Turkish Journal of Clinical Research

Turk J Clin Res. 2025;1(3):201-210
https://doi.org/10.63909/1453035

REVIEW ARTICLE

Robotic rehabilitation in individuals with stroke

İnme geçiren bireylerde robotik rehabilitasyon

Parvin AKBAROV[1], Sevde Nur AKTAS[2]

[1]Azerbaijan Scientific Research Institute of Medical Rehabilitation, Specialist Physiotherapist, Bakü, Azerbaijan
[2]İstanbul Gelişim University, Vocational School of Health Services, İstanbul, Türkiye

Abstract

A cerebrovascular accident (CVA) is defined as a neurological deficit resulting from hemorrhagic or ischemic causes. While the majority of CVAs develop due to ischemic causes (87%), it is a heterogeneous disease. The World Health Organization defines stroke as a clinical condition characterized by various signs and symptoms related to focal cerebral dysfunction, usually due to vascular causes, lasting at least 24 hours, and potentially fatal. Stroke is very common worldwide and is the third leading cause of death in developed countries, after cancer and heart disease. Stroke is divided into two categories: ischemic stroke and hemorrhagic stroke. Post-stroke complications include motor, somatosensory, and cognitive impairments, which may also be accompanied by vision and speech problems. Approximately 10% of stroke survivors are reported to recover spontaneously. Of the remaining 80%, treatment is effective, while the remaining 10% do not recover. Multiple factors influence the recovery process. The rehabilitation program implemented after a stroke aims to provide the patient with functional independence and improve the individual's quality of life. A wide variety of methods are used, including neurophysiological approaches, strengthening exercises, stretching exercises, balance and gait training, manual therapy, sensory training, electrical stimulation, orthotics, biofeedback, mirror therapy, and virtual reality. In recent years, technological advancements have brought many innovations to the field of physiotherapy and rehabilitation. Robotic rehabilitation applications have begun to be used and have become one of the rehabilitation approaches. This review aims to examine the effectiveness of robotic rehabilitation therapy used in individuals with stroke.

Keywords: Stroke, rehabilitation, robotic rehabilitation.

Özet

Serebrovasküler olay (SVO), hemorajik ya da iskemik nedenlerle ortaya çıkan nörolojik defisit olarak ifade edilmiştir. SVO'ların daha çoğu iskemik nedenlere bağlı olarak (%87) gelişmekle birlikte heterojen bir hastalıktır. Dünya Sağlık Örgütü inmeyi; genellikle damarsal nedenlere bağlı olarak ortaya çıkan, en az 24 saat süren ve ölümle sonuçlanabilen fokalserebral fonksiyon bozukluğuna bağlı çeşitli bulgu ve semptomlarla kendini gösteren klinik tablo olarak tanımlamıştır. İnme, dünya genelinde çok yaygın görülmekle birlikte gelişmiş ülkelerde en sık görülen kanser ve kalp hastalıklarından sonra üçüncü önde gelen ölüm nedeni olarak yer alır. İnme iskemik inme ve hemorajik inme olmak üzere iki kısımda incelenir. İnme sonrası komplikasyonlar motor, somatosensoriyel ve kognitif bozuklukları içerir; buna görme ve konuşma problemleride eşlik edebilir. İnmeli bireylerin yaklaşık olarak %10'unun kendiliğinden iyileştiği bildirilmiştir. Kalan kısmın %80'i tedaviden etki alabilmekte %10'u ise iyileşme sağlayamamaktadır. İyileşme sürecini birden fazla faktör etkiler. İnme sonrası uygulanan rehabilitasyon programı hastaya fonksiyonel bağımsızlık kazandırmayı ve bireyin yaşam kalitesini arttırmayı amaçlar. İnme rehabilitasyonunda nörofizyolojik yaklaşımlar, kuvvetlendirme, germe egzersizleri, denge ve yürüme eğitimi, manuel tedavi yöntemleri, duyu eğitimi, elektrik stimülasyonu, ortez, biofeedback, ayna tedavisi, sanal gerçeklik gibi çok çeşitli yöntemler uygulanır. Son yıllarda ise teknolojinin gelişmesi fizyoterapi ve rehabilitasyon alanında da birçok yeniliği getirmiştir. Robotik rehabilitasyon uygulamaları kullanılmaya başlanmış; rehabilitasyon yaklaşımlarından biri olmuştur. Bu derleme çalışmasında inmeli bireylerde kullanılan robotik rehabilitasyon tedavisinin etkinliğinin incelenmesi amaçlanmaktadır.

Anahtar Kelimeler: İnme, rehabilitasyon, robotik rehabilitasyon.

INTRODUCTION

Stroke is one of the leading causes of death and disability worldwide. It has been reported that 17-50% of stroke survivors experience upper extremity problems, which affect their activities of daily living (1). Upper extremity problems in the first 6 months after a stroke It is very important for the rehabilitation of stroke patients; after the 6-month post-stroke period, 30-60% of patients cannot achieve functional recovery in the upper extremity (2,3).

A cerebrovascular accident (CVA) is defined as a neurological deficit resulting from hemorrhagic or ischemic causes. Although the majority of CVAs develop due to ischemic causes (87%), they are a heterogeneous disease. Cerebrovascular diseases are direct involvement of the vessels that feed the brain accompanied by pathological processes (4).

The World Health Organization (WHO) defines stroke as

Corresponding Author: Parvin AKBAROV akbarovparvin@gmail.com
Cite as: Akbarov P, Aktas SN. Robotic rehabilitation in individuals with stroke. Turk J Clin Res. 2025;1(3):201-210

Content of this journal is licensed under a Creative Commons Attribution-NonCommercial-NonDerivatives 4.0 International License
Received: 9 September 2025 | **Accepted:** 6 December 2025 | **Published:** 31 December 2025

Turk J Clin Res. 2025;1(3):201-210
https://doi.org/10.63909/1453035

a clinical condition characterized by various signs and symptoms related to focal cerebral dysfunction, usually due to vascular causes, lasting at least 24 hours, and potentially fatal. Stroke manifests itself with sensory problems, cognitive impairment, motor loss, and speech impairment, occurring after damage to cerebral vessels without any trauma (5,6).

Symptoms appear to reflect the affected hemisphere, and the diagnosis is confirmed by additional neurological examination and computed tomography (7). Cerebrovascular diseases affect the brain with more widespread involvement, resulting in a more global cerebraldysfunction, but the term "stroke" would be inappropriate in these cases. In the vast majority of stroke cases, the history and neurological examination provide sufficient information to localize the lesion to one side of the brain and attribute it to either anterior or posterior cerebral blood flow.

These symptoms reflect the affected hemisphere of the brain; the diagnosis is confirmed by neurological examination and computed tomography. Cerebrovascular diseases affect the brain with more widespread involvement, resulting in a more widespread cerebralIt causes dysfunction, but this is not the case in stroke. Stroke localizes to one side of the brain and develops depending on anterior or posterior cerebral blood flow (7,8).

Epidemiology of Stroke

Stroke is very common worldwide and is the third leading cause of death in developed countries, after cancer and heart disease. It also leads to disability and accounts for a significant portion of hospital and healthcare costs. In the United States, an average of 800,000 people have a stroke each year, approximately 600.000 of whom are experiencing their first stroke (9,10). According to WHO data, 15 million people experience a stroke worldwide each year; 5.5 million die in these cases, and 5 million are reported to have permanent motor impairment (10,11). The damage resulting from stroke creates a socioeconomic burden for both families and society. The annual incidence of stroke is 1.7-3.6 per 1,000 people aged 55-64, 5-9 per 1.000 people aged 65-74, and 13.5-18 per 1,000 people aged 75 and over. Older women are 2-3 times more at risk of stroke than men. Geographic factors influence the risk of stroke; the prevalence of stroke increases with age (11,12).

Stroke Risk Factors

Knowing the risk factors for stroke is crucial for determining prognosis and preventing future attacks. Stroke risk factors are divided into two main groups: modifiable and non-modifiable. Non-modifiable risk factors include age, gender, genetics, and race/ethnicity, while modifiable factors include smoking, alcohol consumption, and diabetes. It includes conditions such as diabetes mellitus, hypertension, and sedentary lifestyle (13).

Non-modifiable Risk Factors for Stroke

People with non-modifiable risk factors are at high risk.

- Age: Stroke is known as a disease of aging; its incidence increases with age every year, and especially in people over 55 years of age, this risk doubles every ten years (14).
- Gender: A review of the literature indicates that stroke is more common in men than in women. The rate of stroke is higher in men due to their higher smoking and alcohol consumption. One study reported that young women are also at higher risk, but men are also at higher risk as they age (15).
- Ethnicity: A review of the literature reveals some ethnic disparities in this regard (16). The incidence of stroke is higher in Blacks, Chinese, and Japanese than in Caucasians. However, these individuals also experience higher mortality rates (17).
- Genetic factors: Family history increases the risk of stroke by 30%. Fabry disease, hyperhomocysteinemia, fibromuscular The genetic transmission of diseases such as dysplasia has been proven; they are implicated in the etiology of stroke. As with other factors, the risks associated with genetic factors vary depending on age, gender, and ethnicity (18).

Modifiable Risk Factors for Stroke

Knowing modifiable risk factors is crucial because these can be controlled through various strategies and measures. Modifiable risk factors include hypertension, diabetes mellitus, andatrial fibrillation. These include

Turk J Clin Res. 2025;1(3):201-210
https://doi.org/10.63909/1453035

heart diseases such as fibrillation and atrial cardiopathy, hyperlipidemia, smoking and alcohol use, nutritional habits and obesity, sedentary lifestyle and inflammation-infection.

Stroke Etiology-Pathogenesis

A stroke is defined as a sudden neurological problem resulting from a disruption in blood circulation in the blood vessels supplying the brain. Understanding neurovascular anatomy is crucial for examining and understanding the symptoms of a stroke. Blood flow to the brain is provided by the circle of Willus. This structure represents the two internal carotid arteries anteriorly and the two vertebral arteries posteriorly. Strokes are divided into two categories: ischemic stroke and hemorrhagic stroke. Ischemic stroke occurs as a result of insufficient blood and oxygen flow to the brain; hemorrhagic stroke occurs as a result of bleeding or leaking blood vessels (19).

Stroke Classification

1) Ischemic Stroke

Ischemic stroke, also known as cerebral infarction, accounts for approximately 85% of all stroke types. In this type of stroke, cerebral blood flow is below normal due to the development of a thrombus or embolism. Reduced or completely interrupted cerebral blood flow can lead to neuronal damage, death, and inflammatory responses. Ischemic stroke is categorized into three groups: thrombotic, embolic, and lacunar (20).

Large artery sclerosis, or thrombolytic stroke, accounts for 50% of all ischemic strokes. Atherosclerosis in large blood vessels leads to thrombolytic stroke. It usually occurs at night, with symptoms appearing in the morning.

Embolic strokes account for 20% of ischemic strokes. In this type of stroke, arterial occlusion is caused by cardiac embolism or an atherosclerotic plaque. Embolic strokes are characterized by sudden loss of consciousness and are frequently accompanied by epileptic seizures. To establish the diagnosis, large-artery atherosclerosis must be excluded, and magnetic resonance imaging (MRI), brain CT, and CT scans must be performed. It occurs in older individuals with infarcts, small vessel occlusions, diabetes, and hypertension; it accounts for 25% of strokes. For this diagnosis, ipsilateral heart disease and major vessel disease that could lead to stenosis must be absent (21,22).

2) Hemorrhagic Stroke

Hemorrhagic strokes have a high mortality rate and account for approximately 15% of all strokes. A rupture in the cerebral artery wall causes blood to leak out of the vessel. Bleeding is classified into two types: subarachnoid and intracerebral. In an intracerebral hemorrhage, abnormal blood accumulates within the brain due to ruptured blood vessels. In a subarachnoid hemorrhage, blood accumulates in the subarachnoid space due to trauma or a cerebral aneurysm (23,24).

Disorders Observed After Stroke

Many different complications can develop in individuals who have had a stroke, both in the early and late stages, and these complications can negatively impact the rehabilitation process and lead to death (25). The incidence of complications has been reported to be approximately 50%. The patient's previous medical condition, pre-stroke disability, advanced age, and existing chronic diseases influence the development of complications. The most common complications of stroke have been reported to be shoulder pain, falls, urinary tract infections, and psychological problems (26,27).

Post-stroke complications include motor, somatosensory, and cognitive impairments, which may be accompanied by vision and speech problems. After a stroke, impairments in the somatosensory system are observed in approximately 90% of patients, depending on the cortical region affected (27). The somatosensory system includes superficial, deep, and cognitive senses. Individuals who have had a stroke experience impairments in identifying objects by touch and in proprioceptive sense. Sensory impairments may also occur on the unaffected side (28,29). Neuropathic pain in stroke patients can also cause numbness, burning, and tingling on the affected side. These sensory disturbances are more intense in the lower extremities, negatively affecting balance and gait, limiting independence. A

Turk J Clin Res. 2025;1(3):201-210
https://doi.org/10.63909/1453035

decrease in subscapular sensation leads to poor balance and greater postural sway while standing (30).

The most common motor deficits after stroke are spasticity, loss of strength, coordination disorders, and dysphagia. Damage to the motor cortex more frequently causes loss of strength on the contralateral side. Motor deficits experienced in stroke patients not only lead to loss of strength but also to rapid fatigue, prolonged reaction time, and excessive effort requirements, so they should be evaluated comprehensively. Spasticity, a motor disorder characterized by increased muscle tone and involuntary muscle activation following an upper motor neuron lesion, is more common in the upper extremities than in the lower extremities in stroke survivors. The elbow, wrist, and ankle are the most commonly affected muscle groups. While increased tone occurs in the deflexor direction of the upper extremity, it is also more common in the lower extremity. Increased tone occurs in the extensor direction (31,32). Dysphagia, one of the common complications after stroke, is defined as difficulty swallowing. This condition can lead to malnutrition, aspiration, and aspiration pneumonia. It is associated with morbidity and morbidity (33).

Cognitive impairment following stroke includes impairments in memory, concentration, attention, speech, spatial and perceptual skills, and higher-level cognitive skills. Other complications of stroke include sleep disturbances, psychological problems, incontinence, decubitus ulcers, deep venous thrombosis, and pulmonary complications (27).

Post-stroke Recovery Mechanism and Neural Plasticity

Approximately 10% of stroke patients have been reported to recover spontaneously. Of the remaining 80%, treatment is effective, while the remaining 10% fail to recover. Multiple factors influence the recovery process (34). Individuals with stroke initially experience severe neurological damage. The recovery process varies depending on factors such as the individual's general medical condition, demographic characteristics, socioeconomic status, lesion size and type, and the time of initiation of treatment. Recovery in stroke is examined under two subheadings: neurological and functional recovery. Neurological recovery occurs most frequently in the first 3 months but can continue for up to 6 months. Some studies have reported that it lasts up to 1 year. Functional recovery, however, takes longer. The recovery process affects the individual's ability to adapt to activities of daily living. Advanced age, a history of previous stroke, the presence of comorbidities, and loss of consciousness are among the poor prognostic factors (35,36).

1) Neurological Recovery

Neuroplasticity is the ability of the damaged nervous system to respond to internal and external factors by restructuring it. It can be defined in every domain, including the system, cell, and molecule. Exercises in a rehabilitation program have been found to stimulate neuroplasticity and are highly effective in planning, memory, and learning. In the acute phase, reorganization occurs from the first day after injury. This reorganization, which continues in the subacute phase, has been reported to last approximately 3 years. Physiotherapy and rehabilitation practices are crucial for achieving complete recovery during this period (37,38). Neurological recovery involves two mechanisms. The first mechanism involves the removal of damaged tissues, the establishment of collateral circulation, and the recovery of damaged ischemic neurons. The second mechanism describes neuroplasticity that develops in the acute or chronic phase (39).

2) Functional Recovery

Functional recovery involves changes in daily living activities. It occurs most rapidly in the first months, reaching a maximum by the end of one year; minimal improvements can be observed thereafter. Stroke survivors experience a flaccid phase in the first few months, where muscle tone is reduced or completely absent. Deep tendon reflexes disappear during this phase. After this phase, an increase in muscle tone is observed. Initially, synergistic patterns emerge, followed by the normalization of muscle tone and subsequent development of isolated movement patterns. The prognosis for the upper extremity is poorer than for the lower extremity. Furthermore, recovery in distal structures occurs later than in proximal structures (22,38).

Turk J Clin Res. 2025;1(3):201-210
https://doi.org/10.63909/1453035

Post-Stroke Rehabilitation Approaches

The rehabilitation process, or motor learning, is a process in which a patient relearns how to move to continue their daily lives. Motor learning is a concept that fosters the development of movement skills, is based on frequent repetition, and, with this repetition, creates permanent changes in the brain. Active participation in goal-oriented rehabilitation and frequent repetition are key to motor learning. This process occurs through plasticity (40).

The rehabilitation program implemented after a stroke aims to restore functional independence and improve the patient's quality of life. The rehabilitation process is implemented with a multidisciplinary approach. The team includes healthcare professionals such as a physician, occupational therapist, physiotherapist, speech therapist, and nurse. Stroke treatment should be initiated in the acute phase and continued with follow-up after the patient is discharged. Before initiating rehabilitation, the active participation status and functional level of the individual's upper and lower extremities should be determined. Neurophysiological approaches are frequently used to restore normal movement patterns, normal tone, and normal posture. Neurophysiological methods such as Kabat and Knott, Brunnstrom and Bobath, Rood, Margaret Johnstone, and Todd-Davies are used in the rehabilitation of stroke patients. While some of these approaches remain valid, different task-focused rehabilitation approaches are also used today (22). Normal range of motion exercises to prevent contractures and deformities, and stretching exercises to stimulate nerves to prevent muscle shortening can be incorporated into conventional approaches. Electrophysical agents can be used to enhance the effectiveness of rehabilitation and maximize functionality (41). In summary, in stroke rehabilitation A wide variety of methods are applied, including neurophysiological approaches, strengthening, stretching exercises, balance and gait training, manual therapy methods, sensory training, electrical stimulation, orthotics, biofeedback, mirror therapy, and virtual reality. In recent years, technological advancements have brought many innovations to the field of physiotherapy and rehabilitation. Robotic rehabilitation applications have begun to be used and have become one of the rehabilitation approaches (42).

1) Electrophysical Treatment Modalities

Electrophysical agents are categorized into three groups: thermal, mechanical, and electromagnetic. These agents prepare individuals for rehabilitation and increase the effectiveness of treatment. The thermal group includes hot and cold agents. Thermal agents have positive effects on pain, tissue healing, and inflammation (43). Cold application is frequently preferred in stroke survivors for inhibiting spasticity and inducing muscle contraction. Mechanical agents such as compression, ultrasound, and hydrotherapy are used to prevent complications. Bandages and compression stockings may be preferred to increase blood circulation and prevent scar tissue formation to prevent deep venous thrombosis, which frequently occurs in stroke survivors. Hydrotherapy is one of the mechanical agents that can be used to improve muscle strength, balance, and cardiovascular fitness. Studies have reported that pulsed ultrasound can be effective for pressure sores, which negatively impact rehabilitation in stroke survivors. Agents such as TENS, NMES, EMGBiofeedback, and FES are among the electrophysical agents preferred for stroke survivors. NMES can be used in individuals without peripheral nerve damage to increase muscle strength and induce muscle contraction. FES current is frequently used for motor learning. EMGBiofeedback is preferred for improving gait and gaining dorsiflexor strength. TENS is widely used for acute and chronic pain (44).

Karakuş et al. reported in their study that the addition of functional electrical stimulation to the standard rehabilitation program had a positive effect on upper extremity motor function in patients with post-stroke hemiplegia (42).

passive neuromuscular electrical stimulation applied to the shoulder girdle and wrist extensors, added to the conventional rehabilitation program in stroke patients, was not superior to the conventional program alone (45).

2) Restrictive-Compulsive Movement Therapy

Rehabilitation approach that aims to restrict the less affected extremity while simultaneously promoting repetitive use of the more affected upper extremity. Neuroplastic changes are achieved with this approach. The Restrictive-Compulsive Movement Therapy program

Turk J Clin Res. 2025;1(3):201-210
https://doi.org/10.63909/1453035

is generally planned to include 6 hours of training per day for 3 weeks in patients with significant functional deficits. The exercise program includes various shaping techniques that gradually increase the difficulty of movements, fine motor skills exercises, and muscle strengthening exercises. Boake et al., in their study on stroke patients, demonstrated that this treatment method provides long-term improvement in upper extremity motor function (46).

3) Splint and Orthosis

Splints are preferred in spasticity management to prevent deformities and stabilizejoints. At the same time, neurophysiologically, they aim to reduce spasticity by providing prolonged tension through reflex inhibition mechanisms.

Orthoses not only prevents abnormal posture and deformities but also allows for correct and high-quality movement in the extremity. However, the effectiveness of these approaches has not been fully demonstrated in the literature (47).

4) Mirror Therapy

Neuroplasticity is a multistage process that progresses from simple to complex levels; it is the human brain's ability to adapt to threatening situations. Understanding the reorganization that occurs in the brain after a stroke is crucial for successful rehabilitation.

Recovery of the affected side increases the activation of that hemisphere for motor recovery and increases the activity of the healthy hemisphere. New rehabilitation approaches aimed at inhibiting neuronal activity are being developed. Imagining or observing a movement activates motor neurons. This occurs through the mirror neuron system. Mirror therapy is based on the activation of this system. The term "phantom pain" has been coined in the literature for the treatment of this type of therapy (48,49). Mirror therapy is frequently preferred in rehabilitation due to its ease of application and the research demonstrating its high therapeutic effectiveness (50).

Increased range of motion and mobility, and improved motor function have been reported in chronic stroke patients treated with mirror therapy. However, some studies have reported no effect on motor function (51,52).

In their study on 53 stroke patients, Demirbaş et al. applied mirror therapy in addition to rehabilitation treatment, but as a result of the study, it was reported that the added mirror therapy did not contribute to motor recovery (53).

5) Virtual Reality

One of the approaches that has emerged recently with the development of technology is virtual reality. Virtual reality allows a person to combine a fictional environment with reality. It is defined as a system with a computer infrastructure. Exercises performed in virtual reality contribute to the development of neuroplasticity (54).

Viau and colleagues examined the effect of virtual reality environments on the process of restoring motor functions of the arm that developed due to stroke; they revealed that virtual reality environments had positive effects on stroke patients with motor impairment (55).

6) Robotic Rehabilitation

Robotic devices are designed to elicit purposeful, repetitive movements through visual and auditory feedback. Robotic rehabilitation devices provide feedback on specific functions at adjustable speeds, compensating for existing muscle or motor control weaknesses and enhancing the individual's perception of recovery. Furthermore, virtual reality game modalities increase individual motivation and encourage treatment. Robotic devices support normal joint movement of the upper and lower extremities in neurological diseases through purposeful, repetitive movements, contributing to the development of muscle strength and coordination. With recent technological advances, robotic rehabilitation has improved autonomous learning skills in individuals by connecting the virtual and real worlds (56, 57). Compared to traditional treatment methods, robotic rehabilitation offers numerous advantages, including providing long-term, uninterrupted treatment, the ability to program and perform multiple functional movements, adjustable speed and repetition rates of exercises tailored to the patient's needs, and remote control (42). Robotic

Turk J Clin Res. 2025;1(3):201-210
https://doi.org/10.63909/1453035

rehabilitation also provides feedback on treatment effectiveness by measuring individual performance. Robotic rehabilitation is a new approach to post-stroke rehabilitation.

In the post-stroke rehabilitation process, devices specific to the upper and lower extremities have been produced, and evidence has been found that these devices improve extremity function. Robotic rehabilitation devices are divided into four categories: orthotic wearable robotic devices, robots that assist with activities of daily living, fixed exercise robots specific to the upper and lower extremities, and robots that provide walking support. Design-wise, robotic rehabilitation devices are categorized into two groups: end-effector and exoskeleton devices. End-effectors allow active participation of the proximal parts of extremities such as the hip and shoulder, while applying resistance to the distal parts. Because the device cannot control the proximal extremity, abnormal movement patterns and posture can occur. This is one of the disadvantages of the device.

Exoskeleton robotic devices are designed using anatomical axes as a reference point; they are designed to match human anatomy. They directly control joint movements, preventing the occurrence of abnormal movements. Specific devices have been developed for the upper and lower extremities to be utilized in post-stroke rehabilitation protocols. It has been demonstrated that the robotic rehabilitation protocol improves motor functions in the upper and lower extremities (58). Robotic rehabilitation devices are divided into four categories: fixed exercise robots specific to the upper and lower extremities, wearable orthosis-like robotic devices, robots that support activities of daily living, and robots that function as walkers (59). Robotic rehabilitation devices are categorized into two groups by design: end-effector and exoskeleton (60,61). End-effector robotic devices function by applying resistance to the distal portion of the extremities. These devices require active participation of proximal joints such as the hip and shoulder. The most significant disadvantage of these devices is that they cannot control the proximal extremity, which can lead to abnormal movement patterns and posture.

Exoskeleton robotic devices, on the other hand, are designed to conform to human anatomy and are manufactured using anatomical axes as reference. In addition to providing direct movement control over joints, it reduces the likelihood of abnormal movement patterns and postures (59).

Lee et al. reported that robotic rehabilitation applied to the upper extremity in the subacute period after stroke had positive effects on spasticity, grip strength, and fatigue (62).

Sale et al. reported positive changes in the shoulder and elbow joints after 6 weeks of treatment in stroke patients, but reported no effect on wrist and hand assessments (63).

Cho et al. conducted a study in which they applied robotic rehabilitation to only 21 stroke patients for six weeks. At the end of the treatment, motor functions were significantly improved according to the Fugl-Meyer Scale (64).

Mehrholz et al., in a study examining the effectiveness of robotic rehabilitation in the lower extremity, found that robotic rehabilitation combined with physiotherapy improved walking in stroke patients (65). In their study comparing conventional therapy with robotic rehabilitation, Lo and colleagues found robotic rehabilitation superior to conventional therapy in the treatment of patients with mild to severe impairments (66). In their 2018 study, Bruni and colleagues demonstrated that end-effector robots were significantly effective in improving walking speed (67). In acute stroke patients, robot-assisted therapy delivered as a dose-matched partial substitution for conventional rehabilitation resulted in greater improvements in gross manual dexterity, upper-limb functional tasks, and patient-reported social participation compared to conventional therapy alone, supporting the potential added value of early-phase robotic interventions (68).

Similarly, a pilot randomized controlled trial assessing kinematic outcomes during an untrained vertical reaching task demonstrated that robot-assisted therapy led to significantly greater improvements in shoulder-elbow coordination, elbow extension, and reduced compensatory trunk movements compared with arm-specific physiotherapy. Moreover, the benefits of robotic

Turk J Clin Res. 2025;1(3):201-210
https://doi.org/10.63909/1453035

training generalized to an untrained three-dimensional reaching task, suggesting that robotic therapy may facilitate improvements in overall motor control strategies rather than solely enhancing task-specific performance (69). These findings indicate that robot-assisted interventions can promote more physiological movement patterns and support the generalization of motor gains beyond trained exercises.

CONCLUSION

While traditional rehabilitation methods have demonstrated some positive therapeutic effects on stroke survivors, there are also areas where they are ineffective. The success of traditional rehabilitation methods varies depending on the specialist's knowledge and application style. Furthermore, the rehabilitation process and evaluations can be tedious for physical therapists. Robotic rehabilitation allows for more efficient time management and the rehabilitation of more patients. Furthermore, a significant advantage of robotic rehabilitation is the reduced workload and the ability to work more comfortably with patients.

Using this new approach in stroke rehabilitation can reduce post-stroke motor deficits, reduce dependence on others, and improve patient comfort. Robotic rehabilitation may be preferred for both lower and upper extremity post-stroke treatment due to these benefits.

Acknowledgement: None.

Ethical Approval: None.

Author Contribution: Idea/Concept: P.A., S.N.A.; Design: P.A., S.N.A.; Supervision: P.A., S.N.A.; Resources: P.A., S.N.A.; Materials: P.A.; Data Collection and/or Processing: S.N.A.; Analysis and/or Interpretation: P.A., S.N.A.; Literature Review: P.A., S.N.A.; Written by: P.A., S.N.A.; Critical Review: P.A., S.N.A.

Financial Disclosure: The authors declare that they have received no financial support for the study.

REFERENCES

1. Feigin VL, Lawes CM, Bennett DA, Anderson CS. Stroke epidemiology: A review of population-based studies of incidence, prevalence, and case-fatality in the late 20th century. Lancet Neurol. 2003;2(1):43-53.
2. Kwakkel G, Kollen BJ. Predicting activities after stroke: What is clinically relevant? Int J Stroke. 2013;8(1):25-32.
3. Pollock A, Farmer SE, Brady MC, Langhorne P, Mead GE, Mehrholz J, et al. Interventions for improving upper limb function after stroke. Cochrane Database Syst Rev. 2014;(11):CD010820.
4. Çoban O. Definitions, Classification, Epidemiology and Risk Factors in Cerebrovascular Diseases. In: Öge E, editor. Neurology. Istanbul: Nobel Medical Bookstore; 2004. p.193-197.
5. Sudlow CL, Warlow CP. Comparing stroke incidence worldwide: What makes studies comparable? Stroke. 1996;27(3):550-558.
6. Warlow CP, Dennis MS, van Gijn J, Hankey GJ. Stroke: A practical guide to management. Blackwell Publishing; 2001. p.28-106.
7. Smith WS, Johnstone SC, Easton JD. Cerebrovascular Diseases. In: Houser SL, editor. Harrison's Neurology in Clinical Medicine. New York: McGraw Hill Companies Inc; 2006. p.233-271.
8. Simon RP, Greenberg DA, Aminoff MJ, editors. Clinical Neurology. New York: McGraw Hill Companies Inc; 2009. p.292-327.
9. Kotila M, Numminen H, Waltimo O, Kaste M. Depression after stroke: Results of the Finnstroke study. Stroke. 1998;29(2):368-72.
10. Mukherjee D, Patil CG. Epidemiology and the global burden of stroke. World Neurosurg. 2011;76(6):S85-S90.
11. Kochanek KD, Xu J, Murphy SL, Miniño AM, Kung HC. Deaths: final data for 2009. Natl Vital Stat Rep. 2011;60(3):1-116.
12. Ihle-Hansen H, Thommessen B, Wyller TB, Engedal K, Fure B. Risk factors for and incidence of subtypes of ischemic stroke. Functional Neurology. 2012;27(1):35-40.
13. Boehme AK, Esenwa C, Elkind MSV. Stroke risk factors, genetics, and prevention. Circ Res. 2017;120(3):472-95.
14. Roger VL, Go AS, Lloyd-Jones DM, Benjamin EJ, Berry JD, Borden WB, et al. Executive summary: Heart disease and stroke statistics-2012 update: A report from the American Heart Association. Circulation. 2012;125(1):188-97.
15. Kapral MK, Fang J, Hill MD, Silver F, Richards J, Jaigobin C, et al. Sex differences in stroke care and outcomes: Results from the Registry of the Canadian Stroke Network. Stroke. 2005;36(4):809-14.
16. Liampas A, Velidakis N, Georgiou T, Vadalouca A, Varrassi G, Hadjigeorgiou GM, et al. Prevalence and management challenges in central post-stroke neuropathic pain: A systematic review and meta-analysis. Adv Ther. 2020;37:3278-91.

Turk J Clin Res. 2025;1(3):201-210
https://doi.org/10.63909/1453035

17. Onat Ş, Erkin G. Risk factors in stroke. FTR Bil J PMR Sci. 2008;1:30-37.
18. Goldstein LB, Bushnell CD, Adams RJ, Chaturvedi S, Creager MA. Guidelines for the primary prevention of stroke: A guideline for healthcare professionals from the American Heart Association/American Stroke Association. Stroke. 2011;42:517-84.
19. 18.Kuriakose D, Xiao Z. Pathophysiology and treatment of stroke: Present status and future perspectives. Int J Mol Sci. 2020;21(20):1-24.
20. Chung JW, Park SH, Kim N, Kim WJ, Park JH, Ko Y, et al. Trial of ORG 10172 in acute stroke treatment (TOAST) classification and vascular territory of ischemic stroke lesions diagnosed by diffusion-weighted imaging. J Am Heart Assoc. 2014;3(4):e001119
21. Adams HP Jr, Bendixen BH, Kappelle LJ, Biller J, Love BB, Gordon DL, et al. Classification of subtype of acute ischemic stroke. Definitions for use in a multicenter clinical trial. TOAST. Trial of ORG 10172 in Acute Stroke Treatment. Stroke. 1993;24(1):35-41.
22. Otman S, Karaduman A, Laçin A. Neurophysiological approaches in hemiplegia rehabilitation. Ankara: Hipokrat K; 2018. p.3-125.
23. Testai FD, Aiyagari V. Acute hemorrhagic stroke pathophysiology and medical interventions: Blood pressure control, management of anticoagulant-associated cerebral hemorrhage, and general treatment principles. Neurol Clin. 2008;26:963-985.
24. Aronowski J, Zhao X. Molecular pathophysiology of cerebral hemorrhage: Secondary brain injury. Stroke. 2011;42:1781-1786.
25. Kaymak Karataş G. Stroke rehabilitation. In: Beyazova M, Kutsal YG, editors. Physical Medicine and Rehabilitation. 3rd ed. Ankara: Güneş Medical Bookstores; 2016. p.2267-2290.
26. Kumar S, Chou SHY, Smith CJ, Nallaparaju A, Laurido-Soto OJ, Leonard AD, et al. Addressing systemic complications of acute stroke: A scientific statement from the American Heart Association. Stroke. 2024;56:15-29.
27. Kumar S, Selim MH, Caplan LR. Medical complications after stroke. Lancet Neurol. 2010;9(1):105-118.
28. Lima NMFV, Menegatti KC, Yu É, Sacomoto NY, Scalha TB, Lima INDF, et al. Sensory deficits in ipsilesional upper extremity in chronic stroke patients. Arq Neuropsiquiatr. 2015;73:834-839.
29. Liampas A, Velidakis N, Georgiou T, Vadalouca A, Varrassi G, Hadjigeorgiou GM, et al. Prevalence and management challenges in central post-stroke neuropathic pain: A systematic review and meta-analysis. Adv Ther. 2020;37:3278-91.
30. Parsons SL, Mansfield A, Inness EL, Patterson KK. The relationship of plantar cutaneous sensation and standing balance post-stroke. Top Stroke Rehabil. 2016;23(5):326-32.
31. Schaechter JD. Motor rehabilitation and brain plasticity after hemiparetic stroke. Prog Neurobiol. 2004;73(1):61-72.
32. Canning CG, Ada L, O'Dwyer N. Slowness to develop force contributes to weakness after stroke. Arch Phys Med Rehabil. 1999;80(1):66-70.
33. Lawrence ES, Coshall C, Dundas R, Stewart J, Rudd AG, Howard R, et al. Estimates of the prevalence of acute stroke impairments and disability in a multiethnic population. Stroke. 2001;32(6):1279-84.
34. Balkan S. Cerebral blood flow and cerebral metabolism. In: Cerebrovascular Diseases. Ankara: Güneş Tıp; 2009. p.29-50.
35. Dombovy ML, Sandok BA, Basford JR. Rehabilitation for stroke: a review. Stroke. 1986;17(3):363-9.
36. Gündüz B. Stroke and factors affecting prognosis. Turk J Phys Med Rehabil. 2006;52:B30-B33.
37. Özocak O, Gündüz Başçıl S, Gölgeli A. Exercise and neuroplasticity. Düzce Univ Health Sci Inst J. 2019;9(1):31-8.
38. Levin MF, Kleim JA, Wolf SL. What do "recovery" and "compensation" mean in patients following stroke? Neurorehabil Neural Repair. 2009;23(4):313-9.
39. Cramer SC, Riley JD. Neuroplasticity and brain repair after stroke. Curr Opin Neurol. 2008;21(1):76-82.
40. Krakauer JW. Motor learning: its relevance to stroke recovery and neurorehabilitation. Curr Opin Neurol. 2006;19(1):84-90.
41. Langhorne P, Bernhardt J, Kwakkel G. Stroke rehabilitation. Lancet. 2011;377(9778):1693-702.
42. Karaduman A, Yıldırım Aksu S, Yalçın Tandoğan O, editors. Post-Stroke Physiotherapy and Rehabilitation. 2nd ed. Ankara: Pelikan Bookstore; 2014. p.155-170.
43. Karakuş D, Ersöz M, Koyuncu G, Türk D, Şaşmaz FM, Akyüz M. Effects of functional electrical stimulation on wrist function and spasticity in stroke: a randomized controlled study. Turk J Phys Med Rehabil. 2013;59(2).87-102.
44. Noh DK, Lim JY, Shin HI, Paik NJ. The effect of aquatic therapy on postural balance and muscle strength in stroke survivors: a randomized controlled pilot trial. Clin Rehabil. 2008;22(10-11):966-76.
45. Kara B, Aytekin E, Çağlar NS, Doğan YP, Çağlar S, Aydemir K, et al. Neuromuscular electrical stimulation therapy effects on the functional and engine recovery of the upper extremity in patients after stroke: a randomized controlled trial. Istanbul Med J. 2021;22(3):202-7.
46. Gürbüz İZ, Akın S. Rehabilitative approaches to movement function in stroke patients. Health Sci Univ J Nurs. 2020;2(3):191-6.
47. Dittner AJ, Wessely SC, Brown RG. The assessment of fatigue: a practical guide for clinicians and researchers. J Psychosom Res. 2004;56(2):157-70.
48. Kwakkel G, Kollen BJ, van der Grond J, Prevo AJ. Probability of regaining dexterity in the flaccid upper limb: impact of severity of paresis and time since onset in acute stroke. Stroke. 2003;34(9):2181-6.
49. Corbetta D, Sirtori V, Moja L, Gatti R. Constraint-induced movement therapy in stroke patients: systematic review and meta-analysis. Eur J Phys Rehabil Med. 2010;46(4):537-44.

Turk J Clin Res. 2025;1(3):201-210
https://doi.org/10.63909/1453035

50. Ramachandran VS, Rogers-Ramachandran D, Cobb S. Touching the phantom limb. Nature. 1995;377(6549):489-90.
51. Yeldan I, Huseyinsinoglu BE, Akinci B, Tarakci E, Baybas S, Ozdincler AR. The effects of early mirror therapy on function improvement of the upper extremity in acute stroke patients. J Phys Ther Sci. 2015;27(11):3519-24.
52. Stevens JA, Stoykov ME. Using motor imagery in the rehabilitation of hemiparesis. Arch Phys Med Rehabil. 2003;84(7):1090-2.
53. Özdolap Ş, Sarıkaya S, Köktürk F, Fixed Assets NB. The effect of mirror therapy on motor recovery and function in upper extremity in stroke patients. West Black Sea Med J. 2018;2(2):173-81.
54. Langhorne P, Coupar F, Pollock A. Motor recovery after stroke: a systematic review. Lancet Neurol. 2009;8(8):741-54.
55. Viau A, Feldman AG, McFadyen BJ, Levin MF. Reaching in reality and virtual reality: a comparison of movement kinematics in healthy subjects and in adults with hemiparesis. J Neuroeng Rehabil. 2004;1:11.
56. Thelen E. Motor development: a new synthesis. Am Psychol. 1995;50(2):79-95.
57. Shadmehr R, Mussa-Ivaldi FA. Signal-dependent noise determines motor learning. Nature. 1998;394(6695):780-4.
58. Hesse S, Schmidt H, Werner C, Bardeleben A. Upper and lower extremity robotic devices for rehabilitation and for studying motor control. Curr Opin Neurol. 2003;16(6):705-10.
59. Demir SÖ. Robot-assisted walking training in patients with spinal cord injury. Turk J Phys Med Rehabil. 2015;61(Suppl):S37-S44.
60. Cao J, Xie SQ, Das R, Zhu GL. Control strategies for effective robot-assisted gait rehabilitation: the state of art and future prospects. Med Eng Phys. 2014;36(12):1555-66.
61. Schwartz I, Meiner Z. Robotic-assisted gait training in neurological patients: who may benefit? Ann Biomed Eng. 2015;43(5):1260-69.
62. Lee SY, Jeon YT, Kim BR, Han EY. Combined treatment of botulinum toxin and robot-assisted rehabilitation therapy on post-stroke upper limb spasticity: a case report. Medicine (Baltimore). 2017;96(51):e9391.
63. Sale P, Franceschini M, Mazzoleni S, Palma E, Agosti M, Posteraro F. Effects of upper limb robot-assisted therapy on motor recovery in subacute stroke patients. J Neuroeng Rehabil. 2014;11(1):1-8.
64. Cho KH, Hong MR, Song WK. Upper limb robotic rehabilitation for chronic stroke survivors: a single-group preliminary study. J Phys Ther Sci. 2018;30(4):580-3.
65. Mehrholz J, Thomas S, Werner C, Kugler J, Pohl M, Elsner B. Electromechanical-assisted training for walking after stroke. Cochrane Database Syst Rev. 2017;5:CD006185.
66. Lo K, Stephenson M, Lockwood C. Effectiveness of robotics-assisted rehabilitation for mobility and functional ability in adult stroke patients: a systematic review. JBI Database Syst Rev Implement Rep. 2017;15:3049-91.
67. Bruni MF, Melegari C, De Cola MC, Bramanti A, Bramanti P, Calabrò RS. What does best evidence tell us about robotic gait rehabilitation in stroke patients: a systematic review and meta-analysis. Clin Neurosci. 2018;48:11-7.
68. Dehem S, Gilliaux M, Stoquart G, Detrembleur C, Jacquemin G, Palumbo S, et al. Effectiveness of upper-limb robotic-assisted therapy in the early rehabilitation phase after stroke: a single-blind, randomised, controlled trial. Ann Phys Rehabil Med. 2019;62(5):313-20.
69. Carpinella I, Lencioni T, Bowman T, Bertoni R, Turolla A, Ferrarin M, et al. Effects of robot therapy on upper body kinematics and arm function in persons post stroke: a pilot randomized controlled trial. J Neuroeng Rehabil. 2020;17(1):10.