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Original Research

Effect of early integrated robot-assisted gait training on motor and balance in patients with acute ischemic stroke: a single-blinded randomized controlled trial

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Abstract

Background: Gait disruption is a common poststroke problem. Robot-assisted gait training (RAGT) might improve motor function, balance, and activities of daily living.

Objective: We compared the clinical effectiveness of early integrated RAGT using the Walkbot robotic gym with an intensity-matched enhanced lower limb therapy (ELLT) program and with conventional rehabilitation therapy (CRT) in patients with acute ischemic stroke.

Methods: A total of 192 patients with acute ischemic stroke were randomly assigned (1:1:1) to receive RAGT, ELLT, or CRT. All three groups received 45 min of training daily, 3 days a week, for 4 weeks consecutively. Before and after the 4-week treatment, the patients were assessed based on a 6-minute walking test (6MWT), functional ambulation classification (FAC), timed up and go (TUG) test, dual-task walking (DTW) test, Tinetti's test, Barthel's index (BI), stroke-specific quality of life (SS-QOL) scale, and gait analysis parameters.

Results: After the 4-week intervention, the results of the 6MWT, FAC, TUG, DTW, Tinetti's test, BI, SS-QOL, and gait in the three groups significantly improved. Compared with ELLT and CRT groups, participants in the RAGT group had a better performance in 6MWT (199.11 ± 60.72 *versus* 182.47 ± 59.72 *versus* 173.69 ± 40.58, $p = 0.035$), FAC (4.10 ± 0.91 *versus* 3.69 ± 0.88 *versus* 3.58 ± 0.81, $p = 0.044$), DTW (10.29 ± 2.38 *versus* 12.92 ± 2.64 *versus* 13.89 ± 2.62, $p = 0.031$), SS-QOL (184.46 ± 20.53 *versus* 165.39 ± 20.49 *versus* 150.72 ± 20.59, $p = 0.012$), velocity (0.66 ± 0.22 *versus* 0.55 ± 0.23 *versus* 0.51 ± 0.20, $p = 0.008$), cycle duration (1.38 ± 0.40 *versus* 1.50 ± 0.38 *versus* 1.61 ± 0.30, $p = 0.040$), and swing phase symmetry ratio (SPSR, 1.10 ± 0.33 *versus* 1.21 ± 0.22 *versus* 1.48 ± 0.25, $p = 0.021$). The TUG, Tinetti's test, BI, and RMT results were similar, however.

Conclusion: In the acute stroke phase, early integrated RAGT showed greater performance in gait rehabilitation than CRT and ELLT.

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Keywords: gait, rehabilitation, robot-assisted gait training, stroke

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Introduction

Stroke is the primary cause of disability in adults worldwide and imposes a heavy burden on patients and their families.[1,2] It has been reported that 30% of stroke patients are unable to walk 3 months after the onset of disease,[3] among which motor and balance dysfunction are the most common clinical manifestations.[4] Walking problems caused by motor and balance dysfunction lead to gait disruption,[5] accompanied by restricted step-up, slower walking speed, and stride asymmetry.[6] According to the principles of the International Classification of Functioning, Disability, and Health (ICF), gait training is not just about restoring a patient's ability to walk, but about achieving a walking ability that enables them to participate in the community.[7] Therefore, improving gait ability has become the primary goal of stroke rehabilitation, and rehabilitation interventions that can effectively improve walking are of great significance in enhancing the quality of life of stroke patients.[8]

For patients with stroke and gait disruption, conventional rehabilitation training (CRT) is mainly carried out step-by-step; gait training starts only when the trunk and standing strength reach their maximum values. Robot-assisted gait training (RAGT) has shown a higher efficacy than CRT owing to its outstanding advantages, including a precise and controllable training mode, low energy consumption, and timely and objective feedback.[9] Based on the principle of motor learning, different training methods can be applied by regulating robot-associated parameters, including guide force, weight support, walking speed, range of motion (ROM) of different joints, and gait deviations.[10] Previous studies have shown that RAGT could improve the movement and balance of the lower limbs in patients with subacute and chronic stroke, and it could be an effective rehabilitation strategy owing to its intensive, repetitive, and task-oriented motor activities.[11,12]

Few studies, however, have focused on an integrated RAGT [treadmill combined with weight support, stepping, gaming, and virtual reality (VR)] started in the acute phase of stroke and systematically evaluated the long-term efficiency of the disease. Thus, this study aimed to investigate whether integrated RAGT in the acute stroke phase has a better effect on motor function and balance than enhanced lower limb therapy (ELLT) and CRT in gait analysis.

Materials and methods

Design

This study was a prospective, single-blinded, randomized controlled trial, which was conducted in accordance with the Declaration of the World Medical Association of Helsinki. The protocol was approved by the Ethics Committee of Shanghai Tenth People's Hospital (no. SHSY-IEC-4. 1/19-199/01), and was registered in the Chinese Clinical Trial Registry (no. ChiCTR1900026225). Detailed information about the study design and intention was provided to potential candidates if they were interested, and all participants or their legal representatives signed an informed consent form before the study.

Participants

This trial included the evaluation of consecutively untreated patients from the outpatient and emergency departments who were diagnosed with acute ischemic stroke and hospitalized in the Neurology Rehabilitation Center of Shanghai Tenth People's Hospital, one of the top stroke centers in China, from 1 October 2019 to 14 September 2021.

The inclusion criteria were as follows: (1) patients aged 18–80 years old; (2) patients with first-ever, unilateral, ischemic stroke confirmed by computed tomography (CT) or magnetic resonance imaging (MRI); (3) the onset of stroke less than 48 h prior to inclusion; (4) patients with an ability to comprehend research-related information; and (5) functional ambulation classification (FAC) score less than 4, demonstrating that patients had limitations in walking independently.

The exclusion criteria were as follows: (1) patients who were considered medically unstable; (2) Mini-Mental State Examination (MMSE) score less than 23, which would hinder safe participation in the study; (3) conditions that limited the use of the lower limb prior to presentation of stroke; and (4) severe cardiomyopathy and other heart diseases or comorbidities that could restrict daily activities.

Grouping and training interventions

A randomized trial design was used. Patients who met the criteria were randomly allocated to the RAGT, ELLT, and CRT groups using the NCSS-PASS program-generated randomization table, at an allocation ratio of 1:1:1. A principal investigator generated random assignment sequences for participants in the NCSS-PASS, and the random assignments were concealed in consecutively numbered sealed opaque envelopes, which were sequentially opened after each patient provided written informed consent.

All participants were treated with comprehensive rehabilitation, including physical, occupational, and speech therapies. Differences among the three groups were observed only in terms of physical therapy components. All patients were trained by the same therapist with greater than 5 years of experience who was nationally accredited by possession of approval.

For the RAGT group, a Walkbot robotic gym was used to assist gait training.[13] This robot is composed of exoskeleton mechanical legs, a treadmill, a weight loss system, a VR system, a game, stepping, and a gait analysis system. It provides active and passive training modes and is equipped with sensors mounted on the hip and knee joints, which can be controlled by a therapist. Before training, the patient's body weight was partly supported by a suspended weight loss system. Subsequently, the patient's lower limbs were fixed on an exoskeleton and their bilateral ankle joints were fixed in a neutral position using lifting straps. The weight loss level was ranged between 20% and 60%, the speed was ranged between 0.30 and 0.83 m/s, and the amount of the reaction force was 100%, which decreased by 5–10% per week. Excluding the time required to install the equipment, the actual time of gait training was 45 min/cycle.

The ELLT program aims to match the intensity and duration of RAGT sessions, consisting of muscle strength training, passive stretching training, sit-to-stand training, bed-wheelchair training, stepping training, balance training, and walking training. ELLT aims to drive neuroplasticity and motor recovery after stroke using the principles of person-centered goal-setting and repetitive functional task practice. The CRT strategy included training through joint ROM, muscle strength training, balance training, and exercise therapy in clinical routine.

All groups were trained for 45 min each day, 3 days per week, for four consecutive weeks, and were controlled for other necessary medications and adjunctive treatments except RAGT, ELLT, and CRT provided in this study. Owing to the random and single-blinded study design, only the evaluator and statistician were blinded to the grouping procedures.

Outcome measures

The primary outcomes of the study were the FAC scores and the results of the 6-minute walk test (6MWT). According to the ICF model,[14] walking capacity relates to the activity domain and can be assessed by the FAC, which evaluates how much human support is needed by a patient, regardless of the need for assistive devices, scoring from 0 to 5.[15] Walking performance is related to activities, participation domains, and environmental factors. Six-minute walk test was used to measure walking performance.[16,17] Participants were asked to walk at their 'normal comfortable' speed as fast and safe as possible; the shorter the time, the greater the walking ability.

The secondary outcomes included an improvement in posture control evaluation according to gait analysis parameters, functional mobility, balance ability, and quality of life. Gait parameters – such as step length, stride length, cadence, velocity, cycle duration, swing time, and ROM of the hip, knee, and ankle joints – were assessed using a three-dimensional motion analysis system.[18] We differentiated sensitive markers at anatomical spots on the joints, and captured and analyzed the ROM of the above-mentioned joints. The timed up and go test (TUG) was used to evaluate functional mobility,[19] in which participants were asked to stand up from a standardized chair, walk straight for 3 m, and then return to the chair and sit down. While performing the TUG, the motor-cognitive interaction-related dual-task walking (DTW) test was conducted.[20] Participants were asked to hold a glass containing the same amount of water and to prevent the water from spilling out. Tinetti's test was used to measure balance ability in the elderly patients.[21] Tinetti's score generally ranges from 0 to 16 points; the higher the score, the greater the balance. Barthel's index (BI) was used to assess the patients' activities of daily living (ADL), generally ranging from 0 to 100.[22] The stroke-specific quality of life (SS-QOL) scale was used to evaluate health-related quality of life specific to stroke survivors.[23] Outcome assessors were blinded to grouping and data interpretation as well.

Statistical analysis

Sample size calculations were performed based on FAC scores as a function of a mean improvement of 1 with an α-value of 0.05 and a $1-\beta$ value of 0.80, representing 20% losses at follow-up. Therefore, 60 participants were required in each group. Statistical analysis was performed using the SPSS software (version 24.0; IBM Corp., Armonk, NY, USA). Continuous variables were expressed

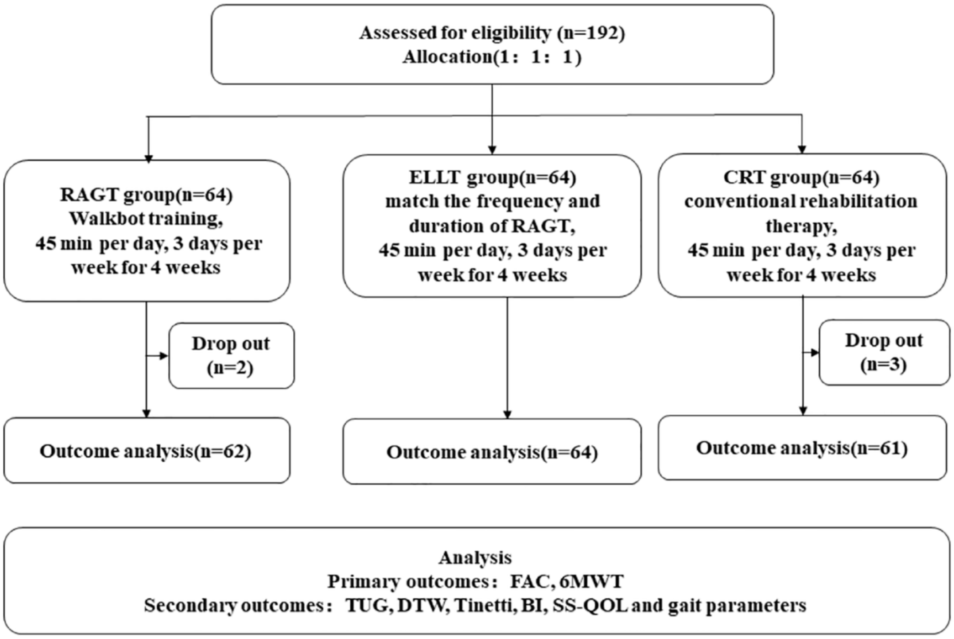

Figure 1. Flow diagram of the study. Gait analysis parameters including gait speed, step length, stride length, cadence, cycle durations, and swing time of affected side/unaffected side during one gait cycle.
6MWT, 6-minute walk test; BI, Barthel's index; CRT, conventional rehabilitation training; DTW, dual-task walking test; ELLT, enhanced lower limb training; FAC, functional ambulatory classification; RAGT, robot-assisted gait training; SS-QOL, stroke-specific quality of life; TUG, timed up and go.

as mean value ± standard deviation (SD). Kolmogorov–Smirnov's test revealed that all clinical and gait analysis parameter data were normally distributed. Differences in baseline parameters among the three groups were analyzed using one-way analysis of variance (ANOVA) for categorical variables, followed by Bonferroni-adjusted post hoc analyses. Statistical significance was set at $p < 0.05$.

Results

Patients' general characteristics

A total of 192 eligible study participants admitted to the neurorehabilitation center were equally randomized to the RAGT, ELLT, and CRT groups ($n = 64$/group). A total of 187 individuals completed the entire training protocol, and five participants dropped out for personal reasons, including two in the RAGT group and three in the CRT group (Figure 1). Evaluations were conducted on participants at admission and after the 4-week training period. The demographic characteristics of the participants who completed the protocol are shown in Table 1. There were no significant differences in age, sex, side and type of stroke, duration, and clinical measures (6MWT, FAC, TUG, DTW, Tinetti, BI, SS-QOL, and gait parameters) at baseline among the three groups. No adverse effects were observed during or after training.

Treatment effects

The assessment scales of the RAGT, ELLT, and CRT groups at baseline and after 4 weeks of therapy are shown in Table 2. Treatment adherence was satisfactory, and all training sessions were completed by all patients. All groups showed statistically significant improvements in all measures (6MWT, FAC, TUG, DTW, Tinetti, BI, and SS-QOL) from baseline to post-treatment assessment.

After 4 weeks of treatment, the patients' performance in the 6MWT in the RAGT group was significantly better than that in the other two groups (199.11 ± 60.72 *versus* 182.47 ± 59.72 *versus* 173.69 ± 40.58, $p = 0.04$). Based on the minimal clinically important difference (MCID), the hypothesis was that the 6MWT in the RAGT group would be greater than that in the CRT and ELLT groups by more than 8 min after 4 weeks of

Table 1. Demographic data of each group.

Variable	RAGT group (*n* = 62)	ELLT group (*n* = 64)	CRT group (*n* = 61)	*p* value
Age (years)	59.36 ± 1.65	55.26 ± 1.32	60.12 ± 1.73	0.22
Male, *n* (%)	33 (53.22)	35 (54.69)	35 (57.38)	0.24
Height (cm)	168.79 ± 7.52	169.88 ± 6.81	169.14 ± 8.01	0.68
Weight (kg)	67.36 ± 7.02	67.17 ± 6.59	68.00 ± 7.94	0.37
NIHSS	9.12 ± 3.39	9.55 ± 4.86	9.01 ± 3.90	0.10
Brunnstrom stage	4.02 ± 0.53	4.08 ± 0.48	4.01 ± 0.57	0.10
Side of lesion				0.09
Left, *n* (%)	28 (45.16)	26 (40.63)	30 (49.18)	
Right, *n* (%)	34 (54.84)	38 (59.37)	10 (50.82)	

CRT, conventional rehabilitation training; ELLT, enhanced lower limb training; NIHSS, National Institute of Health Stroke Scale; RAGT, robot-assisted gait training.
p value was Bonferroni-corrected for pairwise comparisons.

Table 2. Comparison of scale assessment among three groups.

Variable	RAGT group (*n* = 62)		ELLT group (*n* = 64)		CRT group (*n* = 61)		*p* value
	T0	T1	T0	T1	T0	T1	
6MWT	109.75 ± 64.00	199.11 ± 60.72	112.70 ± 52.89	182.47 ± 59.72	113.69 ± 51.73	173.69 ± 40.58	0.04
FAC	2.51 ± 0.66	4.10 ± 0.91	2.53 ± 0.83	3.69 ± 0.88	2.50 ± 0.77	3.58 ± 0.81	0.04
TUG (s)	12.19 ± 6.44	7.39 ± 1.36	12.33 ± 7.01	7.65 ± 1.42	12.00 ± 5.98	8.04 ± 1.39	0.09
DTW (s)	14.32 ± 7.56	10.29 ± 2.38	14.45 ± 8.22	12.92 ± 2.64	14.23 ± 7.00	13.89 ± 2.62	0.03
Tinetti	14.42 ± 2.03	24.64 ± 4.95	14.13 ± 1.97	23.33 ± 6.02	14.14 ± 1.95	20.88 ± 5.04	0.25
	53.12 ± 7.54	86.34 ± 19.25	53.01 ± 7.52	82.79 ± 10.33	53.32 ± 7.49	80.19 ± 18.20	0.16
SS-QOL	120.44 ± 31.45	184.46 ± 20.53	115 ± 30.09	165.39 ± 20.49	113.12 ± 28.75	150.72 ± 20.59	0.01

6MWT, 6-minute walk test; BI, Barthel's index; CRT, conventional rehabilitation training; DTW, dual-task walking test; ELLT, enhanced lower limb training; FAC, functional ambulatory classification; RAGT, robot-assisted gait training; SS-QOL, stroke-specific quality of life scale; T0, evaluation at baseline; T1, evaluation after 4 weeks of training; TUG, timed up and go.
p value is Bonferroni-corrected for pairwise comparisons of T1-T0.

treatment. This demonstrates the potential benefits of early integrated RAGT on walking performance in patients with acute ischemic stroke.

The baseline FAC scores of most of the participants were distributed around 2.5 points, and based on Wilcoxon's rank-sum test, there were no significant differences among the three groups. After 4 weeks of treatment, patients in the RAGT and ELLT groups had greater improvements in FAC scores compared with the CRT group (4.10 ± 0.91 *versus* 3.69 ± 0.88 *versus* 3.58 ± 0.81, $p = 0.04$); however, no statistically significant differences were observed between the RAGT and ELLT groups (3.69 ± 0.88 *versus* 3.58 ± 0.81, $p = 0.08$).

Table 3. Comparison of gait analysis among three groups.

Variable	RAGT group ($n=62$)		ELLT group ($n=64$)		CRT group ($n=61$)		p value
	T0	T1	T0	T1	T0	T1	
Gait velocity (m/s)	0.33 ± 0.22	0.66 ± 0.22	0.36 ± 0.14	0.55 ± 0.23	0.31 ± 0.17	0.51 ± 0.20	0.01
Cadence (step/min)	68.88 ± 11.09	85.45 ± 18.32	67.12 ± 12.33	84.23 ± 13.26	70.11 ± 11.66	80.01 ± 18.14	0.08
Step length (m)	0.32 ± 0.04	0.42 ± 0.05	0.32 ± 0.08	0.40 ± 0.06	0.31 ± 0.07	0.39 ± 0.06	0.09
Stride length (m)	0.60 ± 0.15	0.80 ± 0.08	0.59 ± 0.12	0.77 ± 0.21	0.60 ± 0.13	0.69 ± 0.17	0.12
Cycle duration (s)	1.97 ± 0.36	1.38 ± 0.40	1.89 ± 0.41	1.50 ± 0.38	1.80 ± 0.36	1.61 ± 0.30	0.04
SPSR	1.55 ± 0.40	1.10 ± 0.33	1.54 ± 0.37	1.21 ± 0.22	1.53 ± 0.53	1.48 ± 0.25	0.02
ROM of hip	34.82 ± 4.22	39.13 ± 6.36	34.01 ± 3.12	39.97 ± 6.50	34.97 ± 5.95	39.54 ± 6.46	0.30
ROM of knee	138.18 ± 46.51	139.56 ± 46.97	135.78 ± 40.33	137.14 ± 39.54	135.69 ± 50.31	138.40 ± 47.84	0.60
ROM of ankle	12.92 ± 2.91	19.39 ± 5.94	12.46 ± 4.46	17.20 ± 6.70	12.88 ± 4.12	18.18 ± 6.69	0.12

CRT, conventional rehabilitation training; ELLT, enhanced lower limb training; RAGT, robot-assisted gait training; ROM, range of motion; SPSR, swing phase symmetry ratio; T0, evaluation at baseline; T1, evaluation after 4 weeks of training.
p value is Bonferroni-corrected for pairwise comparisons of T1-T0.

After training, the performance of DTW time in the RAGT group was markedly shorter than that in the ELLT and CRT groups (10.29 ± 2.38 *versus* 12.92 ± 2.64 *versus* 13.89 ± 2.62, $p=0.03$), while the TUG time and Tinetti were similar with those in the ELLT group (7.39 ± 1.36 *versus* 7.65 ± 1.42, $p=0.12$; 24.64 ± 4.95 *versus* 23.33 ± 6.02, $p=0.30$, respectively) and greater than those in the CRT group (7.39 ± 1.36 *versus* 8.04 ± 1.39, $p=0.05$; 24.64 ± 4.95 *versus* 20.88 ± 5.04, $p=0.04$, respectively). From this, we infer that the high efficiency of RAGT in rehabilitation may be derived from the effective activation of motor-cognitive pathways by bilateral intensive training and multisystem perception, which is similar to our previous findings on the upper limbs.[24] BI scores were similar between each pair of groups at 4 weeks. Patients in the RAGT had greater improvements in FAC scores compared with the ELLT and CRT groups (184.46 ± 20.53 *versus* 165.39 ± 20.49 *versus* 150.72 ± 20.59, $p=0.01$).

Gait parameters after training

The results of the gait analysis are presented in Table 3. Most participants in the three groups showed significant improvement in the measured gait parameters. The values of gait velocity, cycle duration, and swing phase symmetry ratio (SPSR) were significantly better in the RAGT than in the ELLT and CRT groups (0.66 ± 0.22 *versus* 0.55 ± 0.23 *versus* 0.51 ± 0.20, $p=0.01$ in velocity; 1.38 ± 0.40 *versus* 1.50 ± 0.38 *versus* 1.61 ± 0.30, $p=0.04$ in cycle duration; 1.10 ± 0.33 *versus* 1.21 ± 0.22 *versus* 1.48 ± 0.25, $p=0.02$ in SPSR). No statistically significant differences in step length and stride length were observed between the RAGT and ELLT groups (0.42 ± 0.05 *versus* 0.40 ± 0.06 *versus* 0.39 ± 0.06, $p=0.09$ in step length; 0.80 ± 0.08 *versus* 0.77 ± 0.21 *versus* 0.69 ± 0.17, $p=0.12$ in stride length), however. Meanwhile, after 4 weeks of treatment, patients in the RAGT group had a greater frequency of cadence than those in the CRT group (85.45 ± 18.32 *versus* 84.23 ± 13.26 *versus* 80.01 ± 18.14, $p=0.04$).

Besides, flexion and extension of the ROM of hip, knee, and ankle in the RAGT group were similar to those in the other two groups after treatment (39.13 ± 6.36 *versus* 39.97 ± 6.50 *versus* 39.54 ± 6.46 in ROM of hip; 139.56 ± 46.97 *versus* 137.14 ± 39.54 *versus* 138.40 ± 47.84 in ROM of knee; 19.39 ± 5.94 *versus* 17.20 ± 6.70 *versus* 18.18 ± 6.69 in ROM of ankle; all $p>0.05$), suggesting that RAGT effectively increased participants' mobility, but not joint ROM, in patients with acute ischemic stroke.

Safety

No serious adverse events, such as secondary stroke or paralysis due to improper training, were found in each group.

Discussion

This study aimed to explore the efficiency of early integrated RAGT for improving motor function and balance in adult patients with acute ischemic stroke. Positive changes in primary outcomes were observed after 4 weeks of treatment in the RAGT, ELLT, and CRT groups. A direct comparison between baseline and 4-week post-therapy assessment scores revealed marked improvements in the RAGT group compared with the ELLT and CRT groups, with positive effects seen for 6MWT, FAC, DTW, SS-QOL, gait speed, and gait symmetry emerging with the same therapeutic duration. Notably, the patients enrolled in this study had acute ischemic stroke, and the therapeutic effect may partly be due to natural recovery.[25] With the design of randomized controlled trials, which effectively balanced natural recovery between groups, the differences in treatment effect between groups could be explained by intervention factors, thus suggesting that the effects of RAGT are independent of spontaneous recovery. These findings revealed that RAGT might be a more clinically effective treatment strategy than ELLT and CRT for adult patients presenting with acute ischemic stroke.

There is a close relationship between kinesiology and clinical evaluation after stroke in terms of motor and balance recovery of the lower extremity. Meanwhile, the results of velocity, SPSR, ROM of the hip and knee, and ankle sensitivity and specificity were inconsistent, most likely because RAGT effectively improved participants' muscular strength, but not stiffness. Reports suggest that muscular strength of the lower limbs is closely correlated with walking ability, stair-climbing ability, and balance control during standing.[26] Myogenic and neurogenic factors are the main causes of muscle strength enhancement. Myogenic factors include the physiological cross-sectional area of the muscle, type of muscle fibers, and initial length of the muscle before contraction, including neurotransmission, neuromuscular coordination, and neural excitation level.[27] Previous studies have pointed out that the muscular strength of the lower limbs of patients with hemiplegia is closely correlated with walking speed and walking independence. Among muscle-associated factors, SPSR is firmly associated with walking speed and walking independence, which are the most important factors determining stride frequency.[28] In addition, the RAGT can synchronize sensory and motor information more reliably, forming a correct sensor-motor circuit. Numerous robots that mimic walking in clinical applications have been designed to balance sensory inputs.[29,30] The Walkbot robotic gym combines the exoskeleton frame with plantar pedal technology,[31] which can ensure the linkage effect of the joints, and it enables patients with a strong sense of leg swing, foot landing, and pedaling, playing a role in the development of the sensor-motor circuit.

The efficacy and effectiveness of the integrated RAGT could be attributed to the following mechanisms. (1) RAGT does not need to follow the principles that gradually increase the density of training during the assisted standing process to improve trunk stability, followed by active standing training under safe conditions to enhance standing ability.[32] Unarmed functional walking training has, however, inadequate intensity, low efficiency, and difficulty in controlling the gait of patients, thus assisting patients in developing a correct pattern for repeated training. Comparably, RAGT employs electromechanical devices that assist stepping cycles by supporting body weight while automatizing the gait process through the support and facilitation of movement in one or several lower limb joints. (2) Robots provide bilateral repetitive and intensive training with greater continuity and consistency, which is consistent with the motor learning theory.[33] Many studies have shown that exercise improves neural remodeling, thereby promoting functional rehabilitation in patients with central nervous system diseases.[34] (3) Neural remodeling is the basis of neuro-rehabilitation models. RAGT provides treadmill, weight support, stepping, gaming, and VR, which lead to sensory-motor-cognitive multi-system sensory feedback.[35]

This study has some limitations. A major limitation is that the onset of stroke was less than 48 h prior to the inclusion of the participants; thus, the current promising effect of RAGT on rehabilitation cannot exclude those of natural recovery.[25] We, however, selected patients who underwent thrombolysis and thrombectomy in another ongoing rehabilitation cohort study to minimize the bias caused by natural recovery. Another limitation is that these results did not include follow-up assessment data of ⩾3 months as outcome measures; thus, attempting to extrapolate the current findings to long-term clinical prognosis should be interpreted carefully. Nevertheless, a longer follow-up assessment was performed to record retention tests in the subacute and chronic phases. In addition, a comparison between Walkbot and the exoskeleton robot is planned at our institute when additional studies will begin in the near future. Furthermore, poststroke cognitive impairment will be assessed as we saw the possibility of an interaction of RAGT with cognitive movement in the study.

Conclusion

The results revealed that compared with CRT and ELLT, RAGT is an effective intervention for acute stroke patients to improve motor and balance performance as well as quality of life, and shows more advantages in gait endurance and changes in gait parameters after 4 weeks of training. The application of the integrated RAGT strategy is beneficial to help patients with acute stroke improve their opportunities for independent social life.

Declarations

Ethics approval and consent to participate

Ethics Committee of the Shanghai Tenth People's Hospital (SHSY-IEC-4.1/19-199/01). Detailed information about the study design and intention was provided to potential candidates if they were interested, and all participants or their legal representatives signed an informed consent form before the study.

Consent for publication

Not applicable for this study.

Author contributions

Guilin Meng: Conceptualization; Data curation; Writing – original draft; Writing – review & editing.

Xiaoye Ma: Formal analysis; Resources; Software; Writing – original draft; Writing – review & editing.

Pengfei Chen: Formal analysis; Investigation; Methodology; Writing – review & editing.

Shaofang Xu: Methodology; Software; Writing – review & editing.

Mingliang Li: Software; Validation; Writing – review & editing.

Yichen Zhao: Investigation; Writing – review & editing.

Aiping Jin: Funding acquisition; Project administration; Visualization; Writing – review & editing.

Xueyuan Liu: Conceptualization; Methodology; Project administration; Writing – review & editing.

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Competing interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Availability of data and materials

The data are available upon request. The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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