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Robotic Rehabilitation in Stroke

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Abstract

Stroke is the most common neurological disease worldwide. Motor impairments after a stroke are often persistent and lead to disability. Engaging in intense, task-specific, and repetitive activities early in the rehabilitation process plays a crucial role in increasing the functional recovery of patients. Robotic rehabilitation, as a neurorehabilitation approach, enables the implementation of repetitive and high-intensity training programs, addressing the need for motor learning after a stroke. When applied in conjunction with conventional approaches, it reduces the labor-intensive components of the physiotherapist's work, contributing to a decrease in workload and allowing physiotherapists to engage in more functional activities. Additionally, it is an efficient method for objectively assessing the patient's functional status. Reviewing the literature reveals that rehabilitation programs supported by robotic devices are more effective in both upper and lower extremity recovery compared to the application of conventional methods alone. In the process of regaining lost motor function after a stroke, robotic rehabilitation has become an effective and alternative method, contributing to the physiotherapists' more efficient work and ensuring a highly repetitive and intense exercise program for patients.

Keywords: Stroke, Robotic Rehabilitation, Neurorehabilitation, Functional Recovery, Motor Learning

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ENTRANCE

Stroke, as defined by the World Health Organization (WHO) under cerebrovascular events, is a clinical syndrome characterized by the rapid onset of focal cerebral function loss signs and symptoms without an apparent cause other than vascular reasons. The criteria for diagnosis include the persistence of symptoms for more than 24 hours. The syndrome presents with different characteristic features, ranging from complete recovery within 1-2 days to partial recovery, mild and severe forms of disability, and even death.

Stroke holds the first place in terms of frequency and importance among adult neurological diseases. It is the most common serious neurological problem worldwide, ranking third in men and second in women as a cause of death after heart disease and lung cancer (Soler, 2010). Approximately 795,000 people experience a stroke each year globally. Of these, around 610,000 are first occurrences, and 185,000 are recurrent strokes (Benjamin, 2018). The WHO reports stroke incidence as 200 per 100,000 people, with variations among countries (Bonita, 1992).

Stroke risk factors can be categorized into non-modifiable and modifiable factors. Non-modifiable risk factors include age, gender, race, and genetic factors. Age is the most potent determinant of stroke, with the incidence doubling every decade after the age of 55, while being rare under the age of 40. Modifiable risk factors encompass hypertension, smoking, alcohol consumption, obesity, cardiovascular issues, diabetes, high cholesterol, and physical inactivity (Grysiewicz, 2008). Hypertension stands out as the most significant risk factor for ischemic and hemorrhagic strokes, as well as transient ischemic attacks (TIAs). According to the World Health Organization (WHO), hypertension is the cause of 62% of strokes (Gresham, 2012).

Strokes offer in two distinct forms based on their causes: ischemic and hemorrhagic. Ischemic strokes constitute approximately 87% of all strokes, while hemorrhagic strokes make up the remaining 13% (Feigin, 2003). The symptoms observed in a stroke vary depending on the location and size of the affected area and may include motor deficits, sensory impairments, cognitive dysfunction, language and speech disorders, visual and perceptual disturbances, and emotional disturbances (Jerrgensen, 1997). Clinical symptoms correlate with the damaged artery and the area it supplies. The affected artery and associated symptoms are listed in Table 1 (Roth, 1996).

Table 1: Artery and Symptoms

Artery	**Symptoms**
Internal Carotid Artery	• Transient Ischemic Attack (TIA) • Amaurosis fugax
Middle Cerebral Artery	• Contralateral hemiplegia • Contralateral hemiparesis • Turning the head and eyes to the side of the lesion • Dysphagia • Aphasia, apraxia, agnosia, hemianopsia • Neglect Syndrome
Anterior Cerebral Artery	• Significant sensorimotor deficit in the opposite leg and foot • Urinary incontinence • Mental disorder

	• Contralateral grasping and sucking reflex • Apraxia, posture and gait disorder
Posterior Cerebral artery	• Hemisensory loss, talamic syndrome • Visual agnosia • Alexia, memory lapses, postural tremor • Weber syndrome

Hemiplegia/hemiparesis is the most common outcome of a stroke, resulting in the loss of movement in the limbs on the opposite side of the brain affected by the damage. Hemiparetic individuals typically exhibit the following clinical features: loss of joint coordination, aberrant muscle tone, abnormal postural adjustments, lack of mobility, inappropriate movement synergies, and weakening of certain muscles (Masiero, 2014). Stroke has a significant societal effect due to persistent reduced limb function and difficulty in activities of daily living (ADLs). In stroke survivors, recovery is limited, with 15%–30% of patients permanently handicapped and 20% needing institutional care three months after onset (Rosati, 2010).

Following a stroke, patients need round-the-clock medical attention as well as intense rehabilitation that frequently necessitates one-on-one manual therapy sessions with the physical therapist. Sadly, current needs and financial constraints prevent its thorough repair. New technologies that increase the efficacy and effectiveness of post-stroke rehabilitation are therefore desperately needed. According to the scientific literature currently accessible, early, intense, task-specific, multimodal stimulation is the key to the most successful rehabilitative therapies (Masiero, 2014).

In traditional therapy methods, physiotherapists have a heavy workload. Additionally, in traditional therapy, the repetition of movements at the same level and their measurement can vary depending on the experience and abilities of the rehabilitation expert (Köse, 2021). Robotic rehabilitation, on the other hand, is an efficient method for the repetitive and consistent performance of movements, allowing for the objective assessment of the patient's functional status. Robotic systems provide opportunities for repetitive and high-intensity training programs, which are essential for motor learning. In this review, approaches to robotic rehabilitation in stroke are being discussed.

Robotic Rehabilitation

Robotik rehabilitation is defined as an approach that, through simulations and sensory input, enables the patient to first learn the movement passively, followed by gradually increasing the patient's activity to successfully complete the movement or assist in improving the patient's functionality. Robotics devices used in robotic rehabilitation can enable the repetition of movements as desired. In appropriate patients, during robot-assisted therapy, specified movements can be completed with support, and the practitioner can observe this process (Hidler, 2011).

Robot-assisted therapy is a potential neurorehabilitation strategy that seeks to improve standard post-stroke treatments. Neurorehabilitative treatments often engage the patient in rigorous, repeated, and task-specific exercise (Iosa, 2016). Robots can give constant, huge, and rigorous training without tiredness, and they can be precisely programmed, tailored, and changeable to meet the patient's demands. Furthermore, robots may provide diverse sensory-motor input, such as visual and aural feedback, which aids in motor learning (Liao, 2011).

Stroke is the most frequent neurological disorder in the world (Feigin, 2019). The first 6 months after a stroke are critically important in terms of neuroplasticity and functional gains. Research indicates that providing rigorous stimulation during the subacute phase (<6 months) and in structured stroke units can considerably improve the effectiveness of rehabilitation interventions (Masiero, 2009). Therefore, individuals with stroke require long-term, regular, and intensive rehabilitation services starting from the early period. In recent years, one way for meeting this demand has been robotic rehabilitation.

With the advancement of technology, the use of robots in the field of rehabilitation has gained momentum. Rehabilitation robots are generally categorized based on their mechanical structures as end-effector robots and exoskeleton robots. End-effector robots are connected to patients from a distal point and do not match joints with human joints. On the other hand, exoskeleton robots make connections from multiple points, and their joint axes match human joint axes, making them similar to human limbs (Lee, 2020).

Robotic technologies provide significant potential for post-stroke rehabilitation. Robotic systems can provide rigorous, task-oriented motor training for patients' limbs as part of a rehabilitation program alongside nonrobotic techniques. This approach reduces labor-intensive components of physical rehabilitation, allowing physiotherapists to focus on functional rehabilitation during individual training and oversee several patients during robot-assisted treatment sessions (Rosati, 2007).

Robotic rehabilitation involves more than just increasing training frequency and intensity. Robotic systems may provide sophisticated multimodal stimulation to patients, including visual, force, and auditory stimulation, in addition to producing basic and repetitive movement patterns like most existing devices. This approach enhances engagement and stimulation compared to traditional hand-over-hand therapy (Timmermans, 2009). Extrinsic feedback can also be employed to offer the patient with knowledge of results and/or performance during robotic training, hence helping the attainment of the goal movement and increasing the subject's involvement in the rehabilitation activity.

Another potential advantage is that robotic systems can measure a variety of kinematic and dynamic parameters as the patient's limb moves, allowing for both online and offline evaluation of several patient performance indicators (e.g., range of motion, velocity, smoothness, etc.) (Timmermans, 2009). These numbers may be utilized to objectively measure the patient's development in relation to the clinical evaluation scales, as well as to tailor the rehabilitation exercise to the patient's individual needs.

Robotic Rehabilitation For Upper Extremity After Stroke

Hemiplegia of the upper extremity is a common condition among hospitalized stroke survivors, accounting for two-thirds of the population (Jorgensen, 1999). Hemiplegia of the upper extremity impairs arm and hand function, negatively affecting everyday activities for stroke survivors (Nakayama, 1994). Rehabilitation therapy is essential for stroke patients to improve their motor skills and quality of life. Repetitive training promotes stroke healing and brain network remodeling. Robots are commonly used in stroke therapy by physiotherapists due to their ability to perform repeated actions accurately and consistently (Masiero, 2014). Robotic treatment provides mechanical help to upper limbs that are unable to move freely due to stroke-related conditions, allowing patients to undertake repeated training with voluntary motions. Takebayashi et al. emphasized the importance of optimizing robotic rehabilitation to maximize functional recovery of the upper extremity post-stroke. In a study comparing bilateral upper extremity robotic therapy with conventional treatment in hemiplegic patients by Tang et al., the robotic therapy group demonstrated better results in improving daily activities and specific neural connectivity directions compared to the conventional therapy group. Takahashi et al. found that the application of robotic therapy significantly made a difference in upper extremity recovery in addition to standard rehabilitation programs. Vanoglio et al. stated that robotic devices are applicable and effective in improving fine hand skills, strength, and reducing arm disability in subacute hemiplegic patients. Lee et al. mentioned that combining robot-assisted therapy with general occupational therapy is more effective in enhancing upper extremity function and daily life activities in stroke-induced hemiplegic patients compared to what is achieved with general occupational therapy alone. In a study conducted by Liao et al., applying robotic therapy in addition to functional training in chronic stroke patients was found to be more effective in improving hemiplegic arm activities and motor functions compared to functional training alone. In a randomized controlled trial conducted by M.-S. Kim et al. to examine the therapeutic effects of a newly developed shoulder robot on post-stroke hemiplegic shoulder pain, the group undergoing robot-assisted shoulder rehabilitation in addition to conventional treatment showed a significantly higher level of improvement in shoulder pain and disability compared to the conventional treatment group.

Robotic Rehabilitation For Lower Extremity After Stroke

Since walking is regarded as the cornerstone of independent mobility, gait recovery must be the main focus of stroke therapy (Selves, 2020). The asymmetry of the measures used to define the gait pattern characterizes the gait function of stroke patients (Patterson, 2010). As a result, the goal of gait therapy should be to correct the coordination issue, which will need extensive, repetitive training (Goffredo, 2019). Conventional gait therapy is typically labor-intensive, putting a heavy physical stress on the physiotherapist as two or three therapists may be needed to manually guide the damaged limb to follow the proper trajectory (Zhu, 2021). The topic of robotic-assisted rehabilitation is rapidly developing and has the potential to be a successful automated training program. Yoo et al. stated that robot-assisted walking training applied in subacute stroke patients, in conjunction with conventional treatment, is more effective than conventional therapy alone in improving walking independence and quality of life. Lee et al., in their study investigating the effects of end-effector lower extremity rehabilitation robot training in subacute stroke patients, found that end-effector lower extremity robot-assisted walking training, when compared to conventional physiotherapy alone, is more effective in improving the walking ability of subacute stroke patients. In another randomized controlled study by Lee et al., it was indicated that robotic rehabilitation treatment is more beneficial than traditional treatment in improving post-stroke balance, walking ability, and lower extremity strength. Zhank et al., in their study aiming to investigate the effectiveness of robotic-assisted walking training on muscle activation and walking function, concluded that robotic-assisted walking training is more effective in improving walking and optimizing muscle activation compared to traditional walking training. In a study by Kim and colleagues comparing the effects of end-effector robot-assisted walking training and body-weightsupported treadmill training on cortical activation in individuals with hemiparetic paralysis, it was found that robot-assisted walking training effectively improves neuroplastic outcomes in hemiparetic paralysis. Bang et al. stated that robot-assisted walking therapy may be more effective than traditional therapy in terms of walking ability, balance, and balance confidence in individuals with chronic stroke. Jayaraman et al. reported that walking training with a robotic exoskeleton increased walking speed in chronic stroke individuals and may be more effective in improving walking endurance and balance compared to functional walking training, encouraging greater corticomotor excitability of lower extremity muscles. Forrester et al. mentioned that modular lower extremity robotic training improves ankle motor control and gait pattern in subacute stroke patients.

Result

Robotic rehabilitation is used as an alternative or in addition to traditional rehabilitation programs to meet the intensive and long-term rehabilitation needs of post-stroke patients, starting from the acute phase. It is particularly included in rehabilitation programs to teach movement passively when patients cannot perform movements and gradually increase activity. As a neurorehabilitative approach, robotic rehabilitation supports neuroplasticity by enabling patients to perform task-specific and intensive repetitive exercises. The addition of robotic devices to rehabilitation programs helps improve motor, sensory, and cognitive gains in stroke survivors by providing essential elements of motor learning, including repetition, feedback, active participation, guidance, and motivation. Upon reviewing the literature, it has been observed that the application of robotic therapy in addition to rehabilitation programs after a stroke is more effective in various parameters, such as motor recovery, upper extremity functions, gaining walking independence, and improving daily life activities when compared to the application of traditional treatment alone. In this context, while providing motor training to post-stroke patients, robotic rehabilitation can be utilized as an effective and alternative method, contributing to the more efficient work of physiotherapists and ensuring a highly repetitive and intense exercise program for patients.

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