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Research Article

A Review on the Effectiveness of Robotic Assisted Therapy on Hand Motor Function in Stroke Patients

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Abstract

Hand dysfunction is a common and disabling consequence of stroke, often affecting a survivor's ability to perform everyday tasks. Robotic-assisted therapy has gained attention as a tool to improve recovery through repetitive, high-intensity, and goal-oriented movement training. This review explores the effectiveness of robotic interventions in enhancing hand motor function among individuals recovering from stroke. Based on findings from 17 peer-reviewed studies, robotic therapy consistently led to improvements in motor skills such as grip strength, finger coordination, and voluntary hand control, particularly when used early in recovery and combined with traditional therapy methods. Devices including end-effector systems and exoskeletons proved especially useful for targeting fine motor movements. The review also emphasizes the importance of neuroplasticity and patient engagement in maximizing therapy outcomes. Overall, robotic-assisted rehabilitation shows strong potential to improve hand function and promote greater independence in stroke survivors.

Keywords: Robotic-Assisted Therapy; Stroke Rehabilitation; Hand Motor Function; Upper Limb Rehabilitation; Post-Stroke Rehabilitation

Introduction

Stroke stands as one of the most prevalent and life-altering neurological conditions, affecting millions of people globally. It results in considerable disruption to both cognitive and motor functions. Beyond the initial acute stage, stroke often leads to long-term complications—particularly upper limb dysfunction—which significantly limits a survivor's ability to carry out everyday tasks. Common issues such as weakness, loss of fine motor skills, and decreased sensory feedback vary in severity depending on the lesion's location and size in the brain [1,2]. The extensive burden of stroke recovery not only impacts the patient's quality of life but also presents substantial demands on global healthcare systems. As a result, innovative rehabilitation strategies are increasingly required to enhance recovery outcomes and foster independence.

The role of upper limb rehabilitation is crucial in post-stroke recovery, as arm and hand impairments are among the most enduring and debilitating consequences of stroke. Around 80% of individuals experience arm or hand dysfunction in the early stages, and approximately 50% continue to face challenges in the chronic phase [3]. These motor impairments affect essential daily tasks such as dressing, feeding, and personal hygiene [4]. Given the hand's central role in interacting with the environment, regaining its function is vital for achieving autonomy. Restoring hand dexterity and grip strength is key to performing skilled and precise actions [5,6].

Traditional rehabilitation typically involves therapist-guided exercises. While beneficial, these conventional approaches are often limited in delivering the volume, intensity, and precision needed to stimulate optimal neuroplastic changes. The ability to provide intensive and repetitive movement training is frequently restricted due to time, effort, and human resource limitations—especially during periods of heightened brain plasticity following stroke [7]. Inconsistent delivery and subjective variation between sessions further challenge the effectiveness of conventional therapy models.

To address these challenges, robotic-assisted therapy has emerged as a promising solution. These robotic systems facilitate repetitive, task-oriented movements that are essential in the early stages of recovery when patients require significant support. They extend therapy duration, improve consistency, and reduce the physical burden on clinicians while enhancing the overall efficiency of rehabilitation [1].

Robotic-assisted rehabilitation offers several advantages over traditional physiotherapy, occupational therapy, and other conventional methods. These devices support structured, measurable, and reproducible treatment plans, helping tailor therapy to the specific needs of each patient [1]. Their technological precision allows for controlled, high-frequency movements that enhance the effectiveness of interventions while reducing variability.

Robotic therapy is built upon well-established scientific principles of neuroplasticity and motor learning. Following a stroke, motor recovery is achieved through relearning movement patterns by reshaping neural circuits. Neuroplasticity, the brain's ability to reorganize itself by forming new connections, underpins this recovery process [8,9]. Rehabilitation capitalizes on this plasticity to reorganize brain regions around damaged areas, fostering new functional pathways. Robotic systems support this by delivering high-repetition, goal-oriented training sessions that would be difficult to achieve manually [10].

Robotic devices used in rehabilitation can be classified mainly into two categories: exoskeletons and end-effector systems. Exoskeleton robots are designed to mimic the structure of the human limb, with aligned joints that support natural movement patterns. They function as external orthoses, guiding joint motion directly [1]. In contrast, end-effector robots apply force at the distal part of the limb, initiating motion that indirectly moves the entire limb through mechanical manipulation [1].

The consistency and control provided by robotic systems promote activity-based brain plasticity, enhancing motor recovery in ways that traditional approaches may not achieve. These devices ensure accurate movement execution, allow real-time monitoring, and provide adaptable treatment based on patient feedback and progress [11]. The ability to objectively track outcomes adds value to long-term treatment planning.

Recent advances in robotics have expanded their application to more intricate tasks, such as fine motor control of the hand and fingers. While earlier devices focused primarily on shoulder and elbow function, modern systems now target hand rehabilitation, acknowledging its importance in achieving daily functional independence [1]. These systems allow detailed training of finger movements, vital for precision tasks such as writing or handling small objects.

Hand function recovery remains one of the most challenging aspects of stroke rehabilitation. As the hand serves as the primary tool for interaction, its recovery is essential for autonomy [5]. Impaired communication between the brain and hand—due to stroke—can lead to delayed signals and loss of control, especially over fine motor actions [12]. Furthermore, the intrinsic muscles of the hand fatigue quickly and tend to atrophy with disuse, making rehabilitation even more difficult [12]. As a result, daily activities such as grooming or meal preparation become extremely challenging for stroke survivors [12].

Integrating robotics with virtual reality (VR) has further enhanced the appeal and effectiveness of therapy. VR offers interactive, game-like environments that increase motivation and engagement. When combined with robotic precision, this approach makes training more immersive and contextually relevant, supporting both physical and cognitive aspects of recovery [11].

In addition, the rise of soft robotic technologies marks a new frontier in rehabilitation. These systems, often made of flexible and lightweight materials, are particularly well-suited for hand therapy. Their safety, portability, and comfort make them ideal for home-based therapy sessions, extending treatment opportunities beyond traditional clinical environments [13].

Robotic therapy supports multiple aspects of rehabilitation, including mobility, proprioception, attention, and cognitive engagement. Rather than replacing therapists, these technologies serve as valuable tools to expand treatment capabilities and provide higher-intensity therapy [14]. Their use allows patients to undergo more repetitions in shorter timeframes, potentially accelerating recovery.

The benefits of robotic therapy depend on several factors, such as the stage of intervention, patient condition, and the specific robotic system in use. While robotic-assisted treatment has demonstrated improvements in strength and motor scores, these improvements do not always translate directly into better functional performance in everyday life [15]. This gap highlights the need to refine robotic protocols to focus not just on impairment-level gains but also on meaningful activity participation.

Stroke recovery is shaped by motor learning and neuroplastic adaptation. Effective rehabilitation must consider factors like practice structure, feedback, and instructional methods to optimize skill reacquisition [16]. Robotic therapy programs should integrate these principles to promote lasting improvements in motor control and coordination.

A thorough evaluation of robotic systems for upper limb rehabilitation reveals a wide variety of designs and applications. Each system is characterized by specific features such as the intended user population, type of assistance provided, mechanical design, and therapeutic goals. Consideration of these factors is essential for creating effective devices that align with clinical needs [17].

Although robotic therapy has shown measurable improvements in motor function, the translation of these gains into real-world functional recovery remains a work in progress. Diverse devices, protocols, and evaluation methods across studies make direct comparisons difficult. This underscores the need for more uniform standards in robotic rehabilitation research and practice [15].

Looking ahead, the future of robotic rehabilitation is bright. Integration of AI, smart sensors, and adaptive learning algorithms may lead to more responsive, personalized therapy solutions. Cost-effective and portable devices could broaden access, making high-quality rehabilitation available in homes and underserved areas [11].

As research into stroke recovery continues and robotic technologies advance, these systems are likely to become an integral part of comprehensive rehabilitation programs. When used alongside traditional therapy, robotic-assisted methods can help increase therapy intensity, improve consistency, and enhance outcomes. The upcoming literature review will focus on evaluating the effectiveness of robotic-assisted interventions specifically in restoring hand motor function after stroke, with attention to both clinical outcomes and future potential for practice.

Objective

To review the efficacy of robotics-assisted therapy in enhancing hand function motor function in post-stroke patients.

Review of literature

S. No.	Authors	Year	Type of study	Outcome measures	Result	Conclusion
1	Hong R, Li B, Bao Y, Liu L, Jin L.	2024	Review study	Fugl-Meyer Assessment (FMA), Barthel Index (BI)	Improved motor recovery, independence, and rehab adherence	Robotic therapy is a promising adjunct
2	Keeling AB., *et al.*	2021	Pilot study	FMA, Wolf Motor Function Test (WMFT), Motor Activity Log (MAL)	Improved motor outcomes; high feasibility and safety	Effective for augmenting stroke rehabilitation
3	Chang WH, Kim YH.	2013	Narrative review	FMA, Modified Ashworth Scale (MAS)	Improved motor function via consistent/intensive training	Effective for subacute upper limb recovery
4	Takahashi CD., *et al.*	2008	Randomized controlled trial	FMA-Hand subscale,Box and Block Test	Enhanced hand motor control and performance	Beneficial especially for hand recovery
5	Casadio M., *et al.*	2009	Randomized controlled trial	FMA,Barthel Index,MAS	Greater motor gains than physiotherapy alone	Integration enhances outcomes
6	Aprile I., *et al.*	2020	Randomized controlled trial	FMA,BI,Action Research Arm Test (ARAT)	Functional gains in moderate impairment cases	Strong evidence for robotic rehab
7	Finley MA., *et al.*	2005	Pilot study	FMA,Stroke Impact Scale (SIS)	Gains measurable even with short duration	Suitable for severe cases
8	Bonanno L., *et al.*	2023	Experimental study	FMA, Functional MRI (fMRI), MAS	Brain plasticity improved; functional gains noted	Supports neuroplasticity enhancement
9	Poli P., *et al.*	2013	Systematic review	FMA,ARAT,BI	Improved motor outcomes and engagement	Robotics improves therapy quality
10	Lum P., *et al.*	2002	Descriptive study	FMA, Functional Independence Measure (FIM)	Potential shown, but adoption limited	Effective but needs broader acceptance

Table 1

Methodology

- Study design: Literature review.

Inclusion criteria

- Focused on robotic-assisted therapy interventions aimed at improving hand and upper limb function in adult stroke survivor.
- Discussed different types of robotic devices, including exoskeletons, end-effector systems, and their clinical application.
- Addressed integration of robotic therapy with conventional rehabilitation approaches.

Exclusion criteria

- Studies focusing solely on gait or lower limb rehabilitation without addressing upper limb or hand function.
- Articles not directly related to robotic-assisted therapy for post-stroke motor recovery.
- **Search engine:** PubMed, chocrane library, embase, research gate.

Result

The result obtained from reviewing 17 articles demonstrates that the robotic-assisted therapy leads to consistent and meaningful gains in hand motor function as reflected by improvements in the Fugl-Meyer assessment. The findings support the incorporation of robotic technologies into rehabilitation programs to accelerate and enhance recovery of motor function in stroke survivors.

Robotic-assisted therapy has shown substantial effectiveness in improving hand motor function in individuals recovering from stroke, with the Fugl-Meyer Assessment (FMA) serving as a primary tool to quantify motor improvements. The upper extremity subscale of the FMA, particularly the hand and wrist components, has been widely used to measure changes in motor control, precision, and strength following robotic intervention.

Multiple studies consistently report that individuals receiving robotic therapy for hand rehabilitation demonstrated significant gains in FMA-hand scores when compared to traditional therapy groups. These improvements were observed in parameters such as grasp strength, finger individuation, coordination, and voluntary movement of the wrist and fingers. Notably, gains were more prominent when therapy was initiated early in the subacute phase, although chronic stroke patients also benefited.

Therapeutic systems designed specifically for the hand—such as end-effector devices and wearable exoskeletons—enabled repetitive, fine motor training involving pinch, grip, and release actions. These targeted movements contributed to increased FMA scores in the distal upper limb segments. Robotic therapy facilitated a high number of repetitions that would be difficult to achieve manually, enhancing neuromuscular reactivation and sensory feedback. This repetitive, task-specific training is strongly associated with plastic changes in motor pathways.

Short-duration interventions, even when limited to a few weeks, showed measurable improvements in the hand section of the FMA, especially in patients with moderate baseline impairments. These effects were attributed to the robots' ability to provide consistent, adaptable assistance levels, encouraging patients to actively participate in therapy without being overwhelmed. Robotic systems that incorporated feedback, visual cueing, or gamified tasks further enhanced engagement and motor performance.

Integration of robotic hand therapy with conventional physiotherapy resulted in even greater improvements, particularly in fine motor control and dexterity. Hybrid programs using robotic gloves or soft robotic devices allowed for better targeting of hand-specific movements, leading to significant improvements in FMA-hand scores. These advancements are particularly valuable in supporting activities of daily living, such as grasping utensils or manipulating small objects.

Evidence from meta-analyses and clinical trials suggests that the robotic approach is especially effective in addressing the commonly persistent hand deficits that follow a stroke. The hand, being one of the most complex and functionally critical components of the upper limb, benefits greatly from the intensity and precision offered by robotic interventions.

Discussion

Robotic-assisted therapy has become a pivotal approach in the rehabilitation of hand motor function following a stroke. The unique advantage of robotic systems lies in their ability to deliver highly repetitive, controlled, and task-specific exercises, which are essential for stimulating motor recovery in the hand. Post-stroke impairment in hand function often results in reduced ability to perform activities of daily living, making focused rehabilitation of fine motor skills a priority. To assess the effectiveness of such targeted therapy, the Fugl-Meyer Assessment (FMA) serves as a standardized and reliable tool for measuring motor recovery, particularly in the hand and wrist segments of the upper extremity.

The FMA includes a dedicated section for evaluating the distal upper limb—specifically wrist and hand functions—making it especially suitable for assessing the outcomes of robotic therapy aimed at improving grasp, grip, finger coordination, and precision tasks. Through structured robotic interventions, patients are guided in performing repetitive finger and hand movements, with assist-as-needed mechanisms allowing for active engagement even in severely impaired individuals. These robot-mediated activities encourage sensorimotor integration and neural reorganization, often reflected in gradual increases in hand-specific FMA scores.

The integration of robotic devices in hand rehabilitation allows for adjustments in resistance, range of motion, and movement patterns based on the patient's evolving capabilities. Real-time biofeedback from the devices plays a critical role in motor learning, helping patients correct abnormal movement patterns. This individualized training supports the restoration of voluntary motor control and improves functional outcomes, which is consistently evident through measurable changes in FMA hand subscale scores.

Robotic systems that focus on distal upper limb rehabilitation often simulate everyday tasks such as grasping a ball, manipulating objects, or performing finger opposition movements. These task-oriented exercises are delivered in a controlled environment, ensuring consistency and safety. Over time, the training induces improvements in coordination, strength, and fine motor precision—all components thoroughly captured by the FMA. The progressive increase in FMA hand scores serves as a quantitative reflection of regained motor abilities and functional independence.

In addition to physical benefits, robotic therapy enhances patient motivation and participation. The interactive and often gamified nature of these devices can increase adherence and engagement, leading to better rehabilitation outcomes. This consistent participation is essential for achieving the intensity of therapy required to induce meaningful improvements in neuroplasticity and functional restoration of the hand.

The FMA's ability to detect small but clinically significant improvements makes it particularly valuable in chronic stroke populations where progress may occur more gradually. Even in subacute or early rehabilitation phases, improvements in FMA hand scores can indicate effective recovery pathways being activated. The use of robotics allows clinicians to deliver a higher dose of therapy than conventional methods alone, and this increased therapy intensity correlates with greater improvements in FMA scores over time.

Robotic-assisted therapy has demonstrated strong potential in restoring hand motor function after stroke. The structured and repetitive movement training it provides aligns well with the demands of neural recovery, particularly in the context of fine motor control. The Fugl-Meyer Assessment remains a gold-standard outcome measure, offering sensitive and objective tracking of motor recovery at the hand level. Its regular use in robotic rehabilitation settings supports both clinical decision-making and long-term progress monitoring, making it an essential component of evidence-based stroke care.

Conclusion

Robotic-assisted therapy has become a valuable addition to post-stroke rehabilitation, offering structured, intensive, and repetitive training that supports the restoration of hand motor function. When used alongside conventional rehabilitation techniques, it contributes to notable improvements in motor abilities, hand coordination, and the capacity to perform everyday tasks independently. Evidence suggests that the effectiveness of this therapy is closely tied to the duration and intensity of sessions, with benefits often emerging after approximately 15 hours of robotic-based training.

The choice of device also plays a critical role. End-effector robots are particularly effective in enhancing grip strength and fine motor skills, while exoskeletons are better suited for improving movements involving the shoulder and elbow. Using both types together may provide a more comprehensive approach to rehabilitation. Additionally, features such as real-time feedback and tactile stimulation support brain plasticity by reinforcing new neural connections essential for motor recovery.

These robotic systems are generally safe, practical, and adaptable to different clinical settings, making them especially helpful for individuals with moderate to severe impairments who require high-intensity, goal-oriented practice. Moving forward, greater emphasis should be placed on developing personalized treatment plans, affordable device options, and methods that ensure improvements carry over into real-life functional tasks.

In summary, robotic-assisted therapy marks a significant advancement in the rehabilitation of stroke survivors. By enhancing hand motor function through targeted, high-dose interventions, it offers new opportunities to improve patient outcomes and support long-term recovery and independence.

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