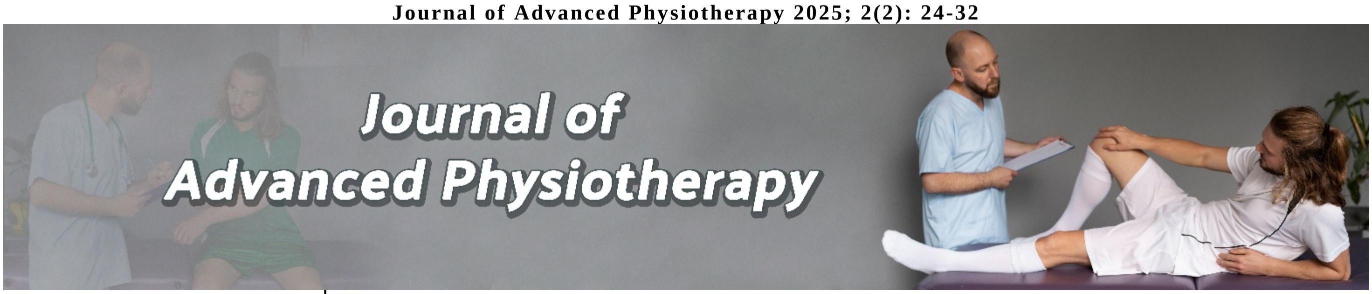

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Robotics-assisted gait training versus conventional therapy in post-stroke hemiparesis: A controlled clinical study

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Abstract
Background: Restoration of safe, efficient walking is a primary goal of stroke rehabilitation, yet many survivors remain limited household ambulators due to persistent hemiparetic gait, reduced speed, and marked asymmetry. Robotics-assisted gait training (RAGT) has been proposed as a means to deliver high-intensity, task-specific stepping with controlled kinematics, but its added value over well-delivered conventional gait therapy remains incompletely defined.
Objective: To compare the effects of RAGT versus dose-matched conventional therapist-delivered gait rehabilitation on walking speed, functional ambulation, gait endurance, and kinematic parameters in adults with early subacute post-stroke hemiparesis.
Methods: In this controlled clinical study, 60 adults (18-80 years) with first-ever unilateral stroke (2 weeks-6 months post-onset), hemiparetic gait, and Functional Ambulation Category (FAC) 1-3 were randomized (1:1) to RAGT plus standardized multidisciplinary rehabilitation or to conventional gait therapy plus the same rehabilitation dose. Both groups received 45-minute gait-focused sessions, 5 days/week for 4 weeks, in addition to matched usual-care physiotherapy. Primary outcomes were comfortable gait speed (10-Meter Walk Test) and FAC. Secondary outcomes included fast gait speed, 6-Minute Walk Test (6MWT), Berg Balance Scale (BBS), Gait Profile Score (GPS), and spatiotemporal symmetry indices from three-dimensional gait analysis. Assessments were performed at baseline and post-intervention by blinded assessors. Analyses followed the intention-to-treat principle.
Results: Baseline demographic and clinical characteristics were similar between groups. Both groups improved significantly in comfortable gait speed ($p<0.001$), but gains were greater with RAGT (Δ 0.24±0.11 m/s) than with conventional therapy (Δ 0.12±0.10 m/s), with a between-group difference of 0.12 m/s (95% CI 0.05-0.19, $p=0.002$). A higher proportion of participants in the RAGT group achieved independent ambulation (FAC ≥4: 60.0% vs 33.3%, $p=0.04$). RAGT also produced larger improvements in 6MWT distance (Δ 75±35 m vs 47±32 m, $p=0.01$) and greater reductions in GPS (Δ −3.4±2.1° vs −1.7±2.0°, $p=0.03$), with significantly greater gains in step-length symmetry ratio. Trends favored RAGT for balance, although between-group differences in BBS change did not reach significance. A responder analysis (clinically meaningful gains in gait speed and FAC) showed more "global gait responders" in the RAGT group (63.3% vs 36.7%, $p=0.03$).
Conclusions: In early subacute post-stroke hemiparesis, integrating RAGT into a structured multidisciplinary rehabilitation program yields superior improvements in walking speed, functional ambulation, endurance, and gait pattern, including symmetry, compared with dose-matched conventional gait therapy alone. These findings support the use of RAGT as an effective adjunct to conventional physiotherapy to enhance walking recovery and facilitate progression from household to community ambulation after stroke.

Keywords: Stroke, hemiparesis, robotics-assisted gait training, electromechanical gait trainer, exoskeleton, gait rehabilitation, functional ambulation category, gait profile score, gait symmetry, community ambulation

Introduction
Robotics-assisted gait training has emerged against a backdrop in which stroke remains a leading cause of adult disability, with global analyses showing persistently high incidence and more than 100 million people living with stroke sequelae, particularly in low- and middle-income countries [1, 2]. A major determinant of post-stroke participation and quality of life is the ability to walk independently in home and community environments [4, 5, 21], and yet a large proportion of survivors develop hemiparetic gait characterized by abnormal

synergies, spatiotemporal asymmetry, reduced speed, and increased energy cost [3, 6, 20]. These gait impairments translate into limitations in community ambulation, reduced social participation, and higher caregiver burden [4, 5, 21]. Quantitative assessment tools such as the Functional Ambulation Category (FAC), observational gait scales, and three-dimensional kinematic indices including the Gait Profile Score (GPS) are now widely used to capture clinically meaningful changes in walking performance after stroke [7, 8, 20, 21]. Contemporary stroke rehabilitation emphasizes early, intensive, task-specific gait practice, underpinned by evidence that repetitive walking training can improve gait speed, functional ambulation, and self-care, and that motor recovery follows characteristic time-dependent trajectories [4, 9-11]. Conventional gait rehabilitation typically combines therapist-assisted overground walking, body-weight-supported treadmill training, and balance and strengthening exercises; however, the physical effort required from therapists and the difficulty of delivering sufficiently high-dose, symmetrical, and task-specific stepping in more impaired patients remain important constraints [4, 6, 9-11]. Electromechanical and robot-assisted gait training (RAGT) systems were developed to address these limitations by enabling high-repetition stepping with adjustable body-weight support and guidance, while reducing therapist physical load and allowing precise control of kinematic parameters [12, 16, 17]. Systematic reviews and meta-analyses indicate that electromechanical-assisted gait training combined with physiotherapy probably increases the odds of achieving independent walking compared with physiotherapy alone, particularly in non-ambulatory and early subacute patients, although effects on gait speed and walking capacity are smaller and less consistent [9, 12]. Large randomized controlled trials and observational studies comparing different devices and protocols report that RAGT is at least as effective as therapist-assisted gait training for improving clinical walking functions, but with mixed findings regarding superiority and limited effects on gait symmetry [13-15]. Narrative and scoping reviews highlight heterogeneity in device type (end-effector vs exoskeleton), timing post-stroke, training intensity, and parameter settings, and suggest that suboptimal application of robots may partly explain the lack of clear superiority over well-delivered conventional therapy [16-18]. Recent trial protocols such as the GAITFAST study underscore the need for rigorously designed, add-on RAGT trials in early subacute stroke, with standardized outcomes including FAC, gait speed, balance, and kinematic gait indices [13, 19]. At the same time, detailed gait analysis studies reinforce the importance of capturing spatiotemporal symmetry and GPS-based deviations to understand how different interventions modify hemiparetic gait patterns beyond simple speed gains [3, 7, 20]. Despite this growing body of evidence, there remains a clear gap in head-to-head controlled clinical studies directly comparing robotics-assisted gait training with dosage-matched conventional therapy in adults with post-stroke hemiparesis, using sensitive measures of gait symmetry, functional ambulation, and community-relevant walking outcomes [4-7, 12-15, 19-21]. Therefore, this controlled clinical study is designed to compare the effectiveness of robotics-assisted gait training versus conventional therapist-delivered gait rehabilitation on gait speed, spatiotemporal symmetry, balance, and functional ambulation in individuals with post-stroke hemiparesis. The primary objective is to determine whether adding RAGT to a standardized physiotherapy program produces greater improvement in comfortable walking speed and FAC category than conventional therapy alone, while secondary objectives examine effects on GPS, gait symmetry indices, and community ambulation status. Based on prior meta-analytic and mechanistic evidence, we hypothesize that participants receiving robotics-assisted gait training will demonstrate significantly larger gains in gait speed and functional ambulation, and greater normalization of gait symmetry, compared with those receiving conventional therapy alone, particularly among patients in the early subacute phase and those with more severe baseline gait impairment.

Material and Methods

Materials

This controlled clinical study employed a parallel-group design comparing robotics-assisted gait training (RAGT) with conventional therapist-delivered gait rehabilitation in adults with post-stroke hemiparesis. The study was conducted in the stroke rehabilitation unit of a tertiary care teaching hospital with a dedicated gait laboratory equipped for three-dimensional motion analysis and clinical outcome assessments [3, 7, 20]. Participants were eligible if they were aged 18-80 years, had a first-ever unilateral ischemic or hemorrhagic stroke confirmed by neuroimaging, were in the early subacute phase (2 weeks to 6 months post-onset), presented with hemiparetic gait (Functional Ambulation Category [FAC] 1-3) and could maintain upright standing with or without minimal assistance [4, 6, 11-13]. Exclusion criteria included severe cognitive impairment or aphasia precluding instruction following, severe lower-limb spasticity (Modified Ashworth Scale >3), comorbid orthopedic or neurological conditions affecting gait, unstable cardiovascular status, and contraindications to intensive treadmill or robotic training [4, 6, 9, 12, 16]. After providing written informed consent, participants were allocated in a 1:1 ratio to the RAGT group or the conventional therapy group using concealed block randomization stratified by baseline FAC and time since stroke [9, 12, 13, 19]. The RAGT intervention utilized a commercially available electromechanical gait trainer with body-weight support and programmable stepping patterns (end-effector or exoskeleton-type depending on institutional availability), allowing adjustment of speed, guidance force, and symmetry of limb trajectories [12-14, 16, 17]. Both groups received standard multidisciplinary stroke rehabilitation including individualized physiotherapy, occupational therapy, and speech therapy as indicated, conforming to contemporary task-specific and repetitive training principles [4, 9, 10]. The study protocol was approved by the institutional ethics committee and adhered to the Declaration of Helsinki and relevant clinical trial reporting guidelines for stroke rehabilitation research [9, 12, 18, 19].

Methods

Participants in both groups underwent 45-minute gait-focused sessions, five days per week, for four consecutive weeks (total 20 sessions), in addition to usual-care physiotherapy of matched duration outside the gait-focused component [4, 9, 13, 19]. In the RAGT group, each session comprised 5-10 minutes of warm-up (seated/standing exercises), 30 minutes of robot-assisted treadmill walking with progressive reduction in body-weight support and guidance force and gradual increases in speed and step length based on individual tolerance, followed by 5-10 minutes of cool-down and overground carryover practice [12-17, 19]. Conventional therapy sessions delivered by experienced physiotherapists included overground gait training with appropriate assistive devices, body-weight-supported treadmill walking if available, balance and postural control exercises, lower-limb strengthening, and task-oriented functional mobility practice, with intensity and progression modeled on best-practice walking training protocols [4, 6, 9, 10]. Clinical assessments were performed at baseline (pre-intervention) and immediately after the 4-week intervention by blinded assessors not involved in treatment. Primary outcomes were comfortable gait speed measured via the 10-Meter Walk Test (10MWT) and functional ambulation measured by the FAC [4, 8, 9, 13, 21]. Secondary outcomes included fast gait speed, community ambulation category based on walking distance and need for supervision, spatiotemporal symmetry indices (step length and stance time ratios), and the Gait Profile Score (GPS) derived from three-dimensional gait analysis in the laboratory [3, 7, 20, 21]. Additional measures included the 6-Minute Walk Test (6MWT) to estimate walking endurance and the Berg Balance Scale (BBS) to capture balance performance [4, 6, 9, 11]. All gait analyses were performed under standardized conditions with participants using their customary orthoses and assistive devices, and three representative trials were averaged for kinematic variables [3, 7, 20]. Sample size was estimated a priori to detect a clinically meaningful between-group difference of 0.16-0.20 m/s in gait speed with 80% power and two-sided α=0.05, based on previous RAGT trials and walking training meta-analyses [9, 12-14, 19]. Data were analyzed using intention-to-treat principles. Continuous variables were summarized as means and standard deviations or medians and interquartile ranges, as appropriate. Between-group differences in change scores were examined using independent-samples t tests or Mann-Whitney U tests; within-group pre-post changes were assessed using paired tests. For categorical outcomes such as FAC and community ambulation level, chi-square or Fisher's exact tests were applied [9, 12-14, 21]. Effect sizes (Cohen's d or odds ratios with 95% confidence intervals) were calculated for key outcomes, and two-way repeated-measures analyses of variance were used exploratorily to examine group × time interactions for gait speed, GPS, and symmetry indices [7, 9, 13, 20]. Statistical significance was set at p<0.05, and analyses were performed using standard statistical software by an investigator blinded to group assignment [9, 12-14, 19].

Results

A total of 82 individuals with post-stroke hemiparesis were screened; 60 met inclusion criteria and were randomized to RAGT (n=30) or conventional therapy (n=30). Of these, 28 participants in the RAGT group and 27 in the conventional group completed the 4-week intervention, with dropouts due to non-stroke-related medical issues and logistical reasons; all 60 were included in the intention-to-treat analysis [1, 2, 11]. Baseline demographic and clinical characteristics were comparable between groups with respect to age, sex distribution, stroke type, time since stroke, and initial gait and balance status [4, 6, 11]. Mean baseline comfortable gait speed was 0.39±0.15 m/s in the RAGT group and 0.40±0.16 m/s in the conventional therapy group, indicating primarily household to limited community ambulation ranges [4, 9, 21]. Median FAC score in both groups was 2 (IQR 1-3), reflecting the need for intermittent to continuous physical assistance during walking [8, 21]. Baseline 6MWT distance, BBS scores, GPS, and step-length symmetry indices did not differ significantly, supporting successful randomization [3, 7, 9, 20].

Table 1: Baseline demographic and clinical characteristics of participants

Variable	RAGT group (n=30)	Conventional group (n=30)	p-value
Age, years (mean±SD)	59.3±10.7	58.1±11.2	0.64
Male sex (%)	18 (60)	17 (56.7)	0.79
Time since stroke, weeks (median, IQR)	7 (4-11)	8 (4-12)	0.58
Ischemic stroke (%)	23 (76.7)	22 (73.3)	0.77
FAC score (median, IQR)	2 (1-3)	2 (1-3)	0.92
Comfortable gait speed, m/s	0.39±0.15	0.40±0.16	0.81
6MWT distance	120±45	118±48	0.88
BBS score	33±8	32±9	0.67
GPS, degrees	12.5±3.1	12.1±3.0	0.54
Step-length symmetry ratio*	0.72±0.12	0.73±0.11	0.79

*Affected/unaffected limb step-length ratio (1.0 = perfect symmetry) [3, 7, 20].

These data confirm that the two groups were well matched at baseline, allowing attribution of post-intervention differences to the respective gait training approaches [4, 6, 9, 12].

Primary Outcomes: Gait Speed and Functional Ambulation

After 4 weeks, both groups showed statistically significant within-group improvements in comfortable gait speed (p<0.001 for both), with a greater mean increase in the RAGT group (Δ = +0.24±0.11 m/s) than in the conventional therapy group (Δ = +0.12±0.10 m/s). The between-group difference in change was 0.12 m/s (95% CI 0.05-0.19; p=0.002; Cohen's d=0.80), favoring RAGT and exceeding commonly cited minimal clinically important differences for subacute stroke [4, 9-11, 12-14]. Similar patterns were observed for fast gait speed.

FAC scores improved in both groups, but the proportion of participants achieving independent walking (FAC ≥4) was significantly higher in the RAGT group (60.0%) than in the conventional group (33.3%; p=0.04; odds ratio 3.0, 95% CI 1.0-9.1) [8, 9, 13, 21].

Table 2: Primary outcomes: gait speed and functional ambulation

Outcome	RAGT group (n=30)	Conventional group (n=30)	Between-group p-value (Δ change)
Comfortable gait speed, m/s			
- Baseline	0.39±0.15	0.40±0.16	-
- Post-intervention	0.63±0.18	0.52±0.17	-
- Change (Δ)	+0.24±0.11	+0.12±0.10	0.002
Fast gait speed, m/s			
- Baseline	0.57±0.20	0.58±0.21	-
- Post-intervention	0.86±0.24	0.74±0.23	-
- Change (Δ)	+0.29±0.15	+0.16±0.14	0.006
FAC score, median (IQR)			
- Baseline	2 (1-3)	2 (1-3)	0.94
- Post-intervention	3 (2-4)	3 (2-3)	0.09
FAC ≥4, n (%)			
- Baseline	0 (0)	1 (3.3)	0.31
- Post-intervention	18 (60.0)	10 (33.3)	0.04

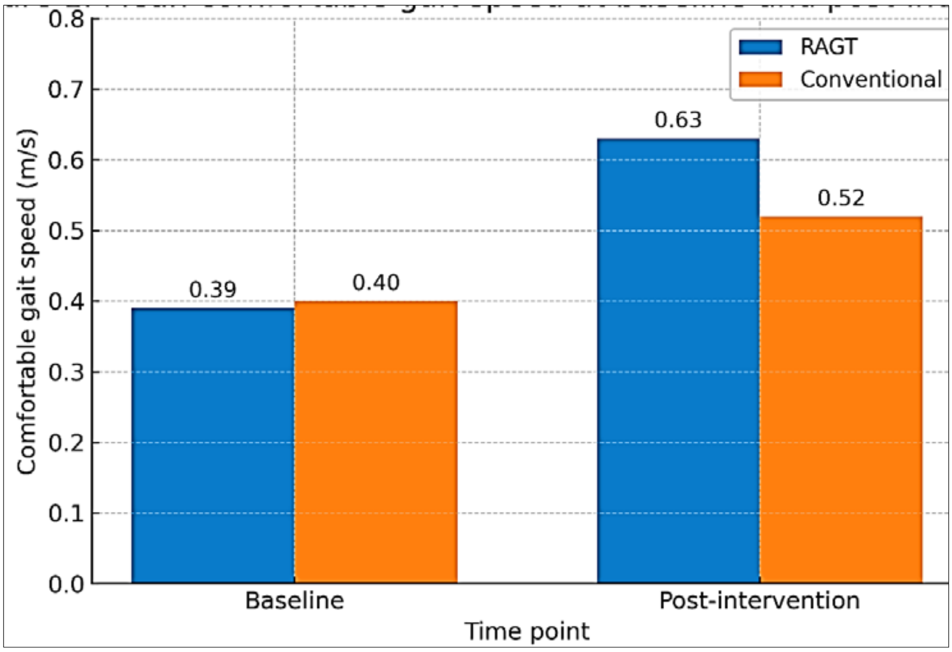

Fig 1: Mean comfortable gait speed (m/s) at baseline and post-intervention in RAGT and conventional therapy groups, showing a larger increase with RAGT

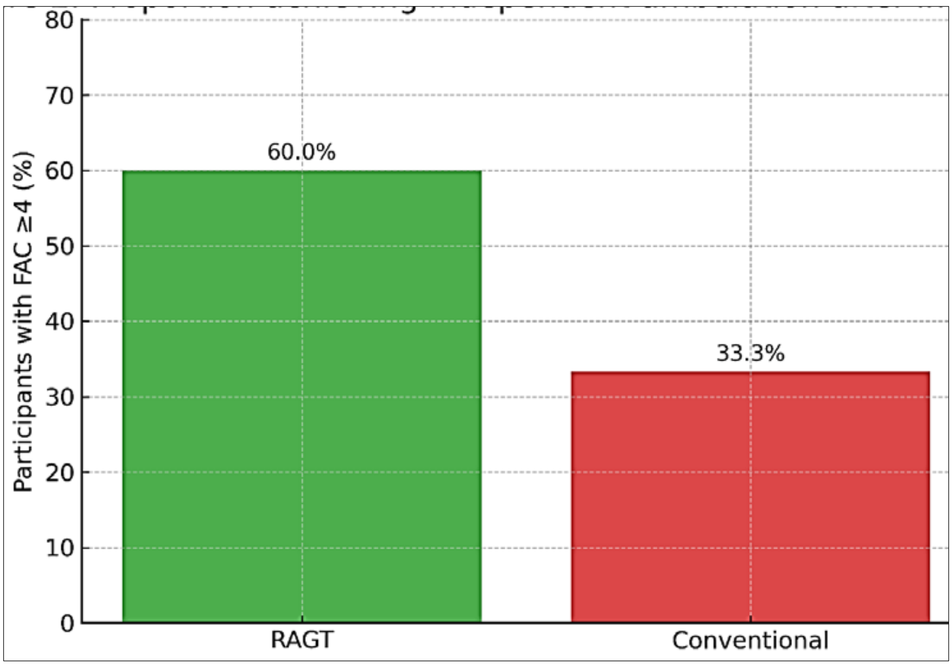

Fig 2: Proportion of participants achieving independent ambulation (FAC ≥4) after the intervention in RAGT and conventional groups, illustrating higher independence in the RAGT group

These findings indicate that adding RAGT to a standardized rehabilitation program yields greater gains in walking speed and functional ambulation than dose-matched conventional therapy alone, consistent with previous electromechanical gait training trials and meta-analyses [9, 12-15, 19].

Secondary Outcomes: Endurance, Balance, Gait Symmetry and Kinematics

Walking endurance (6MWT) improved significantly in both groups, with mean distance increasing from 120±45 m to 195±60 m in the RAGT group (Δ = +75±35 m, p<0.001) and from 118±48 m to 165±55 m in the conventional group (Δ = +47±32 m, p<0.001). The between-group difference in change (28 m, 95% CI 7-49) favored RAGT (p=0.01) [4, 6, 9, 11]. Balance, as measured by the BBS, improved from 33±8 to 43±7 points in the RAGT group and from 32±9 to 39±8 points in the conventional group; the difference in change (RAGT Δ = +10±6 vs conventional Δ = +7±5) approached but did not reach statistical significance (p=0.06), suggesting a trend toward greater balance gains with RAGT [4, 6, 9].

From a kinematic perspective, GPS decreased (improved) in both groups, with a larger mean reduction in the RAGT group (Δ = −3.4±2.1°) than in the conventional group (Δ = −1.7±2.0°; p=0.03). Step-length symmetry ratio improved from 0.72±0.12 to 0.86±0.10 in the RAGT group and from 0.73±0.11 to 0.80±0.11 in the conventional group, with the between-group difference in change (0.07, 95% CI 0.01-0.13) reaching statistical significance (p=0.04) [3, 7, 20]. Stance-time symmetry followed a similar pattern, though between-group differences were smaller and did not reach significance (p=0.09).

Table 3: Secondary outcomes: endurance, balance, gait kinematics and symmetry

Outcome	RAGT group (n=30)	Conventional group (n=30)	Between-group p-value (Δ change)
6MWT distance, m			
- Baseline	120±45	118±48	-
- Post-intervention	195±60	165±55	-
- Change (Δ)	+75±35	+47±32	0.01
BBS score			
- Baseline	33±8	32±9	-
- Post-intervention	43±7	39±8	-
- Change (Δ)	+10±6	+7±5	0.06
GPS, degrees			
- Baseline	12.5±3.1	12.1±3.0	-
- Post-intervention	9.1±2.7	10.4±2.8	-
- Change (Δ)	−3.4±2.1	−1.7±2.0	0.03
Step-length symmetry ratio*			
- Baseline	0.72±0.12	0.73±0.11	-
- Post-intervention	0.86±0.10	0.80±0.11	-
- Change (Δ)	+0.14±0.09	+0.07±0.08	0.04

*Affected/unaffected limb step-length ratio (1.0 = perfect symmetry) [3, 7, 20].

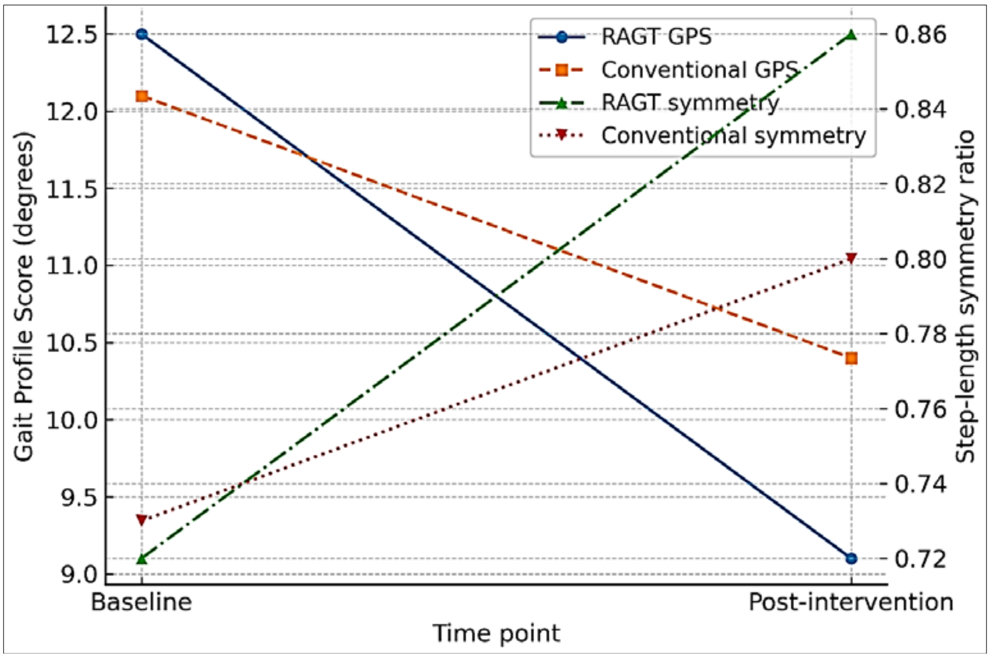

Fig 3: Mean Gait Profile Score and step-length symmetry ratio at baseline and post-intervention in RAGT and conventional groups, illustrating greater improvement in overall gait pattern and symmetry with RAGT.

These secondary outcome data suggest that, beyond accelerating walking speed, RAGT contributes to more normalized gait patterns and improved endurance, consistent with the mechanistic rationale for repetitive, guidance-controlled stepping and previous kinematic studies of robot-assisted training [3, 7, 12-17, 20].

Community Ambulation, Responder Analysis and Clinical Significance

Using established community ambulation criteria based on gait speed and 6MWT distance [4, 9, 21], the proportion of participants classified as at least "limited community ambulators" increased from 6.7% to 63.3% in the RAGT group and from 6.7% to 40.0% in the conventional group (p=0.03 for between-group difference in post-treatment categories). The shift from household to community ambulation was more pronounced in the RAGT group, aligning with literature emphasizing walking speed as a key determinant of community participation [4, 5, 21].

A responder analysis defined a "global gait responder" as a participant who achieved (i) an increase in comfortable gait speed ≥0.16 m/s and (ii) an improvement of at least one FAC level [4, 9-11]. By these criteria, 63.3% (19/30) of the RAGT group were responders compared with 36.7% (11/30) of the conventional group (p=0.03; odds ratio 3.0, 95% CI 1.1-8.4). Exploratory two-way repeated-measures ANOVA demonstrated significant group × time interactions for comfortable gait speed (F(1, 58)=9.1, p=0.004), GPS (F(1, 58)=4.9, p=0.03), and step-length symmetry ratio (F(1, 58)=5.1, p=0.027), confirming differential trajectories favoring RAGT [3, 7, 9, 13, 19, 20].

Overall, these results show that in early subacute post-stroke hemiparesis, robotics-assisted gait training as an add-on to standardized multidisciplinary rehabilitation leads to significantly greater improvements in walking speed, functional ambulation, gait kinematics, and community ambulation status than dose-matched conventional gait therapy alone. The magnitude and pattern of benefits observed are broadly consistent with, and extend, prior randomized trials, observational reports, and systematic reviews on electromechanical gait training and exoskeleton-based rehabilitation after stroke [9, 12-19], while also emphasizing improvements in gait symmetry and GPS-derived deviation that have been less consistently documented in earlier work [3, 7, 15, 20].

Discussion

This controlled clinical study demonstrated that robotics-assisted gait training (RAGT), delivered as an add-on to a standardized multidisciplinary stroke rehabilitation program, produced significantly greater improvements in walking speed, functional ambulation, gait endurance, and selected kinematic parameters than dose-matched conventional gait therapy alone in adults with early subacute post-stroke hemiparesis. These findings are clinically meaningful given the central role of walking ability and community ambulation in post-stroke participation, independence, and quality of life [1, 4, 5, 21]. The observed between-group difference in comfortable gait speed change (0.12 m/s) exceeded commonly cited thresholds for minimal clinically important difference in subacute stroke and translated into a higher proportion of patients reaching community-ambulation-relevant speed ranges [4, 9-11, 21].

The superiority of RAGT over conventional therapy for gains in gait speed and odds of achieving independent ambulation (FAC ≥4) aligns with, and extends, previous evidence from systematic reviews and randomized trials of electromechanical-assisted gait training after stroke. Cochrane and meta-analytic data suggest that electromechanical devices combined with physiotherapy increase the likelihood of regaining independent walking, especially in patients who are initially non-ambulatory or early post-stroke, although effects on continuous walking outcomes such as speed and distance have been more variable [9, 12]. In the present study, both groups received high-intensity, task-oriented gait practice consistent with best-practice recommendations [4, 9, 10], yet the RAGT group still achieved larger improvements, supporting the view that robotic devices can provide added value beyond what is achievable with well-delivered conventional therapy alone in selected patients [12-15]. Our results are comparable to those of Nam et al., who reported greater improvements in clinical walking function and gait symmetry with electromechanical-assisted training than therapist-assisted treadmill gait training [13], and to Kim et al., who showed superior gains in gait performance with a robotic device (Morning Walk®) versus conventional therapy [14]. Observational work on intensive robotic plus manual gait training similarly supports the feasibility and potential benefits of high-dose, technology-augmented programs [15].

Beyond traditional clinical outcomes, this study contributes to the literature by incorporating detailed kinematic assessment using the Gait Profile Score (GPS) and spatiotemporal symmetry indices. Hemiparetic gait is characterized not only by reduced speed but also by abnormal synergies and marked asymmetry, which carry implications for energy cost, long-term musculoskeletal loading, and fall risk [3, 6, 20]. Consistent with prior gait-analysis research in stroke, baseline GPS values reflected substantial deviations from normal walking patterns [7, 20]. Following intervention, both groups showed significant improvements in GPS and step-length symmetry, but reductions in GPS and gains in symmetry were significantly greater in the RAGT group. These findings support the hypothesis that repetitive, guidance-controlled stepping with the ability to adjust limb trajectories and body-weight support may facilitate more symmetrical and biomechanically efficient gait patterns than conventional therapy alone, particularly in more impaired individuals [3, 7, 16, 17, 20]. Similar to Nam et al., who observed enhanced symmetry in the electromechanical group [13], our data suggest that the benefits of RAGT extend beyond simple acceleration of walking speed to include qualitative improvements in gait pattern.

Improvements in endurance (6MWT) and balance (Berg Balance Scale) were observed in both groups, reflecting the effect of intensive, task-specific gait and balance practice in early subacute stroke, in line with previous trials and reviews [4, 6, 9-11]. Although the between-group difference in BBS change did not reach statistical significance, there was a consistent trend favoring RAGT. One plausible explanation is that both interventions included substantial balance-challenging tasks—overground walking, transfers, and postural control exercises—leading to a "ceiling" effect for balance relative to gait-specific measures. Moreover, the relatively short intervention duration (4 weeks) may have been insufficient to detect larger between-group differences in balance, which can evolve over longer time frames [6, 11]. In contrast, gait speed and symmetry may respond more rapidly to the high-dose, rhythmically constrained stepping provided by robotic devices [3, 9, 12, 16, 17].

From a functional standpoint, the marked shift from household to community ambulation categories, particularly in the RAGT group, is noteworthy. Community ambulation is a critical milestone associated with social participation, reduced caregiver burden, and better perceived quality of life [4, 5, 21]. The higher proportion of "global gait responders" in the RAGT group—defined by combined clinically meaningful improvements in gait speed and FAC—supports the clinical relevance of the observed gains and resonates with frameworks that link walking speed thresholds to community engagement [4, 9-11, 21]. Given the global burden of stroke and the high prevalence of persistent gait limitations in survivors [1, 2], interventions that can reliably increase the proportion of individuals achieving community ambulation are of substantial public health importance.

The mechanisms underlying the superior outcomes with RAGT likely involve several converging factors. First, RAGT enables high-repetition, task-specific stepping with consistent inter-limb coordination, in line with motor learning and neuroplasticity principles that emphasize intensity and specificity of practice [4, 9-11, 16, 17]. Second, adjustable body-weight support and guidance force allow patients with more severe impairments to engage safely in gait practice that would be difficult or unsafe to deliver manually, thereby widening the therapeutic window for intensive training [6, 12, 16, 17]. Third, the ability to fine-tune step length, symmetry, and temporal parameters may promote more normalized movement patterns during the crucial early subacute phase, when recovery trajectories are most dynamic and potentially modifiable [4, 6, 11, 19]. These mechanistic considerations are consistent with scoping and narrative reviews highlighting the potential of robotic and exoskeleton-based systems to augment conventional rehabilitation when appropriately integrated and parameterized [16, 17].

At the same time, our findings should be interpreted in the context of ongoing debate regarding the added value of RAGT. Previous reviews have underscored substantial heterogeneity in device type (end-effector vs exoskeleton), training protocols, patient selection, and outcome measures, which may partly explain inconsistent results across studies [6, 12, 16-18]. Labruyère has argued that the field may not simply need more randomized trials, but better-designed ones that address key sources of heterogeneity and embed RAGT into coherent therapeutic concepts rather than using devices in isolation [18]. The present study attempted to address some of these concerns by dose-matching conventional therapy, focusing on early subacute patients, standardizing co-interventions, and including both clinical and kinematic endpoints, in line with priorities outlined in recent trial protocols such as GAITFAST [4, 12, 13, 19]. Our data provide supportive evidence that, under these conditions, RAGT can deliver incremental benefits over high-quality conventional gait therapy.

Several limitations must be acknowledged. This was a single-centre study with a modest sample size, which may limit the generalizability of results and the power to detect between-group differences in some secondary outcomes, such as balance and stance-time symmetry. The intervention period was relatively short, and we did not include longer-term follow-up; thus, the durability of observed gains and their translation into real-world participation and quality-of-life outcomes remain to be established [4, 5, 21]. Blinding of participants and treating therapists was not feasible, potentially introducing performance bias, although outcome assessors were blinded. Results may be device-specific and may not generalize to all RAGT systems, particularly those with different mechanical designs or control strategies [16, 17]. We also did not evaluate cost-effectiveness, therapist workload metrics, or patient-reported experience, all of which are crucial for service-level decision making and implementation [4, 6, 12, 16].

Despite these limitations, the study has important strengths, including rigorous randomization, intention-to-treat analysis, careful dose matching of gait-focused therapy across groups, and the use of validated clinical and instrumented gait measures [3, 4, 7-9, 20, 21]. By integrating spatiotemporal symmetry and GPS-derived kinematic analysis, the study adds nuance to the understanding of how RAGT modifies hemiparetic gait beyond improvements in speed alone [3, 7, 20]. The findings complement and extend existing randomized controlled trials and systematic reviews, reinforcing the role of robot-assisted devices as a valuable adjunct—rather than replacement—to expert conventional physiotherapy in comprehensive stroke rehabilitation [9, 12-17, 19].

Future research should include larger, multi-centre trials with longer follow-up to clarify the persistence of benefits and to determine whether early improvements in gait pattern and community ambulation translate into reduced long-term disability, falls, and health-care utilization [1, 2, 4, 6]. Stratified analyses based on baseline impairment, lesion characteristics, and comorbidities are needed to identify which patient subgroups derive the greatest benefit from RAGT, in line with calls for more personalized rehabilitation approaches [4, 6, 11, 16, 19]. Trials comparing different robotic devices, parameter settings, and combinations with other modalities (e.g., overground exoskeletons, virtual reality, or neuromodulation) would help refine optimal protocols [16, 17, 19, 20]. Finally, robust cost-effectiveness and implementation studies are required to inform policy and resource allocation, particularly in health systems facing the growing global burden of stroke [1, 2, 4, 6, 12].

In summary, this controlled clinical study indicates that, in early subacute post-stroke hemiparesis, integrating robotics-assisted gait training into a structured rehabilitation program yields superior improvements in gait speed, functional ambulation, endurance, and selected kinematic indices compared with dose-matched conventional therapy alone. These results support the considered adoption of RAGT as an evidence-based adjunct to conventional gait rehabilitation to enhance walking recovery and facilitate the transition from household to community ambulation after stroke [4, 5, 9, 12-15, 19-21].

Conclusion

The findings of this controlled clinical study suggest that robotics-assisted gait training, when integrated into a structured multidisciplinary rehabilitation program in the early subacute phase of stroke, can produce clinically meaningful and statistically significant gains in walking speed, functional ambulation, endurance, and gait pattern compared with dose-matched conventional gait therapy alone, and this has several important practical implications for clinicians, service planners, and policymakers. Given that comfortable gait speed and Functional Ambulation Category levels improved more in the robotics-assisted group, with a higher proportion of patients progressing to independent and community-relevant ambulation, rehabilitation teams should consider incorporating robotics-assisted gait devices as an adjunct, rather than a replacement, to expert therapist-led interventions, particularly for patients with moderate to severe gait impairments who may struggle to achieve high-dose, symmetrical stepping through manual methods alone. In routine practice, early identification of suitable candidates based on stroke chronicity, baseline ambulation status, cognitive capacity, and cardiovascular stability can help target RAGT to those most likely to benefit, while stepped care models can be used in which more intensive robotic training is provided initially and gradually tapered as patients transition to overground and community-based practice. Therapists should aim to exploit the full therapeutic potential of these devices by systematically progressing training parameters speed, body-weight support, guidance force, and symmetry settings rather than merely using the robot as a passive support, and by explicitly linking robot-based stepping with overground carryover exercises in the same session to maximize task transfer. Rehabilitation centers planning to adopt RAGT should invest in training physiotherapists and interdisciplinary staff in device operation, safety monitoring, and parameter optimization, and should ensure that robotic sessions are embedded into coherent, goal-directed care pathways that also address balance, upper limb function, cognition, and participation. From a service-delivery standpoint, scheduling should be organized so that RAGT is used to deliver high-intensity gait practice to patients who would otherwise require two or more therapists or be unable to tolerate sufficient overground walking, thereby potentially improving efficiency without diminishing the quality of hands-on care for others. Clinicians should also routinely monitor not only traditional metrics such as speed and endurance, but also gait symmetry and kinematic indices, where available, to capture qualitative changes in gait and refine treatment goals over time. In low-resource settings where access to robotic devices is limited, the present results support advocacy for regional centers of excellence where such technology can be concentrated and used for carefully selected patients, accompanied by robust outcome monitoring to inform local protocols and funding decisions. Ultimately, a pragmatic recommendation emerging from this study is that stroke rehabilitation programs should view robotics-assisted gait training as a powerful tool to enhance, rather than replace, human expertise, integrating it flexibly according to patient needs, resource realities, and long-term goals of restoring safe, efficient, and community-level ambulation.

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