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Neuroprosthetics: The Future of Stoke Rehabilitation for Motor Function

By

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INTRODUCTION

A fulfilling life can be measured by the capability to perform daily tasks and an individual's function, ambulation, and independence. Cerebral vascular accident, commonly known as stroke, is the fifth leading cause of death and disability in the United States; however, up to 80% of strokes are preventable.[1] Most individuals have been exposed to the impact of stroke, whether it be firsthand or through friends, family, or acquaintances. For survivors and caregivers, the consequences of strokes are monumental physically, mentally, and emotionally. According to the National Institute of Health (NIH), about one in six over the age of 65 in America will experience a stroke.[2] The lasting outcomes after a stroke are dependent on the type of stroke and age of the affected individual. Although most stroke survivors regain their functional independence, 15-30% will live with a permanent physical disability.[2] The effects of stroke are life-changing; therefore, it is key to determine post-stroke rehabilitation for best outcomes.

Background

There are two main types of strokes: ischemic stroke and hemorrhagic stroke. An ischemic stroke occurs when a vessel supplying the brain becomes blocked by clots or plaque, which is often a build-up of cholesterol. The normal blood flow is disrupted when a vessel becomes occluded and ischemia occurs. Ischemia is a restriction of the blood supply to tissues that causes a lack of oxygen to the brain, resulting in damage. It can cause inflammation that may continue to cause damage for a prolonged period. This is the most common cause of stroke and accounts for about 80% of strokes.[2] A hemorrhagic stroke is caused by a vessel bleeding into brain tissue. This can occur from an aneurysm, a weakness or bulge in the vessel wall, or from loss of elasticity in the vessel, which causes the vessel to break and blood to be spilled out.[2]

Symptoms occur rapidly when an individual is having a stroke. The most common symptoms of stroke are sudden weakness on one side of the body, confusion, difficulty speaking, loss of balance, vision loss, and sudden onset of a severe headache. The specific symptoms depend on the site of the blockage or aneurysm in the brain's vascular system. Strokes usually affect one hemisphere of the brain and each hemisphere of the brain controls the opposite side of the body. Therefore, if a stroke occurs in the right hemisphere of the brain it will cause deficits on the left side and vice versa.[2]

Risk Factors

There are many risk factors for stroke. Risk factors for stroke include hypertension, age, gender, race, smoking, diabetes mellitus, hyperlipidemia, obesity, atrial fibrillation, coronary heart disease, sickle cell anemia, heavy drinking, drug use, and more.[1] Although people of all ages and demographics can have a stroke, some individuals are at higher risk. For example, African Americans have nearly double the risk of Caucasians of having a stroke, men are more likely to have a stoke than women, and about 75% of strokes occur in individuals over 65 years of age.[3] Due to the mechanism of strokes, most can be prevented with healthy diet, exercise, stress reduction, management of medical conditions, and not smoking.

Consequences of Stroke

While a stroke physically affects the brain, it can impact an individual's entire body and mind. Immediately after an ischemic stroke, the brain suffers from tissue damage that is often irreversible. During a hemorrhagic stroke, the accumulation of blood increases intracranial pressure causing damage to brain tissue. Strokes are extremely time-sensitive because they occur in an essential organ: the brain. The brain is a complex organ that controls bodily functions, thoughts, emotions, and actions. The sooner a stroke is diagnosed and managed, the more promising the outcome for the patient.

Acute stroke management includes dissolving or removing the clot that is causing ischemia or stopping the bleeding of a hemorrhagic stroke. The goal of stroke management is to prevent death, long-term damage, and disability. Common disabilities after stroke include paralysis, hemiplegia, pain, numbness, motor deficits, cognitive deficits, post-stroke depression, aphasia, and dysarthria. Strokes can cause issues with thinking, attention, awareness, judgement, and memory as well. These disabilities are life-changing and require immense adaptation for survivors, families, and caregivers.

Post-Stroke Depression

Depression is common after stroke due to chemical imbalances in the brain, along with loss of function and independence. Research shows that depression after stroke is correlated with suboptimal functional outcomes.[4] Depression management in post-stroke patients is important in order to obtain favorable outcomes in physical rehabilitation. Some risk factors that may exacerbate post-stroke depression include pre-stroke depression, limited social and family support, stroke severity, physical disability, and cognitive impairment. Treatment for depression may include cognitive-behavioral therapy, medications, meditation, and more.

Patient Limitations

The limitations caused by loss of motor function can have detrimental effects on patients and their families. Loss of function after a stroke may decrease quality of life by patient's losing the ability to perform activities of daily living (ADLs), such as lifting, walking, reaching, talking, grasping, and more. The loss of autonomy and capability of performing tasks causes some patients anxiety, depression, and an overall lower satisfaction of life. One possible intervention that has been researched and shown to be beneficial in stroke rehabilitation outcomes is the use of neuroprosthetics.

The Role of Neuroprosthetics in Stroke Rehabilitation

Neuroprosthetics are new and unique tools used to facilitate the rehabilitation of post-stroke patients. Some therapies may be used at home, which makes rehabilitation cost effective and convenient for the patient. Patients are more likely to utilize neurorehabilitation from home due to functional deficits, inability to drive, lack of social support, cost, and more. Studies show how neurorehabilitation using neuroprosthetics is practical, minimally invasive, and low-cost to patients. However, because these interventions are contemporary, compliance and long-term results are currently unknown. Therefore, in patients that suffered a stroke causing motor deficits, do neuroprosthetics increase quality of life, mental health, and motor learning?

Discussion

Studies show that neuroprosthetics, brain-computer interfaces (BCI), and functional electrical stimulation (FES) have the potential to advance outcomes in acute and chronic stroke survivors. BCI is a noninvasive technology that works directly with neuroprosthetics by gathering brain signals, analyzing them, and converting them into commands to carry out actions. This is achieved through electroencephalograms and is done with minimal risk to the patient. The goal of BCI is to restore function and independence in individuals who have neuromuscular disorders.[5] FES is a technology that has is used in rehabilitation to reinforce ascending neurological pathways by providing sensory feedback.[6] This is done by using low-intensity electrical pulses to artificially generate movements in a specific body part. The use of these technologies may provide a mechanism for motor function improvement in post-stroke rehabilitation. Neuroprosthetics have been shown to increase strength and range of motion in conjunction with physical rehabilitation.

Loss of upper extremity function after a stroke remains a massive rehabilitation challenge for patients and clinicians. Although research is limited on the effects of neuroprosthetics, BCI, and stroke patients, there are multiple studies that show the effectiveness and promise of this advanced neurorehabilitation. This is valuable to stroke survivors with neurological deficits because most survivors depend on others for ADLs due to weakness and loss of function. The hope and strive for improvement in motor function can lead to higher satisfaction in life and lower depression rates.

Research

Strokes occur every day leaving many survivors with long term disabilities. Due to shortcomings in the therapy for stroke survivors, studies on different rehabilitations have been conducted. The goal of research in neuroprosthetics is to explore ways that patient care, therapy and rehabilitation can be improved.

A study investigating 18 chronic stroke patients with severe and persistent upper extremity impairments and motor deficits showed an improvement in range of motion, movement velocity, and accuracy. The patients performed a self-paced, three-dimensional reach-to-grasp movement in virtual space with the use of a multi-joint exoskeleton in combination with neuromuscular stimulation on his or her paretic arm. In the end, the closed-loop style provided dependent feedback which led to motor and functional gain. Feedback is constructive for recovery and can ultimately lead to increase in function.[7] This means that patients will have improved ability to lift, grasp, and movement in their affected upper extremity.

Additionally, a 12-week, home-based feasibility study including ten chronic hemiparetic stroke survivors with moderate to severe upper-limb motor impairment evaluated the efficacy of a powered exoskeleton driven by a BCI. This study evaluated if motor-related disabilities could achieve functional recovery through a neuroprosthetic that opened and closed the patient's affected hand. The study assessed neural activity from the unaffected cortical hemisphere to evaluate if it affected the recovery in chronic hemiparetic stroke survivors. Motor function was evaluated before, during, and after each therapy session. Overall, the BCI-driven approach showed a statistically significant average increase in grasp strength and arm strength.[8] Therefore, there is evidence that chronic stroke patients have an opportunity and potential to improve motor function and strength through neurorehabilitation.

Another study analyzed the efficacy of upper arm exoskeletons, FES, and BCI in stroke rehabilitation. A group of five patients with neurological deficits used a hybrid of BCI and FES with an upper limb exoskeleton to perform tasks. The exoskeleton was used to counteract gravity and FES to promote elbow flexion and extension. BCI was used in two different methods to interact with the patient's brain activity: motor imagery and detection of intention of movement. Most patients were able to complete reaching movements using both methods of BCI, however two were unable to complete the task due to fatigue.[6] This shows that this therapy could be used for rehabilitation of the upper limbs after stroke.

Furthermore, a study explored the correlation between motor imagery (MI) and BCIs in addition to conventional rehabilitation in stroke recovery and motor function. This study included 28 hospitalized subacute stroke patients with severe motor deficits. The patients were separated into two randomized intervention groups: one month of BCI mirror imaging training and the control group of one month of mirror imaging training without BCI support. Functional and neurological examinations were performed before and after each intervention. This study showed a better functional outcome in the BCI group with a significantly higher probability of achieving a clinically relevant increase in the Fugl-Meyer Assessment score, which evaluates upper limb function. This intervention is low-cost, effective, and can be initiated soon after a stroke.[9]

A home-based, three-week, non-randomized case series including 29 chronic post-stroke survivors with upper extremity paresis analyzed the success of a neuroprosthetic hand device called the Handmaster. The main outcome measures included several ADLs lifting a two-handled pot, holding a bag while standing with a cane, and a patient-selected ADL. Secondary outcome measures included the ability to lift a 600-gram weight, grip strength, grasp, finger motion, and perceived pain scale. The prosthetic attached to a patient's hand and facilitated upper extremity movement and accuracy. Statistical analyses showed that patients were able to lift a pot, weight, and bag successfully. In addition, grip strength and active finger motion improved, and pain scores significantly decreased.[10]

Finally, a systemic review of 233 articles explored the advances in BCI, focusing specifically on upper limb motor recovery in stroke patients. The findings of the review show that patients benefit from post-stroke BCI training in addition to physical rehabilitation for recovery. Upper motor function was improved using neuroprosthetics and BCI training.[11] Consequently, it appears that the use of neuroprosthetics in stroke rehabilitation, whether acute or chronic, improves outcomes which can improve quality of life.

These studies analyze a multitude of different neuroprosthetics and approaches. Although different neuroprosthetics are used in diverse stroke patients, evidence shows that functionality and motor skills improve. Stroke recovery and rehabilitation can be transformed regardless of what type of neuroprosthetic is used, the type of stroke, and the amount of time after the stroke. The future of life after stroke relies on more research, long-term studies, and follow-up.

Conclusion

Overall, there is limited evidence that shows that neuroprosthetic intervention, BCI, and FES improve the long-term outcomes of chronic and acute stroke survivors. However, the studies completed had statistical evidence that showed progress toward improved upper limb strength and function. These interventions in combination with physical rehabilitation have the potential to facilitate a more fruitful recovery for patients. All studies acknowledged in the limitations that more research should be performed along with long-term follow-up. The studies completed so far have small sample sizes and limited funding, which is a considerable limitation.

As research becomes more pronounced and refined, patients and their families can look forward to advancements in rehabilitation and recovery.

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