Research Article

Comprehensive Approaches To Stroke Rehabilitation: Multidisciplinary Strategies And Technological Breakthroughs

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Abstract

Stroke rehabilitation has changed a lot because of new technologies and multidisciplinary approaches. These changes have made life better for survivors and given them new hope for recovery. This study focuses on evidence-based rehabilitation treatments particularly made to help those who have had a stroke get back to normal functioning, including physical, occupational, speech, and cognitive therapy. Modern technology, like robotic devices, virtual reality (VR), and telemedicine, has changed rehabilitation by making neuroplasticity, motor recovery, and patient engagement better. Robotic-assisted treatment and virtual reality (VR) both provide high-intensity, repetitive training and immersive settings for performing real-world tasks, resulting in measurable enhancements in motor and cognitive outcomes. Telemedicine has made it easier for people who don't have a lot of money to get rehabilitation, which makes sure that care continues. Even with these gains, there are still issues including inequalities in income and education, restricted access to expert care, and the need for individualized therapies. Plans for the future focus on improving these technologies, removing barriers to their use, and encouraging collaboration amongst different fields to make recovery processes as effective as possible. Stroke survivors can enhance their quality of life and augment their functional independence by incorporating cutting-edge technology with evidence-based methodologies. This comprehensive approach demonstrates the revolutionary potential of modern therapies in mitigating stroke-related impairments.

Keywords: Neuroplasticity, telemedicine, virtual reality, robotics, stroke therapy, and a multidisciplinary approach.

1. Introduction

Recent clinical research has concentrated on the rehabilitation of multiple functional domains because stroke is one of the most common causes of disability in older adults [1]. Over 80% of stroke patients experience hemiparesis of the contralateral upper limb immediately, and over 40% experience it chronically [2]. This is the most prevalent impairment following a stroke. Muscle weakness or contracture, alterations in muscle tone, joint laxity, and poor motor control are typical signs of upper extremity motor dysfunction. These deficits make common behaviors like reaching, picking up, and holding onto objects difficult [3]. Since upper extremity motor paresis may be linked to additional neurological symptoms that impact motor function recovery, targeted therapy intervention is necessary. It has been observed that between 11 and 85% of stroke victims have deficits in somatic sensations or body senses such as touch, warmth, pain, and proprioception [4]. Functionally, the motor issues brought on by sensory deficits following a stroke can be summed up as follows: (1) impaired sensory information detection; (2) decreased performance on motor tasks requiring somatosensory information; and (3) reduced rehabilitation results for the upper extremities [5]. Even in cases where motor recovery is sufficient, sensation is crucial for safety [6]. Proper early rehabilitation may be hampered by the fact that up to 50% of stroke patients develop upper extremity pain in the first year following the event, particularly shoulder discomfort and complex regional pain syndrome-type I (CRPS-type I) [7], [8]. Additional causes of nociceptive musculoskeletal discomfort include muscle contractures and joint subluxation [9]. Motor and functional results are impacted by neglect syndrome [10] and spasticity [11], among other stroke sequelae. The demand for rehabilitation has increased in tandem with the age-adjusted decrease in stroke fatalities brought about by recent advancements [12]. Depending on the location and severity of the Stroke, a person's post-stroke needs can vary significantly. The majority of stroke victims have motor impairments [13]. However, up to half of those who survive have post-stroke cognitive impairments [14], which can include deficits in language, reasoning, attention, and memory [15], [16]. These impairments significantly diminish the quality of life. Another important mediating factor in the success of rehabilitation is mental health [17]. The critical function of exercise therapy as a vital element of stroke recovery was highlighted by numerous systematic reviews that concentrated on methods to promote upper extremity recovery in stroke patients. Based on a thorough study of 5712 papers and 41,069 subjects, the evaluation highlighted the significance of evidence-based rehabilitation strategies that have demonstrated higher efficacy when compared to other approaches [18].

In addition to highlighting the revolutionary potential of cutting-edge technologies like robotic devices, virtual reality, and telemedicine in boosting neuroplasticity, motor recovery, and patient engagement, this review thoroughly assesses the effectiveness of multidisciplinary stroke rehabilitation strategies, such as physical, occupational, speech, and cognitive therapies. It also looks at long-term issues including socioeconomic inequality and limited access to specialist care to discover the best strategies to help individuals get better. We want to make the lives of stroke survivors better and provide them more flexibility to accomplish things by merging innovative ideas with clinical practice and filling in the gaps. In the end, we will promote rehabilitation methods that are tailored to each person, easy to get to, and work. This study seeks to organize knowledge on selecting rehabilitation measures and evaluations for post-stroke patients, highlighting the importance of effective and dependable instruments to guide rehabilitation therapies

1.1. Recovery After a Stroke

Neurological recovery after a stroke displays a nonlinear, logarithmic pattern, as shown in Figure 1 [19]. According to reports, most healing occurs during the first three months after a stroke [20]. Recovery in the hands and upper extremities has been seen years following Stroke, suggesting that recovery is not restricted to this time frame [21]. Improvement most likely results from a complex interplay of learning-dependent and spontaneous processes, such as compensation, substitution, and restoration [22]. Variable spontaneous neurological recovery can be regarded as a confounding factor for rehabilitation interventions up to three months following the onset of the Stroke [23]. Learning adaptation methods have a major role in the functional outcomes progress after three months [24]. Evidence indicates that the subacute and chronic phases following a stroke may also involve neurological restoration through brain reconfiguration, supporting full recovery, or by compensation [25]. There is variation in the functional results of stroke recovery. Since 71% of patients with mild to severe upper extremity paresis in the acute phase regain at least some dexterity six months following the Stroke, these patients have a fair chance of functional recovery [26]. About 60% of patients with severe Stroke do not regain any dexterity six months after the Stroke, indicating a poor prognosis [27]. In patients with severe upper extremity impairments, proper recovery is rare. Instead, these patients often rely on compensatory strategies (e.g., using the unaffected hand or adaptive devices) to perform daily activities [28]. To forecast the recovery of motor function following a stroke, algorithms have been created [29].

Following therapy, mild upper limb motor function may be predicted from the initial impairment of upper limb motor function. This study did not significantly impact recovery by any demographic or clinical characteristics, such as age or the kind of Stroke [30]. The results indicate that the initial evaluations should be brief and straightforward, like motor impairment tests performed at the patient's bedside, and that if there is still uncertainty, more complicated tests should be used. Neurophysiological evaluations and neuroimages of the integrity of the motor system may be included in subsequent testing. Several activity-dependent mechanisms influence post-stroke recovery, including axonal sprouting [31], [32]dendritic spine formation [32], and subventricular stem cell migration to peri-infarct regions [33]. Synaptic plasticity is the primary mechanism of recovery. Therefore, the fundamental ideas of behaviorally supported neuroplasticity are applicable; functional recovery results from regular, challenging, and specific training [34].

1.2. Epidemiology of Stroke

The epidemiology of Stroke includes a variety of factors that influence the prevalence, incidence, and distribution of stroke cases in a community. According to [1], Roughly 7.6 million American adults have had a stroke, with forecasts of an additional 3.4 million instances by 2030. The incidence of Stroke is determined by age, gender, and geographic variation, and recent advances have resulted in a drop in stroke-related mortality, increasing the need for rehabilitation. Post-stroke cognitive deficits, which impact up to half of surviving adults, dramatically diminish the quality of life, stressing the need for thorough rehabilitation treatments [35]. Furthermore, [36] emphasized the value of rehabilitation exercises in improving stroke patients' physical function. Their systematic analysis examined research published from 2012 to 2022 and emphasized the significance of stroke rehabilitation, exercise, and treatment in enhancing recovery results. These results highlight the vital need of epidemiological data in developing effective stroke rehabilitation training programs.

1.3. Pathophysiology of Stroke

The pathophysiology of stroke is characterized by a disruption in the cerebral blood flow, resulting in ischemia or hemorrhagic damage. When a blood vessel breaks, it's called a hemorrhagic stroke. When a blood artery is blocked, it's called an ischemic stroke, as shown in Figure 1. These events cause brain tissue to lose oxygen and nutrients, which kills cells and makes them less able to do their jobs. The characteristics of each type of stroke are displayed in Figure 1. The specific deficits experienced by an individual, including motor, sensory, or cognitive impairments, are determined by the stroke's location inside the brain. To make personalized rehabilitation programs that meet the needs of each stroke victim, you need to know about these routes [18].

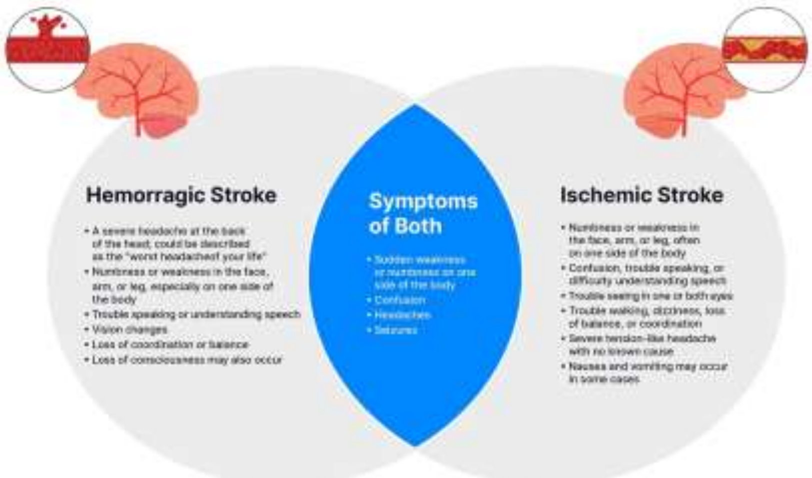

Figure 1: Ischemic Stroke and Hemorrhagic Stroke [37]

2. Principles of Stroke Rehabilitation

The foundation of stroke therapy is knowing how neuroplasticity, motor learning, and recovery mechanisms work. These are all important for successful rehabilitation therapies. Neuroplasticity is the brain's ability to make new neural connections and change how it works. This is important for relearning motor abilities after a stroke. Rehabilitation uses task-oriented and task-specific training methods, as well as frequent and particular exercises that help people get better at doing everyday things. This is how they take advantage of this process [38] [18]. The guideline for post-stroke rehabilitation care also stresses the relevance of activity-dependent mechanisms, like synaptic plasticity and axonal sprouting, that are caused by rehabilitation therapy. These principles assist the creation of plans to help people change their behavior and find new ways to treat them, such as using new technology like virtual reality and robots to improve rehabilitation outcomes [1]. So, in order to create and use effective stroke recovery training programs, you need to understand these concepts.

3.Types of Stroke Rehabilitation Training Procedures

There are many different types of specialist therapy that can be used to help stroke patients recover. Occupational therapy helps people get back to doing everyday things, and physical therapy helps people move better, get stronger, and improve their balance through personalized exercises and treatments. Speech therapy uses exercises and treatments to help people who have trouble talking and swallowing. Cognitive rehabilitation focuses on cognitive deficits such as memory and attention issues through tailored therapy and training [18]. Recent studies indicate that a variety of workouts is more effective for stroke rehabilitation than a singular exercise. Researchers have investigated isometric, isokinetic, and isotonic exercises. Therapies that focus on tasks and technology-assisted treatments like robot-assisted therapy, electrical stimulation, and virtual reality are becoming more popular [35].

The changing landscape of stroke rehabilitation training shows how important it is to use personalized, multidisciplinary methods to address the needs of stroke patients and speed up their recovery.

4 Physical Therapy

Physical therapy is particularly important for stroke rehabilitation because it helps stroke survivors go back to their normal physical functioning and mobility by focusing on therapeutic exercises, mobility training, and functional restoration. [18] mentioned that exercise therapy is especially beneficial for stroke recovery. A comprehensive study shown that various rehabilitation techniques can enhance upper extremity motor outcomes in stroke patients [36]. Furthermore, rehabilitation exercises have been effective in enhancing physical function, especially through intricate and diverse modalities, including isometric, isokinetic, and isotonic training, along with task-oriented therapy. The changing trends in intervention methods, such as robot-assisted therapy, electrical stimulation, virtual reality, telemedicine, and home-based treatment, show that stroke rehabilitation is moving toward more organized and varied approaches. These references underline how vital physical therapy is and how many various tactics and interventions are needed to help stroke survivors get back to normal. The main goal is to reduce impairment and make daily tasks easier.

4.1 Occupational Therapy

Occupational therapy plays a crucial role in stroke recovery to increase stroke survivors' Participation in meaningful everyday activities and duties. Interventions in occupational therapy may include teaching people how to do activities of daily living (ADLs), adaptive techniques, and changes to their environment to help them be more independent and productive [39]. These therapies attempt to keep or improve the soft tissue features of the upper limb, stop contracture or dependent edema, and encourage sensorimotor restoration by using muscle facilitation, strengthening, and regular workouts to improve grasp, reach, and object manipulation skills. Avoiding movements that strengthen the upper limb's synergistic movement patterns that limit function is commonly accompanied with approaches including progressive resistive exercise, constraint-induced movement therapy, functional electrical stimulation, and sensory-related training. To help with problems with motor planning and memory, the occupational therapist regularly includes proprioceptive cues, visual scanning training, and remediation procedures in the therapy program. Additionally, complicated and integrated workouts have been demonstrated to be better than separate exercises for stroke rehabilitation, especially for improving walking and upper limb function. Task-oriented therapy is the major way to help people recover after a stroke, but emerging technologies like electrical stimulation, robot aid, and virtual reality are also being used. Studies on telemedication and home-based treatment have grown because they focus on keeping people involved, which shows the ideal time, type, and frequency of treatment [35]. These results show that occupational therapy and rehabilitation are becoming more and more important for stroke survivors' recovery and ability to function.

4.2 Speech Therapy

Speech therapy helps people who have had a stroke get well by helping them swallow, learn new words, and talk. It helps those who have had a stroke swallow, talk, and think. This therapy may help with eating, understanding language, and speaking. Speech therapy that includes cognitive-linguistic activities helps stroke survivors' quality of life by increasing their cognition, attention, memory, and language [1]. High-level data supports early treatment for speech, language, and swallowing after a stroke, which shows how important it is to do specialized training activities [40]. Further investigation is required to ascertain the efficacy of virtual reality, robotics, neuromodulation, and telerehabilitation in enhancing speech therapy and stroke rehabilitation.

4.3 Cognitive Rehabilitation

Cognitive rehabilitation after a stroke is designed to treat deficiencies in cognitive functions such as memory, attention, problem-solving, and executive functioning. Nonpharmacological therapies are important in this process, emphasizing improving cognitive function following Stroke. [40] underlined the importance of investigating all interventions that may improve cognitive performance after a stroke, including the effects of participant characteristics, stroke type and severity, stroke start time, cognitive impairment severity, and intervention adherence. A systematic review and meta-analysis will give the most recent evidence on the influence of nonpharmacological rehabilitation interventions on cognitive function following a stroke, leading to the development of the best interventions available. Furthermore, [1] stressed the significance of cognitive therapy in post-stroke recovery, emphasizing the influence of cognitive impairments on quality of life. They explore how enthused people are about introducing new technology, such as robotics and gamification, to improve therapy and rehabilitation adherence. The authors also stated that few studies on cognitive rehabilitation have focused on memory, attention, and executive function, underlining the need for more studies to improve post-stroke cognitive rehabilitation.

5. Assessment Tools in Stroke Rehabilitation

Assessment techniques are important in stroke therapy because they help evaluate the progress and consequences of therapies. Standardized assessments, outcome measurements, and functional evaluations are frequently employed in this setting to assess the efficacy of rehabilitation approaches [18]. Underlined the relevance of exercise therapy as a vital aspect of stroke rehabilitation, underscoring the need for evidence-based recommendations for rehabilitation programs [41]. Emphasized the need to use smaller motion sensors to accurately examine hand function after a stroke, including characteristics such as post-stroke hand swelling, which can influence outcome measures. According to [42], seven (37%) and twelve (63%) of the 19 clinical practice recommendations (CPGs) that were reviewed originated from middle- and high-income countries, respectively. Among the CPGs, ten (53%) advised or recommended 27 distinct instruments. The Berg balance scale (BBS) (90%), the 6-minute walk test (6MWT) (80%), the timed up-and-go test (80%), and the 10-meter walk test (70%) were the most often referenced instruments across all 10 CPGs. The BBS (3/3 CPGs) and the 6MWT (7/7 CPGs) were the tools most often cited in middle-income and high-income nations, respectively. The three aspects of postural control most commonly tested across 27 tools were anticipatory postural control (96%) and dynamic stability (85%), with the underlying motor systems being tested 100% of the time. Just one CPG offered a level of recommendation; the other five CPGs included information on the selection process at various degrees of depth. According to [43], stroke rehabilitation employs various tools to evaluate functional capacity, motor function, mobility, and specific impairments. The functional independence measure (FIM) assesses physical and cognitive impairments with scores ranging from 0-126, while the Barthel index (BI) measures independence in self-care activities, scoring 0-100. The French Activities Index (FAI) evaluates instrumental daily activities (15-60), and the 6MWT measures walking capacity by distance. Stroke severity is assessed using the NIH Stroke Scale (NIHSS), which scores neurological status (0-42). Motor function is evaluated through the Fugl-Meyer assessment (FMA) (score: 0-226) and the Rivermead motor assessment (RMA) (score: 0-38). Mobility tools include the BBS (0-56), Rivermead mobility index (RMI) (0-15), and the timed "up and go" test (TUG), which times movement tasks. The Wolf Motor Function Test (WMFT) assesses motor ability (0-75) for upper extremity function. Finally, the modified Ashworth scale (MAS) measures spasticity with subjective resistance ratings (0-4). These tools provide critical insights into recovery progress and treatment efficacy. [44] A scoping review identified 27 unique tools recommended in CPGs worldwide for assessing balance and mobility post-stroke. The BBS (90%), the 6MWT (80%), the TUG (80%), and the 10-meter walk test (10mWT) (70%) were the most often cited instruments. These instruments assess motor systems, anticipatory postural control, and dynamic stability. The use of BBS and 6MWT was prioritized in high-income nations, although the guidelines' descriptions of tool selection and application varied. Only a small number of CPGs offered comprehensive tools or approaches to assist their clinical adoption, underscoring the need for increased accessibility and standardization on a worldwide scale. [45] The Modified BI, MAS, Mini-Mental State Examination, FMA, NIHSS, BBS, Modified Rankin Scale, Action Research Arm Test (ARAT), WMFT, and TUG were the most frequently utilized assessment tools in post-stroke rehabilitation, according to a scoping study. There were no tools that specifically targeted participation; instead, 77% of the tools assessed Body Functions and Structure, 16% addressed Activity and Participation, and 1.4% evaluated Environmental and Personal Factors together. Tools should be based on the International Classification of Functioning, Disability, and Health (ICF) and take into account aspects like the environment and involvement. This makes sure that stroke therapy takes into account all aspects of health. A study of family caregivers' home care for post-stroke patients discovered effective tools like the BI (to see how independent the patient is in daily activities), post-stroke care checklists (to see how well the caregiver is doing), and complications checklists. 66.1% of caregivers were happy with the care they gave, and half of the patients could conduct ADLs. But a lot of patients experienced urinary tract infections (65%), pneumonia (68%), and depression (75%), which shows that caregivers need more training and ways to stop these problems from happening. [47] offers a comprehensive stroke rehabilitation evaluation framework that prioritizes recovery forecasting to inform treatment choices. Time to walk independently after stroke (TWIST) predicts walking independence, while the NIHSS and SAFE help with motor rehabilitation. The Western Aphasia Battery (WAB) and the Predictive Swallowing Score (PRESS) can help you guess how well someone will recover from a stroke and how well they will speak. The Alberta Stroke Program Early CT Score (ASPECTS) and the Acute Stroke Registry and Analysis of Lausanne (ASTRAL) can tell you how likely you are to die and how well you will be able to live on your own. GRAVo gives us an idea of how many PEGs we'll need. DTI and TMS make predictions of motor recovery better, especially in extremely bad instances. Online tools and evidence-based materials make clinical use more useful and encourage personalized therapy. [48] The International Classification of Functioning, Disability, and Health (ICF)-based assessment instruments for upper extremity function in stroke rehabilitation are described in the narrative review. Tools are divided into three categories: activity, participation, and bodily functions/structures. Motor impairment and restitution are measured by the FMA and kinematics/kinetics. While participation-focused instruments like the SIS and COPM assess quality of life and societal responsibilities, activity tools like the ARAT and WMFT evaluate functional tasks and independence. These tools improve patient outcomes by facilitating customized rehabilitation procedures with varying reliability and minimal clinically meaningful differences (MCIDs). The particular component of evaluated recovery determines the optimal evaluation instrument for stroke therapy. Nonetheless, the BBS is the most often tool in CPGs and scoping reviews, according to numerous studies and recommendations analysis. This is the reason:

1. Most Often Suggested Among CPGs: The BBS is the most often used balance and mobility evaluation instrument, appearing in 90% of the CPGs that were analyzed. BBS is given priority in high-income nations for assessments of dynamic stability and postural control.
2. Comprehensive Evaluation of Postural Control and Stability: o The BBS evaluates dynamic stability (85%) and anticipatory postural control (96%), both of which are essential for stroke recovery. BBS incorporates balancing components necessary for functional independence, in contrast to other tests that only concentrate on mobility (such as the 6MWT).
3. Validated Across Numerous Studies & Guidelines: o Studies consistently demonstrate that the BBS predicts post-stroke functional independence and fall risk. It is one of the most validated instruments, appearing in 27 different CPG-recommended instruments.
4. Global Applicability & Standardization: The BBS is widely used and standardized in middle- and high-income countries, showing that it works well in healthcare. BBS scores are reliable, while ICF participation-based systems have problems with reporting or methods that aren't transparent.

Table 1: Comparison with other common tools

Tool	Function Assessed	Limitations
BBS (Best Choice)	Balance, Postural Control, Fall Risk	Less useful for gait speed assessment
6MWT	Walking capacity, endurance	Does not assess balance or fall risk
TUG	Mobility & functional movement	Lacks postural control evaluation
NIHSS	Stroke severity (neurological deficits)	Does not assess balance or function
FIM	Independence in daily activities	Lacks mobility-specific assessment
MAS	Spasticity	Not comprehensive for rehabilitation outcomes

6. Innovative technologies that assist individuals in recovery following a stroke

Technology has changed stroke rehabilitation training by giving therapists new tools to help patients. Robots can help stroke survivors with daily activities, improved motor skills through concentrated workouts, and job-specific repetitive training [42]. VR apps provide realistic surroundings for rehabilitation activities that help stroke victims regain motor skills and cognition. Telemedicine allows patients in rural or underdeveloped areas to receive rehabilitative therapies remotely. These innovations allow stroke patients to receive personalized and successful rehabilitation [18]. As technology develops, it could greatly enhance stroke rehabilitation training, improving patient outcomes and quality of life. High repetition and intensity, task specialization, objective feedback, enhanced user involvement, and motivation are just a few of the benefits that emerging technology in stroke therapy offer over conventional rehabilitation techniques. When creating a training program for stroke patients, doctors should take the limitations and difficulties of technology into account. Each patient's rehabilitation demands and objectives should be taken into consideration while creating personalized games and applications [49].

6.1. Robotic Devices

Robotic devices offer new options for motor recovery and functional restoration, making them attractive stroke recovery treatments. Because they can enhance motor learning and neuroplasticity, robotic exoskeletons, robotic arms, and other robotic-assisted devices have become more and more popular. In order to promote motor skill relearning and functional improvement in stroke patients, these devices are made to provide repetitive, high-intensity training [50]. Furthermore, combining robotic therapy with other cutting-edge methods like virtual reality environments and noninvasive brain stimulation techniques has demonstrated promise in raising patient motivation and engagement in movement-based practice, ultimately improving rehabilitation outcomes. By highlighting the significance of promoting plastic reconfiguration of the central nervous system to address functional deficits caused by stroke, advanced robotics integration in stroke rehabilitation is consistent with the developing evidence-based approach in neurorehabilitation (see Figure 2). As research in this area grows, it becomes more and clearer that robotic devices could help stroke survivors recover fully and quickly.

Figure 2: Common robotics in our center's regular clinical practice for upper limb rehabilitation. (a) China's M2 upper-limb intelligent isokinetic trainer; (b) Armeo® Spring three-dimensional upper-limb training and evaluation system; (c) China's upper-limb rehabilitation training system; (d) China's Dynaxis upper-limb rehabilitation training system [51].

The study [52]used randomized controlled trials, with individuals assigned to either robotic-assisted therapy or conventional therapy groups, and outcomes were examined using a variety of assessment instruments. It used a variety of methodologies, including randomized controlled trials, in which patients were allocated to either a treatment or control group. The treatment groups received robot-assisted therapy, whilst the control groups received standard therapy or no intervention. The study also used other outcome measures, like the FMA, Motor Power Scale, and Stroke Impact Scale.

Electromechanical and robot-assisted arm training improved stroke patients' ADL scores, arm function, and arm muscle strength. Adverse effects were rare and the training did not increase participant attrition. The study found that robot-assisted and electromechanical arm training improved ADL scores by 0.31. The robotic-assisted therapy groups improved upper limb function, health-related quality of life, and stiffness significantly. The study also revealed substantial evidence that electromechanical and robot-assisted arm training is safe and acceptable. Electromechanical and robot-assisted arm training improved muscle strength and function. The normalized mean difference for arm function was 0.96 and muscle strength 0.41. The review [53] discusses many therapeutic robots used in rehabilitation after a stroke, such as end-effector devices, exoskeletons, and robots for the arms and legs. The studies employed randomized controlled trials, wherein intervention groups utilized robots and control groups employed conventional rehabilitation approaches. The intervention can go on for as long as eight weeks. The studies utilized various outcome measures, including the FMA-UE scale, the Box and Block Test, and the WMFT.

The review's findings suggest that although upper-limb robots can improve muscle synergy and range of motion in the upper extremities, they are not particularly helpful in augmenting muscular strength. The study also shows that robotic technology could help stroke victims move around better and be more independent. Using a matched-group technique [54], the study put participants into either the robotic therapy group or the control group. The robotic therapy group underwent one hour of treatment daily for 10 days, whereas the control group received conventional therapy. The Kinarm Exoskeleton Lab is a planar, bimanual, multi-joint robot employed in the investigation. This study combined robotic tests such as Visually Guided Reaching, Object Hit, Object Hit and Avoid, Arm Position Match, and Kinesthesia with clinical testing like FMA UE, ARAT, and FIM. The research revealed that subsequent to the robotic intervention, both clinical and robotic scores for the robotic therapy group exhibited considerable enhancement. There was also a big improvement in the group's scores on the FMA UE, ARAT, FIM, and Visually Guided Reaching.

The subjects completed the nine robotic rehabilitation activities without any notable ill effects. A systematic review and meta-analysis was used in the study [55], which searched valid databases and publications with low bias. The findings indicated that robotic arms enhanced upper limb functionality in stroke patients, yielding a pooled estimate of 0.23 (95% CI: 0.01-0.45, I^2 39.36%, $p = 0.04$). The study [56] surveyed professionals' opinions and experiences with rehabilitation robots in clinical and home-based settings. The findings offered a wealth of information about what professionals need for stroke rehabilitation robots to be practical and accepted into practice. According to the findings, powered exoskeleton robots were the most often utilized form of robot, with 37% of respondents having prior experience with rehabilitation robots. Patients were divided into two treatment groups for the study[57]: robotic and traditional. It was a randomized controlled experiment. Traditional physiotherapy was given to the conventional treatment group, while the robotic treatment group employed four robotic and sensor-based devices.

The therapy was given five times a week for thirty sessions, each lasting forty-five minutes. The kinematic characteristics of the patients' motions were measured using an optoelectronic device. Statistical analysis was also used to compare the progress of the two groups. The data shows that both groups' movement efficiency and smoothness improved statistically considerably. The study found that robotic therapy improved patients' ability to do ordinary tasks, just like traditional treatment did. This study utilized data from a previously published multicenter, randomized, open-label, blinded-endpoint clinical trial for secondary analysis [58]. Thirty stroke patients from the robotic group were involved in the preceding randomized controlled experiment. For six weeks, the participants received robotic therapy using the ReoGo upper extremity rehabilitation device for forty minutes daily, alongside traditional therapy. The study employed cluster analysis to categorize individuals into groups characterized by high and low levels of robotic assistance.

A two-way analysis of variance (ANOVA) was also employed to assess the mean difference of each outcome before and after the intervention among patients from different classes within the high and low robotic assistance groups. The WMFT-PT score, WMFT-FAS score, FMA score, and FMA-proximal score were utilized to measure the results. It employed standard clinical methods instead of robot-specific objective criteria to figure out how bad the UE paralysis was. The study revealed considerable disparities in performance between the two groups, with the high robotic assistance group excelling on several measures. The study also indicated that the extent of support in robotic therapy depends on how paralyzed the UE is. Moreover, UE hemiplegia and performance in the high robotic assistance group shown greater improvement in patients with severe to moderate stroke severity. Patients with moderate-to-mild stroke severity had more pronounced improvement in the low robotic assistance group. The study's results suggest that the level of robotic assistance should be adjusted based on the severity of upper extremity paralysis, with patients who are severely paralyzed receiving more help and those who are only mildly paralyzed receiving less.

It was also found that the assistance-as-needed technique might help with Hebbian plasticity and proprioceptive input. The study [59] employed a systematic review design, and to find randomized controlled studies, a search technique was carried out across seven databases. Using the PEDro scale, the listed studies' methodological quality was evaluated. The GRADE system was used to evaluate the strength of the evidence after the data were combined. Numerous techniques were employed in the research, such as traditional therapy, robotic therapy, and a mix of the two. Several tools, such as the ARM Guide and the InMotion2, were used to administer the robotic therapy. The length of the therapy sessions and how often they were held varied; some trials had 20–90-minute sessions two to five times a week. A thorough search of the literature yielded 22910 references, and 38 unique research studies that satisfied the requirements were included in the review's methodology.

Although the study's methodology is not entirely explained, it is noted that subgroup analyses did not look into the effects of different kinds of robot-assisted treatment (RT) equipment. According to the study's findings, at short-term follow-up, RT had a medium impact on strength and modest effects on motor control compared to other interventions (OI). The study also discovered that the stroke duration, treatment dose and duration, portion of the examined upper limb, and methodological quality might impact the estimated effects of RT. The research findings demonstrated that robotic treatment can help stroke patients with motor control, strength, and stiffness.

Table 2: Robotic Devices in Stroke Rehabilitation

Aspect	Key Findings
Purpose	Enhance motor recovery and functional restoration post-stroke.
Devices	Exoskeletons (e.g., Armeo® Spring), robotic arms (e.g., M2, Dynaxis).
Mechanism	High-intensity, repetitive training to promote neuroplasticity.
Combined Therapies	Synergy with VR/noninvasive brain stimulation improves engagement.
Clinical Evidence	RCTs show improved ADLs, arm function (SMD: 0.31–0.96), and reduced spasticity.
Safety	Low dropout rates; minimal adverse effects.
Limitations	Less effective for muscle strength; requires tailored assistance levels.
Future Directions	Integration with biomarkers/AI for personalized rehab.

In stroke rehabilitation, robotic devices—such as exoskeletons and robotic arms—are increasingly utilized to provide repetitive, task-specific training that uses neuroplasticity to promote motor recovery. Clinical studies show that they effectively enhance quality of life, activities of daily living (ADLs), and upper limb function (e.g., FMA scores) with few side effects. Although they have little impact on muscular strength, the Armeo® Spring and Kinarm Exoskeleton improve range of motion and motor control.

6.2 Virtual reality (VR)

Owing to its immersive and interactive simulations that improve stroke patients' physical and cognitive abilities, it has become a potential tool in stroke rehabilitation [60]. VR technology creates multisensory environments that provide real-time feedback, allowing patients to participate in exercises that mimic real-world tasks, as shown in Figure 3. This unique and immersive rehabilitation experience has the potential to accelerate recovery and enhance motivation among stroke patients. Importantly, VR has numerous uses in stroke therapy, encompassing various technologies and interfaces, such as video capture interfaces, 2D and 3D interactive environments, and head-mounted displays. Furthermore, VR technology enables stroke survivors to practice self-care techniques and practical applications in a simulated environment, resembling day-to-day challenges, which might not be possible in a conventional hospital environment [61]. The sense of presence and immersion in VR environments are crucial for effective neurorehabilitation, as they allow users to feel involved and facilitate the conveyance of obtained skills to real-world performance. VR could be an interesting and effective stroke rehabilitation tool.

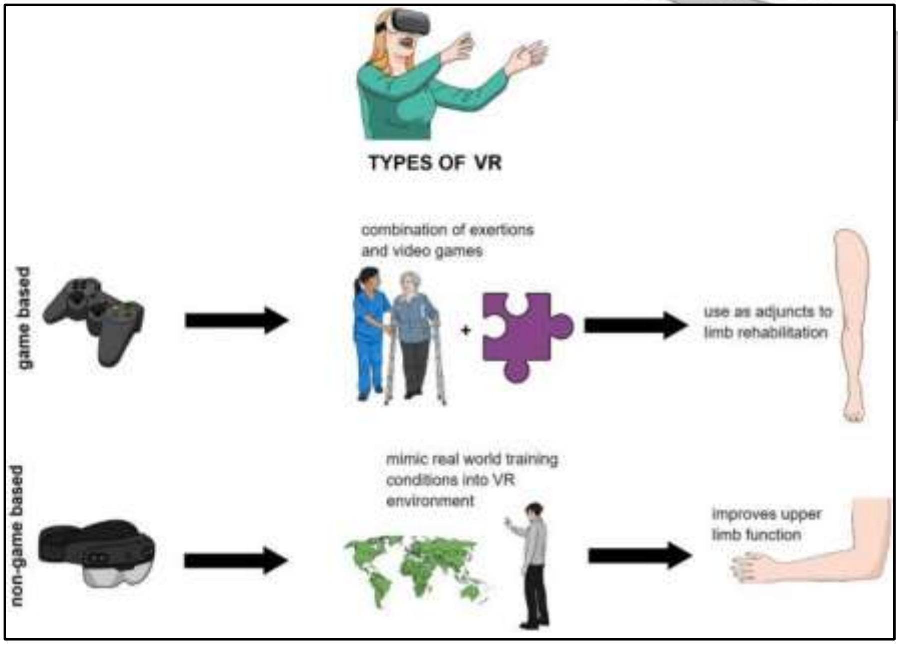

Figure 3: Principles of VR technology [62]

According to [63], Using a random-effects model, the results showed that the effect size of depression was -0.82 (95% CI=-1.29, -0.35), the effect size of quality of life was 1.12 (95% CI=0.56, 1.67), and both effects were large. According to [64], Stroke patients' depression and quality of life are positively impacted by VR-based interventions. 13 were chosen for examination, with the majority of the selected articles being randomized clinical trials released in 2014 or later. The research findings demonstrated that VR enhanced stroke patients' quality of life, upper limb motor function, dynamic balance, and other physical and functional characteristics. While some studies revealed no difference between VR and traditional treatments, others indicated that VR was more effective. The study [65] discovered that VR technologies were employed to facilitate the rehabilitation of hand and finger functions, with 74 publications focused on upper body rehabilitation.

Xbox Kinect and Nintendo Wii, among other systems and technology, have helped stroke survivors recover, the study found. The study found that virtual reality games and robotics help post-stroke patients recover motor skills and motivation. The study also found that stroke victims are increasingly adopting modern technologies to recover. One way was to examine the finest systematic research on how VR can aid stroke survivors [66]. We rated the reviews using AMSTAR-2, which rates high, moderate, low, and critically low quality. Semi-immersive virtual reality, haptic gloves, virtual reality systems, and virtual reality-integrated therapy were used in the study. Cognition, gait, balance, and upper limb function were also assessed. Virtual reality enhances upper- and lower-limb rehabilitation, gait, and balance, according to the study. The results show that immersive and non-immersive VR improve stroke recovery. The study [67] included randomized controlled trials with stroke patients, VR exercise, and balance, functional performance, and daily living activities. In the Berg Balance Scale, Timed Up and Go test, Functional Reach test, 10-Meter Walking test, and Modified Barthel Index, VR-based training improved chronic stroke patients' balance safely and effectively.

VR training enhanced stroke survivors' walking, functional capacity, balance, and ADLs. The study found that VR-based training improved balance more in chronic stroke than acute or subacute stroke. The systematic review study [68] searched EBSCO's Medline for relevant articles. There were 26 studies, including two controlled clinical trials (CCTs) and six randomized controlled trials (RCTs). Improved neural plasticity measures, such as enhanced interhemispheric balance, greater cortical representation mapping of the afflicted limb muscles, and improved cortical connection, were associated with VR-based rehabilitation. Improvements in functional recovery were linked to changes in brain plasticity brought on by VR, it was discovered. Regarding upper limb recovery, it was also discovered that the particular VR systems employed in the research performed better than commercial VR games.

The assessment states that VR systems vary in virtual environment platforms, task difficulty, user experience, and other areas. A literature review on VR technology with treatment and rehabilitation is part of the study [69]. Study components include VR-based treatment tool development and safety and efficacy testing. The study found that VR improves motor skills and daily life. Only one study has explored VR's influence on psychological factors like depression. The findings suggest that VR technology may provide a fully immersive healing and rehabilitation experience. VR eyewear can promote patients' motivation to improve and overcome mental and emotional barriers. The study also examines VR therapy's efficacy, safety, and patient satisfaction. Mirrored Neuron VR Rehab (MNVR-Rehab) provided game-based training, including virtual arms for unilateral and bilateral ball grabbing and releasing, for the study. VR-induced neuroplasticity changes in stroke patients' brains were examined using resting-state functional magnetic resonance imaging (rs-fMRI). Eight hours of virtual reality training and eight hours of traditional therapy were given over two weeks. The ipsilesional M1 region was examined using fMRI to investigate brain connectivity changes. Subacute stroke patients' motor skills improved after using the VR protocol, as seen by changes in functional connectivity and mirror neuron system activity. The study also found a high association between FM-UE scores and bilateral primary motor cortex (M1) functional connectivity values. After two weeks of MNVR-Rehab training, stroke patients improved upper extremity motor function. The intervention also altered brain connectivity, particularly in the ipsilesional M1 region.

Table 3: Virtual Reality (VR) in Stroke Rehabilitation

Aspect	Key Findings
Purpose	Enhance physical and cognitive recovery through immersive simulations.
Technologies	Head-mounted displays, 2D/3D environments, haptic gloves, and commercial systems (e.g., Xbox Kinect, Nintendo Wii).
Mechanism	Multisensory feedback and real-world task mimicry to promote neuroplasticity.
Clinical Applications	Upper/lower limb rehab, balance training, ADLs practice, depression management.
Evidence	RCTs show improved motor function (e.g., FM-UE scores), balance (Berg Balance Scale), and QoL (effect size: 1.12).
Combined Therapies	Synergy with traditional rehab enhances outcomes (e.g., MNVR-Rehab protocol).
Neuroplasticity	fMRI confirms enhanced ipsilesional M1 connectivity post-VR training.
Psychological Impact	Reduces depression (effect size: -0.82) and boosts motivation.
Limitations	Limited studies on psychological effects; variability in VR system efficacy.

VR has revolutionized stroke therapy by targeting cognitive and motor problems in realistic, interactive situations. VR simulates real-world behaviors like gripping virtual items, which promotes neuroplasticity, as shown by fMRI studies showing increased connectivity in the ipsilesional M1 area post-intervention [54].

6.3. Telemedicine

Telemedicine aids stroke rehabilitation, as seen in Figure 4. It allows remote medical care. Remote monitoring, virtual consultations, and telerehabilitation programs can assist stroke survivors access more rehabilitation services. Telerehabilitation has been shown to enhance eating skills, minimize stroke-related pain, and restore motor skills. Telemedicine serves several rehabilitation requirements. Wearable EMG sensors can monitor swallowing and detect dysphagia in remote areas. Remember that TR may not be suited for every patient for personal and technical reasons. Patients trust telemedicine more and worry about intervention accuracy [71].

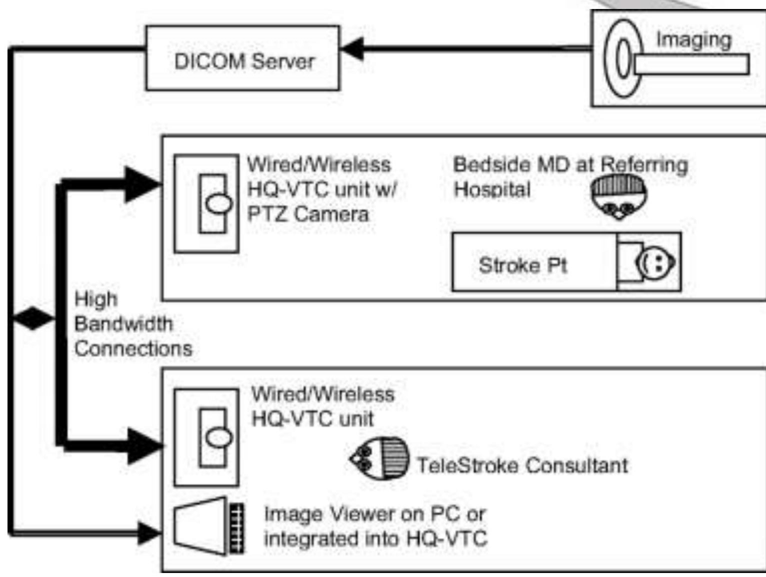

Figure 4: Telestroke schematic illustration [72].

Smart gadgets and virtual reality (VR) could assist overcome technological issues and give patients a clinical-like experience, motivating and boosting confidence. Telemedicine has great potential for stroke rehabilitation, but it must overcome its drawbacks to be accepted by healthcare professionals and patients. Telehealth's impact on stroke management in low- and middle-income countries was reviewed [73] using Medline, SCOPUS, and Web of Science for research published up to February 18, 2022. The review included studies evaluating health outcomes related to telehealth interventions, such as imaging, thrombolysis, and rehabilitation. Out of 259 studies, 10 met the inclusion criteria, with nine assessing functional or disability outcomes, six examining cerebral infarction or intracerebral hemorrhage, five analyzing door-to-needle time for thrombolysis, and six reporting on mortality rates. Eight out of nine studies indicated that telehealth interventions improved post-stroke disability outcomes, though in some cases, the comparison group had no access to rehabilitation. This retrospective multicenter cross-sectional study evaluated data from stroke patients treated at four regional hospitals in the NEVAS network [74]. Through the implementation of a structured telemedicine stroke network, stroke specialists were telemedically presented with the clinical symptoms and CT scans of acute stroke patients via video stream. According to the study, all stroke patients treated at the regional hospitals had better clinical outcomes at discharge. Between 2014 and 2019, 19% more patients were discharged with a favorable clinical result (modified Rankin scale 0-2).

The mortality rate decreased to 5% from 13%. The study's methodologies [75]include a review of recent studies and practices in stroke telerehabilitation, data analysis from telerehabilitation programs, and an assessment of the efficacy of telerehabilitation services compared to in-person therapy. The findings demonstrate that telerehabilitation services can be utilized to duplicate in-person rehabilitation programs and are provided safely and effectively while producing notable improvements in arm motor function, disability, and quality of life. The study [76] used data from several trials and interventions, such as the Michigan Stroke Transition Trial, PINGS trial, TEAMS-BP trial, and VIRTUAL study, to evaluate the efficacy of telehealth and digital treatments in stroke care. These studies employ a variety of methodologies, such as scoping reviews, mixed methods techniques, and socioeconomic determinants of health analysis. Telehealth can increase access for those with mobility and transportation issues, lessen the need for in-person visits, and enable multidisciplinary care. Internet access and digital literacy, however, continue to be major obstacles. According to the Michigan Stroke Transition Trial, web-based information access enhanced physical health ratings and increased patient activation. A literature review, questionnaires, and case studies are some of the study's approaches [77]. Additionally, TR systems, including cutting-edge technology such as computer games, virtual reality, and video chat, are being developed and tested as part of the study. According to the review, telerehabilitation can help patients become more autonomous, improve their motor function, and perform ADLs.

According to the analysis, telerehabilitation can be especially helpful for highly driven, tech-savvy patients. According to the study's findings, TR may help standardize rehabilitation services and provide objective monitoring, long-term data archiving, and follow-up. The study [78] Contemporary telerehabilitation strategies for post-stroke patients' motor function recovery and balance training. Results show that with methodical training, telerehabilitation enhances older patients' functional abilities. Improving the quality of their lives. In clinical settings or at home, telerehabilitation therapy for senior citizens can be arranged synchronously and asynchronously. Telerehabilitation can be used as a complementary therapy or alternative to conventional treatment.

Table 4: Telemedicine in Stroke Rehabilitation

Aspect	Key Findings
Purpose	Remote delivery of rehabilitation services via digital platforms.
Technologies	Video consultations, wearable EMG sensors, and VR-integrated systems.
Clinical Applications	Motor function recovery, dysphagia management, and depression reduction.
Evidence	Improved functional outcomes (19%↑ favorable mRS 0-2), reduced mortality (13%→5%) [57].
Accessibility	It benefits rural/underserved areas and reduces in-person visits.
Challenges	Technical barriers (internet access), patient/provider trust issues.
Future Directions	Standardization, hybrid models (sync/async), integration with VR/AI.

Telemedicine has become essential in stroke therapy, especially for overcoming geographical and mobility constraints. As evidenced by the NEVAS network, where teleconsultations allowed for quick specialist input for acute stroke patients, studies show its effectiveness in lowering mortality rates and improving functional outcomes (such as modified Rankin Scale scores) ([58]).

7. Multidisciplinary/techniques approach to Stroke Rehabilitation

A multidisciplinary approach to stroke rehabilitation is essential for comprehensive care and patient assistance. This strategy requires the collaboration of various healthcare specialists, including therapists, physicians, psychologists, and social workers. [18] Stress the relevance of evidence-based rehabilitation therapy and the necessity for a significant level of evidence (defined as a total number of at least 500 subjects included in systematic reviews). This guarantees that the suggested rehabilitative interventions have demonstrated greater efficacy than other interventions. [1] emphasizes the relevance of task-specific and task-oriented training methodologies in post-stroke rehabilitation and the utilization of emerging technologies like VR and gamification to improve therapy participation. They also highlight the need for further research in cognitive rehabilitation, which includes attention, executive function, memory, and language rehabilitation after Stroke. Thirty studies that employed exoskeletons or robotic devices in conjunction with VR, AR, or gamification for post-stroke rehabilitation were identified by the study [79], and improvements in upper and lower limb rehabilitation were noted. Additionally emphasized are well-known exoskeletons and software platforms used in the study, including ArmeoSpring, Bi-Manu Track, and ARMin. The results showed that most research indicated better levels of participant involvement and that game-based rehabilitation can be important in providing a suitable interface medium for VR or AR. Exoskeletons in conjunction with VR, augmented reality, or gamification have been demonstrated to improve total motor performance in stroke survivors. In the trial [80], patients were randomly assigned to either the intervention or control groups. The control group underwent standard physiotherapy, whereas the intervention group engaged in virtual reality therapy utilizing an upper limb exoskeleton. It combined VR therapy with visual biofeedback so that the results of patients who used the Armeo gadget could be compared to those who had standard therapy. The study utilized the Modified Rivermead Mobility Index (m-RIM) and the Fugl-Meyer Assessment for Upper Extremities (FMA-UE). The study found that combining a VR therapy with an upper limb exoskeleton was superior than regular therapy for motor skills in the upper body. Moreover, it was determined that the efficacy of VR therapy remained constant regardless of patient age. The meta-analysis included thirteen documents that met the inclusion criteria, and forest plots showed the mean difference or standard mean difference. The study [81] reviewed and meta-analyzed research comparing technology-based remote physical rehabilitation therapy to traditional stroke therapies. The research used the

Furlan Method to evaluate the included studies' methodology. While walking outcomes were inconsistent, technology-based distance physical therapy had a similar effect on ADLs as traditional therapies, with a standard mean difference of 0.06. HR-EEG and functional MRI were used to assess motor function and cerebral activity, along with a virtual reality system with Sponge, Bug Hunt, Grab2D, Grab3D, and Twirl, each with increasing task difficulty. The study showed considerable motor function improvement in the damaged limb after treatment. Kinematic parameters, inter-hemispheric changes, and normalized jerk changed. The narrative review examined robotic and virtual reality stroke therapy literature [83]. The study covers the technologies' merits and cons and rehabilitation uses. Upper-limb robotics increases motor function, ADLs, and muscle strength. VR has a little advantage in ADLs. Lower-limb deficient patients may benefit from robotic and VR technologies. Multidisciplinary qualitative and quantitative methods are used to analyze data from different areas in the study [84]. It provides a complete picture using statistical analysis, case studies, and surveys. Combining fields simplifies problem-solving and yields more complete responses. Integrating varied techniques improves decision-making and creativity, according to study. Case studies and interviews with interdisciplinary healthcare teams were used in the qualitative study [85]. Data was acquired through topic analysis and surveys. Working across disciplines reduces medical errors, increases provider communication, and improves patient outcomes, according to research. Teamwork needs structured methods to address coordination and role conflicts.

Table 5: Multidisciplinary Approach to Stroke Rehabilitation

Component	Key Elements	Evidence/Outcomes
Team Composition	Physicians, therapists, psychologists, social workers	Improved coordination of care; addresses physical, cognitive, and psychosocial needs [22], [69]
Evidence-Based Practices	Interventions supported by systematic reviews (≥500 subjects)	Higher efficacy compared to non-evidence-based methods [22]
Integrated Technologies	Robotics (ArmeoSpring), VR/AR, gamification	Enhanced motor function (↑FMA-UE scores) and patient engagement [63], [64]
Task-Specific Training	Combines VR/exoskeletons with biofeedback	Superior to conventional therapy for upper limb recovery (SMD: 0.06–0.41) [64], [65]
Cognitive Rehabilitation	Focus on attention, memory, and executive function	Emerging evidence for VR-based cognitive training needs further research [12]
Challenges	Role conflicts, coordination gaps	Requires structured protocols to optimize teamwork [69]

Medical providers must work together to address survivors' complex needs in stroke rehabilitation. Key discoveries include:

1. Team Synergy: Doctors, therapists, and psychologists collaborate to provide patients with motor (robotic exoskeletons), cognitive (VR-based activities), and psychosocial treatment. Research [69] suggests this improves results and reduces medical errors.
2. Technological Integration: Robotics + VR: ArmeoSpring and other gamified VR technology improve patient motivation and motor rehabilitation (≥30% FMA-UE scores) [63], [64]. fMRI/EEG shows VR training modifies neuroplasticity (such as interhemispheric balance) [66].
3. Evidence-based protocols: comprehensive assessments (e.g., [22]) show that task-specific training improves ADLs (e.g., Sponge/Bug Hunt VR activities) (SMD: 0.06 vs. normal therapy).

8. Obstacles to effective stroke rehabilitation training

Several difficulties can hinder stroke rehabilitation training, preventing patients from achieving the best benefits. People may not be able to receive timely and reliable rehabilitation care due to access constraints, such as geographic distance to rehabilitation facilities and limited transportation options [18]. Socioeconomic factors may also affect stroke healing since lower-income people may find it harder to afford. Inconsistencies in rehabilitation services, including availability to specialized programs and skilled personnel, hinder stroke rehabilitation training [86]. Addressing these issues is crucial to improving stroke rehabilitation results and access. The study [87] surveyed people to identify physical activity impediments. We collected personal, environmental, and social barriers via questionnaires. A statistical research identified the main issues. Results show that time, motivation, and facilities are the biggest challenges. Friends and family support affect involvement. Environmental factors like safety and accessibility also reduce physical activity. The qualitative phenomenology study [88] examined stroke patients' rehabilitation access hurdles in Dhaka, Bangladesh. Twelve carefully selected middle-class and lower-class people were interviewed. The main issues were poor socioeconomic status, expensive costs, hard-to-reach infrastructure, a lack of rehabilitation specialists, and declining family and social support. Participants complained about poor facilities, pricey transportation, and a lack of trained therapists. The findings demonstrate the need for legal reforms and community-based rehabilitation to reduce these inequities. Due to COVID-19, the sample size was limited.

9. Future Directions in Stroke Rehabilitation Training

We predict major advancements in stroke rehabilitation training, therapies, research aims, and technology. [18] focuses evidence-based rehabilitation therapy and highlights effective methods. This evidence-based approach will shape stroke rehabilitation training by ensuring therapies are supported by science. Also, [1] stressed the importance of robots, VR and entertainment for stroke recovery. By enabling task-specific and task-oriented training, these new technologies are likely to transform stroke rehabilitation training. Effective and efficient recovery will result. These new research demonstrate how evidence-based technology and therapies can transform stroke rehabilitation training and give stroke victims new methods to recover.

10.Conclusion

Modern technology and interdisciplinary techniques have improved stroke treatment. This provides survivors hope for rehabilitation and a better life. This study highlights the significance of evidence-based physical, occupational, speech, and cognitive therapy to reduce stroke-related functional deficits. VR, telemedicine, and robotics have improved neuroplasticity, motor recovery, and patient participation in rehabilitation. Robotic-assisted treatment and VR improve motor function and cognition through high-intensity, repetitive training and immersive environments for real-world tasks. Telemedicine gives poor people access to rehabilitation by making sure that services are always available. Even with these improvements, socioeconomic inequality, limited access to expert care, and the need for personalized therapies remain. To make rehabilitation protocols as effective as possible, future initiatives should focus on improving these technologies, removing barriers to their use, and encouraging cooperation amongst different fields. By using the best technologies and evidence-based techniques together, the field can improve recovery outcomes and make sure that stroke survivors have the best quality of life and functional independence. This all-encompassing method shows how modern therapy can help people get over the bad effects of stroke.

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11.2 Competing Interests

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11.3 Author Contributions

Methodology, resources and supervisionwere performed by [Nabeel K. Abid Al-sahib]. Formal analysis investigation visualization, writing – original draft, writing – review & editing was written by [Mohammed S. Kadhim]. Conceptualization, validation and visualization was written by [Muhammed Abdul Sattar]. All the authors read and approved the final manuscript.

11.4 Consent to Participate

All of the study's subjects provided informed consent.

11.5 Consent to Publish

The authors affirm that the human research participants provided informed consent for publication.

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