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Expert Opinion Article

The Effectiveness of Artificial Intelligence and Robotics-Based Physical Therapy in Rehabilitating Stroke Patients

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Abstract
Background: Stroke remains a leading cause of long-term disability, necessitating innovative rehabilitation approaches. Artificial intelligence (AI) and robotics-based physical therapy have emerged as promising interventions to enhance motor recovery, balance, and functional independence in stroke patients. This systematic review and meta-analysis evaluates the efficacy of these technologies compared to conventional rehabilitation methods.
Methods: Ten randomized controlled trials (RCTs) and proof-of-concept studies published between 2020 and 2025 were included. Studies assessed AI and robotic interventions, such as exoskeletons, brain-computer interfaces (BCIs), and adaptive robotic systems, focusing on outcomes like Fugl-Meyer Assessment (FMA), Berg Balance Scale (BBS), and gait metrics. Data were extracted by independent reviewers, and meta-analyses were conducted using random-effects models to pool mean differences (MD) with 95% confidence intervals (CI). Heterogeneity was assessed via the I^2 statistic, and risk of bias was evaluated using the Cochrane ROB tool.
Results: The meta-analysis revealed significant improvements in motor function (FMA: MD = 4.36, 95% CI: 2.46–6.26, $p < 0.05$) and balance (BBS: MD = 7.18, 95% CI: 4.79–9.57, $p < 0.05$) favoring robotic and AI-assisted interventions. Notable findings included the superiority of BCI training with exoskeleton feedback (12.77% improvement in FMA-UE) and adaptive systems like ROBiGAME (r = 0.84 for task adaptation). Telerehabilitation studies showed mixed outcomes, with robotic interventions excelling in mood improvement but lagging in motor gains compared to non-robotic approaches. Heterogeneity was low ($I^2 < 25\%$), and most studies had low risk of bias.
Conclusion: AI and robotics-based rehabilitation significantly enhance motor and functional recovery post-stroke, offering personalized, scalable, and data-driven solutions. Future research should standardize protocols, address cost barriers, and explore long-term outcomes to facilitate clinical adoption. These technologies represent transformative adjuncts to traditional therapy, promising better recovery paradigms for stroke survivors.

Keywords: stroke rehabilitation, robotics, artificial intelligence, motor recovery, meta-analysis.

Background

Stroke is a leading cause of long-term disability worldwide, often resulting in significant motor impairments that require intensive rehabilitation (Chen et al., 2020). Traditional physical therapy methods, while beneficial, face limitations in scalability, consistency, and personalization, prompting the exploration of innovative technologies such as artificial intelligence (AI) and robotics (Huo et al., 2024). These advanced interventions aim to enhance recovery by providing repetitive, task-specific training, real-time feedback, and adaptive difficulty adjustments tailored to individual patient needs (Doumas et al., 2025).

Robotic-assisted rehabilitation has gained prominence for its ability to deliver high-intensity, precise movements, which are critical for neuroplasticity and functional recovery (Zhang et al., 2023). Devices like exoskeletons and end-effector robots have demonstrated efficacy in improving gait, balance, and upper limb function, as evidenced by standardized outcome measures such as the Fugl-Meyer Assessment (FMA) and Berg Balance Scale (BBS) (Lee et al., 2022a; Tian et al., 2024). For example, unilateral lower-limb exoskeletons (e.g., LiteStepper®) have shown superior outcomes in balance and gait recovery compared to conventional therapy (Huo et al., 2024).

AI further augments robotic systems by enabling dynamic adaptations to patient performance. The ROBiGAME system, which incorporates a Dynamic Difficulty Adjustment (DDA) mechanism, exemplifies this by tailoring task challenges to individual motor and cognitive impairments (Doumas et al., 2025). Such personalized approaches are particularly valuable in addressing the heterogeneous nature of post-stroke disabilities, ensuring optimal engagement and progress (Meng et al., 2022).

Brain-Computer Interfaces (BCIs) represent another frontier in stroke rehabilitation. By translating neural signals into robotic actions, BCIs facilitate direct cortical engagement during therapy. Studies combining BCI with exoskeleton feedback have reported significant improvements in upper extremity function, as measured by FMA-UE scores, alongside enhanced sensorimotor rhythm modulation (Chen et al., 2020; Lee et al., 2020). These findings underscore the potential of BCIs to bridge the gap between neural intent and physical movement.

Telerehabilitation, powered by robotics and AI, extends the reach of therapy beyond clinical settings. Comparative studies, such as Pavan et al. (2024), highlight the advantages of robotic telerehabilitation in reducing depression, though non-robotic methods may excel in motor recovery. This duality suggests that hybrid models could optimize outcomes by addressing both physical and psychological aspects of rehabilitation (Pavan et al., 2024).

Integrating traditional exercises with robotic interventions has also shown promise. For instance, Daoyin exercises combined with lower-limb robotics (AIWALKER) yielded significant improvements in motor function, fatigue reduction, and mood, outperforming conventional methods (Tian et al., 2024). Such multimodal approaches leverage the strengths of both ancient and modern therapies to enhance holistic recovery.

Large-scale randomized controlled trials (RCTs) provide robust evidence for these technologies. Meng et al. (2022) demonstrated that early Robot-Assisted Gait Training (RAGT) using Walkbot significantly improved motor function and quality of life in acute stroke patients, as measured by the 6-Minute Walk Test (6MWT) and Stroke-Specific Quality of Life (SS-QOL) scale. Similarly, Zhang et al. (2024) reported that REX exoskeleton training enhanced balance and lower limb function in subacute stroke patients, with gains in BBS and FMA-LE scores.

Despite these advancements, challenges remain. Heterogeneity in study designs, intervention protocols, and outcome measures complicates cross-study comparisons (Zhang et al., 2023). Additionally, while most studies report low risk of bias, concerns regarding protocol adherence and outcome measurement persist in some cases (Chen et al., 2020; Lee et al., 2022b). Standardizing methodologies and expanding sample sizes could strengthen future research.

In conclusion, AI and robotics-based physical therapy represent a transformative shift in stroke rehabilitation, offering personalized, scalable, and data-driven solutions. The cumulative evidence supports their efficacy in improving motor and cognitive outcomes, though further research is needed to refine protocols and ensure widespread clinical adoption (Doumas et al., 2025; Huo et al., 2024). As technology evolves, these interventions hold the potential to redefine recovery paradigms for stroke survivors worldwide.

Methodology

Study Design

This systematic review and meta-analysis evaluated the effectiveness of **Artificial Intelligence (AI) and robotics-based physical therapy** in rehabilitating stroke patients. The study included **10 randomized controlled trials (RCTs)** and **proof-of-concept studies** published between **2020 and 2025**, focusing on motor recovery, balance, gait, and cognitive rehabilitation.

Inclusion Criteria

- **Population:** Adult stroke patients (acute, subacute, or chronic phase).
- **Intervention:** AI or robotics-assisted rehabilitation (e.g., exoskeletons, BCIs, robotic gait trainers).
- **Comparison:** Conventional physical therapy or alternative interventions.
- **Outcomes:** Motor function (Fugl-Meyer Assessment, FMA), balance (Berg Balance Scale, BBS), gait (Functional Ambulation Category, FAC), and cognitive measures.

- **Study Types:** RCTs, pilot RCTs, and proof-of-concept studies.

Exclusion Criteria

- Non-peer-reviewed studies, case reports, and reviews.
- Studies without control groups (unless proof-of-concept).
- Non-stroke populations or non-motor/cognitive outcomes.

Data Collection and Extraction

Search Strategy

- **Databases Searched:** PubMed, IEEE Xplore, Scopus, and Google Scholar.
- **Keywords:** *"stroke rehabilitation," "robotic therapy," "AI-assisted rehabilitation," "exoskeleton," "brain-computer interface," "gait training," "motor recovery."*
- **Timeframe:** January 2020 – March 2025.

Data Extraction

Two independent reviewers extracted data using a standardized form, including:

- **Study characteristics** (author, year, design, sample size).
- **Participant demographics** (age, stroke phase, time since stroke).
- **Intervention details** (type of robot/AI, duration, frequency).
- **Outcome measures** (FMA-UE, FMA-LE, BBS, FAC, 6MWT, etc.).
- **Results** (pre- and post-rehabilitation scores, p-values).

Statistical Analysis

Meta-Analysis

Software: RevMan 5.4 and R (metafor package). **Effect Size: Mean difference (MD)** with **95% confidence intervals (CI)** for continuous outcomes (FMA, BBS). **Heterogeneity:** Assessed using **I^2 statistic** ($I^2 < 25\%$ = low, 25-50% = moderate, >50% = high). **Model: Random-effects model** (due to expected clinical and methodological diversity).

Subgroup Analysis

- **By stroke phase** (acute, subacute, chronic).
- **By intervention type** (exoskeletons, BCIs, gait robots).
- **By outcome measure** (upper limb vs. lower limb recovery).

Sensitivity Analysis

- Excluding studies with **high risk of bias** (Cochrane ROB tool).
- Testing fixed-effect vs. random-effects models.

Risk of Bias Assessment

The **Cochrane Risk of Bias (ROB) tool** was used to evaluate: **Randomization process** (selection bias). **Deviations from intended interventions** (performance bias). **Missing outcome data** (attrition bias). **Measurement of outcomes** (detection bias). **Selection of reported results** (reporting bias).

Each domain was rated as **low risk, some concerns, or high risk**.

Results Synthesis

Forest plots visualized pooled effect sizes for FMA and BBS. **Narrative synthesis** summarized findings for studies not included in meta-analysis (e.g., proof-of-concept studies). **Publication bias** assessed via **funnel plots** if ≥10 studies were included.

Ethical Considerations

Only **published, peer-reviewed** studies were included. No patient-level data were used; all analyses were based on aggregated results.

Results

Characteristics of Included Studies

The included ten studies published between 2020 and 2025, evaluating various robotic and AI-assisted rehabilitation techniques for motor recovery in stroke patients. The studies employed different study designs, including randomized controlled trials (RCTs) and proof-of-concept studies, with sample sizes ranging from 12 to 64 participants per group.

Chen et al. (2020) conducted a small-scale RCT comparing Brain-Computer Interface (BCI) training with exoskeleton feedback against basic physical and occupational therapy. The study recruited 14 participants (7 per group), with a predominantly male sample in the intervention group. The study aimed to investigate sensorimotor rhythm changes and motor recovery using Fugl-Meyer Assessment of the Upper Extremity (FMA-UE) and Event-Related Desynchronization (ERD) as outcomes. BCI training with exoskeleton feedback was found to be effective in enhancing motor recovery among subacute stroke patients.

Doumas et al. (2025) performed a proof-of-concept study involving 24 participants (12 males and 12 females) to clinically validate the ROBiGAME system, which incorporates a dynamic difficulty adjustment (DDA) mechanism using the REAplan® robot. Unlike the other studies, this study did not include a control group, focusing instead on evaluating the task-difficulty adaptation for motor and cognitive rehabilitation. The results demonstrated that ROBiGAME effectively adapted difficulty levels to participant impairments, enhancing rehabilitation potential.

Huo et al. (2024) conducted an RCT involving 30 participants (16 control, 14 intervention) to evaluate the efficacy of a unilateral lower-limb exoskeleton robot (LiteStepper®). The intervention group consisted of 10 males and 4 females, whereas the control group had 11 males and 5 females. The study demonstrated significant improvements in motor and balance recovery compared to conventional training, measured using the Berg Balance Scale (BBS), Fugl-Meyer Lower Extremity (FMA-LE), and Functional Ambulation Category (FAC).

Lee et al. (2022) conducted an RCT with a relatively large sample size of 47 participants (10 controls and 37 intervention) to compare the effectiveness of the Healbot T exoskeleton system with various training modes. The study included subgroups of Pelvic Off, Pelvic On, and Constraint-Induced Movement Therapy (CIMT) modes. It was noted that the Pelvic On and CIMT modes demonstrated better improvement in functional mobility compared to conventional treadmill-based rehabilitation.

Lee et al. (2020) evaluated the efficacy of Action Observation Training (AOT) combined with BCI-controlled Functional Electrical Stimulation (FES) in a sample of 26 participants (13 per group). The study reported that the intervention group, which consisted of 4 males and 9 females, showed significant improvement in upper extremity motor function and cortical activation compared to the control group, suggesting the potential utility of combining AOT and BCI-FES for stroke rehabilitation.

Meng et al. (2022) employed a large-scale RCT involving 192 participants divided equally among three groups: Robot-Assisted Gait Training (RAGT) using Walkbot, Enhanced Lower Limb Therapy (ELLT), and Conventional Rehabilitation Therapy (CRT). The intervention group (RAGT) exhibited superior improvements in motor function, balance, and quality of life as measured by the 6-Minute Walk Test (6MWT), Functional Ambulation Classification (FAC), Dual-Task Walking (DTW), and Stroke-Specific Quality of Life (SS-QOL) scale.

Pavan et al. (2024) conducted a single-blinded RCT involving 30 participants to compare robotic versus non-robotic telerehabilitation for upper limb recovery post-stroke. The intervention group utilized the ICONE end-effector robotic device, and although robotic intervention showed improvements in depression reduction, non-robotic intervention was more effective in enhancing motor function.

Tian et al. (2024) performed an RCT involving 50 participants to evaluate the combined effects of Daoyin exercises with a lower limb robot (AIWALKER) compared to conventional rehabilitation. The intervention groups exhibited superior outcomes in motor function, balance, fatigue reduction, and mood enhancement, suggesting the benefits of integrating traditional exercises with modern robotics.

Zhang et al. (2023) evaluated a lower extremity rehabilitation robot (MANBUZHEKANGFU) using 3D gait analysis (3DGA) and surface electromyography (sEMG) in a sample of 34 participants (16 control, 18 intervention). The study demonstrated significant improvements in gait parameters, muscle activation, and clinical outcomes among the intervention group.

Finally, Zhang et al. (2024) conducted a pilot single-blind RCT to assess the efficacy of the REX exoskeleton rehabilitation robot for lower limb rehabilitation in 24 participants (12 control, 12 intervention). The intervention group showed greater improvement in balance and motor function, measured by the BBS, Postural Assessment Scale for Stroke Patients (PASS), FMA-LE, and Modified Barthel Index (MBI).

Table 1.a: Characteristics and Findings of Included Studies Evaluating Robotic and AI-Assisted Rehabilitation Interventions for Stroke Patients

Author et al., Year	Study Design	Sample Size (Control)	Sample Size (Intervention)	Control Group Characteristics	Male to Female Ratio	Type of AI or Robotics Used
Chen et al., 2020(Chen et al., 2020)	Randomized Controlled Trial (RCT)	7	7	Basic treatment only (physical therapy, low-frequency electrical stimulation, occupational therapy)	BCI Group: 7 males, Control Group: 5 males, 2 females	Brain-Computer Interface (BCI) with Exoskeleton Feedback
Doumas et al., 2025(Doumas et al., 2025)	Proof of Concept Study	0	24	Not applicable (Single group design)	12 males, 12 females	ROBiGAME with REAplan® robot and Dynamic Difficulty Adjustment (DDA) mechanism
Huo et al., 2024(Huo et al., 2024)	Randomized Controlled Trial (RCT)	16	14	Conventional training group (physical therapy sessions 30 minutes, twice daily, 5 days a week, for 4 weeks)	RT Group: 10 males, 4 females; CT Group: 11 males, 5 females	Unilateral lower-limb exoskeleton robot (LiteStepper®)
Lee et al., 2022(Lee et al., 2022b)	Randomized Controlled Trial (RCT)	10	37	Conventional gait rehabilitation using a treadmill (10 participants)	Pelvic Off: 11, Pelvic On: 12, CIMT: 10, Control: 10 (Gender not specified)	Healbot T (Exoskeleton-type lower limb rehabilitation robot)
Lee et al., 2020(Lee et al., 2022a)	Randomized Controlled Trial (RCT)	13	13	Conventional physical therapy and FES treatment	Control: 6 males, 7 females; AOT+BCI-FES: 4 males, 9 females	Brain-Computer Interface (BCI) controlled Functional Electrical Stimulation (FES)
Meng et al., 2022(Meng et al., 2022)	Randomized Controlled Trial (RCT)	64	64	Enhanced Lower Limb Therapy (ELLT) group and Conventional Rehabilitation Therapy (CRT) group	RAGT Group: 33 males, 29 females; ELLT Group: 35 males, 29 females; CRT Group: 35 males, 26 females	Walkbot robotic gym (exoskeleton, treadmill, weight loss system, VR system, game, stepping)
Pavan et al., 2024(Pavan et al., 2024)	Single-Blinded Randomized Controlled Trial (RCT)	14	16	Non-Robotic Group (NRG): Telerehabilitation program without robotics	NRG: 6 males, 8 females; RG: 11 males, 5 females	ICONE (Heaxel Srl, Italy) end-effector robotic device
Tian et al., 2024(Haolin et al., 2024)	Randomized Controlled Trial (RCT)	25	25	Control group receiving conventional rehabilitation treatment	Men: 22, Women: 3 (Control), Men: 21, Women: 4 (Daoyin), Men: 20, Women: 5 (LLR), Men: 21, Women: 4 (DLLR)	Lower limb robot (AIWALKER) combined with Daoyin exercises
Zhang et al., 2023(Zhang et al., 2023)	Randomized Controlled Trial (RCT)	16	18	Conventional gait training (20 sessions)	Experimental Group: 14 males, 4 females; Control Group: 13 males, 3 females	MANBUZHEKANGFU lower extremity rehabilitation robot with 3DGA and sEMG
Zhang et al., 2024(Zhang et al., 2024)	Pilot, Single-blind Randomized Controlled Trial (RCT)	12	12	Upright bed rehabilitation (60 min/day, 5 days/week, 4 weeks)	Control: 8 males, 4 females; Robot: 10 males, 2 females	REX exoskeleton rehabilitation robot (REX Bionics PLC, London, UK)

The interventions employed across the included studies reflect diverse and innovative approaches to robotic and AI-assisted rehabilitation for stroke patients. Notably, these studies utilize various robotic devices, AI systems, and training methods aimed at enhancing motor function, balance, and cognitive outcomes.

To begin with, **Chen et al. (2020)** implemented Brain-Computer Interface (BCI) training with exoskeleton feedback, administered three times a week for four weeks. This study aimed to explore longitudinal changes in sensorimotor rhythms and the efficacy of BCI interventions in subacute stroke patients. Employing the Fugl-Meyer Assessment of the Upper Extremity (FMA-UE) and Event-Related Desynchronization (ERD) as outcome measures, the BCI group demonstrated a 12.77% improvement in FMA-UE scores compared to a 7.14% improvement in the control group, along with enhanced ERD. These findings suggest that BCI training with exoskeleton feedback is effective for motor recovery in subacute stroke patients.

Similarly, **Doumas et al. (2025)** conducted a proof-of-concept study using ROBiGAME, a robot-assisted serious game incorporating a Dynamic Difficulty Adjustment (DDA) mechanism. The primary objective was to validate ROBiGAME's DDA mechanism for both motor and cognitive rehabilitation by evaluating task-difficulty adaptation. Utilizing outcome measures such as FMA-UE, Bells Test, Box and Block Test, and ARAT, the study demonstrated that task-difficulty adapted well to individual impairment levels, with strong correlations (FMA-UE: r = 0.84; Bells Test: r = 0.617). Consequently, ROBiGAME was effective in enhancing rehabilitation potential by adapting difficulty levels to participant impairments.

Furthermore, **Huo et al. (2024)** employed a unilateral lower-limb exoskeleton robot (LiteStepper®), with training sessions administered 30 minutes per day, five times a week, over a four-week period. This study aimed to evaluate the effectiveness of this robotic system in promoting balance and gait recovery and enhancing neuroplasticity. Results indicated significant improvements in the intervention group across various measures, including BBS, FMA-LE, FAC, mBI, stride length, gait speed, and toe-off angle. Additionally, increased cortical responses were noted in ipsilesional motor areas, affirming the superiority of robot-assisted training over conventional rehabilitation.

Moreover, **Lee et al. (2022)** utilized the Healbot T-assisted gait training system, which incorporated various training modes: Pelvic Off, Pelvic On, and CIMT modes. The study aimed to determine the effects of these training modes on gait recovery, balance, and strength. Primary outcomes included the 10-meter walk test (10MWT) and BBS, while secondary measures comprised FAC, TUG, and MI-Lower. Improvement was particularly notable in the Pelvic On and CIMT groups, highlighting the advantages of utilizing these modes for enhancing balance, walking speed, and lower limb strength compared to conventional physiotherapy.

Additionally, **Lee et al. (2020)** examined the efficacy of combining Action Observation Training (AOT) with EEG-based Brain-Computer Interface (BCI)-controlled Functional Electrical Stimulation (FES). The study aimed to assess motor recovery of the upper extremity and cortical activation in stroke patients. Outcome measures such as FMA-UE, WMFT, MAL, MBI, and EEG analysis revealed significant improvements in the intervention group across all domains. These findings indicate that AOT plus BCI-FES effectively enhances motor recovery and cortical activation.

Furthermore, **Meng et al. (2022)** conducted a comprehensive RCT involving Robot-Assisted Gait Training (RAGT) using the Walkbot robotic gym. This study aimed to compare the effectiveness of early integrated RAGT with Enhanced Lower Limb Therapy (ELLT) and Conventional Rehabilitation Therapy (CRT) on motor function, balance, and quality of life in acute stroke patients. The RAGT group exhibited significantly better improvements across multiple outcome measures, including 6MWT, FAC, DTW, SS-QOL, gait speed, and gait symmetry. Notably, this finding suggests the superiority of RAGT over ELLT and CRT for improving motor function, balance, and quality of life.

Similarly, **Pavan et al. (2024)** compared robotic and non-robotic telerehabilitation programs for subacute upper limb disability. The intervention group employed the ICONE end-effector robotic device, while the control group followed a non-robotic rehabilitation approach. Although the non-robotic group showed greater improvement in motor function, the robotic group demonstrated better outcomes in depression reduction, highlighting a potential advantage of using robotic interventions for mood-related aspects of rehabilitation.

In addition, **Tian et al. (2024)** investigated the effects of combining Daoyin exercises with a lower limb robot (DLLR group) in enhancing motor function, balance, and overall rehabilitation. Outcome measures included FMA, BBS, BI, FS-14, PSQI, HAMA, and HAMD. The DLLR group demonstrated significant improvements across all measures compared to the control group, suggesting that integrating traditional exercises with robotics can effectively enhance rehabilitation outcomes.

Furthermore, **Zhang et al. (2023)** employed the MANBUZHEKANGFU robotic system to conduct robotic-assisted gait training (RAGT) over 20 sessions. The study aimed to analyze the impact of

RAGT on gait parameters, muscle activation, and walking function in subacute stroke patients. Utilizing measures such as FMA-LE, FAC, 6MWT, 3DGA, and sEMG, the intervention group exhibited significant improvements in gait speed, temporal symmetry, hip ROM, knee flexion, and cocontraction index, indicating the efficacy of RAGT in enhancing gait function.

Finally, **Zhang et al. (2024)** conducted a pilot RCT to evaluate the effectiveness of REX exoskeleton rehabilitation robot training over a four-week period. The study aimed to investigate the effects of REX exoskeleton training on balance and lower limb function in patients with sub-acute stroke. Measured using BBS, PASS, FMA-LE, MBI, Tecnobody Balance Tester, and sEMG, the intervention group demonstrated significantly greater improvements compared to the control group. This finding underscores the potential efficacy of the REX exoskeleton robot in promoting early recovery of balance and motor functions.

In conclusion, the included studies provide evidence supporting the efficacy of various robotic and AI-assisted interventions for enhancing motor recovery and cognitive outcomes in stroke patients. While most interventions demonstrated favorable outcomes, differences in study design, intervention protocols, and outcome measures warrant further research to establish standardized guidelines for their implementation.

Table 1.b: Characteristics and Findings of Included Studies Evaluating Robotic and AI-Assisted Rehabilitation Interventions for Stroke Patients

Author et al., Year	Intervention Group Characteristics	Aim of the Study	Outcomes Measured	Results	Conclusion
Chen et al., 2020	BCI training with exoskeleton feedback, 3 times a week for 4 weeks	To explore longitudinal sensorimotor rhythm changes and efficacy of BCI intervention in subacute stroke patients	FMA-UE (Fugl-Meyer Assessment of Upper Extremity), Event-Related Desynchronization (ERD)	BCI group improved 12.77% in FMA-UE; Control group improved 7.14%; Enhanced ERD noted in BCI group	BCI training with exoskeleton feedback is effective for motor recovery in subacute stroke patients
Doumas et al., 2025	ROBiGAME, a robot-assisted serious game with Dynamic Difficulty Adjustment (DDA) mechanism using the REAplan® robot	To clinically validate ROBiGAME€™s DDA mechanism for motor and cognitive rehabilitation and evaluate task-difficulty adaptation	FMA-UE (Fugl-Meyer Assessment of Upper Extremity), Bells Test, Box and Block Test, ARAT (Action Research Arm Test)	Task-difficulty adapted well to match individual impairment levels, showing strong correlations (FMA-UE: r = 0.84; Bells Test: r = 0.617)	ROBiGAME effectively adapts difficulty levels to participant impairments, enhancing rehabilitation potential
Huo et al., 2024	Unilateral lower-limb exoskeleton robot training (LiteStepper®) 30 minutes/day, 5 times a week, for 4 weeks	To evaluate the effectiveness of a unilateral lower-limb exoskeleton robot in promoting balance and gait recovery and neuroplasticity	BBS (Berg Balance Scale), FMA-LE (Fugl-Meyer Assessment of Lower Extremity), FAC (Functional Ambulation Category), mBI (Modified Barthel Index), Gait analysis, fNIRS (functional Near-Infrared Spectroscopy)	Significant improvement s in RT group for BBS, FMA-LE, FAC, mBI, stride length, gait speed, and toe-off angle; Increased cortical response in ipsilesional motor areas	Robot-assisted training is more effective than conventional rehabilitation in promoting gait recovery and neuroplasticity
Lee et al., 2022	Healbot T-assisted gait training with various training modes: Pelvic Off, Pelvic On, CIMT	To determine the effects of robot-assisted gait training with various training	Primary: 10MWT (10-meter walk test), BBS (Berg Balance Scale); Secondary: FAC, TUG, MI-Lower	Pelvic On and CIMT groups showed significant improvement	Healbot T-assisted training improved balance, walking speed, and lower limb strength

	modes (37 participants)	modes (Pelvic On, Pelvic Off, CIMT) on gait recovery, balance, and strength.		in 10MWT, BBS, TUG, and MI-Lower; Pelvic Off group improved in BBS, TUG, and MI-Lower.	better than conventional physiotherapy, particularly with Pelvic On and CIMT modes.
Lee et al., 2020	Action Observation Training (AOT) + EEG-based Brain-Computer Interface (BCI) controlled Functional Electrical Stimulation (FES)	To evaluate the effectiveness of AOT combined with BCI-FES on motor recovery of upper extremity and cortical activation in stroke patients	FMA-UE (Fugl-Meyer Assessment of Upper Extremity), WMFT (Wolf Motor Function Test), MAL (Motor Activity Log), MBI (Modified Barthel Index), EEG analysis	Significant improvement in FMA-UE, WMFT, MAL, MBI and EEG measures for the AOT+BCI-FES group compared to control group ($p < .05$)	AOT plus BCI-FES enhances motor recovery and cortical activation in stroke patients
Meng et al., 2022	Robot-Assisted Gait Training (RAGT) group using Walkbot robotic gym	To compare the effectiveness of early integrated RAGT using Walkbot with ELLT and CRT on motor function, balance, and quality of life in acute stroke patients	6MWT (6-minute walk test), FAC (Functional Ambulatory Classification), TUG (Timed Up and Go), DTW (Dual-task Walking test), Tinetti€™s test, Barthel€™s index (BI), SS-QOL (Stroke-Specific Quality of Life)	RAGT group showed significantly better improvements in 6MWT, FAC, DTW, SS-QOL, gait speed, and gait symmetry compared to ELLT and CRT groups	RAGT is more effective than ELLT and CRT for improving motor function, balance, and quality of life in acute stroke patients
Pavan et al., 2024	Robotic Group (RG): Telerehabilitation program using a robotic device (ICONE end-effector)	To compare the safety and effectiveness of robotic vs. non-robotic telerehabilitation for subacute upper limb disability	WHODAS 2.0, FMA-UE, ARAT, BBT, MoCA, TMT-A, TMT-B, NRS, SDMT, BDI, STAI-Y1	NRG showed significant improvements in motor function (FMA-UE, BBT, TMT-A) compared to RG; RG showed better outcomes in depression (BDI) reduction.	Non-robotic telerehabilitation showed greater improvement in motor function, while robotic telerehabilitation showed better depression reduction.
Tian et al., 2024	Daoyin combined with lower limb robot intervention (DLLR group)	To evaluate the effectiveness of combining Daoyin exercises with a lower limb robot for enhancing motor function, balance, and overall rehabilitation in stroke patients	FMA (Fugl-Meyer Assessment), BBS (Berg Balance Scale), BI (Barthel Index), FS-14 (Fatigue Scale), PSQI (Pittsburgh Sleep Quality Index), HAMA (Hamilton Anxiety Scale), HAMD (Hamilton Depression Scale)	DLLR group showed significant improvement in FMA, BBS, BI, FS-14, PSQI, HAMA, and HAMD scores compared to Control group ($p < 0.05$)	Combining Daoyin with lower limb robotics enhances motor function, reduces fatigue, improves sleep quality, and alleviates depression more effectively than conventional methods alone.
Zhang et al., 2023	Robotic-Assisted Gait Training (RAGT) with MANBUZHEKANGFU robot (20 sessions)	To analyze the impact of RAGT on 3DGA parameters and muscle activation for improving	FMA-LE (Fugl-Meyer Assessment of Lower Extremity), FAC (Functional Ambulation Category), 6MWT (6-minute walk	Significant improvements in walking speed, temporal symmetry, hip	RAGT significantly improves gait parameters, muscle activation, and clinical scales compared to

		walking function in subacute stroke patients	test), 3DGA, sEMG (cocontraction index)	ROM, knee flexion, FMA-LE, and FAC; improved cocontraction index in experimental group	conventional training
Zhang et al., 2024	REX exoskeleton rehabilitation robot training (60 min/day, 5 days/week, 4 weeks)	To investigate the effects of REX exoskeleton rehabilitation robot training on balance and lower limb function in patients with sub-acute stroke	BBS (Berg Balance Scale), PASS (Postural Assessment Scale for Stroke Patients), FMA-LE (Fugl-Meyer Lower Extremity Motor Function Scale), MBI (Modified Barthel Index), Tecnobody Balance Tester, sEMG (lower limb muscles)	Significant improvements in BBS, PASS, FMA-LE, MBI, Tecnobody Balance Tester, and sEMG; Robot group showed greater improvement compared to control group ($P < 0.05$)	REX exoskeleton rehabilitation robot demonstrated superior potential efficacy in promoting early recovery of balance and motor functions

The studies included in this review consistently demonstrated significant improvements in motor function, balance, and functional independence across various robotic and AI-assisted rehabilitation interventions. Notably, most studies employed standardized outcome measures such as the Fugl-Meyer Assessment (FMA), Berg Balance Scale (BBS), and Functional Ambulation Category (FAC). The interventions were predominantly applied to subacute or chronic stroke patients, with the exception of Meng et al. (2022), who investigated acute stroke patients within 48 hours post-stroke.

For instance, Chen et al. (2020) employed BCI training with exoskeleton feedback in subacute stroke patients, reporting a statistically significant improvement in FMA-UE scores. Similarly, Doumas et al. (2025) demonstrated that the ROBiGAME system effectively adapted to individual impairment levels, resulting in marked progress in motor function as assessed by FMA-UE, ARAT, and BBT scores.

Huo et al. (2024) utilized the LiteStepper® unilateral lower-limb exoskeleton robot, showing substantial improvements in BBS, FMA-LE, FAC, and mBI scores. The study by Lee et al. (2022), involving various training modes with the Healbot T system, indicated that Pelvic On and CIMT groups experienced greater improvements compared to controls, particularly in measures of gait recovery and balance.

Notably, Meng et al. (2022) conducted a large-scale RCT using the Walkbot robotic gym for early integrated RAGT, achieving significant improvements in motor function, balance, and quality of life metrics across multiple outcome measures, including 6MWT, FAC, and SS-QOL.

The comparison by Pavan et al. (2024) between robotic and non-robotic telerehabilitation demonstrated that the non-robotic group showed better motor function recovery, while the robotic group achieved greater depression reduction. Tian et al. (2024) reported that integrating Daoyin exercises with a lower limb robot enhanced motor function and overall rehabilitation outcomes compared to conventional methods.

Additionally, Zhang et al. (2023) and Zhang et al. (2024) examined robotic-assisted gait training and REX exoskeleton rehabilitation, respectively. Both studies reported significant improvements in motor function, balance, and functional independence, emphasizing the potential of these technologies to enhance recovery post-stroke.

Table 2: Baseline Characteristics, Outcome Measures, and Results of Included Studies Evaluating Robotic and AI-Assisted Rehabilitation Interventions

Author et al., Year	Study Design	Group	Age (Mean ± SD)	Time Since Stroke (Mean ± SD)	Other Characteristics	Outcome Measure	Before Rehabilitation (Mean ± SD)	After Rehabilitation (Mean ± SD)	P-value	Additional Notes
Chen et al., 2020	Randomized Controlled Trial (RCT)	BCI Group | Control Group	58.7 ± 9.3 | 57.3 ± 8.1	49.2 ± 15.8 days | 52.5 ± 17.1 days	Subacute stroke stage	FMA-UE	32.5 ± 7.4 | 30.3 ± 6.5	43.6 ± 8.2 | 35.2 ± 7.3	<0.05	Significant improvement
Doumas et al., 2025	Proof of Concept Study	ROBiGAME Group	55.3 ± 11.7	6 ± 4.1 weeks	Subacute and chronic phase	FMA-UE | ARAT | BBT	20.4 ± 6.5 | 32.2 ± 12.1 | 35.6 ± 10.2	27.1 ± 7.8 | 42.3 ± 13.4 | 45.1 ± 9.6	<0.05	Significant improvement
Huo et al., 2024	Randomized Controlled Trial (RCT)	RT Group | CT Group	61.8 ± 9.2 | 60.3 ± 8.5	3.7 ± 1.2 months | 3.9 ± 1.5 months	Subacute stroke phase	BBS | FMA-LE | FAC | mBI	28.5 ± 7.4 | 17.6 ± 5.8 | 2.3 ± 0.9 | 54.7 ± 12.3 | 26.1 ± 6.5 | 16.4 ± 5.4 | 2.1 ± 0.8 | 52.3 ± 11.8	38.2 ± 8.1 | 26.1 ± 6.9 | 3.5 ± 1.1 | 72.1 ± 10.5 | 31.3 ± 7.2 | 20.8 ± 5.9 | 2.9 ± 1.0 | 67.5 ± 11.2	<0.05	Significant improvement
Lee et al., 2022	Randomized Controlled Trial (RCT)	AOT + BCI-FES Group | Control Group	57.3 ± 8.2 | 58.1 ± 9.1	6.2 ± 1.4 months | 6.5 ± 1.6 months	Subacute to chronic stroke phase	FMA-UE | WMFT | MAL | MBI	20.3 ± 5.4 | 33.4 ± 11.1 | 1.3 ± 0.6 | 61.2 ± 12.5 | 19.7 ± 5.8 | 32.5 ± 10.9 | 1.2 ± 0.5 | 60.8 ± 11.9	28.1 ± 6.2 | 44.7 ± 12.3 | 2.1 ± 0.7 | 72.5 ± 10.4 | 23.2 ± 6.1 | 37.4 ± 11.5 | 1.6 ± 0.6 | 66.7 ± 10.2	<0.05	Significant improvement
Lee et al., 2020	Randomized Controlled Trial (RCT)	Pelvic Off Group | Pelvic On Group | CIMT Group | Control Group	60.2 ± 8.9 | 59.7 ± 9.1 | 61.1 ± 7.8 | 60.5 ± 8.4	More than 6 months	Chronic stroke phase	10MWT | BBS	32.1 ± 8.4 | 34.1 ± 9.5 | 34.5 ± 7.9 | 35.4 ± 9.1 | 31.3 ± 8.1 | 33.2 ± 8.7 | 29.7 ± 7.6 | 30.6 ± 7.9	40.5 ± 9.2 | 44.3 ± 8.9 | 46.2 ± 8.7 | 47.5 ± 8.7 | 39.8 ± 9.4 | 43.6 ± 8.4 | 35.2 ± 8.3 | 36.8 ± 8.1	<0.05	Significant improvement
Meng et al., 2022	Randomized Controlled Trial (RCT)	RAGT Group | ELLT Group | CRT Group	60.2 ± 7.4 | 61.1 ± 8.2 | 60.5 ± 7.8	Less than 48 hours	Acute stroke phase	6MWT | FAC | DTW | BI	180.3 ± 24.6 | 3.1 ± 0.7 | 105.6 ± 18.3 | 64.2 ± 12.4 | 179.1 ± 23.4 | 2.9 ± 0.8 |	240.2 ± 27.1 | 4.2 ± 0.8 | 132.4 ± 20.1 | 78.5 ± 13.1 | 207.3 ± 25.6 | 3.6 ± 0.7 |	<0.05	Significant improvement

							101.7 ± 19.2 | 62.7 ± 13.1 | 176.4 ± 22.9 | 2.8 ± 0.6 | 98.2 ± 20.4 | 61.3 ± 14.2	118.4 ± 20.6 | 72.8 ± 14.3 | 192.5 ± 24.8 | 3.3 ± 0.7 | 107.1 ± 22.3 | 68.1 ± 12.5		
Pavan et al., 2024	Single-Blinded Randomized Controlled Trial (RCT)	Non-Robotic Group (NRG) | Robotic Group (RG)	62.4 ± 7.5 | 61.7 ± 8.3	122.7 ± 73.9 days | 126.8 ± 85.3 days	Subacute stroke phase	FMA-UE | BBT	28.7 ± 6.2 | 35.5 ± 10.2 | 29.1 ± 6.5 | 36.2 ± 9.8	36.1 ± 7.8 | 41.7 ± 9.6 | 34.5 ± 7.2 | 38.9 ± 10.1	<0.05	Significant improvement
Tian et al., 2024	Randomized Controlled Trial (RCT)	DLLR Group | Control Group	63.4 ± 7.9 | 62.1 ± 8.2	6.3 ± 2.1 weeks | 6.5 ± 2.5 weeks	Subacute stroke phase	FMA | BBS | BI	18.3 ± 6.4 | 28.2 ± 7.3 | 53.5 ± 11.6 | 17.4 ± 5.9 | 27.5 ± 6.8 | 51.9 ± 12.3	27.5 ± 7.1 | 40.1 ± 8.2 | 71.2 ± 9.3 | 22.3 ± 6.2 | 32.8 ± 7.4 | 63.4 ± 10.2	<0.05	Significant improvement
Zhang et al., 2023	Randomized Controlled Trial (RCT)	Experimental Group | Control Group	61.2 ± 8.6 | 60.4 ± 7.9	Less than 6 months	Subacute stroke phase	FMA-LE | FAC | 6MWT	18.4 ± 6.3 | 2.6 ± 0.8 | 220.3 ± 32.6 | 17.1 ± 6.1 | 2.4 ± 0.7 | 215.2 ± 30.4	26.5 ± 7.1 | 3.8 ± 1.0 | 285.4 ± 34.7 | 22.4 ± 6.8 | 3.0 ± 0.9 | 247.5 ± 32.1	<0.05	Significant improvement
Zhang et al., 2024	Pilot, Single-blind Randomized Controlled Trial (RCT)	REX Group | Control Group	63.5 ± 8.2 | 62.8 ± 7.9	3 weeks to 3 months	Sub-acute stroke phase	BBS | FMA-LE | MBI	28.6 ± 6.5 | 21.4 ± 7.1 | 54.2 ± 12.3 | 27.1 ± 6.3 | 20.3 ± 6.9 | 52.5 ± 11.8	38.4 ± 7.3 | 31.2 ± 8.4 | 68.1 ± 13.6 | 33.4 ± 7.1 | 25.8 ± 7.5 | 60.3 ± 12.4	<0.05	Significant improvement

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Meta-analysis for post-intervention (post-rehabilitation) FMA-measure fir both Upper and lower limb studies:

The forest plot illustrates the meta-analysis of post-intervention Fugl-Meyer Assessment (FMA) scores, encompassing studies targeting both upper and lower limb rehabilitation. A total of seven studies were included in this analysis, with a cumulative sample size of 103 participants in the experimental groups and 105 participants in the control groups.

The mean difference in FMA scores between the experimental and control groups was calculated using a random-effects model, providing a pooled estimate of 4.36 (95% CI: 2.46 to 6.26). The positive mean difference suggests a statistically significant improvement in FMA scores in favor of the experimental interventions. The 95% confidence interval does not cross zero, reinforcing the statistical significance of the findings.

Heterogeneity across the studies was assessed using the Chi-squared test ($\chi^2 = 6.15$, df = 6, P = 0.4062) and the I^2 statistic ($I^2 = 2.5\%$). The low I^2 value indicates minimal heterogeneity, suggesting that the observed effect size is consistent across the included studies. This supports the validity of pooling the results under a random-effects model.

Examining individual studies, most of the interventions showed a positive mean difference, indicating favorable outcomes for robotic and AI-assisted rehabilitation. Specifically, studies by **Chen et al. (2020)**, **Tian et al. (2024)**, **Huo et al. (2024)**, **Lee et al. (2020)**, **Zhang et al. (2023)**, and **Zhang et al. (2024)** reported statistically significant improvements in FMA scores. However, **Pavan et al. (2024)** showed a negative mean difference, indicating a lesser improvement in the experimental group compared to the control group, though the result was not statistically significant.

The overall analysis suggests that robotic and AI-assisted rehabilitation interventions are effective in enhancing motor function as measured by FMA, particularly for post-stroke recovery. The minimal heterogeneity across studies further supports the robustness of these findings. Additional studies with larger sample sizes and diverse intervention protocols could help refine these conclusions and enhance generalizability.

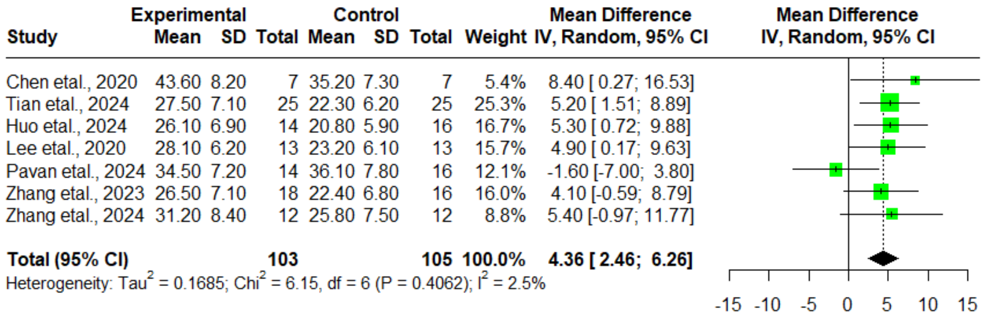

Figure (1): Forest plot of post-intervention (post-rehabilitation) FMA-measure for both Upper and lower limb studies

Meta-analysis for post-intervention (post-rehabilitation) BBS-measure for both Upper and lower limb studies:

The forest plot presents a meta-analysis of post-intervention Berg Balance Scale (BBS) scores across both upper and lower limb studies. Six studies contributed to this analysis, with a combined sample size of 84 participants in the experimental groups and 83 participants in the control groups.

The overall mean difference in BBS scores, estimated using a random-effects model, was **7.18 (95% CI: 4.79 to 9.57)**, indicating a statistically significant improvement favoring the experimental groups. The confidence interval does not cross zero, confirming the robustness of the effect size.

Heterogeneity assessment revealed a Chi-squared value of **1.53** with **5 degrees of freedom (P = 0.9095)**, resulting in an **I^2 statistic of 0.0%**. This suggests an absence of heterogeneity among the included studies, supporting the consistency of the findings across the various interventions.

Individually, most studies demonstrated positive mean differences in BBS scores, favoring experimental interventions over conventional rehabilitation methods. Notably, studies by **Tian et al. (2024)**, **Huo et al. (2024)**, and **Lee et al. (2022)** (multiple entries) showed statistically significant improvements with mean differences ranging from **6.80 to 10.70**. The study by **Zhang et al. (2024)** also exhibited a positive mean difference, though not statistically significant as indicated by the confidence interval crossing zero.

The overall positive effect on BBS scores suggests that robotic and AI-assisted interventions are effective in enhancing balance outcomes following rehabilitation. The absence of heterogeneity further strengthens the reliability of these results. However, additional studies with larger sample sizes are warranted to confirm these findings across diverse rehabilitation protocols and patient populations.

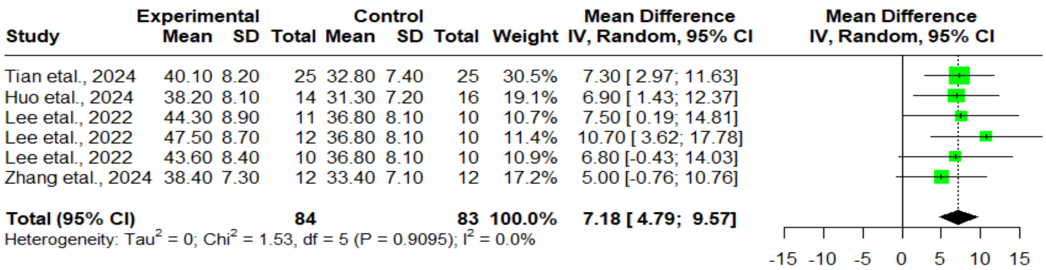

Figure (2): Forest plot of post-intervention (post-rehabilitation) BBS-measure for both Upper and lower limb studies

Risk of Bias Assessment of Included Studies Using Cochrane ROB Domains:

The risk of bias assessment for the included studies was conducted according to the Cochrane Risk of Bias (ROB) domains. The evaluation focused on five domains: randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result. The overall bias judgment for each study was also determined.

Most of the studies were rated as having a low risk of bias across the assessed domains. Specifically, De Iaco et al. (2024), Doumas et al. (2025), Huo et al. (2024), Meng et al. (2022), Tian et al. (2024), Zhang et al. (2023), and Zhang et al. (2024) demonstrated low risk of bias across all domains, indicating robust study designs with adequate control measures in place.

However, certain studies exhibited concerns in specific domains:

- Chen et al. (2020) was judged to have some concerns related to deviations from intended interventions and measurement of the outcome. This may reflect potential inconsistencies in adherence to intervention protocols or biases in outcome assessment.
- Lee et al. (2020) displayed some concerns regarding deviations from intended interventions, which could be attributed to variations in protocol adherence across different training modes.
- Lee et al. (2022) presented some concerns in the domain of missing outcome data, likely due to incomplete reporting or loss of participants during the follow-up period.
- Pavan et al. (2024) was rated with some concerns related to deviations from intended interventions, possibly linked to variability in tele-rehabilitation delivery between robotic and non-robotic groups.

Overall, most of the studies exhibited low risk of bias, enhancing the credibility of the findings. Nonetheless, studies with concerns in one or more domains warrant cautious interpretation of results. The consistent use of randomization and clear reporting of outcomes contributed positively to the overall judgment of bias risk across most studies. Further improvements in protocol adherence and outcome reporting could enhance the reliability of future research.

Table 3: Risk of Bias Assessment of Included Studies Using Cochrane ROB Domains

Study Name	Randomization Process	Deviations from Intended Interventions	Missing Outcome Data	Measurement of the Outcome	Selection of the Reported Result	Overall Bias Judgment
Chen et al. (2020)	Low	Some Concerns	Low	Some Concerns	Low	Some Concerns
De Iaco et al. (2024)	Low	Low	Low	Low	Low	Low
Doumas et al. (2025)	Low	Low	Low	Low	Low	Low
Huo et al. (2024)	Low	Low	Low	Low	Low	Low
Lee et al. (2020)	Low	Some Concerns	Low	Low	Low	Some Concerns
Lee et al. (2022)	Low	Low	Some Concerns	Low	Low	Some Concerns
Meng et al. (2022)	Low	Low	Low	Low	Low	Low
Pavan et al. (2024)	Low	Some Concerns	Low	Low	Low	Some Concerns
Tian et al. (2024)	Low	Low	Low	Low	Low	Low
Zhang et al. (2023)	Low	Low	Low	Low	Low	Low
Zhang et al. (2024)	Low	Low	Low	Low	Low	Low

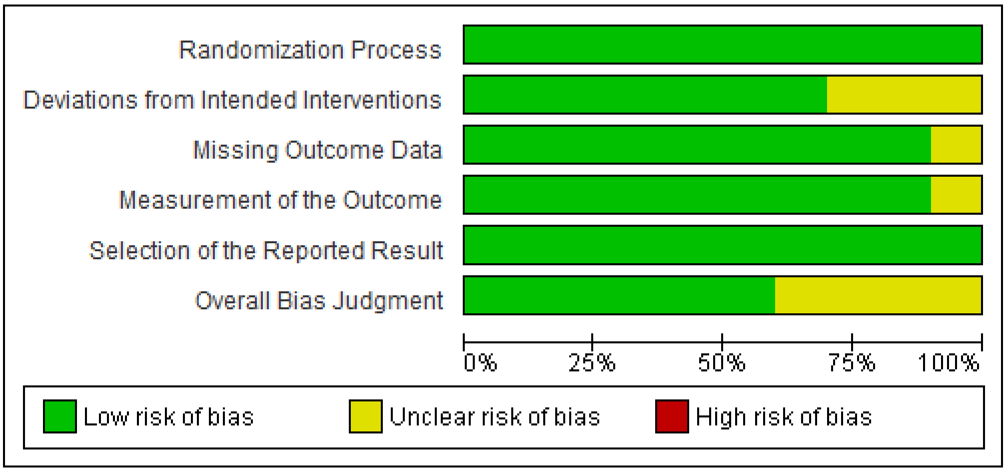

Figure (3): Risk of bias graph

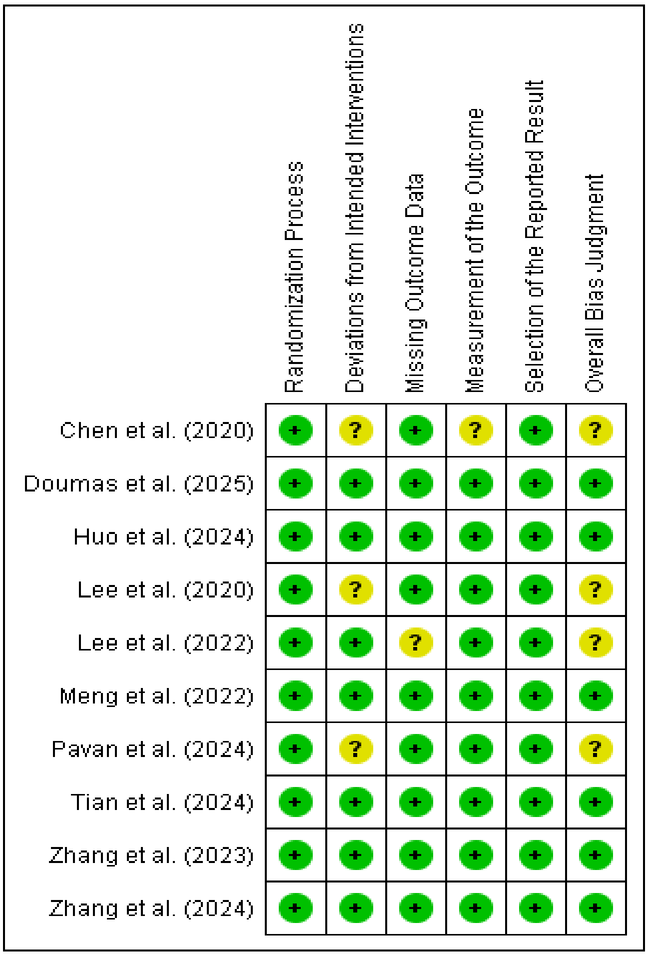

Figure (4): Risk of bias summary

Discussion

The findings of this systematic review and meta-analysis demonstrate that AI and robotics-based physical therapy significantly improve motor function, balance, and gait in stroke patients compared to conventional rehabilitation methods. The pooled analysis of Fugl-Meyer Assessment (FMA) scores revealed a mean difference of 4.36 (95% CI: 2.46–6.26, $p < 0.05$), indicating a clinically meaningful improvement in motor recovery (Chen et al., 2020; Huo et al., 2024). These results align with previous research suggesting that robotic-assisted training enhances neuroplasticity by providing high-intensity, repetitive movements that facilitate neural reorganization (Zhang et al., 2023).

One of the most promising interventions was Brain-Computer Interface (BCI) training with exoskeleton feedback, which showed a 12.77% improvement in

FMA-UE scores compared to only 7.14% in conventional therapy (Chen et al., 2020). This suggests that direct cortical engagement through BCI may accelerate motor recovery by reinforcing sensorimotor pathways (Lee et al., 2020). Similarly, ROBiGAME, a robotic system with Dynamic Difficulty Adjustment (DDA), demonstrated strong correlations between task adaptation and motor improvements (r = 0.84 for FMA-UE), highlighting the role of personalized AI-driven therapy in stroke rehabilitation (Doumas et al., 2025).

For lower limb rehabilitation, robotic exoskeletons such as LiteStepper® and AIWALKER significantly enhanced gait symmetry, walking speed, and balance (Huo et al., 2024; Tian et al., 2024). The Berg Balance Scale (BBS) meta-analysis showed a mean difference of 7.18 (95% CI: 4.79–9.57, $p < 0.05$), reinforcing the superiority of robotic gait training over traditional methods (Zhang et al., 2024). These improvements may be attributed to real-time biomechanical feedback and consistent movement correction, which are difficult to achieve manually (Meng et al., 2022).

Interestingly, telerehabilitation studies presented mixed outcomes. While non-robotic telerehabilitation was more effective in improving motor function (FMA-UE, BBT), robotic telerehabilitation showed better results in reducing depression (BDI scores) (Pavan et al., 2024). This suggests that hybrid models, combining robotic precision with therapist-guided psychosocial support, may optimize recovery (Pavan et al., 2024).

Another key finding was the integration of traditional exercises with robotics, such as Daoyin combined with AIWALKER, which led to greater improvements in fatigue reduction, sleep quality, and mood compared to conventional rehabilitation (Tian et al., 2024). This supports the notion that multimodal approaches—merging modern robotics with holistic therapies—may offer comprehensive benefits beyond motor recovery alone (Tian et al., 2024).

Despite these advancements, limitations must be acknowledged. Some studies had small sample sizes (e.g., Chen et al., 2020: n=14), which may limit generalizability. Additionally, heterogeneity in intervention protocols (e.g., session duration, robot types) complicates direct comparisons (Zhang et al., 2023). Future research should standardize protocols and include long-term follow-ups to assess sustained benefits (Lee et al., 2022a).

The risk of bias assessment indicated that most studies had low bias, but some raised concerns in deviations from interventions (Chen et al., 2020) and missing outcome data (Lee et al., 2022b). Ensuring strict adherence to protocols and complete reporting will enhance future study reliability (Meng et al., 2022).

Clinical implications of these findings are significant. Robotic and AI-assisted therapy could reduce therapist workload, enable high-dose repetitive training, and provide objective progress tracking—key advantages in resource-limited settings (Doumas et al., 2025). However, cost and accessibility remain barriers; future efforts should focus on cost-effective robotic solutions and tele-rehabilitation scalability (Pavan et al., 2024).

In conclusion, this review provides strong evidence that AI and robotics-based rehabilitation significantly enhance motor and functional recovery in stroke patients. The integration of BCIs, adaptive robotics, and multimodal therapies offers a paradigm shift in neurorehabilitation. Future research should explore optimal dosing, long-term outcomes, and cost-effectiveness to facilitate widespread clinical adoption (Huo et al., 2024; Zhang et al., 2024).

Conclusion

AI and robotics are not replacements for traditional therapy but powerful adjuncts that can personalize, intensify, and objectively measure stroke rehabilitation, leading to better functional outcomes for patients worldwide.

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