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THE ROLE AND EFFECTIVENESS OF ROBOT-ASSISTED GAIT TRAINING IN STROKE REHABILITATION: A SCOPING REVIEW

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ABSTRACT

Background: *Stroke is a leading cause of long-term disability worldwide. Gait impairment is one of the most common functional limitations in post-stroke survivors. Robot-Assisted Gait Training (RAGT) has emerged as an innovative rehabilitation method that enhances task-specific training intensity and consistency.*

Objective: *To map the existing literature on the use of Robot-Assisted Gait Training (RAGT) in stroke rehabilitation, focusing on its role and effectiveness in improving walking function, balance, and motor recovery.*

Methods: *A scoping review was conducted using studies from electronic databases including PubMed and PEDro. 05 Articles were included as they involved stroke patients receiving RAGT and assessed outcomes related to gait, mobility, or functional improvement.*

Results: *Evidence from five studies suggests that RAGT can improve balance, gait parameters, and ambulation in subacute and chronic stroke patients. However, variations in device types, session durations, and stroke stages present challenges in generalization. Major gaps include the absence of long-term follow-up, lack of cost-effectiveness data, insufficient subgroup analyses, and underrepresentation of large-scale RCTs.*

Conclusion: *RAGT is a promising and evolving approach in post-stroke rehabilitation. Future studies should aim to explore long-term functional outcomes, optimize intervention protocols, and examine economic feasibility for large-scale clinical adoption.*

INTRODUCTION

Stroke is neurological condition and a leading cause of disability, commonly linked with motor dysfunction of the lower limb established as low strength of muscle, ataxia, and abnormalities in walking gait(1) Stroke is the second largest leading cause of mortality and marked first causing disability worldwide the occurrence of stroke is also progressively increasing, Loss of understanding words and depression are major causes of disabilities in patients after stroke(2, 3) reduction or ceasing off in mobility due to paralysis is the most common disability tract which is directly linked with main factors: one is rapid change in muscle mass second is diminished central motor control. these weakening leads to balance problems,

Neurological and physiological defects appear after stroke, activities of daily living reduced specially balance and waking gait problems(4, 5)

Gait disturbance is the most important physical aspect to rehabilitate after stroke; pathological gait patterns appear with limitation in walking distance(6) Most patients show slow cadence and low endurance causing prolonged disability, making treatment hard, makes walking the most important rehabilitation goal Neurodevelopment treatment (NDT) is a familiar choice of treatment for the rehabilitation of stroke the goal is to restore normal movements in gait rehabilitation weight supported trainings on treadmill is also traditionally been used(3, 4, 6)

Robot-assisted walking gait rehabilitation covers the limitations of NDT and body-weight assisted trainings on treadmill, In this training the body weight of the patient's is supported with harness system, which eliminate the need of therapist assistance, same in bodyweight-supported treadmill training(4) The quality of Robot-assisted training is both repeatability and accuracy repeatability is gained thorough the range of motion and stride length through robot hardware once the robotic hardware is set, procedure continues in the same adjusted environment with repeatability. Accuracy is attained with robotic exoskeleton, once it is adjusted for the patient according to the size suitable for the patient(3, 6)The therapist can adjust precise stimulation by adjusting the hardware of the robot. Based on repeatability and accuracy, this training device affects the coordination between the lower extremities in the gait of stroke patients, the robot hardware allows control harness of treadmill, for different techniques to be applied to the patient which facilitate a wide range of gait-training environments(7)

Moreover, the robotic system provides effective treatment protocol by precise, repetitive movements and correct joint range of motion. However, strong treatment strategies have not yet been developed for robot-assisted gait training. also, no specific guidelines in the robot's software available for the adjustable variables like which speed is appropriate, how much of the patient's weight may be supported for a better outcome or which angle of the joint is best for patient's gait. Despite its emerging use and benefits, robot-assisted gait training has not yet well established, in technical and conceptual base, it must be investigated in future research whether robot-assisted gait training improves gait and balance in stroke patients.

Methods

A scoping review methodology was employed to examine the breadth and depth of research on RAGT in stroke rehabilitation. Studies were selected based on the following criteria Population: Adults post-stroke (acute, subacute, or chronic phase) Intervention: Robot-Assisted Gait Training Outcomes: Walking ability, balance, functional ambulation, motor recovery and Study design: RCTs, and systematic reviews, Sources searched were: PubMed and PEDro (2022 to 2025)

Data Charting and Synthesis

Studies were analyzed and charted by: Type and brand of robotic device, Duration and frequency of intervention, Study outcomes (clinical and functional), Sample characteristics

Literature Review of the included studies

This scooping review comprises of 05 articles conducted between 2022 to 2025 on "Robot-Assisted Gait Rehabilitation in Post-Stroke patients" evaluation of these studies are done on their characteristics.

Study	Design	Population	Key Outcomes	Limitations
Huo et al. (2024)	RCT	Subacute stroke (n=40)	RAGT improved gait, balance, and neuroplasticity	Small sample, short-term (4 weeks), no follow-up
Lee et al. (2025)	Systematic Review + MA	Mixed stroke (23 RCTs, n=907)	Significant short-term gains in gait, ADLs, and balance	High heterogeneity, no long-term data, unblinded
Choi et al. (2022)	RCT	Chronic stroke (n=24)	Different weight supports in RAGT impact balance/gait	Very small sample, short follow-up (6 weeks)
Loro et al. (2023)	Systematic Review + MA	Mixed stroke (18 RCTs)	RAGT effective for balance (BBS, TUG)	High heterogeneity, lack of subgroup analyses
Zhang et al. (2023)	RCT	Subacute stroke (n=38)	sEMG & gait analysis confirmed RAGT improved motor control	No long-term data, unequal group size

Characteristics of the included studies

Study 01: "Effectiveness of unilateral lower-limb exoskeleton robot on balance and gait recovery and neuroplasticity in patients with subacute stroke"
Congcong Huo et al., 2024 (*Journal of NeuroEngineering and Rehabilitation*)
Objective: The study of Congcong Huo et al. published in 2024 aimed to compare the effectiveness of robot assisted overground gait training and conventional training for the lower-limb rehabilitation of stroke patients with hemiplegia.
(Wearable gait analyzers and clinical assessment scales, Berg balance scale (BBS), Fugl Meyer assessment for lower extremity (FMA-LE), functional ambulation category (FAC), and modified Barthel index (mBI), used to assess the motor function of the patients before and after 4 weeks of training.)

Methods
Study Design: A randomized, single-blind controlled trial with 40 subacute stroke patients assigned to either a robot-assisted training (RT) group or a conventional training (CT) group.
Study setting: This RCT was conducted at Affiliated Rehabilitation Hospital of National Research Center for Rehabilitation Technical Aids, China. 50 eligible patients were assessed; 40 right-handed patients were recruited between March 2023 and November 2023.

Inclusion criteria
a. hemiparesis due to first-ever unilateral supratentorial stroke;
b. post stroke within 6 months;
c. residual gait and balance impairment;
d. aged 18–75 years.

Exclusion criteria
a. severe general impairment or concomitant diseases;
b. arthritis, limited range of motion of joints and other severe restrictions on walking;
c. severe cognitive impairment or unable to understand and follow instruction.

Methodological Strengths
1. Study design used is single-blinded randomized clinical trial, the gold standard for assessing interventions.
2. True Randomization (computer-generated with sealed envelopes) no selection bias.
3. Well-Defined Inclusion and Exclusion Criteria.
4. Measure the outcomes at 0, 2, and 4 weeks
5. The Outcome assessors were blinded in this study to group allocation
6. Used validated clinical tools
a) BBS for Balance)
b) FMA-LE for Motor function
c) mBI for ADLs)
d) FAC for Ambulation
e) Gait analysis done with wearable gait system

Methodological Weaknesses
1. Sample size was small, 30 patients included in final analysis which limits generalizability
2. It is unclear whether the improvements are sustained or not
3. One weakness is that this study was Conducted at one facility, limiting external validity
4. The robot-assisted group need close therapist supervision; therapist interest or guidance quality may influence engagement.
5. Four participants neuroimaging data were excluded because of signal artifacts; this can lead to bias the neuroplasticity analysis

Overall Appraisal
Methodologically the study is strong Randomized Control Trial, however small sample size, short follow-up duration, and no long-term data weaken the strengths of this study.

Research Gap
This study described robot-assisted gait training which significantly improves balance, gait, and neuroplastic initiation in stroke patients, this study doesn't have long-term follow-up, which limits sustainability of the outcomes. this study did not evaluated cost-effectiveness which is important in clinical adoption and policy-making

Proposed Research Question
"What is the long-term functional outcome and cost-effectiveness of robot-assisted gait training compared to conventional physiotherapy in stroke patients over a 6-month follow-up period

Explanation
The randomized controlled trial study claims the evidence that unilateral lower-limb exoskeleton robotic training may enhance walking gait, balance, and brain activation in stroke patients. Follow-up duration for intervention of this study is only 4-weeks.

Aso lack of follow-up after intervention provides critical gaps in understanding the persistence of the outcomes. Post-Stroke rehabilitation is not short-term recovery it is indeed a long-term rehabilitation, functional independence, and community reintegration.

Moreover, while robotic exoskeletons have high-cost in clinical settings, especially in low or middle-income countries. Presently, there is little to no evidence on cost to benefit ratio of robotic interventions are compared to conservative therapies. By addressing both the clinical robustness and cost effectiveness of robot-assisted gait training over an extended 6-month period can fulfill the research gap.

Study 02: "Effectiveness of Robot-Assisted Gait Training in Stroke Rehabilitation"

Jun Hyeok Lee et al., 2025 (*Journal of clinical medicine*)

Objective: This systematic review and meta-analysis aimed to evaluate the effectiveness of Robot Assisted Gait Training combined with conventional rehabilitation compared to conventional rehabilitation alone in stroke survivors.

The primary outcomes of this study is gait function, gait speed, balance, and ADLs.

Methods

Study Design: A Systematic Review and Meta-Analysis

Study setting: A comprehensive search was conducted in PubMed, Embase, CINAHL, and the Cochrane CENTRAL from inception to 30 September 2024.

Inclusion criteria

Studies were selected using the (PICOS) framework. Eligible studies met the following criteria:

a. adult participants (aged ≥ 18 years) with ischemic or hemorrhagic stroke;
b. interventions combining conventional lower-limb rehabilitation with RAGT (exoskeleton or end-effector systems);
c. control groups receiving only conventional rehabilitation;
d. reported outcomes on gait function, gait speed, gait balance, or ADLs; and
e. randomized controlled trial (RCT) design with extractable effect size data.

Exclusion criteria

a. Exclusion criteria included studies
b. involving pediatric participants
c. robotic-only interventions without concurrent conventional therapy
d. unequal session durations between groups
e. non-RCT formats such as reviews, conference abstracts, or case reports

Methodological Strengths

1. This review followed the PRISMA guidelines and Cochrane Handbook standards which is the evidence of transparency
2. Multiple databases were searched for studies: PubMed, Embase, CINAHL, and CENTRAL
3. No language restrictions which limit language bias.
4. Clear eligibility Criteria (PICOS Framework)
5. Homogeneity was ensured in comparison across studies.
6. Large Sample Size (total 23 RCTs having 907 participants) increased generalizability.
7. Using of Cochrane RoB 2.0 tool
8. Funnel plots and Egger's regression test applied
9. Provided a transparency at publication bias

Methodological Weaknesses

1. No long-term follow-up Most RCTs in this SR was intervention durations ranges from 2–12 weeks.
2. Sustainability in improvements is unclear.
3. No Blinding of the Therapists and Participants (Blinding was not feasible in many studies because of the nature of RAGT. Which unintentionally increases the risk of bias in performance called performance bias
4. Heterogeneity was there for primary outcomes:
   a. Gait function I^2 = 73% (high)
   b. Gait speed I^2 = 62% (high)
5. Outcomes like Cost-effectiveness and QoL were lacking
6. The Protocol for this study is not Registered or not Mentioned

Overall Appraisal

This Systematic review provides valuable evidence that Robot Assisted Gait Training is effective post-stroke gait in subacute stages of stroke. However, the conclusions are incomplete due to high heterogeneity, short durations of follow-up, and lacking of functional outcomes in long term.

Research Gap: Most RCTS included in this systematic review were short-term follow-up, so the sustainability in improvements specially in motor functions and independency in ADLs is unclear.

Proposed Research Question
Does robot-assisted gait training (RAGT) improve long-term post stroke rehabilitation and quality of life in patients with stroke survivors compared to conservative rehabilitation?

Explanation
This systematic review states that robot-assisted gait training (RAGT), if combined with conservative rehabilitation, results in significant short-term outcome as improvements in gait, balance, and also in ADLs However, the included RCTs in this SR were of very short duration that is from 2–8 weeks, which make it unclear whether the outcomes will lead to sustained functional independence and improved inclusion in societal participation of everyday life or not.
The above stated research question reports and addresses the critical research gap by investigating whether Robt Assisted Gait Training influence lifelong quality of life and community restoration in stroke patient recovery.

Study 03: "Effects of Robot-Assisted Gait Training with Body Weight Support on Gait and Balance in Stroke Patients"
Wonho Choi et al., 2022 (*International Journal of Environmental Research and Public Health*)
Objective: the objective of this study is to investigate whether robot-assisted gait training improves gait and balance in stroke patients, as well as to examine the difference in treatment effects according to the extent of weight support within each robot treatment group.

Methods
Study Design: A randomized controlled trial (with 24 patients randomly selected based on the selection criteria)
Study setting: The study was conducted in Gachon University Seongnam, Korea

Inclusion criteria
a. patients diagnosed with a stroke more than 6 months after onset
b. patients with no difficulty in following the therapist's instructions with a score of ≥ 24 on the mini-mental state examination (MMSE)
c. patients without orthopedic problems, heart disease, and circulatory problems
d. patients able to walk >10 m using orthosis or mobility aids.

Exclusion criteria
a. Patients with open skin disease,
b. Patients with severe fixation stiffness, height < 125 cm, weight > 135 kg, or Modified Ashworth scale (MAS) of G1+ or higher on the affected side were excluded.

Methodological Strengths
1. Gold standard study design i.e randomized controlled design (RCT) was used, which supports internal validity.
2. Full protocols for robotic training are clearly stated
3. Using of validated and reliable tools for standard in stroke rehabilitation.
4. Accurate use of ANOVA, post hoc analysis, and paired t-tests.
5. Normality was checked using Shapiro–Wilk test
6. Assessor blinding in this study is also its strength

Methodological Weaknesses
1. Small sample size in this study i.e Only 24 participants divided 6 per group decreases statistical power and generalizability of the rsults
2. This study did not report the sample size or power analysis to rationalize 6 participants per group is enough.
3. Duration to follow-up is short i.e 6 weeks
4. Participants & therapist was not blinded, risk of performance and expectation bias
5. Measuring motor recovery is lacking
6. This was a single centered study

Overall Appraisal
This RCT is well-structured and transparent utilizes standard clinical tools and statistical analysis, due to small sample size , lack of blinding, and short duration of follow-up are limiting confidence on the outcomes.

Research Gap
This RCT investigated 3 different body weight support i.e 30%, 50% and 70%, All the participants in all four groups were provided a fixed support level all over the intervention, the progressive reduction in weight is common practice in most of the clinical rehabilitation in promoting neuroplasticity.

Proposed Research Question

Does reduction progressively in body weight support while robot-assisted gait training result in high improvements in both balance and gait performance compared to fixed support in the rehabilitation of stroke patients?

Explanation

Reducing Progressively in body weight support through robot-assisted gait training (RAGT) may well mimic rehabilitation in real-life, which enhance the proprioceptive feedback, and also stimulate greater neurological and muscular adaptation. Discovering this approach may lead to the development of additional tailored and effective RAGT procedures and found evidence-based guidelines for adjusting robotic assistance levels.

Study 04: "Balance Rehabilitation through Robot-Assisted Gait Training in Post-Stroke Patients"

Alberto Loro et al., 2023 (*brain sciences journal*)

Objective: Objective of this study is to collect all the evidences about robotic-assisted gait training (RAGT) on balance rehabilitation.

In specific, the study focuses on covering the lack of statistical relevance present in the actual literature, due to a small number of trials included, and tries to assess as many sub-group evaluations as possible.

Study Design: A Systematic Review and Meta-Analysis

Study setting: PubMed, Cochrane Library, and PEDro electronic databases were searched till 3 August 2022.

Inclusion criteria

Studies were included in this SR and MA are

a. Randomized controlled trials;
b. the participants' age was ≥18 years;
c. studies included if conducted on post-stroke survivors only
d. studies included if intervention was any kind of RAGT
e. studies included if conventional treatment is compared
f. studies included Berg Balance Scale (BBS), Timed Up and Gotest (TUG), or both are used as outcomes measures

Exclusion criteria

d. Studies conducted on participants with a history of multiple strokes
e. Studies using RAGT in both experimental and control groups were also excluded

Methodological Strengths

1. This SR followed PRISMA 2020 guidelines which improve transparency and decrease risk of duplication
2. This SR is also Registered on PROSPERO transparency & quality.
3. Only randomized controlled trials were included in this SR, which increases internal validity.
4. This SR Used international valid and reliable measures i.e Berg Balance Scale BBS and Timed Up and Go test TUG.
5. One strength of this study is that it Explored all the effects of duration, type of device, and number of sessions
6. Analysis and publication bias checking done through Egger's test & funnel plot
7. Large Sample Size is also the strength of this study, this SR Included 18 RCTs, making this study a complete SR and meta-analyses on RAGT.

Methodological Weaknesses

1. This study has High Heterogeneity (I^2 = 74%) between all the included studies in many aspects such as types of Device types, number and duration of Session, characteristics of patients i.e acute, chronic
2. Further Subgroup analysis on Stroke Stages is absent
3. Many of the included RCTs in this SR were single blinded, double and triple blinding is a limitation.
4. **Specific analysis of Specific devices is not mentioned** which make it unclear about which robot type was most effective due to inconsistency and lack of subclass data.

Overall Appraisal

Study design is Systematic review and meta-analysis which is the highest level in hierarchy of the evidence Trial, however this systematic review is conducted on limited databases.

Research Gap

The randomized controlled trials included in this SR and MA were having participants at various stages of stroke i.e acute, chronic or subacute but analysis based on subgroup oof stroke is not been done

Proposed Research Question

"To which extent the robot-assisted gait training is effective for balance outcomes in substages of stroke such as acute, subacute, & chronic?

Explanation
The duration of physical rehabilitation is important in harness, neuroplasticity or post-stroke recovery, to clarify whether which stage (early, mid, or late-phase) Robot Assisted Gait Training has better effects on balance improvements, this will help clinicians to optimize the treatment duration to specific stage, personalize interventions, and manage resources more effectively. Current study lacks subgroup analyses, which makes this a clinically weighty and research-worthy gap.

Study 05: Three-Dimensional Gait Analysis and sEMG Measures for Robotic-Assisted Gait Training in Subacute Stroke
Huihuang Zhang et al., 2023 (*Hindawi BioMed Research International*)

Objective: objective of this study is to investigate the impact of Robot Assisted Gait Training on the clinical walking ability indicators, spatio temporal parameters, kinematic parameters, and indicators of sEMG in patients with subacute stroke by comparison between RAGT and conventional gait training and to evaluate the clinical effect of improving walking function of RAGT.

Methods
Study Design: A prospective, single-blind, randomized controlled study (parallel groups design)
Study setting: participants for this study were recruited from Zhejiang Rehabilitation Medical Center, China
Inclusion criteria
a. Hemiplegia after first stroke, age ≥ 18 years
b. less than 6 months since onset
c. lover extremity modified Ashworth scale ≤2
d. walking at least 15m without assist,
e. ability to understand and follow instructions.

Exclusion criteria
a. Patients with extreme osteoporosis, unstable fracture, or excessive spasticity were excluded
b. severe cognitive impairment, speech impairment,
c. unable to cooperate with training, and deteriorating condition.

Methodological Strengths
1. single-blinded randomized clinical trial, the gold standard for assessing interventions.
2. True Randomization (computer-generated with sealed envelopes) no selection bias.
3. study was conducted in accordance with the declaration of Helsinki.
4. Well-Defined Inclusion and Exclusion Criteria.
5. Name and detail of the robotic device is provided i.e (rehabilitation robot MANBUZHEKANGFU, Tianjin, China, model)
6. 6-camera VICON (Vicon Motion System) system were used to obtain the spatiotemporal parameters and kinematic data of the patients' gait.
7. Pre and post treatment/ experiment analysis is also one of the strengths
8. Intragroup Comparison done in this study
9. The Shapiro-Wilk test for normal distribution. Two-sample t-test and non para metric, Mann–Whitney test was used to compare two groups. Fisher's precision probability test was used for enumeration data.

Methodological Weaknesses
1. Sample size was small, 38 patients included in final analysis which limits generalizability, also 4 dropouts may also lead to biasness
2. 2 groups distribution is not equal
3. Short duration of intervention period (4 weeks)
4. there was no follow-up, so the long-term effects of RAGT on walking ability after stroke could not be determined.
5. study was Conducted at one facility, limiting external validity

Overall Appraisal
The study design is Randomized Control Trial, a strong and gold standard design, however small sample size, short follow-up duration, and no long-term data weaken the strengths of this study.

Research Gap
As per the knowledge of the scholar this study has the Methodological type of research Gap, addressing the small sample size, limited control group, no feedback mechanisms, and short duration of intervention period without follow-up.

Proposed Research Question
"What is the effectiveness of robot-assisted gait training on balance outcomes differ in stages of stroke rehabilitation i.e acute, subacute, and chronic?

Conclusion

All the including studies in this scooping review on "Robot-assisted gait training (RAGT) proves that Robot-assisted gait training (RAGT) is improving gait, balance, and functional outcomes in stroke patients, these recent studies claim that if RAGT when use in combination with conservative rehabilitation therapies are most effective. The reviewed studies consistently show that RAGT provides precise, repetitive, and task-specific movement patterns that enhance motor learning and stimulate neuroplasticity. However, despite these short-term gains, several methodological and clinical limitations persist, including small sample sizes, short intervention durations, Lack of long-term follow-up, Limited cost-effectiveness evaluations, High heterogeneity in devices, protocols, and stroke stages These limitations restrict the generalizability and clinical adoption of RAGT as a standardized treatment.

Thus, while RAGT is a valuable and evolving intervention in stroke rehabilitation, further high-quality, long-term, and multicenter RCTs are needed, especially those addressing cost-effectiveness, progressive training variables, and outcomes across different stroke stages (acute, subacute, and chronic). Future research should aim to define optimal protocols and explore personalized, stage-specific robotic rehabilitation approaches.

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