Egypt. J. Chem. Vol. 67, SI: M. R. Mahran, pp. **2245 - 2257** (2024)

Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Brain Stroke: Physical Therapy and Rehabilitation Techniques-An Updated Review

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Abstract

Background: Stroke, or cerebrovascular accident (CVA), is a leading cause of mortality and long-term disability worldwide, significantly impacting physical, emotional, and socioeconomic well-being. It is categorized into ischemic (80% of cases) and hemorrhagic strokes, with modifiable risk factors such as hypertension, smoking, and physical inactivity playing a critical role in prevention. Post-stroke rehabilitation aims to optimize functional recovery, promote independence, and enhance quality of life through tailored physical therapy interventions.

Aim: This review aims to provide an updated overview of physical therapy and rehabilitation techniques for stroke recovery, emphasizing evidence-based interventions across acute, sub-acute, and chronic phases. It also explores emerging technologies and their role in enhancing rehabilitation outcomes.

Methods: The review synthesizes findings from recent studies and clinical trials on stroke rehabilitation, focusing on physical therapy interventions such as task-specific training, gait training, sensory recovery, spasticity management, and strength training. It also examines the integration of advanced technologies like virtual reality (VR), robotics, and exoskeletons in rehabilitation programs.

Results: Physical therapy interventions, including repetitive task practice, early mobilization, and task-specific training, significantly improving motor function, balance, and quality of life in stroke survivors. Emerging technologies like VR and robot-assisted gait training (RAGT) show promise in enhancing recovery outcomes. Strengthening exercises, sensory interventions, and spasticity management strategies further contribute to functional improvement. However, the efficacy of some interventions, such as sensory recovery techniques, requires further validation through large-scale trials.

Conclusion: Stroke rehabilitation is a multifaceted process that requires a holistic, patient-centered approach. Physical therapy, combined with emerging technologies, plays a pivotal role in optimizing recovery. Future research should focus on refining protocols, addressing limitations, and exploring innovative interventions to improve outcomes for stroke survivors.

Keywords: Stroke rehabilitation, physical therapy, motor recovery, gait training, spasticity management, robotics, virtual reality, task-specific training.

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1. Introduction

Stroke, also known as cerebrovascular accident (CVA), is a focused neurological impairment caused by a variety of vascular diseases that affect cerebral function. Stroke continues to be a leading cause of death worldwide [1,2] and contributes significantly to long-term disability, affecting several functional domains [3,4,5]. Based on their underlying pathophysiology, strokes are often divided into two categories. The first type of stroke, known as an ischemic stroke or cerebral infarction, occurs when a major cerebral artery becomes blocked as a result of embolic events or thrombosis. Roughly 80% of all stroke cases are of this kind [6]. The second kind of stroke, known as a hemorrhagic stroke, happens when blood vessels burst, causing blood to spill into or surrounding the brain parenchyma. With a 15% to 20% incidence rate, hemorrhagic stroke is frequently caused by persistent hypertension, cerebral aneurysms, anticoagulant medication, severe injury, or old age [7]. In order to avoid stroke, it is essential to address modifiable risk factors such smoking, high blood pressure, poor eating habits, and physical inactivity. Changes in lifestyle, such as controlling blood pressure, quitting smoking, maintaining a healthy diet, and engaging in regular exercise, have been demonstrated to dramatically lower the incidence of stroke [8,9,10]. In addition to its physical effects, stroke causes significant emotional and financial hardships for those who experience it as well as their families.

Sweden reports more than 25,000 new cases of stroke annually, compared to almost 600,000 new cases in the United States [11]. According to a longitudinal study carried out in the Netherlands, the incidence of stroke is expected to rise from 1.8 per 1,000 people in 2000 to 2.8 per 1,000 people by 2020 [12]. Stroke has a significant financial impact; according to Evers et al., cerebrovascular accidents cost an average of 3% of healthcare spending in six major states [13]. Previous

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Receive Date: 01 December 2024, Revise Date: 26 December 2024, Accept Date: 31 December 2024
DOI: 10.21608/ejchem.2025.344348.10982

research indicates that the substantial financial burden of stroke is reflected in the United Kingdom, where costs associated with the condition account for between 4% and 6% of the National Health Service budget [14]. The annual incidence of stroke is 1.33 to 1.58 instances per 1,000 people [15], and the direct and indirect expenses are estimated to be around nine billion pounds in the UK alone [16]. In addition, a 2012 survey found that 2,850 occurrences of prenatal stroke were identified, with a diagnostic rate of 34.2 per 100,000 infants. Pregnancy-related stroke incidence, death, and disability rates were greater than previously reported, according to the study, especially for African American women, who had a higher risk profile [17]. A comprehensive survey of about 480,687 people in China revealed an incidence rate of 345 cases per 100,000 and an annual prevalence of 1,596 instances per 100,000, highlighting the condition's pervasiveness [18].

Optimizing functional recovery, encouraging independence, and improving patients' overall quality of life are the main goals of physical therapy and rehabilitation programs following a stroke [19,20]. To meet each person's specific needs, a range of customized therapies are used [21,22,23]. One of the most popular forms of rehabilitation is physical therapy, which aims to restore activities of daily living (ADLs) like walking, dressing, and personal hygiene by enhancing strength, balance, and coordination [24, 25]. Targeted exercises, stretching routines, range-of-motion exercises, and instruction in the use of mobility aids, such as walkers and canes, are frequently included in therapeutic efforts [26]. Another essential part of stroke rehabilitation is occupational therapy, which helps patients restore their ability to perform ADLs including cooking, cleaning, and self-care [27]. To improve functional independence, this may entail making changes to the surroundings, including adding grab bars or using assistive technology, like adapted cutlery [28]. Additionally essential to the rehabilitation process is speech and language therapy, especially for patients who have dysphagia or communication impairments. Evidence-based methods are used by speech therapists to enhance swallowing function, language comprehension, and speech production [21]. For stroke survivors who exhibit buccal hemineglect, Sire et al. stressed the value of integrating focused oral therapies into multidisciplinary rehabilitation programs [29]. Other rehabilitative techniques, like music therapy, recreational therapy, and cognitive-behavioral therapy, are becoming more and more acknowledged for their therapeutic effects in stroke rehabilitation in addition to these fundamental therapies [30,31,32]. Each patient's unique needs, preferences, and functional abilities serve as a guidance when choosing interventions. In conclusion, physical therapy and post-stroke rehabilitation are essential for promoting healing and raising quality of life. Maximizing functional outcomes and fostering long-term independence need a comprehensive, multidisciplinary approach that incorporates occupational, speech, and physical therapy and is customized to each person's specific needs [33].

Framework for Rehabilitation

Because they understand how important physical therapy is to reducing complications and improving quality of life, developed countries have made great progress in creating comprehensive rehabilitation frameworks for stroke patients. The unique impairments, activity restrictions, and recovery objectives of each patient are taken into consideration by rehabilitation therapists when creating interventions. Through a range of activities that target obstacles to optimum health, these therapies frequently concentrate on optimizing functional and psychological recovery [34]. Susan B. O'Sullivan states that there are three types of rehabilitation interventions: restorative, which try to improve impairments, activity limitations, and participation restrictions; preventive, which try to minimize secondary impairments and potential complications; and compensatory, which change the task or environment to improve functional performance.

Acute Phase

Usually, rehabilitation begins in the intensive care unit (ICU) or a dedicated stroke unit within 72 hours of the stroke start. An overview of the recovery process, including the estimated duration, care plan, and expected limitations, is given to patients and their caregivers during this phase [35]. Early, coordinated care in stroke units has been shown to dramatically lower fatality rates, shorten hospital stays, and limit long-term disabilities [35]. Positioning, functional mobility training, activities of daily living (ADLs) training, range-of-motion (ROM) exercises, splinting, and bed mobility are the main interventions that are implemented during the acute period. It has been demonstrated that early mobilization, started after proper monitoring, can enhance the patient's state of consciousness, lessen mental deterioration, minimize stress and anxiety, and avoid the negative effects of extended bed rest and deconditioning. Early mobilization also reduces the likelihood that maladaptive movement patterns may emerge. Recent clinical trials examining early mobilization, aphasia management, dysphagia treatment, and upper limb rehabilitation with therapies starting within seven days of stroke onset were emphasized by Bernhardt et al. [36]. The significance of early rehabilitation in maximizing recovery during the crucial period for brain repair is shown by these experiments. However, there are several difficulties because of the intricacy of these studies, especially when they involve acute and rehabilitative care settings. For patients with acute ischemic stroke, early mobilization within 24–48 hours of stroke start is safe and practical, according to a pilot study by Poletto et al. in a Brazilian public hospital [37]. When compared to the control group, which followed conventional treatment procedures commonly found in Brazilian hospitals, the intervention group, which was mobilized early, shown notable improvements.

Sub-Acute Phase:

Inpatient rehabilitation centers or home-based rehabilitation programs are frequently recommended for patients who advance to the sub-acute phase, usually six months later. Bilateral (B/L) training assisted walking with or without electromechanical aid [39], and constraint-induced movement therapy (CIMT) [38] are possible interventions during this phase. Exercise should be done six days a week for up to three hours each day, according to the prescribed schedule [40]. Transitional

care units (TCUs) offer 60- to 90-minute rehabilitation sessions five days a week to patients who need less intense assistance [41]. During this stage, improving strength, balance, endurance, and mobility are the main objectives of physiotherapy [42, 43]. The effectiveness of time-matched conventional training (CT) and virtual reality rehabilitation training (VR) for the upper extremities in the sub-acute phase following a stroke was compared in a research by Brunner et al. [44]. Four to five weekly sessions lasting up to 60 minutes each were given to participants for a maximum of 30 days of extra intervention. According to the study, VR training improved upper extremity function just as well as CT, and it also had the added advantage of being an entertaining and compelling addition to conventional rehabilitation exercises.

Chronic Phase:

Patients usually start home exercise programs (HEPs) six months after a stroke and get education on the value of sustaining exercise intensity, preventing falls, changing positions, and promoting general health. It has been demonstrated that community-based fitness programs, especially those that involve water activities, enhance functional outcomes in this demographic [45]. In a study of stroke patients in the chronic stage, Ward et al. showed that upper limb motor dysfunction was considerably decreased by 90 hours of physical therapy spread over three weeks (five sessions per week) [46]. Similar findings were made by Daly et al., who discovered that a 12-week physical therapy program consisting of 300 hours of treatment (five sessions per week) significantly decreased upper limb motor impairment in individuals who had suffered a chronic stroke [47]. Curiously, the study found that all three treatments produced similar gains in motor function, indicating that the type of therapy intervention had no discernible impact on results. In conclusion, the acute, sub-acute, and chronic phases form the framework for stroke rehabilitation, and each stage's specific needs are met by customized interventions. In order to maximize rehabilitation, minimize deficits, and improve the general quality of life for stroke survivors, early mobility, intensive therapy, and community-based initiatives are essential.

Physical Therapy Interventions

Stages of Motor Recovery

An essential part of evaluating motor recovery is measuring muscle tone. Patients who have had a stroke frequently begin with flaccid paralysis, a temporary state that lasts anywhere from a few days to several weeks, and then develop spasticity or hypertonicity, which can worsen with time. A combination of therapies is usually used for motor rehabilitation, as no single exercise program has been shown to be uniformly beneficial. Proprioceptive neuromuscular facilitation (PNF), neurodevelopmental therapy (NDT), functional training, and motor learning techniques have all been shown to aid in recovery; no single strategy has been shown to be more effective than the others [45,48].

Strategies to Improve Motor Learning

Practice and experience drive the internal process of motor learning, which alters one's capacity to execute skillful motions over time. Paresis affects 80 to 90 percent of stroke survivors, resulting in severe motor impairment, diminished independence in ADLs, and impaired functional capacities [11]. A number of crucial techniques, such as repeated repetition, mental practice, active patient participation, and consistent feedback, can support optimal motor learning. Reinforcing neuronal circuits and fostering functional recovery require these components [49, 50].

Interventions to Improve Sensory Function

Enhancing sensory and motor function requires making the most of the damaged side. For sensory recovery, mirror therapy has proven to be a successful intervention, especially when it comes to treating five sense deficiencies [51]. About 50% of stroke patients have sensory abnormalities, especially in tactile and proprioceptive discrimination, which affects sensory integration, the brain's capacity to absorb and interpret sensory information [52]. Assessments of sensory function usually entail determining how well a patient can decipher and distinguish between various sensory stimuli, which are frequently mapped to certain dermatomes. Repetitive sensory discrimination tasks, electrical and thermal stimulation, bilateral simultaneous movements, compression techniques (such as pressure splints and weight bearing), intermittent pneumatic compression, joint mobilizations, and magnetic stimulation are all effective interventions for sensory recovery. To confirm their effectiveness, more study is necessary as the evidence for these therapies is still weak [53,54]. Additionally, when proprioception and cervical strength are targeted, head turns, visual scanning exercises, and laser point drills can enhance hand-eye coordination, gaze stabilization, visual neglect, and balance.

Interventions to Improve Hemianopsia and Unilateral Neglect

Individuals who suffer from unilateral neglect or hemianopsia typically show little awareness of the contralateral side and often do not recognize their deficiencies. It is helpful to employ training methods that prioritize using the hemiparetic side. Positioning patients and interacting with them from the neglected side is advised for caregivers. Exercises that effectively correct these impairments include voluntary motions of the neglected limb, verbal and visual cueing, and active visual scanning approaches [55]. Recovery can be further improved by including everyday utilitarian activities like dusting, holding utensils, and pouring water. By maximizing visual, auditory, and proprioceptive inputs on the damaged side, therapists might try to optimize the patient's attention. Other methods that can help enhance focus and motor performance include reaching exercises, proprioceptive neuromuscular facilitation (PNF) chop and lift patterns, and sensory stimulation (e.g., vibration, tapping, or brushing) [56].

Interventions to Improve Flexibility and Joint Integrity

Active and passive range-of-motion (ROM) exercises, stretching, soft tissue and joint mobilizations, positioning strategies, arm cradling, tabletop polishing, and sitting forward-leaning exercises are some methods to improve flexibility and joint integrity. In order to control spasticity and preserve joint alignment, resting splints are frequently used [57]. In order to maintain soft tissue

length and avoid contractures, proper positioning and postural alignment are essential. To treat upper limb deficits, orthotic devices such neutral or extended wrist splints, finger placement splints, and volar splints for the forearm are frequently used. Ankle-foot orthoses (AFO), foot orthoses (FO), knee-ankle-foot orthoses (KAFO), and hip-knee ankle-foot orthoses (HKAFO) are all useful treatments for lower limb contractures. According to new research, stroke patients' kinematics and motor function are considerably improved by upper-limb robot-assisted therapy [58]. Combining robotic equipment with traditional physiotherapy improves healing results. For instance, patients with ankle plantar flexor spasticity have shown notable gains when using a robotic ankle-foot therapy system. Robot-assisted gait training (RAGT) has the potential to allow high-intensity gait training in subacute stroke patients while lessening the physical strain on therapists, according to a review by Calafiore et al. [59]. RAGT has not been demonstrated to be more effective than conventional therapy alone, despite the fact that it aids in gait recovery when used in conjunction with it. The effectiveness of RAGT in stroke rehabilitation requires more randomized controlled trials (RCTs). In conclusion, physical therapy treatments for stroke victims include a comprehensive strategy that focuses on joint integrity, flexibility, unilateral neglect, hemianopsia, motor recovery, and sensory function. There is potential to improve recovery results and stroke survivors' quality of life by combining traditional therapies with cutting-edge technologies, like robotic-assisted devices.

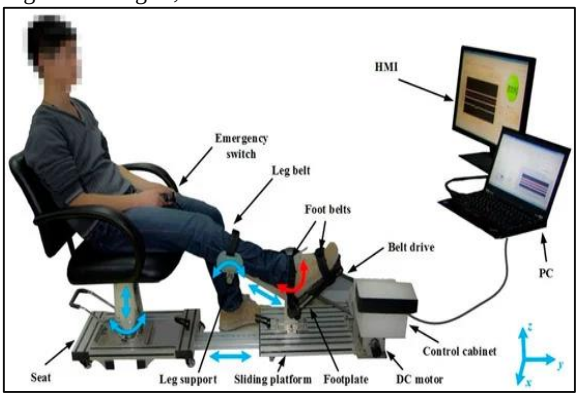

Figure 1: Robot-Assisted Therapy.

Interventions to Improve Strength

Most stroke victims have decreased dexterity and muscle weakness after the event. Strengthening activities ought to be a crucial part of stroke recovery, according to Ada et al. Strengthening muscles for functional tasks like standing, eating, reaching, and grasping can be achieved with methods including muscle re-education, virtual learning, and progressive resistance exercises. It has been demonstrated that these techniques are safe and do not cause spasticity or other negative side effects [61,62]. Elastic bands, free weights, progressive resistance exercise (PRE) equipment, hydrotherapy, and aquatic exercises are some ways to increase muscle power. Muscle contraction and motor recovery can also be aided by methods like vibration, cryotherapy, fast, strong taps to the muscle belly, and electrical stimulation with the right settings. By regaining, enhancing, or preserving muscle strength, power, and endurance, strengthening activities improve muscle performance. They also help with tissue remodeling, equilibrium, and quality of life. Strength training frequently uses equipment like Swiss balls, sandbags, free weights, and elastic resistance bands [63].

Interventions to Improve Hypertonicity

The lack of independent motions like hip flexion, knee extension, and elbow extension is frequently the result of hypertonicity, which is defined by increased muscular tone. Since there is little correlation between functional impairment and muscle tone, these impairments are often ascribed to poor motor control rather than spasticity alone [65]. Paresis, decreased dexterity, tiredness, and muscular tissue alterations are typical symptoms [66]. Maintaining the length of spastic muscles requires both daily stretching and early mobilization. Botulinum toxin (BoNT) injections into the muscles work well to lessen localized stiffness and the pain that goes along with it. Repetition is usually necessary every three to four months, with the therapeutic impact peaking one to four weeks after injection [67]. For instance, patients with plantar flexion and inversion that impair heel striking and stance may benefit from BoNT injections into the tibialis posterior and toe plantar flexors. In their review of high-dose botulinum toxin type A (BoNT-A) for post-stroke spasticity (PSS), Baricich *et al.* discovered that doses above the current regulatory limits were both safe and effective for a subset of patients with generalized or multifocal spasticity, improving their functional outcomes [68]. Proprioceptive neuromuscular facilitation (PNF) approaches, which seek to produce maximal voluntary elongation and inhibit autogenic inhibition, persistent stretching, and rhythmic rotations are further therapies for hypertonicity [69,70].

Interventions to Improve Postural Control and Balance

Because stroke alters the center of gravity (COG) and the ability to align the center of mass (COM) within the base of support (BOS), it has a substantial impact on postural control and balance. Consistency, symmetry, and making the most use of the afflicted side are the main goals of physiotherapy. Standing balancing exercises, unsupported sitting with an extended hemiparetic knee, sit-to-stand transfers, and strength training with increasing resistance and isokinetic equipment are some of the interventions. Walking exercises, trunk motions, upper and lower extremity movements, and sensory inputs are also advantageous. When walking, wearing a protecting belt improves safety and reduces the risk of falls [71]. Using cutaneous, proprioceptive, and auditory input, proprioceptive neuromuscular facilitation (PNF) is a successful treatment for increasing motor output, balance, and gait speed. Therapists help patients stand symmetrically, distributing their weight evenly over both lower limbs. Walkers and parallel bars are examples of assistive equipment that can encourage upright alignment and lessen the need for upper extremity support. Balance and postural control are further improved by exercises including high-stepping, marching in place, heel-toe contact, and diagonal weight changes [71]. Walking, stability, and postural control can all be enhanced by task-oriented reaching and

manipulating exercises. Individuals with restricted voluntary control can reach down to touch the ground or practice side-to-side, forward, and backward motions on a tabletop. Regaining functional independence is aided by exercises like modified plantigrade standing, reaching for items on a shelf, and using utensils with the afflicted hand [72,73].

The SPIDER Program

A unique intervention called the SPIDER program was created to help people with neurological diseases become more mobile and independent. It makes use of an SPIDER cage that has elastic strings fastened to a waist belt to offer resistance and support when exercising. This system helps to develop body balance, verticalization, coordination, and muscle strength. Patients in wheelchairs benefit most from the SPIDER cage because it allows them to stand independently. Customized resistance levels are possible because the force produced by the elastic cords varies depending on the expander type and the cage's attachment height [74]. In conclusion, post-stroke rehabilitation programs that focus on balance, strength, hypertonicity, and postural control are critical to enhancing functional results and quality of life. Stroke survivors' recovery and independence can be greatly improved by combining traditional treatments, cutting-edge methods like botulinum toxin injections, and creative initiatives like SPIDER.

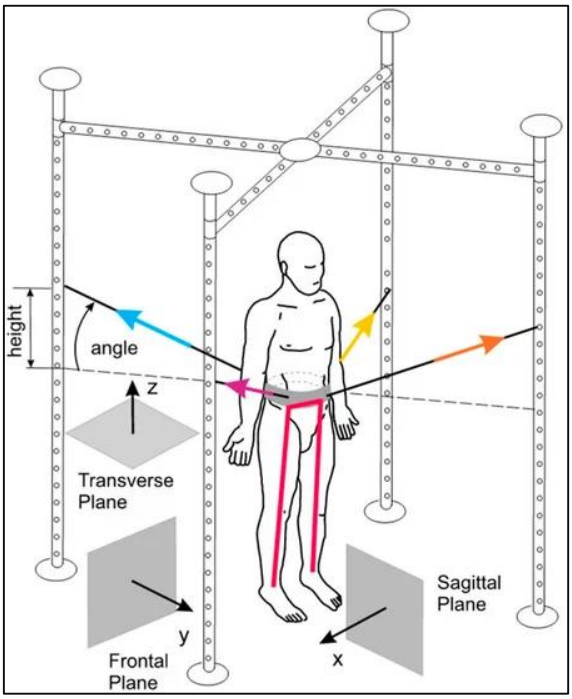

Figure 2: The SPIDER Device.

Gait Training

The main objective of gait training, a fundamental component of physical rehabilitation after a cerebrovascular accident (CVA), is to restore functional mobility and independence in day-to-day activities. To treat gait problems, physical therapists use a range of modalities and approaches, such as task-specific training and treadmills. Furthermore, they educate and counsel patients, family members, and caregivers about potential issues such shoulder pain and falls [75]. The chance of recovering the ability to walk 150 feet (45 meters) unassisted is greatly impacted by stroke-related deficits [76]. A crucial stage in the recovery from a stroke is community ambulation. According to research, 80% of acute stroke patients can regain their ability to walk after six weeks of gait training, and 95% can do so after eleven weeks. 34% of patients are able to walk 150 ft on their own by 12 weeks [77]. Significant differences ($p < 0.05$) were seen in walking abilities, stride characteristics, upright motor control, and proprioception among 147 stroke survivors. Individuals with unilateral motor deficits who walked at 25 cm/s were able to walk around the house, and those who walked at 80 cm/s were likely to be able to go around the community without any difficulties [78]. Compensatory patterns including circumduction, stiff knee gait, tibial external rotation during mid-swing, lack of toe load, knee hyperextension, and contralateral trunk tilting are characteristics of hemiplegic gait. Task-specific overground locomotor training and treadmill training are frequently used to alleviate these deficits.

Task-Specific Overground Locomotor Training

This method focuses on helping stroke victims restore their motor skills and walking endurance through functional exercises. Patients perform a range of behaviors, such as side walking, cross-stepping, stair climbing, stepping up and down, walking through doorways, walking forward and backward, and dual-tasking (e.g., walking while carrying an object or chatting). Activities that promote balance, such walking straight forward, are also included. Walking is slow at first, but patients are encouraged to increase their speed and rhythm over time [80,81]. By giving patients real-time audible and visual feedback, electromyographic biofeedback is an adjunctive therapy that improves motor function and enables patients to adjust motor unit activity during task-specific training [82].

Virtual Reality (VR) in Gait Training

The potential of integrating VR with traditional rehabilitation techniques was emphasized by Bui et al. VR systems combine important neurorehabilitation concepts like movement tracking and reinforced feedback with immersive, inspiring worlds that mimic real-world situations. In both clinical and residential settings, these characteristics allow doctors to customize rehabilitation programs to meet the needs of specific patients. To maximize VR as a therapeutic tool and guarantee its successful integration into stroke therapy, more study is required [83].

Conventional Physical Therapy and Treadmill Training

According to studies, walking abilities, independence, and gait patterns can all be much enhanced by starting traditional physical therapy six to eight months after a stroke. Moderate-intensity activities and treadmill training are examples of interventions [84,85]. Exercises that emphasize knee flexion during the stance phase and proprioceptive training are especially useful in lowering knee hyperextension, which is a prevalent problem among subacute stroke survivors. Although not always harmful, knee hyperextension can cause knee pain, greater energy expenditure, gait asymmetry, and decreased walking

speed. Through exercises including controlled terminal knee extension, resistance drills, heel rises, and controlled marches, treatment approaches aim to enhance posterior chain recruitment, proprioception, and knee stabilization [86]. It has been demonstrated that treadmill training speeds up recuperation. According to Macko et al., six months of 40-minute treadmill workouts improve stroke survivors' functional mobility and peak fitness [85]. According to a randomized study, hemiparetic patients' gait ability was considerably enhanced by three weeks of treadmill training and four months of physical treatment [81]. Walking speed can be increased more effectively with fast-speed treadmill training than with slow or variable-speed training [86,88]. In the early stages of rehabilitation, balance training that uses visual cues and repetitive practice is crucial. Commonly used methods include zigzag walking, side-to-side training, and straight walking [87,88]. Based on patient performance, user-driven treadmills (UDTMs) use algorithms to instantly modify walking speed. UDTMs enhance forward propulsion, stability, and speed in stroke patients when used in conjunction with electrical muscle stimulation (EMS) [88,89,90]. Fast-speed treadmill training is superior to low-speed or variable-speed training in terms of increasing walking speed, according to a randomized pilot research conducted in 2001 [88,91].

Electromechanical Robot-Assisted Gait Training

Robot-assisted gait training (RAGT) is an emerging modality that enhances walking ability, postural balance, and muscle strength in stroke patients. RAGT devices provide support and guidance during walking, reducing the physical burden on therapists and enabling high-intensity training. This approach improves postural reactions, increases quadriceps and tibialis anterior strength, and reduces fall risk by enhancing swing phase control [94].

Neurophysiological Basis of Gait Recovery

Electromyographic (EMG) study of lower leg muscle activation during gait has been the subject of recent studies. Three problems can be identified in stroke patients with poor gait control: (1) excessive stretch reflexes that interfere with gait control, (2) loss of centrally produced muscle activation patterns, and (3) inappropriate muscle group co-activation [92,93]. Patients can reestablish corrected walking patterns with task-oriented instruction, manual aid, and bodyweight support systems. Initially, overhead harnesses are utilized to prevent falls and stabilize posture. As improvements are seen, full weight-bearing treadmill walking is gradually introduced [95,96,97]. In conclusion, a variety of therapies, such as task-specific overground training, treadmill training, virtual reality, and robot-assisted therapy, are included in gait training for stroke recovery. These methods seek to increase muscle strength, walking ability, and balance in order to improve stroke survivors' functional independence and quality of life.

Analysis of Present Data:

Stroke Rehabilitation: A Comprehensive Overview

Stroke remains one of the leading causes of mortality and disability worldwide, profoundly impacting individuals and society [99]. A significant complication of stroke is the loss of functional movement, which severely affects daily life, as motor function is essential for performing everyday activities. Over 70% of stroke survivors experience movement difficulties or other neurological impairments [100]. Physical therapy interventions have been demonstrated to improve motor function, reduce disability, enhance physical activity and fitness levels, and improve quality of life. Additionally, physical therapy has been linked to structural brain remodeling, which may contribute to motor recovery post-stroke. As such, physical therapy is a critical component of stroke management and rehabilitation [101].

Repetitive Practice and Task-Specific Rehabilitation

Systematic reviews have demonstrated that repetitive practice of daily chores can moderately improve mobility and activities of daily living (ADLs) in stroke patients [3]. Based on the patient's unique impairments, activity restrictions, and rehabilitation objectives, therapists customize therapies. Stroke rehabilitation is a proactive process that starts in the acute hospital setting, continues via structured rehabilitation programs, and extends into community reintegration. Rehabilitation activities focus both functional and psychological recovery [102]. In the intensive care unit (ICU) or stroke unit, low-intensity rehabilitation usually begins 72 hours after the stroke occurs. Patients and caregivers are given information about the recovery process, treatment plan, and potential obstacles. 64 hospitalized stroke patients were randomly assigned to one of three intervention groups—strength training, functional task practice, or routine care—in a 2002 study on acute stroke rehabilitation techniques. According to the study, two important aspects of upper extremity rehabilitation were task specificity and stroke severity. Functional results were considerably improved after 20 hours of upper extremity-specific treatment spread over four to six weeks. Functional task practice showed more long-term benefits than resistance strength training, even though both offered immediate benefits [103].

Acute, Sub-Acute, and Chronic Phase Interventions

Range-of-motion (ROM) exercises, splinting, bed mobility, functional mobility training, ADLs training, early mobilization, and positioning are all crucial therapies during the acute period. It has been demonstrated that mirror treatment improves visuospatial neglect, emotional health, motor impairments, and post-stroke pain [102]. The emphasis switches to enhancing movement, stamina, strength, and balance during the sub-acute phase. Even beyond the sub-acute phase, aerobic exercise has been shown to help stroke survivors [104], and early overground bodyweight-supported training is especially beneficial during this time [105]. Task-specific therapies can offer long-lasting benefits for motor impairments and deficits throughout the chronic phase [106].

Evidence-Based Rehabilitation Strategies

Several evidence-based rehabilitation strategies have been shown to improve motor recovery post-stroke. These include:

- **Constraint-Induced Movement Therapy (CIMT)** for upper limb impairment and motor function [109].
- **Robot-Assisted Training** for upper limb function and gait rehabilitation [107].

- **Long-Distance Walking and Cardio-Respiratory Training** to improve endurance [3].
- **Bilateral Training** for motor function of the arms [109].
- **Mirror Therapy** for upper and lower limb recovery [110].
- **Bobath Technique** and **Early Mobilization** for mobility improvement [110].

While no single intervention is universally effective, a combination of therapies tailored to the patient's needs can yield significant benefits.

Sensory Impairment and Spasticity Management

Sensory impairment is a common complication of stroke, with interventions including formal visual screening [112], repetitive sensory discrimination activities, sensory stimulators, mirror therapy, heat stimulation, and intermittent pneumatic compression to enhance upper limb sensations [51]. Homonymous hemianopia (HH) is a significant cause of morbidity post-stroke [113]. Spasticity management strategies, such as myofascial release [57], have also been explored, though further research is needed to establish their efficacy.

Strengthening and Functional Training

Strengthening exercises play a vital role in improving muscle strength, power, endurance, balance, and quality of life. Equipment such as free weights, sandbags, Swiss balls, and elastic resistance bands are commonly used. A review by Mentiplay et al. highlighted the importance of ankle dorsiflexors in walking speed, while knee flexors are crucial for postural stability and functional tasks like sitting and standing [115,116]. Functional electrical stimulation (FES) has been shown to enhance muscle mass, strength, and functional mobility, with effects persisting even after the intervention period [42,114].

Gait Training and Robot-Assisted Rehabilitation

Task-specific overground locomotor training and treadmill training are effective interventions for improving gait in stroke patients. Robot-assisted gait training (RAGT) and exoskeletons have shown promise in enhancing walking ability, postural balance, and muscle strength [117,118]. However, further research is needed to optimize protocols and establish objective measures for clinical application.

Role of Physical Therapist:

A physical therapist's contribution to stroke survivors' rehabilitation is varied and includes many interventions meant to maximize functional recovery, encourage independence, and improve general quality of life. Leading cause of long-term impairment, stroke offers special difficulties requiring a patient-centered, evidence-based rehabilitation strategy. By customizing treatments to the particular needs of every patient across the acute, sub-acute, and chronic periods of recovery, physical therapists significantly help to address these problems. Their knowledge of movement science, together with their capacity to include new technologies and treatment approaches, makes them invaluable members of the multidisciplinary team charged with stroke recovery.

Acute Phase: Early Mobilization and Prevention of Complications

Usually starting within 72 hours of stroke occurrence, the physical therapist's main responsibility in the acute phase is to start early mobilization and avoid secondary problems. Early mobilization has been demonstrated to increase consciousness, slow down mental decline, and lower the hazards connected with extended bed rest including pressure sores, muscle atrophy, and joint contractionures. Working collaboratively with other medical specialists in stroke units or intensive care environments, physical therapists use treatments including bed mobility training, range-of-motion (ROM) exercises, and positioning. These exercises assist keep joints integrity, stop spasticity, and lower the possibility of maladaptive movement patterns. Physical therapists also set reasonable expectations and offer emotional support during this crucial stage, thereby guiding patients and caregivers on the healing process.

Sub-Acute Phase: Intensive Rehabilitation and Functional Training

Usually within six months following a stroke, patients enter the sub-acute phase and the emphasis moves to intense therapy aiming at enhancing strength, balance, endurance, and mobility. Individualized programs created by physical therapists could call for strength exercises, gait training, and task-specific training. Methods like bilateral training and constraint-induced movement treatment (CIMT) are used to improve motor performance in the impacted limbs. Virtual reality (VR) and robot-assisted gait training (RAGT) are two emerging technologies increasingly included in rehabilitation programs to offer interesting and successful therapeutic experiences. These technologies improve motor learning and provide real-time feedback—which is absolutely essential for supporting accurate movement patterns. By means of focused interventions like mirror therapy and visual scanning activities, physical therapists also treat sensory deficits including hemianopsia and unilateral neglect. Physical therapists enable patients to become functionally independent and get ready for community reintegration by combining conventional techniques with creative ideas.

Chronic Phase: Maintenance and Community-Based Rehabilitation

Beyond six months following a stroke, the physical therapist's focus moves to preserving gains made in previous phases and advancing long-term health in the chronic phase. Many times advised to maintain physical activity levels and prevent deconditioning include home exercise programs (HEPs) and community-based fitness initiatives like water therapy. To help patients manage residual deficiencies, physical therapists teach them fall prevention, correct posture, and the value of ongoing exercise. Through therapies include stretching, botulinum toxin injections, and proprioceptive neuromuscular facilitation (PNF), they also treat ongoing conditions such spasticity and hypertonicity. Physical therapists enable stroke survivors to confidently and resiliantly negotiate the chronic phase by encouraging empowerment and self-efficacy.

Motor Recovery and Sensory Rehabilitation

The physical therapist's job mostly consists of helping motor recovery and resolving sensory problems. Paresis, spasticity, and sensory deficits—which greatly affect their capacity to engage in daily activities—of course affect stroke survivors as well. To encourage neuroplasticity and functional recovery, physical therapists use a range of approaches including sensory discrimination activities, motor learning strategies, and repeated task repetition under which include For patients with hemiparesis, for example, mirror therapy has been demonstrated to increase motor ability and lower discomfort. Analogous approaches to improve sensory integration and proprioception are thermal and electrical stimulation. Physical therapists enable patients to regain control over their motions and enhance their general quality of life by treating both motor and sensory disabilities.

Gait Training and Mobility Restoration

A pillar of stroke recovery, restoring gait and mobility is mostly dependent on physical therapists. Task-specific overground training and treadmill training are among the gait training methods designed to meet the particular needs of the patient and aims for recovery. Assistive equipment such walkers and ankle-foot orthoses (AFOs) help physical therapists facilitate effective and safe ambulating. Exoskeletons and robot-assisted gait training (RAGT) are two emerging technologies increasingly used to give high-intensity, repeated exercise while lowering the physical load on therapists. These technologies help patients to reach more freedom in their daily life by improving postural control, muscle strength, and walking speed.

Spasticity Management and Postural Control

Common problems in stroke therapy are spasticity and poor postural control; physical therapists use a variety of techniques to handle these problems. Techniques including stretching, splinting, and posture help to keep muscles length and stop contractures. Injections of botulinum toxin are given to lower localized spasticity and enhance functional results. To improve postural stability, physical therapists also create balance training programs combining sensory stimulation, weight-shifting activities, and proprioceptive exercises. Physical therapists assist patients in reaching more symmetry, coordination, and confidence in their movements by addressing spasticity and postural control.

Education and Psychosocial Support

Apart from physical treatments, physical therapists educate stroke sufferers and their families as well as offer psychological assistance. Patients are informed by them of the need of following fall prevention techniques, lifestyle changes, and rehabilitation programs. By creating a compelling therapeutic atmosphere, physical therapists also help with the emotional and psychological issues related to stroke, including sadness and anxiety. Physical therapists are especially important in encouraging long-term rehabilitation and well-being by arming patients with knowledge and emotional fortitude. A physical therapist plays a multifarious and dynamic role in stroke recovery, including a variety of therapies catered to the particular requirements of every patient. Physical therapists help to maximize recovery results from early mobilization in the acute phase to extensive functional training in the sub-acute phase and long-term maintenance in the chronic phase. Physical therapists help stroke patients regain independence, enhance their quality of life, and reintegrate into their communities by combining evidence-based techniques with new technologies and offering comprehensive care. Their knowledge, compassion, and commitment make them indispensable in the multidisciplinary endeavor to meet the significant challenges presented by stroke.

Future Directions and Limitations

This review highlights the need for physical therapy interventions in stroke rehabilitation; yet it also underlines the need for more research to solve these constraints and evaluate the quality of the data supporting these treatments. Comprehensive studies including a range of patient demographics are necessary to establish best practices and ensure the safety and efficacy of novel treatments. Pilot studies should be given first importance in order to look at the probable benefits and negative effects of new treatments including virtual reality, robots, and exoskeletons in therapeutic environments. All things considered; stroke rehabilitation calls for a multimodal approach including evidence-based, task-specific, context-specific therapies suited to the particular needs of the patient. Physical therapy is crucial for stroke survivors to improve general quality of life, sensory rehabilitation, and motor ability. Future studies should focus on enhancing developing technologies, simplifying rehabilitation procedures, and filling in the gaps in the current body of data if we are to increase stroke recovery results.

Conclusion:

Stroke rehabilitation is a critical component of recovery, addressing the physical, sensory, and cognitive impairments that significantly impact patients' quality of life. This review highlights the importance of physical therapy interventions, which are tailored to the unique needs of stroke survivors across acute, sub-acute, and chronic phases of recovery. Early mobilization, task-specific training, and repetitive practice have been shown to improve motor function, balance, and independence, while advanced technologies like virtual reality (VR) and robot-assisted gait training (RAGT) offer promising avenues for enhancing rehabilitation outcomes. In the acute phase, early interventions such as positioning, range-of-motion exercises, and functional mobility training are essential for preventing complications and promoting recovery. The sub-acute phase focuses on intensive therapies like constraint-induced movement therapy (CIMT) and bilateral training, which improve endurance, strength, and locomotion. In the chronic phase, home exercise programs and community-based fitness activities, including water-based exercises, help maintain gains and promote long-term functional independence. Emerging technologies, such as VR and robotics, are revolutionizing stroke rehabilitation by providing immersive, motivating environments and enabling high-intensity training with reduced physical burden on therapists. However, while these innovations show great potential, further research is needed to establish standardized protocols and validate their efficacy through large-scale randomized controlled trials

(RCTs). Sensory impairments and spasticity, common complications of stroke, require targeted interventions such as mirror therapy, repetitive sensory discrimination activities, and botulinum toxin injections. Strengthening exercises and functional training further enhance muscle performance, balance, and overall quality of life. Despite the progress made, limitations in the current evidence base, such as the lack of large-scale studies and standardized protocols, highlight the need for continued research. In conclusion, stroke rehabilitation is a dynamic and evolving field that integrates conventional therapies with cutting-edge technologies to optimize recovery. A multidisciplinary, patient-centered approach is essential for addressing the diverse needs of stroke survivors. Future research should focus on refining rehabilitation protocols, exploring innovative interventions, and addressing gaps in the evidence base to improve outcomes and enhance the quality of life for individuals affected by stroke.

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