Supplementary materials

Limb guidance system in robot-assisted gait training for clinical functional improvement in stroke patients: a narrative review

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Available online: https://www.panafrican-med-journal.com/content/series/54/1/18/full/

Content

Annex 1: summary of studies on RAGT published between 2021 to 2025

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Author details, reference, country and study design	**Device type, brand**	**Objective(s)**	**Sample size**	**Protocol (duration + sessions + procedures)**	**Outcome measures**	**Results**	**Conclusion**	**Limitations (+ PEDro score)**
(Chien et al., 2021) [8] Taiwan Non-randomized, clinical trial	End-effector; HIWIN MRG-P100 (HIWIN Technologies, China); tilt-table style (upright, non-suspension); programmable trajectories & speeds	To compare additional RAGT plus standard hospital rehabilitation versus standard rehabilitation alone in acute stroke	n=80 acute stroke (<3 months); robotic n=54; control n=26	3 wks (21 sessions); all received daily standard neurorehabilitation (45–60 min); robotic group received additional 30-min RAGT after each session	• BBS • Brunnstrom Stage	No significant between-group difference in mean BBS; robotic group showed greater category improvement in Brunnstrom Stage	Addition of RAGT to standard hospital neurorehabilitation produced slightly greater functional improvement in acute stroke	Non-random allocation (selection bias); unequal group sizes; no assessor blinding; unequal total training dose; PEDro 5/10 (Fair)
(Li et al., 2021) [12] China Non-inferiority RCT (5 hospitals)	Exoskeleton; BEAR-H1 (MileBot Robotics, Shenzhen, China)	To evaluate efficacy and safety of BEAR-H1 exoskeletal robot for locomotor function in subacute stroke	n=114 subacute stroke (≤6 months post-stroke); robotic n=57; control n=57	4 wks (80 sessions); robotic: BEAR-H1 training 30 min, 2×/d, 5 d/wk; control: therapist-assisted gait training 30 min, 2×/d, 5 d/wk	• 6MWT • FAC • FMA-LE	Both groups improved in 6MWT, FAC, FMA-LE; no significant between-group difference; robotic group improved	BEAR-H1 improved locomotor function but was not superior to conventional locomotor training	Non-inferiority design (not superiority); short intervention duration; limited follow-up; no assessor blinding; early prototype device;

						earlier and showed higher mean gains in 6MWT		PEDro 6/10 (Good)
(Son et al., 2021) [13] South Korea Parallel group RCT	Exoskeleton ; Healbot T; with transverse pelvic motion capability	To evaluate the effect of transverse pelvic motion during robotic gait training in stroke patients	n=24 chronic stroke (2–30 years post-onset); pelvis-on n=12; pelvis-off n=12	4 wks (10 sessions); ~30 min/session; Healbot T; pelvis-on: transverse pelvic motion enabled; pelvis-off: no transverse pelvic motion	• Stride length • Cadence • Walking speed	Both groups improved in stride length; pelvis-on group showed greater increase in cadence and walking speed	Pelvic movement during robotic gait training improved gait parameters compared to training without pelvic motion	Small sample size; short duration; absence of functional scales (e.g., FAC/FIM); baseline height difference between groups; focus on mechanistic (EMG) rather than functional outcomes; PEDro 7/10 (Good)
(Yu et al., 2021) [14] China RCT	Exoskeleton ; A3 Gait Training & Evaluation System (NX Corp, China); treadmill-based; adjustable BWS and guidance force	To compare early robotic gait training (RT) with conventional overground gait training (PT) to determine the more beneficial treatment for gait improvement	n=54 subacute stroke (<12 wks); robotic n=27; control n=27	2 wks (14 sessions); 1×/d, 7 d/wk Robotic: 50 min GT with A3 + 70 min PT; speed 1.2–2.6 km/h; BWS 50→0%; guidance 100→10% Control: 50 min conventional overground GT + 70 min PT	• FMA • TUG • Stride time • Single & double stance phase time • Swing phase time • Stride length • Gait speed • Cadence • Step width, toe out angle	Robotic group improved stride length and gait speed	Robot-assisted training may be more beneficial for improving spatial gait parameters, while conventional training may better improve gait width	High withdrawal rate (possible recruitment bias); short duration; no follow-up; PEDro 8/10 (Good)

(Aprile et al., 2022) [10] Italy RCT (Multi-center)	End-effector; G-EO System (Reha Technology AG, Switzerland); fixed frame, foot-plate based; + Hunova platform (Movendo Tech, Italy)	To evaluate the effectiveness adding trunk control to RAGT on balance, activity, and participation measures in subacute stroke patients.	n=36 subacute stroke (2 wks–6 months); RAGT-only n=17; RAGT+trunk n=19	4 wks (12 sessions); 45 min, 3×/wk RAGT-only: RAGT RAGT+trunk: RAGT + trunk/balance training (Hunova)	• BBS • Ambulation Index (AI) • FAC • 10MWT • 6MWT • TUG • Motricity Index • MAS-LL • mBI • Walking Handicap Scale (Assessed at: wk0 & wk4)	Motricity Index increased and MAS-LL decreased significantly only in RAGT+trunk group	Addition of trunk control to RAGT improved lower limb strength and reduced spasticity in subacute stroke	Small sample; short duration (4 wks); no long-term follow-up; lack of blinding; limited generalisability; no comparison with conventional gait therapy; PEDro 8/10 (Good)
(Lee et al., 2022) [15] South Korea RCT	Exoskeleton; Healbot T (T-Robotics Co. Ltd, South Korea); exoskeleton-based GT robot with pelvic control and CIMT therapy mode	To determine the effects of robot-assisted gait training with various training modes in patients post stroke	n=47 chronic stroke (>6 months) Pelvic-off n=11; pelvic-on n=12; CIMT n=10; control n=10	4 wks (10 sessions); 30 min/session Pelvic-off: RAGT (pelvic-off mode) Pelvic-on: RAGT (pelvic-on mode) CIMT: RAGT (CIMT mode) Control: conventional treadmill GT	• 10MWT • BBS • FAC • TUG • Motricity Index of the Lower Extremities (MI-Lower) (Assessed at: wk0 & wk4)	Compared with control: • Pelvic-on group showed greater improvement in TUG and BBS • CIMT group showed greater improvement in 10MWT and MI-Lower	Healbot T-assisted gait training with pelvic motion and CIMT modes were more helpful in improving balance, walking ability, and lower limb strength compared with conventional	Small group sizes; no long-term follow-up; PEDro 8/10 (Good)

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(Meng et al., 2022) [16] China RCT	Exoskeleton ; Walkbot (P&S Mechanics, Korea); treadmill-type with VR and BWS	To compare clinical effects of early integrated RAGT using Walkbot robotic gym to enhance lower limb therapy (ELLT) program and conventional rehabilitation therapy (control) on motor function, balance, and gait parameters in patients with acute ischemic stroke	n=187 acute ischemic stroke (<2 days); RAGT n=62; ELLT n=64; control n=61	4 wks (12 sessions); 45 min/day, 3×/wk RAGT: Walkbot training (active & passive modes; weight support; VR) ELLT: muscle strength; stretching; sit-to-stand; balance; walking Control: conventional rehabilitation (joint ROM; strength; balance; exercise therapy)	• 6minWT • FAC • Gait analysis parameters • gait velocity • cadence • step length • TUG • Tinetti's test • Barthel's index (Assessed at: w0 & w4)	RAGT group showed greater gains in 6MWT, FAC, and gait parameters compared with ELLT and control	Early integrated RAGT demonstrated superior gait rehabilitation performance in acute stroke compared with CRT and ELLT	Short-term effects only; limited to acute phase; therapists not blinded; PEDro 8/10 (Good)
(Lee et al., 2023) [17] Taiwan RCT	Exoskeleton ; FREE Walk (FREE Bionics, Hsinchu, Taiwan)	To examine the effects of exoskeleton-assisted RAGT on lower limb strength, walking speed, motor function, and quality of life in stroke.	n=38 stroke (<6 months); robotic n=17; control n=21	4 wks Robotic: RAGT 3 d/wk + conventional physiotherapy 2 d/wk Control: conventional physiotherapy 5×/wk	• TUG • 6MWT (Assessed at: wk0 & wk4)	Robotic group showed significantly greater improvement in 6MWT compared with control	Exoskeleton-assisted RAGT improved walking speed in stroke patients	No blinding; no long-term follow-up; small sample size; PEDro 6/10 (Good)
(Miyagawa et al., 2023) [18]	Exoskeleton ; Curara® type 4 (AssistMotio	To examine the effect of the wearable rehabilitation	n=35 subacute stroke (14–90	2 wks (10 sessions); 30 min ±5 min, 5×/wk	• 10MWT • 6minWT • TUG • BBS	No significant between-group difference in	Further studies are required to confirm	Small sample; short intervention; no post-intervention

Japan Parallel-group RCT	n Inc., Japan)	robot "Curara®" on gait training in stroke patients	days post-stroke); robotic n=17; control n=18	Robotic: RAGT using Curara® Control: therapist-assisted GT	• Gait parameters • Stride duration • Stride length • Gait speed • Cadence (Assessed at: day 0, day 7 & day 14)	10MWT or 6MWT; stride duration and cadence improved more in robotic group	effectiveness of Curara® in improving gait parameters	follow-up; no report of blinding; PEDro 7/10 (Good)
(Pournajaf et al., 2023) [9] Italy RCT (8 intensive subacute rehabilitation centers)	Exoskeleton: Lokomat Pro (Hocoma AG, Switzerland) End-effector: G-EO System™ (Reha Technologies, Italy)		n=89 first-time stroke with pyramidal syndrome; end-effector n=30; exoskeleton n=31; control n=28	4–7 wks (20 sessions); 30 min, 3–5×/wk End-effector: G-EO System™ Exoskeleton: Lokomat Pro Control: conventional overground GT	• 10 MWT • TUG • 6minWT • MI-LL • MAS-LL • FAC • mBI (Assessments at: wk0 & wk4-wk7 (after completion of interventio)	10MWT; 6MWT; TUG; and mBI significantly improved in both robotic groups versus control. End-effector showed greater improvement in 10MWT versus exoskeleton.	RAGT demonstrated greater walking improvement than conventional GT. End-effector robots may be more effective than exoskeletons for improving gait speed.	Variable treatment completion duration (4–7 wks); no blinding; no long-term follow-up; PEDro 6/10 (Good)
(Jin et al., 2024) [19] China RCT	Exoskeleton; LiteStepper® (Angelexo Science Co., Zhejiang,	To assess the effectiveness of the LiteStepper® unilateral lower limb exoskeleton (ULLE) combined	n=85 stroke (<1 month); robotic n=43; control n=42	3 wks (21 sessions); 1×/d, 7 d/wk Control (60 min): FES 20 min; comprehensive training 40 min	• BBS • FAC • 6minWT • Barthel Index	BBS improvement from baseline to day 21 significantly greater in robotic group.	LiteStepper® ULLE combined with conventional treatment improved	Short duration; no follow-up; no blinding; unequal exercise dosage; PEDro 7/10 (Good)

	China); unilateral lower limb exoskeleton (ULLE)	with conventional treatment for balance function training in patients with post-stroke hemiplegia		(neuromuscular facilitation; hip/knee control; ankle dorsiflexion; affected limb support; balance; GT) Robotic (100 min): control protocol (60 min) + ULLE (passive stretch 10 min; unilateral RAGT 20 min; passive stretch 10 min)	(Assessed on: d0, d14 & d21)	FAC, 6MWT, and Barthel Index improved more in robotic group at day 14 and day 21.	balance function in post-stroke hemiplegia.	
(Kim et al., 2024) [11] South Korea RCT	Exoskeleton ; Lokomat® (Hocoma AG, Zurich, Switzerland) + high-definition tDCS	To investigate whether simultaneous application of HD-tDCS could enhance the training effects of robot-assisted gait training (RAGT) on gait and physical function in chronic stroke patients.	n=24 chronic stroke; real stimulation n=12; placebo n=12	4 wks (10 sessions); 45 min/session; 30 min stimulation Real group: HD-tDCS at 2A + RAGT Placebo group: sham stimulation (0A) + RAGT	• 10MWT • TUG • FAC • FRT • BBS • DGI • FMA • Korean MBI (K-MBI) (Assessed at wk0, wk4, and 1 month follow-up)	Real stimulation group showed significant within-group improvements in 10MWT, TUG, FRT, BBS, DGI, FMA-LE, and FMA; maintained at 1-month follow-up. Significant time × group interaction favoring real stimulation in FMA and K-MBI.	HD-tDCS combined with RAGT improved gait and physical function in chronic stroke; effects maintained after training.	Small sample; no comparison with conventional therapy; electrode modeling based on template MRI (not individualized); PEDro 8/10 (Good)

(Kóra et al., 2024) [20] Hungary RCT	Exoskeleton ; ReStore™ Soft Exo-Suit (ReWalk; Fototronic Ltd., Budapest, Hungary)	To determine the effect of employing a robotic soft exoskeleton in therapy on the development of early mobilization, gait, and coordination in stroke patients	n=30 subacute stroke (2–4 wks post-stroke); robotic n=15; control n=15	5 wks (15 sessions) Robotic: high-intensity agility program using ReStore™ (warm-up 5 min; dimensional walk 10 min; slalom/obstacle walking 2 min ×5; weight-bearing walk alternating intensities 6 min) Control: similar structured program without robotic device	• mRS • Barthel Index • BBS • 10MWT • 6minWT (Assessed at: wk0, wk3 & wk5 (follow up))	Robotic group showed significant within-group improvements and significant between-group differences at follow-up in mRS and Barthel Index. Greater improvements in BBS, 10MWT, 6MWT, and static balance in robotic group; sustained at follow-up.	Soft exoskeleton -assisted therapy improved gait, balance, and mobility in subacute stroke, with sustained effects after training.	Notable drop-out rate Short follow-up period Potential selection bias: high initial withdrawals before baseline Technical limitation: device-fit and sizing challenges, maintenance
(Kim et al., 2025) [21] South Korea RCT	End-effector; Morning Walk® (Curexo Inc., Korea)	To investigate the effects of HIIT-based RAGT on walking ability, static and dynamic balance, and lower limb function.	n=44 chronic stroke (>6 months); robotic n=22; control n=22	8 wks (24 sessions); 30 min, 3×/wk Robotic: alternating moderate (RPE 10–12) and high-intensity RAGT (RPE >14) Control: treadmill GT (RPE 13–15), speed progressively	• 10MWT • 2MWT • FAC • BBS • FMA-LE (Assessed at: wk0 & wk8)	Robotic group showed significantly greater improvements in 10MWT, FAC, BBS, 2MWT, and FMA-LE compared with control	HIIT-based RAGT may be effective for improving gait and functional outcomes in chronic stroke	No comparison with steady-state RAGT; small sample; no long-term follow-up; lack of blinding; PEDro 7/10 (Good)

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				increased to maintain target RPE				
(Liang et al., 2025) [22] China RCT	Exoskeleton ; Kickstart® Walk Assist System (Real Star Rehabilitation, Shanghai, China); passive exosuit with ExoTendon ® energy-return system	To evaluate the effectiveness of the Kickstart® Walk Assist system in improving lower limb muscle strength and walking ability in stroke patients.	n=46 subacute stroke (1–6 months); robotic n=23; control n=23	4 wks (20 sessions); 20 min, 5×/wk Robotic: conventional therapy + passive exosuit Control: conventional therapy + therapist-guided GT	• FMA-LE • 10MWT • Gait speed • Stride length • Temporal symmetry ratio Assessed at: wk0, wk2, wk4, wk8 (4 wks post-intervention)	Robotic group showed greater improvements in FMA-LE at wk4 and wk8, and in 10MWT at wk8. Stride length improved earlier in robotic group (wk2) compared with control (wk8).	Kickstart® Walk Assist improved lower limb strength and motor function and accelerated walking recovery in subacute stroke.	Short intervention; small sample; limited follow-up duration; potential assessor bias (single-blind design); PEDro 9/10 (Excellent)
(Tollár et al., 2025) [23] Hungary RCT	Exoskeleton ; ReWalk model (Fototronic Kft., Budapest, Hungary); ReStore Soft Exo Suit	To assess the immediate and lasting effects of combination of agility exergaming and RAGT on clinical and mobility outcomes in persons with acute ischemic stroke.	n=75 acute ischemic stroke (5 days post-stroke) Control n=15; robotic n=15; EXE1 n=15; EXE2 n=15; combination n=15	3 wks (15–30 sessions); 5 d/wk Control: sitting group exercise 30 min + individualized walking/balance therapy 30 min, 1×/d Robotic: RAGT (HR 110–130), 40 min, 1×/d EXE1: high-intensity non-immersive agility exergaming (RPE 14–16/20), 25 min + agility training 25 min, 1×/d	Primary outcomes: • Modified Rankin Scale (mRS) Secondary outcomes: • Barthel Index (BI) • BBS • 6minWT w/o robot • 6minWT with robot	No significant between-group difference in mRS. BBS, 10MWT, and 6MWT (with and without robot) improved in EXE1, EXE2, robotic, and combination groups.	Exergaming, RAGT, and their combination improved balance and walking outcomes, with sustained effects after detraining. Higher daily exergaming dose improved	Unequal exercise volume across groups; short intervention duration; small sample size; PEDro 7/10 (Good)

				EXE2: same exergaming protocol, 2×/d Combination: morning exergaming (25+25 min) + evening RAGT (40 min)	• 10mWT (Assessed at: Wk 0, Wk 3, and Wk 8 (follow-up after 5 weeks))	The combination group showed greater improvement in 6MWT, with sustained effects at wk8.	balance; combination training produced greater walking distance gains.	
(Alingh et al., 2021) [24] Netherlands Multicenter RCT (2 inpatient rehabilitation centers)	Hybrid; LOPES-II; assist-as-needed (AAN); gradually reduced BWS; multi-degree-of-freedom (mDOF) gait training	To compare the effect of assist-as-needed robotic to conventional training on the gait pattern and functional gait tasks during post-stroke inpatient rehabilitation.	n=32 subacute stroke (<10 wks); LOPES-II n=17; conventional n=15	6 wks (total sessions varied) Robotic: 3×30-min LOPES-II/wk + up to 2×30-min conventional GT/wk Control: 3–5×30-min conventional GT/wk	• Gait speed • Step width, length • Single-support time • Symmetry ratios • 6MWT • 10MWT • TUG • Functional Gait Assessment • FMA-LE • Motricity Index- leg score (Assessed at: wk0, wk6 & wk10)	Both groups improved in gait speed. No overall superiority of AAN mDOF robotic training. Robotic group showed better foot clearance and greater paretic knee flexion improvement.	AAN mDOF robotic training was not superior to conventional training for overall gait efficiency but may improve specific gait pattern abnormalities (e.g., reduced knee flexion during swing).	Small sample; unequal total therapy dose; PEDro 8/10 (Good)

(Molteni et al., 2021) [25] Italy Multicenter RCT (5 hospitals)	Exoskeleton; Ekso™ (Ekso Bionics, USA); overground wearable powered exoskeleton	To assess the efficacy of employing an overground wearable powered exoskeleton for gait training in subacute stroke subjects, investigating the clinical effects compared to conventional gait training.	n=75 subacute stroke (<6 months); robotic n=38; control n=37	3 wks (15 sessions); 5×/wk Both groups: 120 min conventional rehabilitation daily Robotic: +60 min Ekso™ GT Control: +60 min conventional GT	• 6MWT • 10MWT • FAC • MAS-LL • Motricity index • mBI • WHS	Both groups improved significantly in 6MWT and other measures; no significant between-group differences.	Overground exoskeleton-assisted GT produced clinical outcomes comparable to conventional GT in subacute stroke.	Short intervention; unequal age distribution; no assessor blinding; PEDro 6/10 (Good)
(Lin et al., 2022) [26] Taiwan RCT	Hybrid; MRG-P100 (HIWIN Technologies, China)	To evaluate the effectiveness of robotic walking plus trunk rehabilitation compared with robotic gait training alone on balance, walking ability, and participation measures in subacute stroke patients.	n=40 subacute stroke (10–60 days); robotic n=20; control n=20	3–4 wks (15 sessions); 30 min, 5×/wk Robotic: RAGT (5 min warm-up; 20 min training; 5 min cool-down) Control: conventional inpatient rehabilitation	• AROM • MMT • FMA-LE • FMA-total • Postural Assessment Scale for Stroke (PASS) • BBS • Tinneti test balance and gait subscores • 3MWT • 6MWT • TUG (Assessed at: wk0, wk3@4 (after	RAGT group significantly outperformed control only in FMA-LE and FMA-total. No superiority in other measures.	Hybrid RAGT improved lower limb function but was not superior to conventional rehabilitation in other domains.	Device not widely validated; PEDro 8/10 (Good)

					completing intervention) & 3 months follow-up)			
(Wall et al., 2023) [27] Sweden RCT subsample	Exoskeleton ; single-leg Hybrid Assistive Limb (HAL) (Cyberdyne Inc., Japan); voluntary EMG mode; treadmill with BWS	To evaluate whether the addition of electromechanic ally-assisted gait training to conventional training resulted in better gait pattern function than conventional training alone.	n=17 stroke (<8 wks); robotic n=10; control n=7	4 wks (16 sessions) All: conventional team-based rehab 5×/wk Robotic: +HAL RAGT 4×/wk (single-leg; voluntary mode; treadmill with BWS)	• FAC • 2MWT • BBS • FMA-LE Assessed at: wk0 & wk4	No significant between-group differences in gait pattern, kinematic, kinetic, or spatiotempor al parameters. Both groups showed similar gait patterns.	Adding HAL-assisted training to conventional rehabilitatio n did not improve gait deviation or asymmetry compared with conventional training in this small, severely impaired stroke sample.	Small sample; missing pre-intervention gait analysis data; short intervention; no blinding; PEDro 7/10 (Good)
(Yokota et al., 2023) [28] Japan RCT	Exoskeleton ; Hybrid Assistive Limb (HAL-FL05) (Cyberdyne Inc., Japan); biped, non-medical welfare model	To investigate efficacy of early gait training using Hybrid Assistive Limb (HAL) in improving walking and independence compared with conventional physical therapy (CPT) in patients	n=32 acute stroke (within 10 days); robotic n=22; control n=10	2–4 wks (20 sessions); 20 min/session; 1–3 sessions/d, 5–6 d/w Robotic: HAL 3 d/wk + 2–3 d/w conventional PT Control: conventional PT only	• FIM • FAC • FMA • mRS (Assessed at: wk0; post-20 sessions; 3-month follow-up)	No significant between-group differences in any outcome measures.	HAL gait training did not improve walking ability or independen ce compared with conventional PT after 20 sessions.	Small sample; short duration; limited intervention dosage; use of non-medical device; high exclusion rate (selection bias risk); no blinding reported; PEDro 7/10 (Good)

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		with severe walking disability after stroke.						

Abbreviations:

wk: week, wks: weeks, d: day, x: times, min: minutes, RCT: randomized controlled trial, FAC: Functional ambulation categories, GT: gait training, K-MBI: Korean MBI, 2MWT: 2 Minute Walk Test; BBS: Berg Balance Scale; FMA: Fugl-Meyer Assessment, PASS: Postural Assessment Scale for Stroke, CPT: conventional physical therapy, FMA-LE: Fugl-Meyer Assessment lower extremity, BWS: Body Weight Support, DOF: Degrees of Freedom, 10MWT: 10-Meter Walk Test, 6MWT: 6-Minute Walk Test, TUG: Timed Up and Go Test, VR: virtual reality, FIM: Functional Independence Measures, mRS: modified Rankin Scale, WHS: Walking Handicap Scale, MAS-LL: Modified Ashworth Scale of The Affected lower Limb, AROM: active range of motion, PASS: Postural Assessment Scale for Stroke, MMT: manual muscle test, ROM: range of motion

Note: One study included both exoskeleton and end-effector RAGT groups compared with a conventional overground gait training group. This study was counted once in the total number of included studies but was considered under both exoskeleton and end-effector categories during device-specific synthesis.