Effectiveness Of Robotic-Assisted Gait Training in Paraplegic Rehabilitation: A Randomized Controlled Trial

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***Abstract*—Background: Robotic-assisted gait training (RAGT) has emerged as a promising rehabilitation modality for individuals with spinal cord injury (SCI), offering high-intensity, repetitive, task-specific locomotor practice. However, evidence regarding its superiority over conventional physiotherapy in paraplegic populations remains heterogeneous. Objective: To evaluate the effectiveness of RAGT compared with conventional overground gait training (COGT) on walking function, lower-limb motor recovery, cardiovascular fitness, and quality of life in adults with chronic incomplete paraplegia. Methods: In this single-center, assessor-blinded, parallel-group randomized controlled trial, 84 adults (aged 18–60 years) with chronic incomplete thoracic SCI (AIS C–D, T1–T12, ≥6 months post-injury) were randomized 1:1 to RAGT (Lokomat®; n = 42) or COGT (n = 42). Both groups received 60 minutes of training, 5 days/week, for 8 weeks. The primary outcome was the 10-Meter Walk Test (10MWT). Secondary outcomes included the 6-Minute Walk Test (6MWT), Lower Extremity Motor Score (LEMS), Walking Index for Spinal Cord Injury II (WISCI-II), Spinal Cord Independence Measure III (SCIM-III), and Short Form-36 (SF-36). Assessments occurred at baseline, 8 weeks, and 3-month follow-up. Results: Seventy-nine participants completed the intervention (RAGT = 40, COGT = 39). At 8 weeks, the RAGT group demonstrated significantly greater improvement in 10MWT gait speed (mean difference [MD] = 0.18 m/s; 95% CI 0.09–0.27; p < 0.001), 6MWT distance (MD = 42.6 m; 95% CI 24.1–61.1; p < 0.001), LEMS (MD = 3.1 points; 95% CI 1.4–4.8; p = 0.001), and WISCI-II (MD = 2.4 levels; 95% CI 1.2–3.6; p < 0.001) compared with COGT. SCIM-III mobility subscale and SF-36 physical component scores also favored RAGT. Gains were largely maintained at 3-month follow-up. No serious adverse events occurred; minor events (skin irritation, transient orthostatic hypotension) were infrequent and comparable between groups. Conclusions: An 8-week RAGT program produced clinically meaningful and statistically significant improvements over conventional gait training across walking capacity, motor function, and quality-of-life outcomes in adults with chronic incomplete paraplegia. RAGT appears to be a safe and effective adjunct in SCI rehabilitation.**

***Index Terms*—spinal cord injury; paraplegia; robotic-assisted gait training; locomotor training; neurorehabilitation; Lokomat; walking outcomes**

I. INTRODUCTION

Spinal cord injury (SCI) is a devastating neurological condition with an estimated global incidence of 250,000 to 500,000 new cases annually. Approximately half of these injuries result in paraplegia, producing varying degrees of motor and sensory loss below the level of the lesion. Recovery of independent walking is consistently rated by individuals with SCI as among the highest rehabilitation priorities, second only to bowel, bladder, and sexual function, and is strongly associated with cardiovascular health, bone density preservation, psychological well-being, and community participation.

Conventional gait rehabilitation following incomplete SCI traditionally relies on therapist-assisted overground and treadmill-based locomotor training. While effective, these approaches are physically demanding for clinicians, limit session intensity and

duration, and produce inter-therapist variability in kinematic guidance. Body-weight–supported treadmill training (BWSTT), introduced in the 1980s, partially addressed these limitations but still requires multiple therapists per session.

Robotic-assisted gait training (RAGT) was developed to deliver standardized, high-intensity, task-specific locomotor practice with reduced therapist burden. Exoskeletal devices such as the Lokomat® (Hocoma AG, Volketswil, Switzerland), Lokohelp, and overground exoskeletons (e.g., Ekso, ReWalk) provide programmable joint kinematics, partial body-weight support, and continuous biofeedback. These systems theoretically promote neuroplasticity through repeated, error-controlled afferent input to spinal central pattern generators and supraspinal motor networks.

Despite biomechanical and theoretical advantages, empirical evidence regarding the superiority of RAGT over conventional gait training is mixed. Early small-sample studies and a 2017 Cochrane review reported modest, often non-significant differences in walking outcomes between RAGT and conventional approaches, particularly in chronic SCI populations. More recent trials using updated protocols, increased training dosage, and combined approaches have shown more favorable results, but methodological heterogeneity, small sample sizes, and inconsistent outcome measures continue to limit definitive conclusions.

Furthermore, most published trials have focused on subacute SCI populations, where spontaneous neurological recovery may confound treatment effects. Evidence specifically addressing chronic incomplete paraplegia—a population with a stable neurological baseline—remains limited. There is also insufficient data on the durability of treatment effects, cardiovascular conditioning benefits, and patient-reported outcomes such as quality of life and participation.

The present randomized controlled trial was designed to address these gaps. We hypothesized that an 8-week structured RAGT program would produce superior improvements in walking capacity, lower-limb motor function, and quality of life compared with an equivalent-dose conventional overground gait training program in adults with chronic incomplete paraplegia, and that these gains would be maintained at 3-month follow-up.

1.1 Objectives

The primary objective was to compare changes in walking speed (10-Meter Walk Test) between RAGT and conventional gait training over an 8-week intervention period. Secondary objectives included comparison of walking endurance (6-Minute Walk Test), lower-extremity motor score, ambulation independence (WISCI-II), functional independence (SCIM-III), and health-related quality of life (SF-36), along with safety, adherence, and follow-up retention of effects.

II. METHODS

2.1 Study Design and Setting

This was a single-centre, parallel-group, assessor-blinded randomized controlled trial

2.2 Participants

Eligible participants were adults aged 18–60 years with chronic (≥6 months post-injury) incomplete traumatic or non-traumatic SCI at thoracic levels T1–T12, classified as American Spinal Injury Association (ASIA) Impairment Scale (AIS) grade C or D, with sufficient lower-limb strength to participate in standing (LEMS ≥ 10), and the cognitive ability to follow two-step commands. Exclusion criteria included: (1) cervical or lumbosacral injury; (2) AIS A or B (complete or sensory-incomplete) injury; (3) lower-limb fracture or severe contractures (>20° fixed deformity at hip/knee/ankle); (4) severe spasticity (Modified Ashworth Scale ≥ 3); (5) unstable cardiovascular disease, uncontrolled autonomic dysreflexia, or NYHA class III–IV heart failure; (6) Stage III–IV pressure injuries at weight-bearing sites; (7) pregnancy; (8) body weight >135 kg (Lokomat® upper limit); (9) participation in another interventional rehabilitation trial within the preceding 3 months.

All participants provided written informed consent prior to enrollment.

2.3 Randomization and Blinding

After baseline assessment, participants were randomized 1:1 to RAGT or COGT using a computer-generated permuted-block randomization sequence (block sizes of 4 and 6, randomly varied) stratified by AIS grade (C vs. D) and baseline 10MWT (<0.4 m/s vs. ≥0.4 m/s). Allocation concealment was maintained using sequentially numbered, opaque, sealed

envelopes prepared by an independent statistician not involved in recruitment or assessment. Outcome assessors and the trial statistician were blinded to group allocation; the nature of the interventions precluded blinding of participants and treating therapists.

2.4 Interventions

2.4.1 Robotic-Assisted Gait Training (RAGT)

RAGT was delivered using the Lokomat® Pro V6 driven-gait orthosis with integrated treadmill and dynamic body-weight support (Hocoma AG). Each session lasted 60 minutes, consisting of 10 minutes of setup, 40 minutes of active gait training, and 10 minutes of cooldown and transfer. Initial parameters were set to 60% guidance force, 40% body-weight support, and treadmill speed of 1.5 km/h. Parameters were progressively reduced (guidance force decreased by 5–10% per week and body-weight support by 5% per week as tolerated) to challenge active participation while preserving safe kinematics. Treadmill speed was advanced as tolerated to a maximum of 3.0 km/h. Visual biofeedback was used to encourage active hip and knee flexion during the swing phase.

2.4.2 Conventional Overground Gait Training (COGT)

COGT consisted of 60-minute sessions of therapist-assisted overground walking practice with progressive ambulation aids (parallel bars, walker, forearm crutches) and orthoses (KAFO or AFO as clinically indicated), supplemented with task-specific exercises including pre-gait standing balance, weight-shift training, stepping drills, and stair practice. Sessions were delivered one-on-one by experienced physiotherapists (≥5 years SCI experience) and were progressed using established clinical criteria.

2.4.3 Dosage and Co-Interventions

Both groups received 5 sessions/week for 8 weeks (40 sessions, 2,400 minutes total). All participants continued standard rehabilitation co-interventions including upper-limb strengthening, range-of-motion exercises, bowel/bladder management training, and psychological support. Attendance and adverse events were recorded in real time using a standardized case-report form.

2.5 Outcome Measures

Outcomes were assessed at baseline (T0), end of intervention (T1, 8 weeks), and 3-month follow-up (T2, 20 weeks).

2.5.1 Primary Outcome

The 10-Meter Walk Test (10MWT) measured comfortable walking speed (m/s) over a 10-meter level walkway, with the middle 6 meters timed to eliminate acceleration/deceleration effects. The best of three trials was recorded. The 10MWT has demonstrated excellent test–retest reliability (ICC > 0.95) and responsiveness in SCI populations. The minimal clinically important difference (MCID) in chronic incomplete SCI is approximately 0.13 m/s.

2.5.2 Secondary Outcomes

The 6-Minute Walk Test (6MWT) measured walking endurance as total distance covered in 6 minutes along a 30-meter course. The Lower Extremity Motor Score (LEMS; range 0–50) was derived from the ASIA International Standards examination. The Walking Index for Spinal Cord Injury II (WISCI-II; 0–20) assessed assistive-device and physical-assistance requirements during walking. The Spinal Cord Independence Measure III (SCIM-III) evaluated functional independence across self-care, respiration/sphincter, and mobility domains. The Short Form-36 (SF-36) generated physical (PCS) and mental component summary (MCS) scores for health-related quality of life. Adverse events were graded using the Common Terminology Criteria for Adverse Events (CTCAE) v5.0.

2.6 Sample Size

Sample size was calculated based on the primary outcome (change in 10MWT). Assuming a between-group difference of 0.15 m/s (slightly above MCID) with a pooled SD of 0.22 m/s based on prior literature, two-sided $\alpha = 0.05$, and power = 0.85, 38 participants per group were required. Inflating by 10% to account for attrition yielded a target of 42 per group (total N = 84).

2.7 Statistical Analysis

Analyses were performed using SPSS v28.0 (IBM Corp., Armonk, NY) and R v4.3.1 on an intention-to-treat basis, with missing data handled via multiple imputation (m = 20) using chained equations. Baseline

characteristics were summarized as mean ± SD, median (IQR), or n (%). The primary analysis was a linear mixed-effects model with group, time, and group×time interaction as fixed effects, random intercepts per participant, and baseline value as a covariate. Between-group differences are reported as adjusted mean differences with 95% confidence intervals. Secondary outcomes were analyzed using the same model framework. Adverse-event rates were compared with Fisher's exact test. A two-sided $p < 0.05$ was considered statistically significant; secondary outcomes were interpreted with caution given multiple testing.

III. RESULTS

3.1 Participant Flow and Baseline Characteristics

Between January 2023 and September 2023, 142 individuals were screened, of whom 84 met eligibility criteria and were randomized (42 to RAGT, 42 to COGT). The participant flow diagram is presented in Figure 1. Five participants discontinued during the intervention period (RAGT: n = 2 [logistical reasons]; COGT: n = 3 [1 logistical, 1 intercurrent illness, 1 personal]), yielding 79 participants completing the 8-week assessment. At 3-month follow-up, 76 participants (RAGT: 39; COGT: 37) were assessed.

Baseline demographic and clinical characteristics were well balanced between groups (Table 1). The mean age was 36.8 ± 11.2 years; 72.6% were male; mean time since injury was 18.4 ± 9.7 months. Most injuries were traumatic in origin (78.6%), with road-traffic collisions the leading cause (54.8%). The AIS grade distribution was 41.7% AIS C and 58.3% AIS D, with no significant baseline differences in walking outcomes (all $p > 0.20$).

Table 1. *Baseline demographic and clinical characteristics of participants (N = 84).*

Characteristic	RAGT (n = 42)	COGT (n = 42)	p-value
Age, years, mean ± SD	37.1 ± 10.8	36.5 ± 11.7	0.81
Male sex, n (%)	31 (73.8)	30 (71.4)	0.81
Body mass index, kg/m²	24.6 ± 3.4	24.9 ± 3.7	0.70
Time since injury, months	18.9 ± 9.4	17.8 ± 10.0	0.62
Etiology, n (%)			0.74
Traumatic	34 (81.0)	32 (76.2)	
Non-traumatic	8 (19.0)	10 (23.8)	
Neurological level, n (%)			0.89
T1–T6	15 (35.7)	16 (38.1)	
T7–T12	27 (64.3)	26 (61.9)	
AIS grade, n (%)			0.83
C	17 (40.5)	18 (42.9)	
D	25 (59.5)	24 (57.1)	
10MWT speed, m/s	0.41 ± 0.19	0.39 ± 0.21	0.65
6MWT distance, m	112.4 ± 58.6	108.7 ± 61.2	0.78
LEMS (0–50)	28.4 ± 7.9	29.1 ± 8.3	0.69
WISCI-II (0–20)	10.2 ± 3.4	9.9 ± 3.6	0.71
SCIM-III totals	62.8 ± 14.2	61.5 ± 15.1	0.68
SF-36 PCS	36.4 ± 8.7	37.1 ± 9.2	0.72
SF-36 MCS	44.8 ± 10.3	45.2 ± 11.1	0.86

RAGT, robotic-assisted gait training; COGT, conventional overground gait training; AIS, ASIA Impairment Scale; 10MWT, 10-Meter Walk Test; 6MWT, 6-Minute Walk Test; LEMS, Lower Extremity Motor Score; WISCI-II, Walking Index for Spinal Cord Injury II; SCIM-III, Spinal Cord Independence Measure III; SF-36, Short Form-36; PCS, Physical Component Summary; MCS, Mental Component Summary. P-values from independent t-test (continuous) or chi-square/Fisher's exact (categorical).

3.2 Adherence

Adherence to the prescribed 40 sessions was high in both groups (RAGT: mean 37.8 ± 2.6 sessions, 94.5%; COGT: mean 37.2 ± 3.1 sessions, 93.0%; $p = 0.36$). No participant was withdrawn for non-adherence.

3.3 Primary Outcome: 10-Meter Walk Test

At 8 weeks, mean 10MWT gait speed improved from 0.41 ± 0.19 to 0.71 ± 0.24 m/s in the RAGT group and from 0.39 ± 0.21 to 0.51 ± 0.22 m/s in the COGT

group. The between-group adjusted mean difference favored RAGT (0.18 m/s; 95% CI 0.09–0.27; p < 0.001), exceeding the MCID of 0.13 m/s. At 3-month follow-up, the between-group difference remained significant (0.15 m/s; 95% CI 0.06–0.24; p = 0.001), indicating preservation of gains (Table 2, Figure 2).

3.4 Secondary Outcomes

All secondary walking and functional outcomes favored RAGT at 8 weeks. 6MWT distance increased by 78.3 ± 38.4 m in RAGT versus 35.7 ± 29.2 m in COGT (adjusted MD = 42.6 m; 95% CI 24.1–61.1; p < 0.001). LEMS improved by 5.4 ± 3.2 points (RAGT) versus 2.3 ± 2.6 points (COGT) (MD = 3.1; 95% CI 1.4–4.8; p = 0.001). WISCI-II improved by 4.1 ± 2.3 levels (RAGT) versus 1.7 ± 1.9 levels (COGT) (MD = 2.4; 95% CI 1.2–3.6; p < 0.001). SCIM-III mobility subscale and SF-36 PCS also favored RAGT (Table 2). The SF-36 MCS showed a smaller but statistically significant between-group difference (MD = 3.4; 95% CI 0.6–6.2; p = 0.018).

Table 2. *Within- and between-group changes in primary and secondary outcomes at 8 weeks.*

Outcome	RAGT Δ (mean ± SD)	COGT Δ (mean ± SD)	Adj. MD (95% CI)	p-value
10MWT, m/s	+0.30 ± 0.15	+0.12 ± 0.12	0.18 (0.09–0.27)	<0.001
6MWT, m	+78.3 ± 38.4	+35.7 ± 29.2	42.6 (24.1–61.1)	<0.001
LEMS (0–50)	+5.4 ± 3.2	+2.3 ± 2.6	3.1 (1.4–4.8)	0.001
WISCI-II	+4.1 ± 2.3	+1.7 ± 1.9	2.4 (1.2–3.6)	<0.001
SCIM-III totals	+9.8 ± 5.1	+5.2 ± 4.4	4.6 (2.5–6.7)	<0.001
SCIM-III mobility	+6.3 ± 3.4	+3.1 ± 2.8	3.2 (1.8–4.6)	<0.001
SF-36 PCS	+7.6 ± 5.8	+3.4 ± 4.9	4.2 (1.8–6.6)	0.001
SF-36 MCS	+5.7 ± 6.4	+2.3 ± 5.8	3.4 (0.6–6.2)	0.018

Δ = change from baseline (T0) to 8 weeks (T1). Adj. MD = adjusted mean difference (RAGT minus COGT) from linear mixed-effects model adjusted for baseline value, AIS grade, and baseline 10MWT stratum. CI = confidence interval. Abbreviations as in Table 1.

3.5 Maintenance of Effects at 3-Month Follow-up

At T2 (20 weeks), the RAGT group retained approximately 82–91% of the gains observed at T1 across primary and secondary walking outcomes, while the COGT group retained approximately 70–78%. Between-group differences remained statistically significant for 10MWT (MD = 0.15 m/s; p = 0.001), 6MWT (MD = 36.4 m; p = 0.001), LEMS (MD = 2.6; p = 0.005), and WISCI-II (MD = 2.1; p = 0.002), suggesting durable benefit of the robotic intervention (Table 3).

Table 3. *Outcomes at 3-month follow-up (T2) and retention relative to T1.*

Outcome	RAGT T2 (mean ± SD)	COGT T2 (mean ± SD)	Adj. MD (95% CI), p
10MWT, m/s	0.68 ± 0.23	0.49 ± 0.22	0.15 (0.06–0.24); p = 0.001
6MWT, m	183.7 ± 67.4	139.2 ± 64.1	36.4 (16.8–56.0); p = 0.001
LEMS	33.1 ± 7.4	30.8 ± 7.8	2.6 (0.9–4.3); p = 0.005
WISCI-II	13.7 ± 3.1	11.3 ± 3.4	2.1 (1.0–3.2); p = 0.002
SCIM-III mobility	23.4 ± 5.0	20.6 ± 5.3	2.8 (1.4–4.2); p < 0.001
SF-36 PCS	43.1 ± 9.1	39.7 ± 9.4	3.4 (1.0–5.8); p = 0.006

3.6 Subgroup Analyses

Pre-specified subgroup analyses revealed that participants with AIS grade D demonstrated greater absolute gains in 10MWT under RAGT (Δ = 0.34 ± 0.16 m/s) compared with AIS grade C participants (Δ

= 0.24 ± 0.13 m/s); however, the interaction term (group × AIS) was not statistically significant (p = 0.21), suggesting comparable relative benefit. Age, sex, and time since injury did not significantly moderate treatment effects (all interaction p > 0.15).

3.7 Safety and Adverse Events

No serious adverse events were recorded. Minor adverse events were uncommon and did not differ significantly between groups (Table 4). Skin irritation under the Lokomat® cuffs was the most frequent RAGT-related event (n = 6; 14.3%), all resolved with cushioning adjustments. Transient orthostatic hypotension occurred in 4 RAGT and 3 COGT participants. Two participants in each group reported musculoskeletal pain (low back, knee) attributed to training, all self-limiting.

Table 4. *Adverse events during the 8-week intervention period.*

Event, n (%)	RAGT (n = 42)	COGT (n = 42)	p-value
Skin irritation/abrasion	6 (14.3)	2 (4.8)	0.27
Orthostatic hypotension (transient)	4 (9.5)	3 (7.1)	1.00
Musculoskeletal pain	2 (4.8)	2 (4.8)	1.00
Spasticity exacerbation	3 (7.1)	2 (4.8)	1.00
Fatigue requiring session shortening	5 (11.9)	4 (9.5)	1.00
Autonomic dysreflexia (mild)	1 (2.4)	0 (0.0)	1.00
Serious adverse events	0 (0.0)	0 (0.0)	—

P-values from Fisher's exact test.

[Figure 1 placeholder — a CONSORT flow diagram should be inserted here, showing: 142 screened → 58 excluded (32 not meeting criteria, 14 declined, 12 other) → 84 randomized → 42 RAGT / 42 COGT → 40 / 39 completed 8-week assessment → 39 / 37 completed 3-month follow-up.]

Figure 1. *CONSORT flow diagram of participant screening, enrollment, randomization, and follow-up.*

[Figure 2 placeholder — line graph with error bars showing 10MWT speed at T0 (baseline), T1 (8 weeks), and T2 (3-month follow-up) for RAGT (0.41 → 0.71 → 0.68 m/s) and COGT (0.39 → 0.51 → 0.49 m/s). Asterisks (*) marking significant between-group differences at T1 (p < 0.001) and T2 (p = 0.001). Dashed horizontal line at 0.13 m/s above baseline indicating MCID threshold.]

Figure 2. *Mean 10-Meter Walk Test (10MWT) gait speed (m/s) across time points by group.*

*[Figure 3 placeholder — grouped bar chart with 95% CI error bars for Δ 10MWT, Δ 6MWT (rescaled), Δ LEMS, Δ WISCI-II in RAGT vs. COGT. Statistical significance markers (** p < 0.01, *** p < 0.001) above each pair.]*

Figure 3. *Bar chart comparing within-group mean change (Δ) at 8 weeks across primary and secondary walking/motor outcomes.*

IV. DISCUSSION

This randomized controlled trial demonstrated that an 8-week structured Lokomat®-based RAGT program produced significantly greater improvements than equivalent-dose conventional overground gait training across walking speed, walking endurance, lower-limb motor function, ambulation independence, functional mobility, and health-related quality of life in adults with chronic incomplete paraplegia. The between-group difference in the primary outcome (0.18 m/s in 10MWT) exceeded the established MCID for this population and was preserved at 3-month follow-up.

4.1 Comparison with Existing Literature

Our results align with several recent meta-analyses suggesting that, when delivered at sufficient intensity and dosage, RAGT can yield superior locomotor gains compared with conventional training in incomplete SCI. The magnitude of improvement observed here (mean Δ = 0.30 m/s in RAGT) is larger than reported in earlier work, which we attribute to several methodological features: a homogeneous chronic incomplete paraplegic population, a protocol emphasizing progressive reduction in guidance force to maximize active participation, integrated biofeedback to promote volitional engagement, and a

high training dose (40 sessions). In contrast, the negative or null findings of earlier trials may reflect lower training intensity, mixed tetra- and paraplegic samples, or insufficient parameter progression.

The disproportionately larger benefit on the 6MWT (a measure of endurance) compared with the 10MWT (a measure of comfortable speed) is noteworthy and may indicate that RAGT confers additional cardiopulmonary conditioning benefit beyond pure neuromotor recovery. Sustained body-weight–supported walking at higher cadences than achievable overground may provide an aerobic stimulus that is otherwise difficult to deliver in chronic SCI populations with limited overground capacity.

4.2 Mechanisms

Several mechanisms likely underlie the superior outcomes observed with RAGT. First, the device delivers thousands of consistent, kinematically accurate step cycles per session, providing dense afferent input to spinal locomotor circuits and supraspinal sensorimotor networks. Second, the progressive reduction of guidance force creates an "assist-as-needed" paradigm that drives active participation, a principle increasingly supported by motor-learning research. Third, real-time visual biofeedback enhances motivation and volitional engagement of residual descending pathways. Fourth, body-weight support enables training at functional gait speeds earlier in rehabilitation, reducing the compensatory movement patterns that often accompany overground practice in weaker patients.

4.3 Clinical Implications

These findings have direct implications for SCI rehabilitation programs. Where access permits, RAGT should be considered as a primary modality for chronic incomplete paraplegic patients with sufficient lower-limb activation to engage with the device, particularly when goals include walking-speed and endurance restoration. The favorable safety profile and high adherence rate further support its integration into routine practice. Importantly, the maintenance of effects at 3 months suggests that gains acquired through RAGT translate into durable functional change, not merely transient task-specific improvement.

However, cost, infrastructure requirements, and trained personnel remain meaningful barriers, particularly in low- and middle-income settings. Future work should examine cost-effectiveness, optimal dosing thresholds, and the comparative effectiveness of newer overground exoskeletons against treadmill-based systems.

4.4 Strengths and Limitations

Strengths of this trial include a pre-registered design with CONSORT-compliant reporting, assessor blinding, an active comparator with matched dosage, robust statistical analysis using intention-to-treat principles and mixed-effects modeling, and a 3-month follow-up window. Limitations should be acknowledged. First, the single-center design may limit external generalizability. Second, blinding of participants and treating therapists was not feasible. Third, the sample size, although adequately powered for the primary outcome, was insufficient for definitive subgroup conclusions or rare-event detection. Fourth, follow-up was limited to 3 months; longer-term maintenance and effects on community participation, employment, and healthcare utilization remain unexplored. Fifth, neurophysiological biomarkers (e.g., motor evoked potentials, gait kinematics) were not collected and would have strengthened mechanistic inference. Finally, the use of a single robotic platform (Lokomat®) limits generalizability to other device types, including overground exoskeletons.

4.5 Future Directions

Multicenter trials with longer follow-up, neurophysiological outcome measures, and head-to-head comparisons between treadmill-based and overground exoskeletal systems are warranted. Studies examining combination protocols—RAGT plus non-invasive spinal stimulation, pharmacological adjuncts, or virtual-reality–enhanced training—may further improve outcomes. Health-economic analyses are needed to inform service-delivery decisions.

V. CONCLUSION

In adults with chronic incomplete paraplegia, an 8-week structured Lokomat®-based robotic-assisted gait training program produced significantly greater and clinically meaningful improvements than conventional overground gait training in walking speed, endurance, lower-limb motor function,

ambulation independence, and quality of life, with a favorable safety profile and durable effects at 3-month follow-up. RAGT should be considered an effective component of contemporary SCI rehabilitation where access permits.

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