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REVIEW ARTICLE

Robotic rehabilitation of the upper extremity after stroke: A review

İnme sonrası üst ekstremitenin robotik rehabilitasyonu: Derleme

Parvin AKBAROV[1], Khayala AGHAMIRZAYEVA[2], Muhammed KILINC[3], Deran OSKAY[4]

[1]Yeni Klinika Hospital, Department of Yeni Robotic Rehabilitation Center, Baku, Azerbaijan
[2]Hacettepe University, Department of Neurology, Ankara, Türkiye
[3]Hacettepe University, Faculty of Physical Therapy and Rehabilitation, Ankara, Türkiye
[4]Gazi University, Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation, Ankara, Türkiye

Abstract

Stroke remains one of the leading causes of morbidity and mortality worldwide and represents a major contributor to long-term disability. Among the various neurological impairments observed after stroke, upper extremity dysfunction is particularly common and often results in significant loss of motor control, sensory deficits, and reduced functional independence. These impairments severely affect patients' quality of life and limit their ability to perform activities of daily living. Despite advances in neurorehabilitation, conventional therapeutic approaches, including physiotherapy and occupational therapy, often yield limited functional recovery, especially in patients with moderate to severe deficits. Factors such as insufficient therapy intensity, variability in therapist-dependent interventions, and challenges in maintaining patient motivation contribute to suboptimal outcomes. In this context, robotic rehabilitation has emerged as an innovative and promising approach, offering repetitive, task-specific, and intensive training with high precision and reproducibility. Robotic rehabilitation has been shown to improve upper extremity motor performance, enhance functional recovery, and support neuroplasticity in patients after stroke. Robotic-assisted rehabilitation systems enable objective assessment of motor performance and allow the delivery of personalized therapy protocols, potentially enhancing neuroplasticity and functional recovery. The aim of this review is to evaluate the effectiveness of robotic rehabilitation in improving upper extremity function, motor recovery, and activities of daily living in patients following stroke. Moreover, these systems can reduce the physical burden on therapists and facilitate long-duration training sessions. However, despite the growing interest in robotic rehabilitation, the current body of literature remains heterogeneous, with many studies consisting of small sample sizes, case series, or non-standardized methodologies, which limits the generalizability of findings.

Keywords: Stroke rehabilitation, robotic rehabilitation, upper extremity, neuroplasticity, motor recovery.

Özet

İnme, dünya genelinde morbidite ve mortalitenin önde gelen nedenlerinden biri olmaya devam etmekte olup, uzun dönemli sakatlığın başlıca belirleyicilerinden birini temsil etmektedir. İnme sonrasında gözlenen çeşitli nörolojik bozukluklar arasında üst ekstremite disfonksiyonu özellikle yaygın olup, sıklıkla motor kontrol kaybı, duyu kusurları ve fonksiyonel bağımsızlıkta azalma ile sonuçlanmaktadır. Bu bozukluklar, hastaların yaşam kalitesini ciddi biçimde olumsuz etkilemekte ve günlük yaşam aktivitelerini yerine getirme kapasitelerini sınırlamaktadır. Nörorehabilitasyon alanındaki ilerlemelere rağmen, fizyoterapi ve ergoterapiyi içeren konvansiyonel tedavi yaklaşımları, özellikle orta ve ağır düzeyde defisitleri olan hastalarda, çoğu zaman sınırlı fonksiyonel iyileşme sağlamaktadır. Yetersiz tedavi yoğunluğu, terapiste bağlı müdahalelerdeki değişkenlik ve hasta motivasyonunun sürdürülebilirliğine ilişkin güçlükler gibi faktörler, optimal olmayan sonuçlara katkıda bulunmaktadır. Bu bağlamda, robotik rehabilitasyon; yüksek hassasiyet ve tekrarlanabilirlik ile tekrarlı, göreve özgü ve yoğun eğitim sunan yenilikçi ve umut verici bir yaklaşım olarak ortaya çıkmıştır. Robotik rehabilitasyonun, inme geçiren hastalarda üst ekstremite motor performansını iyileştirdiği, fonksiyonel iyileşmeyi hızlandırdığı ve nöroplastisiteyi desteklediği gösterilmiştir. Robotik destekli rehabilitasyon sistemleri, motor performansın nesnel olarak değerlendirilmesine olanak tanımakta ve kişiselleştirilmiş tedavi protokollerinin uygulanmasını mümkün kılarak nöroplastisiteyi ve fonksiyonel iyileşmeyi artırma potansiyeli taşımaktadır. Ayrıca, bu sistemler terapistlerin fiziksel yükünü azaltabilmekte ve uzun süreli eğitim seanslarının uygulanmasını kolaylaştırmaktadır. Bu incelemenin amacı, inme geçiren hastalarda üst ekstremite fonksiyonunu, motor iyileşmeyi ve günlük yaşam aktivitelerini geliştirme konusunda robotik rehabilitasyonun etkinliğini değerlendirmektir. Bununla birlikte, robotik rehabilitasyona yönelik artan ilgiye rağmen, mevcut literatür hâlen heterojen bir yapı sergilemekte; birçok çalışma küçük örneklem büyüklükleri, olgu serileri veya standartlaştırılmamış metodolojiler içermekte olup, bu durum bulguların genellenebilirliğini sınırlamaktadır.

Anahtar Kelimeler: İnme rehabilitasyonu, robotik rehabilitasyon, üst ekstremite, nöroplastisite, motor iyileşme.

Corresponding Author: Parvin AKBAROV akbarovparvin@gmail.com
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INTRODUCTION

Stroke causes a significant portion of disability and death on an international scale. The prevalence of stroke-related deaths is disproportionately more severe in low- and middle-income countries. The World Stroke Organization (WSO) states in its 2022 report that globally, one stroke occurs every 3 seconds (1, 2). In 2016, 13.7 million newly identified cases of stroke were recorded, of which, ischemic stroke constituted approximately 87% of the cases. Upper limb functional impairment caused by stroke, is a major contributor to the heightened difficulties stroke patients experience in the execution of activities of daily living (3). Severe damage to the brain's motor control regions is manifested by a significant inability to execute movements with the arms and hands. This loss of mobility severely diminishes a person's independence and overall quality of life (4). Upper limb functional loss typically presents as complete paralysis (hemiplegia) or partial paralysis (hemiparesis) (5). It is associated with diminished muscle strength, loss of motor control, diminished performance of activities involving small movements (fine motor control), and spasticity in one or more of the upper extremities. This condition in patients leads to significant inability to perform self-care tasks, which include, but are not limited to, eating, dressing, and maintaining personal hygiene (6, 7).

Patients who lose the ability to use their upper limbs have a higher chance of falling (8). Their loss of balance can cause them to sustain further injuries (8). Further, this can lead to an increase in complications after a stroke and an increase in the likelihood of a patient being readmitted to the hospital (9). The loss of upper extremity function after a stroke can also have mental health implications. Patients may experience a loss of autonomy due to an inability to execute a number of ordinary daily activities, and this may lead to clinical depression and anxiety (10). Patients of a younger age may also be impacted by this as they may experience limited opportunities in employment and increased social isolation, which can be a significant contributing factor to the economic impact of the loss of upper extremity function (11). Rehabilitation to recover upper extremity functionality should commence as soon as possible after the stroke (12). Important functional recovery methods include robotic rehabilitation, neurophysiological methods, and mirror therapy (13). Additional functional gains may be achieved in the long run with improved patient motivation and adherence to an exercise regimen (13). The loss of upper extremity functionality during a stroke increases the risk of mortality, highlighting the importance of early detection and initiation of emergency medical treatment and rehabilitation (14). Traditional approaches to rehabilitation include physiotherapy, in which the physiotherapist performs manual therapy, and the patient is engaged in both passive and active exercise, as well as methods to promote and enhance neuroplasticity and functional movement (15). Amongst other objectives, repetitive goal-oriented movements (16) establish individualized exercise programs to enhance the patient's muscle strength, coordination, and increase their range of motion.

Robotic Rehabilitational Systems incorporates technology-based systems that help assist patient mobility and guide movements for repetitive exercises (17). Robotic systems evaluate patient movements while providing feedback instantly, offering better control of the rehabilitation process (18). This technique could be of great benefit for those patients that suffer from severemotor disabilities (19). Most of the benefits of robotic rehabilitation are that it allows the opportunity for repetitive and high intensity exercise (20), enables goal setting through objective feedback (21), and increases patient motivation and level of involvement through gamification of exercises and use of interactive apps (22). Robotic systems have been shown to reduce the amount of time taken for motor recovery (19). To the best of the author's knowledge, the primary aim of this review is to evaluate the effectiveness of robotic rehabilitation systems in the upper extremities following a stroke.Therefore, the aim is to evaluate the evidence to date on the impact of robotic rehabilitation on motor recovery of the upper extremities, functional use of the upper extremities, and the performance of the upper extremities in activities of daily living, and the use of robotic systems focused on upper extremity rehabilitation.

The secondary aim of this review is to evaluate the data reported in the literature based on Fugl-Meyer Assessment (FMA) scores in order to determine the effectiveness of robotic upper extremity rehabilitation in the literature.

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Robotic Rehabilitation

Research suggests that some aspects of human–robot interaction result in higher success rates. In this case, the focus was on the authors' studies in this area, and on clinically tested robotic devices for the upper extremities. Additionally, some suggestions were made about what future studies should focus on. The authors explain that one of the notable advantages of robotic systems is that they lend themselves to much greater treatment intensities than conventional therapies, and this possibility, among others, is deserving of further study. More specifically, the authors conclude that the development of home systems that can provide the patients with greater access to high-dose assisted movement therapy and can enhance patient's motivation is of great importance (23).

Robot-Assisted Training

The past four decades have witnessed the emergence of Robot-Assisted Stroke Rehabilitation (24). Robots are capable of providing therapy that is intensive, repetitive, and specific to a particular task. Additionally, Robots are able to incorporate a variety of different therapy methodologies including active, assistive, or resistive (25). The focus of Robot-Assisted Training is two-fold: the interactive process of the patient attempting to move and the robot aiding these movements. therapy is consistently and precisely administered. Fatigue is not a factor as the robot is programmed to execute a specific task. The robot has the ability to operate under different assistance modes (passive, active-assisted, active). The robot captures and measures multiple patient behaviors, while simultaneously performing numerous therapeutic functions (25). The integration of Virtual Environment Technology has the potential to further increase the motivation of patients to improve (26). Furthermore, Robotic devices are capable of programmable force generation, which is essential to performing passively-assisted movements. Robotic devices allow patients to perform movements in a semi-autonomous manner (27). The mechanical manipulation and other assistive features of a robotic device do not provide identical replication to a therapist. Robotic devices possess numerous limitations in terms of response speed, sensation, and strength (27). Furthermore, robotic devices cannot reproduce the complexities of the neuromuscular system. Most commercially available robotic devices are designed to assist with the rehabilitation of the upper extremities.

Clinical evidence indicates that robot-assisted therapy is beneficial for improving mobile ease, and progression is made regarding functionality. However, additional research is warranted to ascertain the concrete effectiveness of robotic therapy approaches in relation to traditional therapy methods. Furthermore, the considerable potential that robotic systems possess to prolong the duration of rehabilitation remains largely unexplored. Indeed, most studies to date evidence that the amount of time spent engaging in robot-assisted therapy is always less than 30 hours. Therefore, the construction of robotic systems for home use is prioritized to rehabilitate patients in an effort to improve the duration of rehabilitation interventions by providing patients with the ability to practical more exercises (23).

From an actuating technologies perspective, electric motors have historically been the standard, although recent advances with the soft robotics paradigm have created pneumatic muscle actuators. While these soft actuators have the aforementioned advantage of providing soft movements that are less injurious in contact with the human body, their need for air under pressure to operate is a significant requirement that inhibits portability. In their mechanical transmission systems, a linkage mechanism, or Bowden cables is the standard, although most recent research in this area aims to produce lower friction and more biomechanically compatible movements along with a cable system that is designed to produce a motion that mimics a human tendon. The field of artificial sensors is divided into two groups: physical sensors (torque, position, and force) and biosignal sensors (EMG and EEG). Of the two methods, the EMG systems offer the greatest potential for active control by patients who have voluntary muscle control in the fingers. Conversely, EEG brain–computer interfaces, particularly in earlier-stage patients, are more likely to active participant in the control of movements (28).

Robotic Upper Extremity Rehabilitation

Cortical Reorganization and the Effects of Robot-Assisted Therapy

Robot-aided therapy may improve reorganization of the

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brain's cortex and recovery of motor function post chronic stroke (29, 30). Chronic stroke patients may experience robotic training cortical reorganization as measured by Functional Magnetic Resonance Imaging (fMRI) (31).

Advancements in Robot-Assisted Rehabilitation

The goal of robotic rehabilitation is to facilitate the brain's recovery of control of neuromuscular paralyzed limbs by using a method involving repetitive, measurable, and intensive motor activities of the paralyzed limbs. Early robotic rehabilitation systems include the MIT-Manus system that is designed to facilitate movement of the arm and the MIME system that is designed for bilateral movement. More recently, exoskeletal rehabilitation systems that integrate and modify the functionality of the hand by controlling movement at the finger joints have been developed. Furthermore, the recent generation of rehabilitation robots that can sense and respond to movement intention of the patient as detected by EMG and EEG encourage a shift in rehabilitation from passive to active participation by the patient (28).

The Importance of Integrated Design in Robotic Systems

Most existing reviews analyze separately mechanical design criteria of robotic systems or training paradigms. However, clinically effective robotic rehabilitation systems require integrated design of training and hardware components. In this regard, an efficient robotic upper extremities rehabilitation system should integrate four key aspects: (i) patient individuality (patient-specific parameters), (ii) the theories of neurology and rehabilitation (plasticity, motor learning), (iii) hardware technology (mechanical-design characteristics), and (iv) training paradigm (interactive training and motivational components) (28).

Training Paradigms and Human–Robot Interaction

In robotic rehabilitation, the training modes are structured at different levels as passive, assistive, active-assistive, active, and resistive. Dynamic shifts between these modes are recommended depending on the rehabilitation stage of the patient. Functionally or activity-based (based on activities of daily living) levels can be targeted for training. To improve human–robot interaction, modern systems adopt a three-tiered approach for this: (i) induction: movement intention is stimulated by task-based, mirror therapy, or virtual reality scenarios; (ii) intention detection: movement intention is captured from the patient through EMG, EEG, or force sensors; and (iii) feedback: visual, auditory, or tactile channels provide real-time performance information.

There are technological advances in upper limb robotic rehabilitation; however, there is a lack of evidence regarding clinical validity. A few main factors contribute to this, including a lack of robust methodology, a lack of personalization, and a lack of standardized evaluation. Furthermore, studies are limited on gamified feedback mechanisms that sustain patient motivation, as well as studies on portable mechanisms that are designed for home use. \s\n The clinical efficacy of rehabilitation robots is based on the highly interactive and synergistic architecture of hardware and training paradigms. The next generation of robotic rehabilitation systems is expected to offer personalized and adjustable training, active participation through biosignal training, functionality to support home use and portability. This may provide a better mechanism to help stroke patients regain hand functionality and facilitate activities of daily living (28). A great deal of activity has taken place in the past few years involving the design and development of robots for the rehabilitation of sensorimotor functions of the nervous system. However, the majority of the emphasis on these developments has been technology and not enough on their clinical utility. In fact, rehabilitation robots should be designed from the perspective of the neurophysiological mechanisms of both intact and impaired sensorimotor systems, and that type of design would require a good deal of integrative and cross-disciplinary design (28).

The rehabilitation of sensorimotor functions following CNS damage relies on the use of retraining neuroplasticity processes in order to promote and support the initiation of movements that allow the individual to perform activities of daily living independently. To achieve this, the client's physiological muscle activation must be facilitated through exercises, appropriately peripheral receptor-stimulating exercises, and the use of rehabilitation robots developed to help remediate the aforementioned functions and have the latest sensor and interaction control technologies that continuously assess and adapt the support to the client's needs.

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Despite advances made in this area, new challenges and issues persist. To achieve the best functional results, the rehabilitation process and methodology must be informed and guided by the latest neurophysiology and clinical practice. However, functional recovery is finite, and the use of rehabilitation robots should also seek to incorporate neurophysiology and advanced engineering (26).

When used optimally, robot-assisted therapy has the potential to create improvements that transcend those achieved with traditional therapies by providing a uniform rehabilitation environment, variable assistance and support, increased rehabilitation intensity and dosage, and lessened physical workload on the therapist. For these reasons, rehabilitation robots are regarded as primary and significant adjunctive instruments for the rehabilitation therapy process in clinical practice and, due to their uncomplicated construction design, are ideally suited to facilitate the continuation of therapy in the patient's home.

The field of rehabilitation robotics integrates the most recent technological advances with the oldest and most accepted techniques of clinical neurorehabilitation. Central nervous system (CNS) damage can lead to loss of the ability to use and sense a body part. Intensive neuroplasticity-based therapy is the primary way to help such individuals regain their ability to use the affected parts of their bodies and achieve functional autonomy. Robotic devices used in rehabilitation therapy can augment standard therapy techniques because they offer a unique opportunity to provide an equally high volume of therapy repetitions and therapy environment standardization. Furthermore, they can objectively measure rehabilitation therapy outcomes and provide individualized adjustable assistance and physical support to the patient. Robotic devices help to improve motor performance and also help to support and sustain patient motivation, engagement, and compliance with the rehabilitation therapy program. There are three primary categories of robot-assisted rehabilitation therapy devices, which are also known as rehabilitation robots: exo-skeletal, end effector, and wearable robots. Exo-skeletal robots are usually positioned in parallel to the joints of the patient and mechanically control them through the entire movement rehabilitation training cycle. These devices are highly effective in rehabilitation training of the affected upper and/or lower limbs of those patients with severe paresis. In contrast, end effector devices are robotic systems that have lower resistance (impedance) and are driven from the distal side of the robot. These end effector devices allow the patient to actively participate in the upper and/or lower limb movement and, thus, create a more natural functional movement pattern. In addition, wearable rehabilitation robots have gained significant popularity in recent years, especially for rehabilitation therapy that patients can complete at home and for functional assistance. These devices are also highly regarded for their lightweight, portable, and easily donned and doffed (user-friendly) designs. Research outcomes consistently demonstrate that robotic-assisted rehabilitation therapy, when the number of repetitions and the intensity of rehabilitation robots are equal to those of traditional rehabilitation methods, results in comparable functional rehabilitation outcomes to traditional rehabilitation methods.

Research findings have shown that some of the most important factors that enhance the success of robotic therapies include starting treatment as soon as possible, preserving the integrity of the corticospinal tract, and including motivation in the exercise (eg, involving the use of virtual reality). Robotic devices will have limited success in the control of the upper extremities as the recovery of hand and finger function is limited. Therefore, incorporating ultraprecision pressure sensors and closed-loop control systems in robotic devices is necessary in order to achieve the required clinical success. Additionally, for the training to be functionally relevant to the performance of activities of daily living, the training of bimanual or even collaborative coordinated tasks is of growing importance.

In summary, rehabilitation robots should be regarded in clinical settings, not as systems that replace the current physiotherapy and occupational therapy methods, but as effective systems that enhance the current methods. Recovery is influenced by a myriad of factors, including the patient (type and localization of lesion, integrity of the CST, etc.), the time of the intervention (acute, subacute, chronic), the amount of rehabilitation (rehabilitation dose), and the intervention's control of the targeted neurophysiological mechanisms. The evolution of rehabilitation systems will undoubtedly require a high level of collaboration among the various

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fields of engineering, neurophysiology, physiotherapy, occupational therapy, and clinical medicine. The integration of lightweight, wearable, sensor-based, and AI-powered robotic systems with long-term customized telehealth rehabilitation systems is expected to not only improve the rehabilitation of the impaired motor function, but also to facilitate the restoration of the patients' functional independence.

METHODS

This study was designed as a systematic review aimed at evaluating the effectiveness of robotic-assisted therapy as a rehabilitation tool for improving upper extremity function following stroke. A comprehensive literature search was conducted covering the period between 2000 and 2026 using major electronic databases, including PubMed, Google Scholar, and PEDro. The search strategy incorporated a combination of relevant keywords such as "stroke," "stroke rehabilitation," "upper limb rehabilitation," "robotic rehabilitation," "robotic upper limb rehabilitation," and "robot-assisted therapy," with various combinations applied to maximize retrieval of relevant studies.

A total of 173 articles were initially identified through the database search. The screening and selection process was performed independently by two reviewers (P.A. and K.A). Initially, titles and abstracts were assessed for relevance, and full-text versions were obtained for studies that met the preliminary inclusion criteria. Each study was then independently evaluated for eligibility. Duplicate studies were removed, and any discrepancies between reviewers were resolved through discussion and consensus. Following full-text evaluation, studies that met the predefined inclusion criteria were included in the final analysis.

The inclusion criteria were defined to ensure relevance and comparability across studies. Eligible studies focused on upper extremity rehabilitation following stroke, incorporated robotic-assisted therapy, provided full-text access, and were published within the specified timeframe. Additionally, studies were required to include the Fugl–Meyer Assessment (FMA) as an outcome measure, given its widespread use and validity in evaluating upper extremity motor function. To further enhance homogeneity, only studies with at least two comparison groups—such as robotic rehabilitation versus conventional therapy, or robotic rehabilitation combined with exercise versus conventional therapy—were included.

Additional methodological criteria were applied to reduce heterogeneity and improve the consistency of the findings. Studies were included only if they clearly reported the duration and number of treatment sessions. Interventions that were excessively short (e.g., ≤4 sessions) or non-standardized in duration were excluded or evaluated separately, as were studies with overly prolonged or inconsistent treatment protocols. These criteria were implemented to allow for a more structured comparison of intervention effects and to ensure a more homogeneous dataset.

Exclusion criteria comprised studies involving animal models, case reports, and studies lacking full-text availability. By applying these inclusion and exclusion criteria, the review aimed to standardize outcome measures and minimize variability, thereby enabling a more reliable assessment of the effects of robotic rehabilitation on upper extremity recovery after stroke.

DISCUSSION

Results from this systematic review show that most studies involving robotic therapy show effectiveness in motor recovery in upper extremity rehabilitation after a stroke. These studies consider several factors that affect these gains such as stroke stage, treatment dose, target region, type of robotic system, and individual neurophysiological factors (26, 28, 32).

The data from several meta-analyses show that robotic arm rehabilitation has a small to moderate positive effect on upper extremity and hand functions. In the assessment of proximal and distal joints, no notable increases in specific joint ranges of motion indicate that robotic therapy focuses on general functional improvements instead of specific joint movements (26). This is because most robotic systems on the market are designed to perform repetitive actions and ignore functional goal integration.

The dose of therapy is one of the most paramount factors that contributes to how beneficial robotic therapy will be.

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Analyses of divided studies indicate that 30–60-minute durations provide the greatest function increases (26). This is also true due to the fact that an increase in duration beyond 60 minutes does not appear to provide any benefit. This shows that less duration, factors like intensity, number of movements, and the difficulty of the tasks are the primary contributors to rehabilitation (32). These factors indicate an incorporation of motor learning theories and how they advocate for high levels of effort and purposeful activity, as they are the primary catalysts for neuroplastic changes.

The greatest evidence of robotic rehabilitation seen through the lens of the stage of stroke as such, appears in the subacute stage. This is attributed to the window of neuroplasticity, which is a period of spontaneous biological recovery. Functional recovery fostered through rehabilitation in the early phases supports processes such as synaptic growth, dendritic remodeling, and axonal reorganization, which in turn assist to provoke greater motor recovery. This is opposed to recovery in the subacute phases and the sparse evidence in the acute phases, whereby recovery in the chronic phases becomes dependent on the dose of treatment suggesting that the timing of rehabilitation is a determining factor in the clinical relevance of the rehabilitation programme.

There is considerable heterogeneity in the literature regarding the effectiveness of robotic rehabilitation for improving individual hand function following stroke. Although several small-scale randomized controlled trials have demonstrated statistically significant improvements in specific subcomponents of the Fugl–Meyer Assessment for the hand, these findings are not consistently supported by parallel improvements in muscle strength, as measured by indices such as the Motricity Index. This discrepancy suggests that robotic rehabilitation may primarily facilitate improvements in motor control and coordination rather than directly enhancing muscular strength. Such findings reinforce the notion that recovery of hand function is a multifactorial process involving not only motor output but also sensory integration, proprioceptive feedback, and higher-order cognitive mechanisms. Furthermore, functional recovery is closely linked to neuroplastic changes, including cortical reorganization within motor-related brain regions, which may be more effectively stimulated through repetitive, task-specific robotic training.

In addition to its neurophysiological effects, robotic rehabilitation has been shown to positively influence key factors such as motor learning, patient motivation, and adherence to therapy. The ability of robotic systems to provide consistent, repetitive, and quantifiable training may enhance engagement and facilitate more structured rehabilitation programs. However, an important limitation highlighted in the literature is that robotic therapy does not consistently demonstrate superiority over conventional therapy when matched for the number of repetitions. This observation suggests that the benefits of robotic rehabilitation cannot be attributed solely to mechanical assistance or increased training intensity. Rather, the therapeutic efficacy of robotic systems appears to depend on their ability to actively engage patients through meaningful, goal-directed activities.

Therefore, for robotic rehabilitation to achieve optimal outcomes, it should not be applied as a standalone modality but rather integrated into a comprehensive rehabilitation framework. The incorporation of multimodal sensory feedback systems, such as visual, auditory, and haptic cues, may enhance patient engagement and promote active participation. Additionally, combining robotic therapy with task-oriented training that mimics activities of daily living may further facilitate functional recovery and improve the transfer of motor gains to real-world performance. Future research should focus on developing standardized protocols that integrate robotic assistance with these complementary strategies to maximize both motor and functional outcomes.

The robotic systems that have been researched to date show that there is little to no difference between the clinical outcomes from the exoskeleton and the end-effector. This reinforces the idea that the outcome is more related to the therapy content and the amount of therapy [dose], and less on the engineered outcome of the robotic device. This reiterates the need for an individualized approach to therapy, particularly with robotic systems, which can be more expensive.

Robotic therapy should be viewed as just one tool, and not a stand-alone superior therapy. It's role, among other therapies, is to bring more options to the approach, in order to meet the goals of the rehabilitation system.

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Most of the studies suggest that robotic rehabilitation is a valuable component of neurorehabilitation programs as it provides the possibility for neurorehabilitation therapies to be conducted with high intensity and in a task focused manner. The low level of functional independence achieved by the patients and the low level of functional independence achieved by the patients and the low level of functional independence achieved by the patients and the low level of functional independence achieved by the patients and the low level of functional independence achieved by the patients and the low level of functional independence achieved by the patients and the low level of functional independence Where functional independence and the performance of activities of daily living are concerned, the gains are low, it indicates that future robotic systems must address not only the generation of movements but also the functional relearning and daily use of movement.

Defining prescriptive exercise, robotic therapies that incorporate artificial intelligence, biosignal based control systems, and home based telerehabilitation systems will likely enhance the intensity of the therapies and the functional gains to daily life activities.

CONCLUSION

Robotic upper extremity rehabilitation is a method that can be used alone and is a safe and effective way to promote recovery of motor functions after a stroke, and, it should not be viewed as a stand alone method, but, as part of a comprehensive and individualized rehabilitative and task-oriented approach to rehabilitation. Taking into account the entire body of literature, we can conclude that robotic rehabilitation of the upper limbs can be considered a promising and effective method of rehabilitation for individuals who have suffered a stroke.

Most studies have focused on interventions that target only gross motor functions and grip strength. They have addressed other skills required for activities of daily living (ADLs), such as fine motor skills, only to a limited extent. There is a lot of methodological heterogeneity between the studies due to the differences in the types of robotic systems, treatment duration, number of treatment sessions, and the evaluation scales used. This heterogeneity underscores the need for more standardized treatment protocols and more focused objective research in this area. In this regard, the study to be conducted intends to add to the literature by more systematic and protocol-oriented research on the effectiveness of robotic systems for the rehabilitation of fine motor skills, which is one of the numerous existing gaps.

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