, Mahidol University under Grant number (IO) R016737001.

Conflict of Interest

The authors report no conflicts of interest.

Registration Number of Clinical Trial

Thai Clinical Registry (ID no. TCTR20250525005) on May 25th, 2025.

Author Contributions

Conceptualization and methodology, P.S., P.U.D., K.S., G.G., and J.P. ; Investigation, P.S. ; Formal analysis, P.S. and J.P. ; Visualization, P.S. ; Writing – original draft,

P.S., P.U.D. and J.P. ; Writing – review and editing, P.S., P.U.D., K.S., G.G. and J.P. ; Funding acquisition, P.S. and J.P. ; Supervision, P.U.D., K.S., G.G. and J.P. ; All authors have read and agreed to the final version of the manuscript.

Use of Artificial Intelligence

The authors declare they have not used artificial intelligence.

Institutional Review Board Statement

This study was approved by the Siriraj Institutional Review Board, Faculty of Medicine Siriraj Hospital, Mahidol University (Si 776/2024) on October 3rd, 2024. Written informed consent was obtained from all participants before enrollment. The study was conducted in accordance with the protocol approved by the Siriraj Institutional Review Board.

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