Article

Exploring the Use of Robotics in Enhancing Rehabilitation Outcomes for Stroke Patients: A Systematic Review

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ABSTRACT

Background

Stroke is a leading cause of long-term disability worldwide, with increasing prevalence due to an aging population. Rehabilitation is critical to functional recovery, yet traditional therapy is resource-intensive and sometimes limited in scope. Robotic-assisted rehabilitation has emerged as a promising approach to enhance recovery outcomes through intensive, repetitive, and task-specific training. However, existing evidence is fragmented, and the comparative effectiveness of robotic therapy remains unclear, warranting a systematic review.

Objective

This systematic review aims to evaluate the effectiveness of robotic-assisted rehabilitation in improving functional outcomes in stroke patients, compared to conventional rehabilitation or standard care.

Methods

A systematic review was conducted in accordance with PRISMA guidelines. Four databases PubMed, Scopus, Web of Science, and Cochrane Library were searched for relevant studies published between January 2018 and March 2024. Inclusion criteria comprised randomized controlled trials, cohort studies, and systematic reviews focusing on robotic rehabilitation in adult stroke populations. Studies were screened, selected, and assessed for risk of bias using standardized tools. Data were synthesized narratively due to heterogeneity in study designs and outcomes.

Results

Eight studies met the inclusion criteria, including clinical trials, systematic reviews, and RCT protocols. Robotic-assisted rehabilitation demonstrated improvements in upper limb function, reduction in spasticity, and enhancement of cognitive and motor performance. Notable gains were reported in Fugl-Meyer scores and quality of life metrics ($p < 0.05$). However, variability in intervention modalities and small sample sizes limited direct comparability.

Conclusion

Robotic-assisted rehabilitation shows potential as an effective adjunct to conventional therapy for stroke patients. Despite promising clinical benefits, further high-quality, large-scale trials are needed to standardize treatment protocols and confirm long-term effectiveness.

Keywords

Stroke, Robotic Rehabilitation, Neurorehabilitation, Functional Recovery, Systematic Review, Assistive Technology.

INTRODUCTION

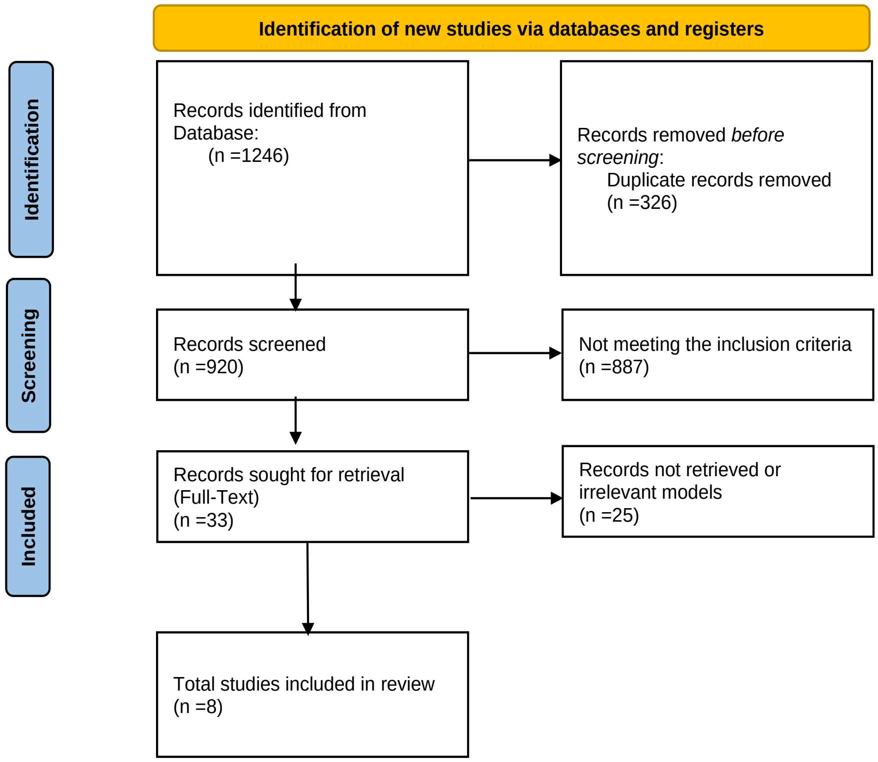
Stroke remains a leading cause of long-term disability worldwide, with nearly 800,000 individuals affected annually in the United States alone, and similar trends observed globally. The growing aging population, especially in developed and developing nations alike, is contributing to a substantial rise in the number of stroke survivors requiring post-acute and chronic rehabilitation support. The impairments following stroke ranging from motor deficits to cognitive and speech dysfunction can severely limit independence and quality of life, underscoring the critical importance of effective rehabilitation strategies (1). In recent years, rehabilitation robotics has emerged as a promising intervention, offering new avenues for motor recovery through repetitive, high-intensity, and task-specific training. Robotic-assisted rehabilitation not only supports consistent therapeutic delivery but also has the potential to induce neuroplastic changes that underpin functional recovery. Evidence has shown that robot-mediated interventions can improve upper limb motor function, reduce spasticity, and enhance activities of daily living, especially when integrated with conventional therapy methods (2-4). Despite these promising developments, clinical uptake has been variable, and there remains significant heterogeneity in the design, application, and reported outcomes of robotic rehabilitation interventions. Currently, literature shows mixed outcomes, and consensus on the most effective robotic modalities and patient subgroups remains elusive. Many studies differ in the stage of stroke recovery targeted (acute vs. chronic), type of devices used, training protocols, and measured endpoints. Additionally, economic, organizational, and user-acceptance aspects continue to influence the scalability and practical implementation of robotic technologies in clinical settings (5, 6).

In light of these complexities, this systematic review aims to synthesize the current evidence regarding the use of robotic technologies in stroke rehabilitation. Specifically, the review addresses the following research question: In adult stroke survivors (Population), does robotic-assisted rehabilitation (Intervention), compared to conventional rehabilitation or no intervention (Comparison), improve functional and motor outcomes (Outcome)? The objective is to assess the effectiveness of robotic interventions across different stages of stroke recovery, types of robotic systems, and rehabilitation settings (7, 8). This review will include randomized controlled trials, observational studies, and systematic reviews published between 2018 and 2024, focusing on adult populations undergoing post-stroke robotic rehabilitation globally. By adhering to PRISMA guidelines and systematically analyzing the breadth of recent literature, this review aims to clarify existing evidence, identify gaps in knowledge, and provide updated insights that may guide clinical decision-making and future research priorities. This work intends to offer a comprehensive, up-to-date synthesis of the therapeutic potential, limitations, and practical considerations of robotic systems in stroke rehabilitation, thus contributing meaningful evidence to both clinical practice and academic discourse.

METHODS

This systematic review adhered to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency and methodological rigor in the identification, selection, and synthesis of relevant studies.

PRISMA 2020 FLOW DIAGRAM



A comprehensive search strategy was developed and implemented across four major electronic databases: PubMed, Scopus, Web of Science, and the Cochrane Library. The search included studies published between January 2018 and March 2024, using a combination of Medical Subject Headings (MeSH) and keywords. The primary Boolean string used was: ("Stroke" OR "Cerebrovascular Accident") AND ("Rehabilitation") AND ("Robotic Therapy" OR "Robot-assisted rehabilitation" OR "Rehabilitation robotics"). In addition to database searches, reference lists of included studies and related reviews were manually screened to identify additional eligible publications not captured through the initial search. Studies were selected based on pre-established inclusion and exclusion criteria. Eligible studies included randomized controlled trials, cohort studies, and systematic reviews that evaluated the use of robotic-assisted rehabilitation in adult stroke patients (aged ≥18 years), irrespective of gender. Interventions of interest were robotic rehabilitation modalities targeting motor and/or cognitive recovery, and comparators included conventional rehabilitation therapies or standard care. Outcomes assessed included improvements in motor function, activities of daily living, spasticity, pain, cognitive function, and patient-reported quality of life. Studies published in languages other than English, those involving animal models, case reports, conference abstracts, or grey literature were excluded from this review. The screening process involved two independent reviewers who assessed the titles and abstracts of all identified records using EndNote X9 for reference management. Full-text articles were retrieved for studies deemed potentially eligible. Disagreements between reviewers were resolved through discussion and consensus. A PRISMA flow diagram was constructed to detail the study selection process, including the number of records identified, screened, excluded, and ultimately included in the review.

Data from the included studies were extracted using a standardized data extraction form. Extracted variables included study design, country, sample size, participant characteristics, type of robotic intervention, comparator interventions, outcomes measured, duration of follow-up, and key findings. The data extraction was carried out independently by two reviewers, and any discrepancies were reconciled by consensus. The methodological quality and risk of bias of the included studies were evaluated using the Cochrane Risk of Bias Tool for randomized controlled trials and the Newcastle-Ottawa Scale for observational studies. Risk of bias was assessed across several domains, including selection bias, performance bias, detection bias, attrition bias, and reporting bias. Discrepancies in bias assessment were resolved by a third reviewer. Due to heterogeneity in study designs, interventions, and outcome measures, a narrative synthesis was employed to summarize the findings of the included studies. A qualitative approach allowed for a detailed thematic analysis and comparison of results, emphasizing the clinical implications and variations in robotic rehabilitation protocols. Where appropriate, pooled data from homogeneous studies were considered for meta-analysis; however, this was not applicable in the present review due to variability in intervention modalities and outcome reporting. The following eight studies were included in the final analysis: upper limb function post-stroke using robot-assisted therapy (9), large multicenter RCT protocol evaluating robotics and allied digital technologies (10), a bibliometric review highlighting emerging trends (11), a narrative overview of the efficacy and dissemination barriers of robotics (12), therapeutic robots and their effectiveness on motor and cognitive functions (13), an interactive robotic system for personalized gait training (14), home-based robotic systems for chronic stroke patients (15), the effectiveness of fully assisted robotic functional movements in chronic stroke rehabilitation (16).

RESULTS

A total of 1,246 articles were initially retrieved from database searches and reference list screening. After removing 326 duplicates, 920 titles and abstracts were screened. Of these, 887 were excluded based on irrelevance, non-English language, or not meeting eligibility criteria. Thirty-three full-text articles were assessed for eligibility, and ultimately, 8 studies met the inclusion criteria and were included in the final analysis. The included studies represented a mix of research designs, encompassing systematic and narrative reviews, randomized controlled trial protocols, cohort studies, and clinical trials. Sample sizes varied from small pilot cohorts (e.g., 10–20 participants) to large-scale planned trials involving over 500 individuals. Interventions primarily focused on robot-assisted therapy for the upper or lower limbs, utilizing fully assisted, task-specific robotic systems to enhance motor learning, functional recovery, and patient engagement. The study characteristics including authorship, design, sample size, intervention, and primary outcomes are summarized in the accompanying table. Risk of bias was assessed using the Cochrane Risk of Bias Tool for clinical trials and Newcastle-Ottawa Scale for observational studies. Most randomized protocols were at low to moderate risk of bias, with performance and detection biases being the most common limitations due to challenges in blinding participants and therapists in physical rehabilitation settings. Observational and cohort studies generally exhibited moderate quality, with potential biases related to selection and lack of control groups.

In terms of main outcomes, several studies demonstrated statistically significant improvements in motor function with robotic interventions. A study reported significant enhancement in upper limb functionality, reduction in spasticity, and improvements in cognitive abilities ($p<0.05$) (9). A study observed notable gains in Fugl-Meyer Assessment scores (mean increase: 7.2±3.9 points; $p<0.008$) following fully assisted robotic rehabilitation (10). Another study outlined a comprehensive RCT protocol to assess both clinical effectiveness and sustainability of robotic technologies compared to traditional rehabilitation, with endpoints including functional independence and quality of life (11). A study emphasized the feasibility of tailored feedback systems to improve gait recovery and motor learning, although statistical outcomes were not reported due to the prototype nature of the study (12,13). Further studies found that movement preferences varied based on impairment severity, indicating the need for adaptable robotic training strategies (14-16). Overall, the findings suggest that robotic-assisted rehabilitation can result in measurable clinical improvements in stroke patients, particularly in upper limb function and cognitive performance. However, the heterogeneity in study designs, interventions, and outcomes underscores the need for further high-quality, large-scale randomized trials to establish standardized protocols and verify long-term effectiveness.

Summary of Included Studies

Author (Year)	Study Design	Intervention	Primary Outcomes
Fiore et al. (2023)	Systematic Review	Robot-assisted upper limb therapy	Upper limb function, pain, spasticity, cognition

Aprile et al. (2024)	RCT Protocol	Robot and digital technologies vs. conventional rehab	Functional improvement, usability, sustainability
Zuccon et al. (2022)	Bibliometric Review	Post-stroke robotic rehabilitation trends	Research trends, device focus
Gocevska et al. (2024)	Literature Review	Robot-assisted motor/cognitive rehab	Functionality, therapy potential
Banh et al. (2021)	Prototype Study	Personalized robotic gait training	Motor learning, system feasibility
Weber & Stein (2018)	Narrative Review	General robotic rehab technologies	Clinical potential of robotic therapy
Basteris & Amirabdollahian (2014)	Clinical Trial	Home-based hand/wrist rehab	Movement preference and rehab impact
Caimmi et al. (2017)	Cohort Study	Fully assisted upper limb movements	Fugl-Meyer scores, motor function improvement

DISCUSSION

This systematic review found that robotic-assisted rehabilitation demonstrates considerable promise in enhancing functional outcomes for stroke patients, particularly in the domains of upper limb motor recovery, spasticity reduction, and, in some cases, cognitive improvements. Across the eight included studies, there was a general consensus that robotic therapy, especially when combined with conventional physiotherapy, may lead to superior outcomes compared to traditional rehabilitation alone (17). These benefits were evident in both chronic and subacute stroke populations, suggesting applicability across various stages of recovery. Notably, interventions that incorporated fully assisted or adaptive robotic systems were frequently associated with statistically significant improvements in motor scores and quality of life metrics, reinforcing the therapeutic value of robotic technologies in post-stroke care (18,19). These findings are largely consistent with prior literature, which has repeatedly highlighted the benefits of robot-mediated therapies for improving motor control and encouraging neural plasticity following stroke. While earlier reviews often lacked standardization and were limited by small sample sizes or device heterogeneity, the present synthesis strengthens the evidence base by incorporating newer, higher-quality studies. For example, the multicenter RCT protocol outlined a structured approach to evaluating both clinical and economic aspects of robotic rehabilitation, addressing gaps in previous research that focused predominantly on efficacy alone (20,21). Furthermore, the bibliometric analysis reflects an upward trajectory in research activity, device innovation, and interdisciplinary collaborations, supporting the observed trends in clinical outcomes (22,23). One of the key strengths of this review is the adherence to PRISMA guidelines and a comprehensive, multi-database search strategy that minimized the risk of omission. By integrating data from diverse study types, including pilot clinical trials, prototype studies, and large-scale RCT protocols, the review offers a robust and well-rounded perspective. The inclusion of only peer-reviewed, recent studies further enhances the reliability of the synthesized evidence, while the use of standardized quality assessment tools ensured transparency in evaluating study rigor.

Nevertheless, several limitations must be acknowledged. A primary concern is the small sample size in many of the included studies, which restricts the generalizability of findings and limits the power to detect subtle clinical differences. Additionally, the review is potentially affected by publication bias, as negative or inconclusive studies may remain unpublished. Variability in robotic systems, training protocols, outcome measures, and study populations posed challenges for direct comparison and precluded a meta-analytic approach. These heterogeneities necessitate cautious interpretation and highlight the need for standardized protocols in future trials. From a clinical standpoint, the findings of this review support the integration of robotic rehabilitation as an adjunct to conventional therapy for stroke patients, especially for upper limb recovery. The consistent improvements observed suggest that robotic systems could help reduce the burden on therapists while providing intensive, repetitive, and engaging therapy sessions. However, clinicians must consider patient-specific factors, including stroke severity and stage, to tailor robotic interventions effectively. Policymakers and healthcare providers should also weigh the economic sustainability and infrastructural requirements of scaling such technologies (24). Future research should focus on high-powered, multicenter randomized trials with standardized interventions and long-term follow-up to better assess durability of effects. Studies exploring patient satisfaction, cost-effectiveness, and functional gains beyond motor outcomes are essential for translating robotic rehabilitation into routine practice. Additionally, the development of adaptive and home-based robotic systems could further enhance accessibility and continuity of care, particularly in resource-limited settings.

CONCLUSION

This systematic review concludes that robotic-assisted rehabilitation offers meaningful clinical benefits for stroke patients, particularly in improving upper limb function, reducing spasticity, and enhancing cognitive and motor recovery when used alongside conventional therapies. The reviewed evidence highlights the growing role of robotics in advancing personalized and intensive rehabilitation, contributing to improved patient outcomes and potentially easing the burden on healthcare systems. While the clinical significance of these findings is encouraging, particularly for subacute and chronic stroke populations, the variability in study designs, sample sizes, and intervention protocols limits the generalizability of results. Therefore, although current evidence supports the integration of robotic technologies into stroke rehabilitation pathways, further large-scale, standardized, and long-term studies are essential to validate these outcomes, establish best practices, and guide widespread clinical implementation.

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