Effectiveness of Robot-Assisted Lower Limb Rehabilitation on Balance in People with Stroke: A Systematic Review, Meta-analysis, and Meta-regression

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Abstract. The objective of this study was to evaluate the effectiveness of robot-assisted lower-limb rehabilitation on balance in stroke patients and to explore the covariates associated with these effects.

A systematic literature search was carried out in four databases (MEDLINE (Ovid), CINAHL, PsycINFO, and ERIC) for studies published from inception to 25th of March 2022. Studies on robot-assisted lower-limb rehabilitation with a randomized controlled trial (RCT) design, participants with stroke, a comparison group with conventional training, and balance-related outcomes were included. Studies were assessed for Cochrane Risk of Bias 2 and quality of evidence. Meta-analysis and meta-regression were performed.

A total of 48 (RCT) with 1472 participants were included. The overall risk of bias in the included studies was unclear ($n = 32$), high ($n = 15$) or low ($n = 1$). Compared to conventional rehabilitation, robot-assisted lower-limb rehabilitation interventions were more effective for balance improvement (Hedges' $g = 0.25$, 95% CI: 0.10 0.41). In meta-regression, a relationship between the training effect was observed with the time since stroke, explaining 56% of the variance ($p = 0.001$), and with the ankle robots, explaining 16% of the variance ($p = 0.048$). No serious adverse events related to robot-assisted training were reported.

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Robot-assisted lower-limb rehabilitation may improve balance more than conventional training in people with stroke, especially in the acute stage. Robot-assisted lower-limb rehabilitation seems to be a safe rehabilitation method for patients with stroke. To strengthen the evidence, more high-quality RCTs with adequate sample sizes are needed.

Keywords: Robotics · Lower extremity · Exercise · Stroke Rehabilitation · Postural Balance · Meta-Analysis

1 Introduction

Stroke is one of the main causes of disability [1], with motor impairment being the most common [2]. Since stroke may affect the visual, vestibular, and somatosensory systems, balance impairments are common after stroke [3]. These impairments increase the risk of falls, with 73% of patients with stroke falling in the first year [4]. Poor balance impairs independent living and daily activities and increases the fear of falling in patients with stroke [3].

Robot-based neurorehabilitation is a rapidly growing field that uses robots to treat neurological injuries [5]. Systematic reviews have indicated that robot-assisted rehabilitation has more positive outcomes for stroke patients in improving walking and motor recovery than conventional training [6, 7]. Robotic devices can be classified into exoskeletons, end effectors, and upper- and lower-limb robots [8]. Exoskeletons (e.g. Lokomat) uses programmable drives or passive elements to move a patient's knees and hips during gait [9]. End-effector-type devices (e.g., Gait Trainer) have footplates that mimic the stance and swing phases of gait [9]. Other robots for lower-limb rehabilitation include ankle robots [10] and robotic mobile devices [11, 12].

Previous review studies on robot-assisted lower-limb stroke rehabilitation have focused on gait outcomes. A Cochrane review [7] found that combining automated electromechanical and robot-assisted gait training with conventional physiotherapy increased the odds of independent walking and walking speed, but not walking capacity in a 6-min walk. This type of training may be beneficial during the acute rehabilitation phase [7].

A few review studies [13–18] have examined the outcomes of balance. Zheng et al. [13] studied the effects of robot-assisted therapy on the balance of patients with stroke. Separate meta-analyses of the Berg Balance Scale (BBS) and Fugl-Meyer balance scale scores showed that robot-assisted therapy was more effective than conventional treatment, with the exception of the Timed Up and Go test (TUG). The effects were not influenced by the type of robotic device or if robot-assisted therapy was combined with other interventions. A single meta-analysis that combined all balance outcomes was not conducted.

The most recent systematic review and meta-analysis by Loro et al. [14] found that compared with conventional training, the Berg Balance Scale results improved more in patients who received robot-assisted gait training, but TUG test results did not differ between groups. The results of different balance measures were not included in the analyses. Meta-regression was restricted to intervention-related factors, and a longer treatment duration was associated with better balance (TUG).

To the best of our knowledge, in studying the effects of robot assisted training on balance in people with stroke, no previous meta-analysis of randomized controlled trials (RCT) has investigated the effects of all kinds of lower-limb robotic training but limited mainly to gait training only. Previous meta-analyses did not pool different balance measures in the same analysis, leading to a limited number of studies included in the main analysis. Therefore, the aim of this systematic review and meta-analysis was to provide new and more extensive information about the effectiveness of robot-assisted lower-limb rehabilitation on balance in people with stroke and explore the association of covariates with this effect.

The following questions were addressed: 1) Does the effect of robot-assisted lower-limb rehabilitation differ from that of conventional rehabilitation on outcomes measuring balance in persons with stroke? 2) Are study factors, such as personal, clinical, or intervention characteristics, associated with the effects of robot-assisted rehabilitation on balance?

2 Methods

The protocol for this systematic review was registered in PROSPERO (CRD 42022319241). Reporting followed the PRISMA guidelines [19] (Supplementary Material).

2.1 Data Sources and Searches

The first phase of a systematic literature search was conducted in a larger project that studied the effectiveness and meanings of robotics, virtual reality, and augmented reality in medical rehabilitation [20]. The National Library of Medicine (MEDLINE), Cumulative Index to Nursing and Allied Health Literature (CINAHL), Psychological Information Database (PsycINFO), and Education Resources Information Center (ERIC) databases were searched from inception to November 12, 2019. An updated search was conducted after this review was registered from the same databases for studies published between August 2019 and March 25, 2022. The search strategy used either MeSH or keyword headings related to therapies and rehabilitation, robotics, robotic devices, and RCT study design. The search strategy for the Ovid MEDLINE database is presented in Supplementary Material. In addition, reference lists of previously published systematic reviews were searched to identify potential publications not included in the database search.

2.2 Study Selection

The screening for this review was performed in two phases. The first phase served the larger project with wider scope [20] and included a screening of potential studies using the PICOS (patient, intervention, comparison, outcome, study design) framework as follows: P) Adults or children requiring medical rehabilitation, I) Any type of robotic device designed for rehabilitation purposes, C) Conventional rehabilitation, wait-list-control, or other training modality different from experimental group, O) Body functions and structures, activities, or participation according to International Classification of Functioning, Disability and Health (ICF), or quality of life, and S) RCT or crossover RCTs. The second phase was carried out after the updated search with more specified PICOS criteria to identify eligible studies of interest in this particular review: P) Adults (18 years of age or older) with stroke requiring medical rehabilitation, I) Any type of rehabilitation and physiotherapy intervention including lower-limb robotic device designed for rehabilitation purposes, C) Conventional rehabilitation and physiotherapy intervention without the use of a robotic device, O) Validated and standardized measures of balance, S) RCTs and crossover RCTs. Studies focusing on patients with other neurological disorders, comparing robot-assisted interventions with other robotic training modalities, and studies reporting only self-reported measures of balance (e.g., balance confidence) were excluded.

Two researchers (AK, SH, RY, MK, OI, and EA) independently screened the study titles and abstracts according to the inclusion criteria using Covidence [21]. After the completion of title and abstract screening, two researchers (AK, MK, SH, RY, EA, and OI) independently evaluated potential studies in the full-text phase by applying the inclusion criteria and reporting the reasons for exclusion of ineligible studies. A third reviewer (EA) evaluated the studies in case of disagreement.

2.3 Data Extraction and Quality Assessment

Data extraction was performed in Covidence according to the pre-determined format to report participants, interventions, and outcomes of the studies included in the review (Supplementary Material). Twelve original researchers were approached via email because of inadequate outcome data (emails were sent no more than three times), of which six researchers responded and provided the requested outcome data (Supplementary Material).

The Cochrane Risk of Bias 2 tool (RoB 2) [22] was used for the quality assessment of the included studies. Two researchers (RY, AK, MK, and OI) independently performed data extraction and quality assessment, and a third reviewer (EA) evaluated the studies in case of disagreement. If applicable, the previously published protocols and registry records of the included studies were retrieved to assess the risk of bias.

2.4 Data Synthesis and Analysis

The results of all eligible studies were pooled in a meta-analysis to provide an overall estimate of the effect of robot-assisted lower limb rehabilitation. Balance improvement was the primary measure of the treatment effect. The outcomes of balance were prioritized according to validity and reliability to combine the results from the studies in the analysis. A priority list of the chosen balance outcomes and the rationale thereof are provided in Supplementary Material. If the direction of the values differed, the values of each outcome variables were multiplied by -1 when needed so that the higher values reflected in the same direction in the analyses [23]. Only the first part of the trial was analyzed if the study used a randomized controlled crossover design. In the meta-analysis, the mean and standard deviation (SD) post-treatment values of continuous outcomes were obtained to calculate the intervention effect size (Hedges' g) and 95%

confidence intervals (CI) between the groups. The scale of Hedges' g was interpreted as follows: 0.20 to less than 0.50 was considered a small effect, 0.50 to less than 0.80 was considered a medium effect, and >0.80 was a large effect [24]. A random-effects model with restricted maximum-likelihood estimation was used in the meta-analysis because effect sizes are independent across studies, and it was hypothesized that effect size would vary across the populations tested. We computed the test of heterogeneity using a Q-test to confirm that the study effect size varied across samples, and the I^2 index was used to compute the variance explained by this heterogeneity. Bias caused by selective publication within studies was evaluated by assessing the funnel plot of the trial mean differences for asymmetry [25]. Effect sizes, corresponding variances and funnel plots were computed with Metafor package for R [26] and forest plots with forest plot package for R [27].

Meta-regression analysis was conducted with Metafor package for R. We computed Univariate Mixed effects model with intercept and restricted maximum-likelihood estimation to investigate whether certain study or clinical characteristics explain the proportion of the variance in the observed effect in the meta-analysis. Overall, 10 different covariates were analysed in relation to the quality of the study (risk of bias), content of intervention (study duration, number of training sessions per week, time of one training session, weekly total intensity of training, type of limb robotic device, robotic training alone or combined with conventional training), and clinical characteristics of rehabilitees (age, female sex in percent, time since stroke in months, and mean score of baseline Berg Balance Scale). Heterogeneity accounted for by the covariates was measured using (pseudo) R^2 [28].

The certainty of evidence according to the outcomes and meta-analysis was evaluated using the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) guideline [29]. The quality of evidence was classified as high (i.e., further research is unlikely to change our confidence in the effect estimate), moderate (i.e., further research is likely to have an important effect on our confidence in the effect estimate), low (i.e., further research is highly likely to have an important effect on our confidence in the effect estimate), or very low (i.e., any estimate of the effect is highly uncertain).

3 Results

3.1 Study Selection

Database searches generated 2099 studies (Fig. 1). After the removal of duplicates and exclusion of irrelevant studies in two phases, first, according to the PICOS criteria of the larger project and second, the PICOS criteria of this review, 48 RCTs were included in the review and 41 were included in the meta-analysis. A list of excluded studies is provided in Supplementary Material with references and justifications for exclusion. All the included studies were published in English between 2006 and 2021. Detailed characteristics of the studies in the narrative synthesis (n = 48) are provided in Supplementary Material.

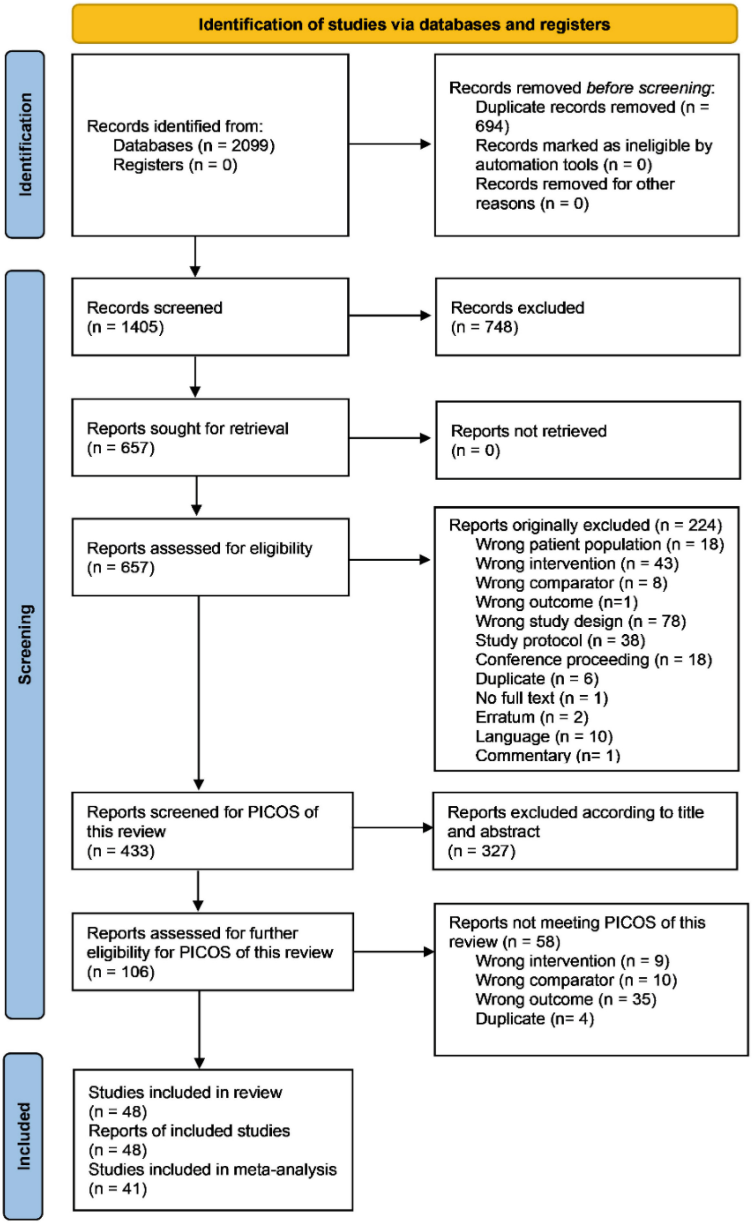


Fig. 1. Prisma flow diagram

3.2 Study Characteristics

Participants. A total of 1472 participants were involved in included studies. The sample sizes ranged from 6 to 37 in the experimental groups (mean: 15.39 ± 6.55 participants) and from 6 to 30 in the comparison groups (mean: 14.96 ± 5.77). The mean age of the participants ranged from 44 to 76 years (mean: 59.87 ± 6.01 years). The percentage of women in the study group ranged from 0 to 64%. The mean time since stroke ranged from 11 days to 10 years (mean: 24.66 ± 33.67 months). More participants with ischemic stroke (67%) than with hemorrhagic stroke were involved. The type of stroke was not reported in 7 studies. Participants' functional ability varied at baseline, with some studies showing that all participants were able to walk and ambulate independently, while others had no participants who could walk without personal assistance.

Interventions. The duration of interventions ranged from 2 weeks to 20 weeks (mean: 5 ± 3 weeks). The most frequently used intervention duration was 4 weeks. The frequency of training ranged from twice a week to seven times a week (mean: 4 ± 1 times a week) and one session lasted 20–105 min (mean: 51 ± 25 min). The interventions were carried out in rehabilitation units and clinics (n = 17), hospitals and medical centres (n = 24), outpatient clinics (n = 3), or at home (n = 1). In three studies, the settings were not designated. Exoskeleton-type robotic devices were used in 34 studies, with Lokomat used in 13 studies. The other robotic devices used were end-effectors (n = 5), robotic ankle (n = 6), and robotic mobile devices (n = 3). In 21 studies, robot-assisted lower limb rehabilitation was offered with conventional rehabilitation or physiotherapy. Twenty-three studies had a follow-up period after intervention. Descriptions of the robot-assisted training protocols and devices are provided in Supplementary Material.

Comparisons. In 47 studies, the comparison groups underwent regular physiotherapy or conventional gait training. In one study, the control group underwent exercise training at home. Most often, comparison groups focused on gait training; however, in some studies, stretching and functional training were used for comparison. In all the studies, the training amount was similar between the comparison and intervention groups.

Outcomes. Balance was assessed using several measures. The results of the Berg Balance Scale (n = 35), Tinetti Balance Test (n = 3), and Timed Up and Go test (n = 9) were used in the studies included in the meta-analysis. One study assessed balance using the Sensory Organization Test (SOT), but this study was not included in the meta-analysis as balance was measured with laboratory devices. Thus, combining SOT with other balance measures was not considered appropriate for this meta-analysis.

3.3 Methodological Quality

The overall risk of bias in the included studies was unclear (n = 32), high (n = 15), or low (n = 1) (Fig. 2). The risk of bias in selective reporting was unclear in 41 studies (85%), high in five studies (11%), and low in two studies (4%). A funnel plot (Fig. 3) did not show any clear evidence of publication bias. The certainty of the evidence estimated using GRADE was considered low. The GRADE level was downgraded due to several studies with unclear or high risk of bias and inconsistency related to the heterogeneity of the original studies. The GRADE assessment is presented in 'Summary of Findings' -table. The risk of bias assessment of each included study as well as the 'Summary of Findings' -table are provided in Supplementary Material.

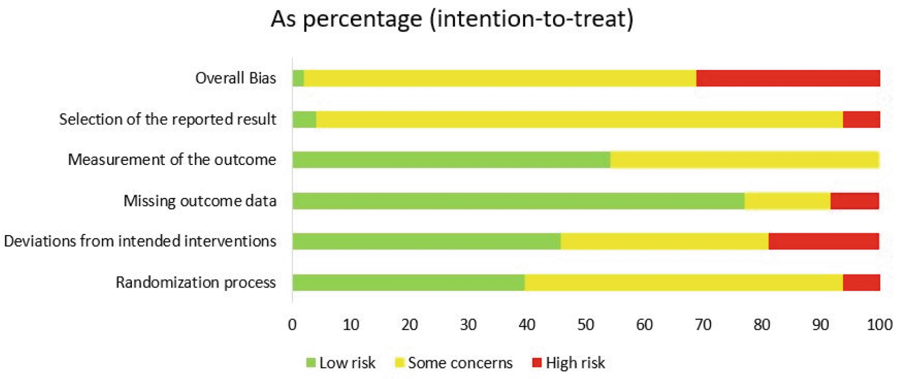


Fig. 2. Risk of Bias (%, intention-to-treat)

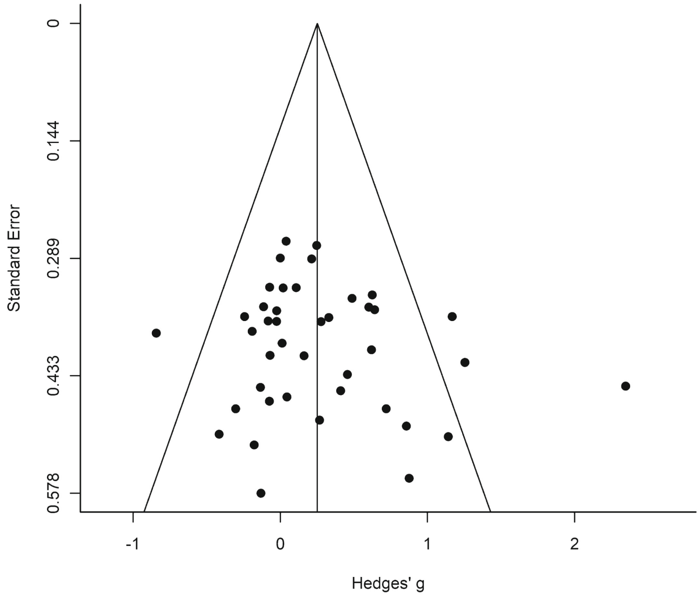


Fig. 3. Funnel plot

3.4 Effectiveness of Robot-Assisted Lower-Limb Rehabilitation on Balance

When comparing robot-assisted lower-limb rehabilitation to conventional rehabilitation methods in stroke patients, robot-assisted training showed a significant effect on the improvement of balance (Hedges' g = 0.25, 95% CI 0.10 to 0.41, 1192 participants, 41 studies; low-quality evidence) (Fig. 4). The level of statistical heterogeneity in the overall analysis was moderate ($I^2 = 42.7\%$).

3.5 Meta-regression

In meta-regression (Table 1), a relationship between the robot-assisted training effect and time since stroke was observed, explaining 56.0% of the variance of observed balance and indicating that the shorter the time in months since the stroke event, the greater the improvement in balance scores in the robot-assisted group compared with the conventional training group (point estimate −0.007; 95% CI, −0.012 to −0.003; p = 0.001) (Fig. 5). A relationship was also observed between the robot-assisted training effect and ankle robots, explaining 16.3% of the variance of observed balance (point estimate 0.552, 95% CI: 0.004 to 1.100, p = 0.048), indicating that more improvement in balance was achieved with ankle robots than with other types of robotic devices.

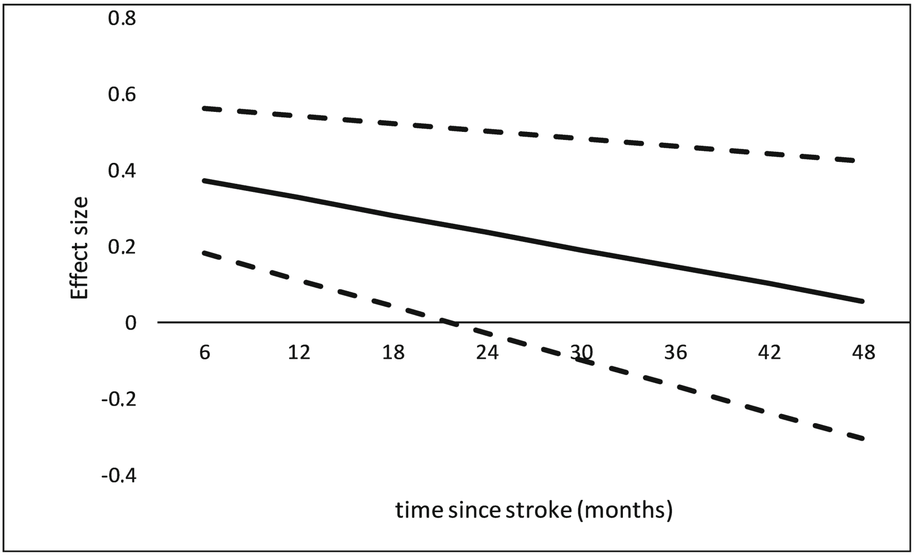
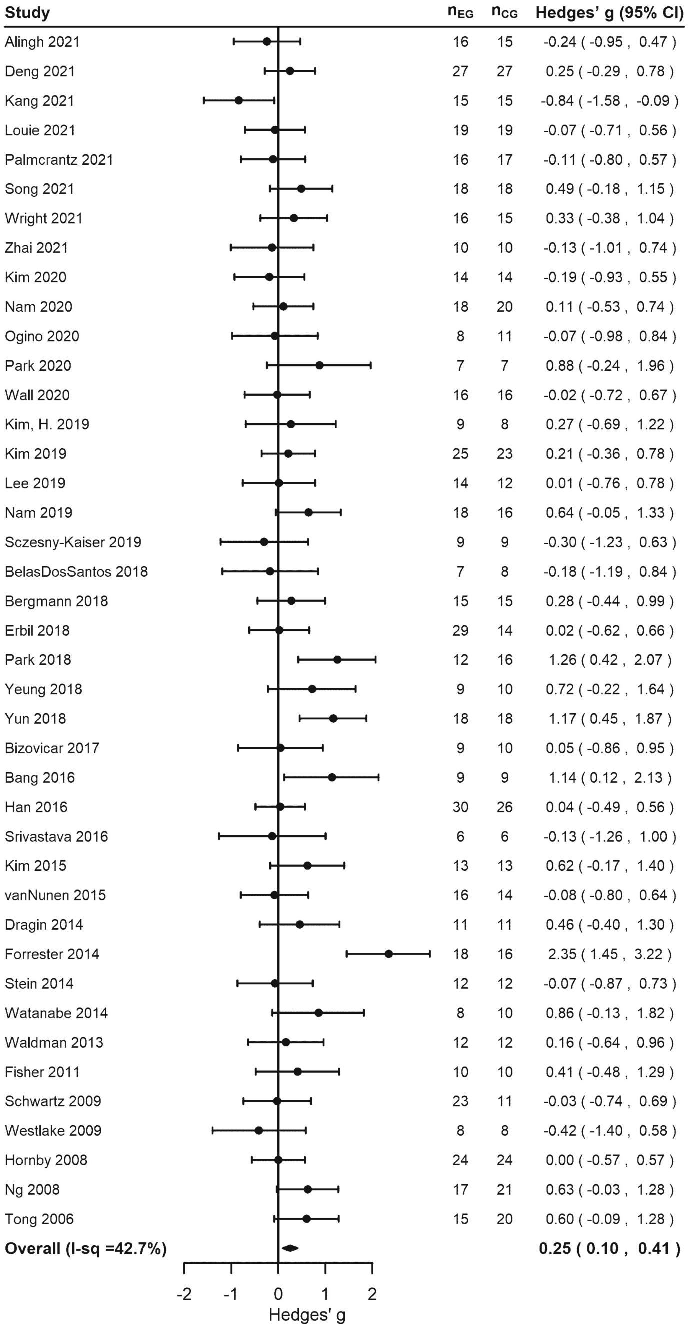


Fig. 4. Estimated effect of robot-assisted lower-limb rehabilitation (solid line) with 95% CI (dashed lines) according to time since stroke in months.

3.6 Adverse Events

Six of the 48 studies reported adverse events related to robot-assisted lower-limb rehabilitation. These events were mild, and no study reported serious adverse events. In a study by Calabro et al. [30], seven out of 20 patients in the experimental group experienced mild skin irritation and shank strap locations at the thigh. Hornby et al. [31] reported that two participants out of 24 dropped out because of leg pain during robotic training and one participant experienced pitting edema. In a study by Sczesny-Kaiser et al. [32], one of nine patients discontinued robot-assisted intervention due to intensive fatigue after each training session. In a study by Kang et al. [33], one person in the robot training group had recurrent skin problems and experienced skin abrasion in the tribal



Study	n_{EG}	n_{CG}	Hedges' g (95% CI)
Alingh 2021	16	15	-0.24 (-0.95 , 0.47)
Deng 2021	27	27	0.25 (-0.29 , 0.78)
Kang 2021	15	15	-0.84 (-1.58 , -0.09)
Louie 2021	19	19	-0.07 (-0.71 , 0.56)
Palmcrantz 2021	16	17	-0.11 (-0.80 , 0.57)
Song 2021	18	18	0.49 (-0.18 , 1.15)
Wright 2021	16	15	0.33 (-0.38 , 1.04)
Zhai 2021	10	10	-0.13 (-1.01 , 0.74)
Kim 2020	14	14	-0.19 (-0.93 , 0.55)
Nam 2020	18	20	0.11 (-0.53 , 0.74)
Ogino 2020	8	11	-0.07 (-0.98 , 0.84)
Park 2020	7	7	0.88 (-0.24 , 1.96)
Wall 2020	16	16	-0.02 (-0.72 , 0.67)
Kim, H. 2019	9	8	0.27 (-0.69 , 1.22)
Kim 2019	25	23	0.21 (-0.36 , 0.78)
Lee 2019	14	12	0.01 (-0.76 , 0.78)
Nam 2019	18	16	0.64 (-0.05 , 1.33)
Sczesny-Kaiser 2019	9	9	-0.30 (-1.23 , 0.63)
BelasDosSantos 2018	7	8	-0.18 (-1.19 , 0.84)
Bergmann 2018	15	15	0.28 (-0.44 , 0.99)
Erbil 2018	29	14	0.02 (-0.62 , 0.66)
Park 2018	12	16	1.26 (0.42 , 2.07)
Yeung 2018	9	10	0.72 (-0.22 , 1.64)
Yun 2018	18	18	1.17 (0.45 , 1.87)
Bizovicar 2017	9	10	0.05 (-0.86 , 0.95)
Bang 2016	9	9	1.14 (0.12 , 2.13)
Han 2016	30	26	0.04 (-0.49 , 0.56)
Srivastava 2016	6	6	-0.13 (-1.26 , 1.00)
Kim 2015	13	13	0.62 (-0.17 , 1.40)
vanNunen 2015	16	14	-0.08 (-0.80 , 0.64)
Dragin 2014	11	11	0.46 (-0.40 , 1.30)
Forrester 2014	18	16	2.35 (1.45 , 3.22)
Stein 2014	12	12	-0.07 (-0.87 , 0.73)
Watanabe 2014	8	10	0.86 (-0.13 , 1.82)
Waldman 2013	12	12	0.16 (-0.64 , 0.96)
Fisher 2011	10	10	0.41 (-0.48 , 1.29)
Schwartz 2009	23	11	-0.03 (-0.74 , 0.69)
Westlake 2009	8	8	-0.42 (-1.40 , 0.58)
Hornby 2008	24	24	0.00 (-0.57 , 0.57)
Ng 2008	17	21	0.63 (-0.03 , 1.28)
Tong 2006	15	20	0.60 (-0.09 , 1.28)
Overall (I-sq =42.7%)			**0.25 (0.10 , 0.41)**

Fig. 5. Forest plot

Table 1. Results of the Meta-regression Analysis on Covariates Concerning the Study Factors and the High Risk of Bias domains

Covariates		Estimated Effect Size	SE	Lower CI	Upper CI	P	R^2 (%)	
Study factors								
Age (years)		0.018	0.013	-0.008	0.044	0.181	4.6	
Female (%)		0.012	0.006	-0.001	0.024	0.068	22.0	
Time since stroke (months)		-0.007	0.002	-0.012	-0.003	0.001	56.0	**
Intervention duration (weeks)		-0.040	0.030	-0.098	0.019	0.182	4.5	
Number of sessions per week		0.041	0.070	-0.096	0.178	0.557	0.0	
Session duration (min/session)		0.000	0.003	-0.006	0.007	0.954	0.0	
Intervention volume (min/week)		0.000	0.001	-0.001	0.001	0.943	0.0	
Type or interv.	Robotic exercise	Ref.						
	Robotic in addition to other exercise	-0.034	0.162	-0.351	0.283	0.834	0.0	
Type of robots	Other robotic types	Ref.						
	Exoskeleton	-0.285	0.181	-0.639	0.070	0.115	10.1	
	End-effector	0.120	0.230	-0.332	0.571	0.603	0.0	
	Ankle	0.552	0.280	0.004	1.100	0.048	16.3	*
	Robot mobile devices	-0.211	0.576	-1.340	0.917	0.714	0.0	
Berg Balance Scale at baseline (points)		-0.011	0.007	-0.024	0.002	0.099	9.4	
High Risk of Bias								
Overall		-0.285	0.156	-0.590	0.020	0.067	13.2	
Randomization process		-0.028	0.309	-0.635	0.578	0.927	0.0	
Deviations from intended interventions		-0.177	0.181	-0.532	0.178	0.330	0.0	
Missing outcome data		-0.259	0.216	-0.683	0.165	0.231	1.6	
Measurement of the outcome		-	-	-	-	-	0.0	
Selection of the reported result		-0.327	0.314	-0.942	0.288	0.298	0.0	

SE: Standard Error; CI: 95% Confidence Interval
* <0.05; ** <0.01

area. Palmcrantz et al. [34] reported that six persons experienced adverse events related to robotic training, including occasional transient redness or abrasion of the skin and discomfort or pain related to pressure from the HAL suit, attached shoes, or electrodes. In a study by Louie et al. [35], one person reported knee pain while wearing the robotic device, and three experienced transient pain or discomfort while using the exoskeleton. It did not affect their intervention adherence and could be resolved through device sizing adjustments. No adverse events occurred during robot-assisted training in 24 studies, and information related to adverse events was not provided in 18 studies.

4 Discussion

This systematic review and meta-analysis assessed the effectiveness of robot-assisted lower-limb training interventions on balance compared to conventional rehabilitation protocols in people with stroke. Robot-assisted interventions had a small, significant effect on balance (Hedges' g 0.25) [24]. The methodological quality of the studies was unclear and the evidence (GRADE) was low. Meta-regression showed that robot-assisted lower-limb rehabilitation was most effective in the early stages of rehabilitation and the sooner after stroke onset, the more significant the improvements. Ankle training robots may be the most beneficial, but the evidence is uncertain due to the small number of studies (n = 6). To the best of our knowledge, this is the largest review on this topic, with 41 RCTs and 1192 participants in the quantitative synthesis. We studied factors related to interventions, population, and study quality. Our intervention included all types of lower-limb robotic training and balance assessment combined with different measures based on a priority list. This study also reported adverse events from lower-limb robotic training and used GRADE to assess the evidence certainty.

Previous studies have shown that improvements in balance performance using conventional balance training interventions can be achieved at all stages of stroke rehabilitation, even more than 10 years post-stroke [36]. Based on our results, it appears that beneficial changes in the balance of stroke patients can be achieved with robot-assisted interventions. Similar findings were also reported in the Cochrane review [7] where the authors found that robot-assisted gait training may be more effective in enhancing walking-related outcomes in the acute stages of stroke rehabilitation in comparison to the chronic stages. Furthermore, the study revealed that using end-effector type devices for training exclusively resulted in significant improvements in gait speed and walking capacity for stroke patients, as opposed to conventional training methods [7]. Our review's findings suggest that the effect size for was higher also for balance outcomes of patients in the acute phase compared to those in the chronic phase. However, the effect sizes were not affected by whether the exoskeleton or end-effector type of robot was used.

The results of our study are mainly in line with those of other studies [13, 14] assessing the effectiveness of robot-assisted lower-limb rehabilitation on balance in patients with stroke, indicating that significant improvements in balance outcomes can be achieved with robot-assisted lower-limb training protocols. In our study, all suitable outcomes were included in the same meta-analysis; therefore, the results are not fully comparable with those of earlier studies [13, 14], which conducted independent meta-analysis for different outcomes of balance. However, the interpretations appear similar.

We conducted a meta-regression analysis to explore the association with the effects of covariates that were not investigated in previous studies. Our study differed from the previous meta-regression on this subject by Loro et al. [14], which focused on factors related to intervention protocols. They found an association between TUG results and treatment duration, indicating that the longer the robotic treatment phase, the greater the improvement in the TUG results. However, in our study, the effect sizes were not affected by any of the intervention-related covariates, such as treatment duration. It should be noted that Loro et al. [14] included only patients recovering from their first-ever stroke event, whereas our study also included recurrent events. Nevertheless, the results of our study did not provide clear answers regarding which training duration or intensity was the best for balance improvement. Future research should investigate the effects of different robotic training protocols to provide professionals important information for clinical settings.

Our study showed that the shorter the time since stroke, the greater the improvement in balance scores in the robot-assisted group than in the conventional training group. This suggests that robot-assisted training could be a useful alternative for individuals in the early phases of rehabilitation. Our meta-regression results also showed that baseline balance test scores and participant age did not affect the effect sizes of the analysis, indicating that robot-assisted training may be an option for people of different ages and levels of balance ability. Additionally, the results did not differ whether robotic training was the only training method or combined with some conventional training methods, contradicting the statement by Loro et al. [14] that a combination of robot-assisted gait training and conventional training is the most effective. Our findings suggest that the level of risk of bias in the original studies did not influence the results.

Robot-assisted training may be more beneficial than conventional training in improving balance in persons with stroke because it enables higher-intensity training, especially for most disabled patients [5]. Additionally, it may be beneficial for early retraining after stroke, when there is maximum plasticity and potential for recovery [37]. This may explain why robot-assisted training seems to improve balance and gait abilities more than conventional training, especially during the acute phase of recovery [7].

Previous reviews of robotic lower-limb rehabilitation in stroke patients have not reported any adverse events. Our study found that these events were mild and rarely reported, indicating that robotic lower-limb devices are generally safe for most patients with stroke. No adverse events occurred in 24 of the 48 studies included in the review. Six studies reported adverse events mostly related to skin irritation, discomfort, or pain during training. Many of these issues can be prevented by properly adjusting the robotic device before training.

4.1 Study Limitations

This review has some limitations that should be considered when interpreting the results and generalizability of the evidence. The quality assessment revealed several ratings of unclear and high risk of bias in the included studies, which led to the downgrading of the evidence quality. Almost all the studies had some concerns in the selection of the reported results' domain in the RoB 2 tool due to the lack of registration of the original study. One potential methodological limitation in these studies is the inability to blind participants and therapists, which may lead to performance bias [3]. Funnel plots were visually inspected and no clear evidence of publication bias was observed.

Statistical heterogeneity was present in the meta-analysis conducted for this review, which was one reason for downgrading the GRADE quality of evidence. There were many potential sources of heterogeneity among the included studies. Participant characteristics such as age, time since stroke event, stroke type, and severity of impairment at baseline differed widely across the studies. In addition, the use of robotic devices, duration and intensity of interventions, comparison training procedures and settings varied, and whether robot-assisted training was combined with other training. One limitation is the small sample sizes in the included studies; in many cases, the sample sizes were less than 20 in the experimental and comparison groups. Because of some methodological limitations and heterogeneity in the included studies, the certainty of the evidence is low, and more high-quality RCTs with adequate sample sizes are needed to improve the quality of evidence on this subject.

The challenge in studying the effects of robotic training is the rapid development of technology in relation to the slow production of effectiveness information. Newer technology may have different effects or disadvantages. On the other hand, it can be assumed that with the development of technology and professional competence, the goal is to improve the rehabilitation process.

4.2 Conclusions

The results of this systematic review and meta-analysis show that robot-assisted lower-limb rehabilitation may improve balance more than conventional training in stroke patients, especially in the early stages of rehabilitation. Robot-assisted lower-limb rehabilitation also seems to be a safe rehabilitation method for stroke patients. This evidence suggests that physiotherapists and other rehabilitation professionals may consider robot-assisted lower limb rehabilitation as a useful rehabilitation method for improving balance in patients with stroke. However, more high-quality RCTs are required to strengthen this evidence.

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