International Journal of Aquatic Science
ISSN: 2008-8019
Vol 12, Issue 02, 2021

Robot-supported Treatments in Stroke Rehabilitation

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Abstract: Robotic rehabilitation treatment is advantageous for individuals with motor problems caused by stroke or spinal cord illness because it can offer high-dose and high-intensity training. Robotic devices used in motor rehabilitation are classified as end-effector and exoskeleton; this article discusses the therapeutic applications of both types. Neurologic rehabilitation attempts to alleviate impairments and limitations so that individuals who have had a severe stroke may resume regular self-care and everyday activities as independently as possible. New strategies for improving recovery are being developed in response to a growing understanding of how various types of training, the progressive task-related practice of skills, strength and fitness exercise, neurostimulation, and drug and biological manipulations can induce adaptations at multiple levels of the nervous system. Recent clinical trials have established the efficacy of various novel treatments for the management of walking, reach and grip, aphasia, visual field loss, and hemi-inattention.

Keywords: Stroke rehabilitation · Clinical trials · Robotics

1. INTRODUCTION

Stroke continues to be the most significant cause of long-term disability in the United States, accounting for $38 billion in annual costs. Around 650,000 people survive a new stroke each year, and 7 million Americans live with stroke-related problems [1]. Despite evidence that involvement in conventional rehabilitative therapy reduces impairment following stroke [2, 3], less than a third of stroke survivors get inpatient or outpatient care [3, 4]. Among individuals who do have access to treatments, the regularity with which they are used varies by geography and socioeconomic position. For these patients, rehabilitation options have dwindled as subacute stroke hospital stays have decreased to less than 16 days on average and as Medicare has limited outpatient therapy sessions to 15 per year [4]. In consequence, these program reductions may restrict rehabilitative gains and increase caregiver obligations. In contrast to these budgetary realities, the science of stroke therapy points to new approaches for improving results.

Advances in science using animal models have increased our understanding of the genetic, molecular, physiological, cellular, and behavioral adaptations that drive and may restrict function recovery [5]. Novel therapeutic approaches that target learning and memory processes, neurogenesis, and axonal regeneration, as well as neurotransmitters and growth factors, may aid the model's recovery process. Noninvasive techniques such as functional and structural magnetic resonance imaging (MRI) and neuronal excitatory and inhibitory stimulation tools such as transcranial magnetic stimulation (TMS) are being used to characterize changes in connectivity between brain regions following a stroke in patients [6]. Engineering and computer science are also being used to develop therapeutic techniques for patients. For example, wireless health and communication technologies have enabled the development of wearable sensors that can remotely monitor the quality and quantity of walking practice, smartphone apps that can be used to cue practice, and telerehabilitation programs that allow treatment in the home or community [7].

The number of properly powered, randomized control studies proving the efficacy of innovative interventions compared to established medicines has considerably surpassed the development of novel methods. Clinical trials can be complicated by patients' pathoanatomic and functional variability, the difficulty and cost of administering an intervention, and uncertainty about the best timing, dosage, and duration of therapy [8]. Additionally, outcome measurements in clinical trials are frequently proxy measures for patient performance rather than direct evaluations of the kinds, amount, and quality of physical functioning [9]. When assessing upper extremity usage, walking, exercise, and involvement in home and community activities [10], current measures may fall short of capturing clinically significant changes in physical or cognitive impairments, disability, or health-related quality of life and participation [11]. Despite these confounding variables, current studies give valuable information about behavioral, pharmaceutical, and neurostimulation therapies for stroke, as well as a near-future promise for biological interventions in the most severely impaired patients.

2. OVERVIEW OF CARE IN REHABILITATION

Patients are admitted to inpatient stroke rehabilitation when they cannot walk without significant human help and are reliant on other self-care activities but have sufficient memory, attention, and home support to be released without the requirement for skilled nursing placement [12]. In the United States, Medicare requires patients to endure at least three hours of therapist-directed therapy each day, often initiated between five to ten days of stroke onset. Internationally, the time interval from stroke onset and rehab admission is 1-6 weeks, and the duration of inpatient treatment is 3-8 weeks but is longer in Japan, which has a more extensive post-stroke care system [13]. The goals of inpatient therapy may include increased independence in self-care activities (e.g., feeding, grooming, bowel and bladder care); ability to perform safe toilet and wheelchair transfers; walking with or without assistive devices such as canes and orthoses that brace the ankle and help control the knee; improved receptive and expressive language skills; and improved executive, visuomotor, and cognitive abilities. Patients engage with therapists in the outpatient setting to improve and develop these abilities to increase their functional independence in the home and community [14]. Throughout rehabilitation, physical, occupational, and speech therapists enable patients to practice essential tasks, set and update realistic goals within the constraints of residual reflexive and voluntary neural control and instill a daily skills practice regimen of increasing intensity and difficulty. Additionally, therapists may employ neuromuscular facilitation strategies to begin guiding the re-acquisition of motor abilities before progressing to more complicated movements that constitute goal-directed behaviors [15].

3. PRINCIPLES UNDERLYING REHABILITATIVE THERAPIES

Two fundamental concepts impact how patients are treated. The first is that the adult central nervous system is adaptable, or plastic, and capable of reorganizing itself to regain impaired

cognitive and motor skills. Animal studies have identified genetic and metabolic mechanisms involved in forming new anatomic connections and rearranging functional networks (e.g., axonal sprouting, dendritic proliferation, and neurogenesis) [16]. Changes in brain activity patterns observed in patients using MRI and other non-invasive imaging methods show regional plasticity of the neuronal ensembles that encode actions and ideas. These changes occur over time and are related to learning and experience and behavioral adaptations to compensate for the loss of pre-stroke neuronal control. Thus, just like in healthy individuals, the brains of stroke victims undergo continuous morphological and physiological changes due to motor learning.
The second tenet is that gradual, competent motor exercise is required for sustained improvement at any point after stroke onset. To be effective, training must engage the brain's attention, motivation, and learning networks. Additionally, improved benefits need a greater degree of sparing in the neural networks that reflect the components of behavior. Although observational studies indicate that peak functional improvements occur three months after commencement, these studies do not take into consideration additional changes associated with frequent exercises, such as increased walking speed and distance or increased coordination when using an afflicted hand [17]. Extensive randomized controlled studies in neurologic rehabilitation have demonstrated that 2-12 weeks of competent motor practice can result in long-lasting functional gains in individuals who were weeks to years post-onset of hemiparesis [18-20]. Thus, beginning with early rehabilitation, clinicians should establish a routine of daily repeated skill practice in their patients that may be carried over to the outpatient environment and everyday activities.

4. MOBILITY INTERVENTIONS

a. Muscle Strength And Fitness

Clinicians should prioritize strategies for stroke survivors to improve their overall fitness and muscular strength in both affected and unaffected limbs. Pre-morbid deconditioning due to sedentary behavior exacerbates the inactivity associated with new neurologic impairment [21]. Indeed, stroke patients take half as many steps, use their afflicted arm much less, and have significantly longer daily inactive times than healthy age-matched individuals [22-24]. Additionally, due to central weakness, inactivity, and muscular atrophy, it becomes more difficult for the hemiparetic individual to get an aerobic benefit from exercise [25]. This is concerning because secondary stroke prevention recommendations involve a half-hour of moderate-intensity exercise daily [26]. Additionally, increased physical activity is connected with increased neurogenesis, improved performance on cognitive tests, decreased age-related hippocampal shrinkage, and a decreased chance of developing vascular dementia [27, 28].

Standard rehabilitative therapy includes isometric and isokinetic muscle strengthening to increase the strength and endurance of damaged and unaffected muscle groups. For the majority of patients, sets of moderate resistance training with weights or elastic bands are possible. Simply standing and sitting five to ten times during television advertisements can demonstrate proximal leg strength. Aerobic exercise training can condition the body and enhance walking speed and endurance, whether on a treadmill, while walking overground, or when recumbent cycling [29]. The most striking effects of aerobic exercise training have been observed in chronic stroke patients who have regained adequate motor function to engage in moderate- to vigorous-intensity physical activity [30]. However, issues remain regarding the most effective methods for providing and reinforcing aerobic activity, such as a support group

[31] and ensuring exercise compliance [32]. In addition to more formal exercise, physicians should urge more frequent daily walks over greater distances and at higher rates.

b. Walking And Balance Training On The Ground

Over-ground gait training is a critical component of conventional physical therapy for improving dynamic balance and ensuring safe home ambulation. The parallel bars provide a controlled setting for patients to develop trunk and head control, sit-to-stand balance and eventually walking. Over-ground training focuses on clearing the paretic foot to begin leg swing, knee stability, and stepping with a more rhythmic, safe gait pattern, if necessary with the use of an assistive device or orthotic. A Cochrane study discovered a favorable association between the quantity of over-ground training and slight increases in gait speed without a substantial increase in adverse events such as falls [33]. Falls are a frequent complication of stroke recovery, with a rate of over 40% for more than one fall in the first year [34]. Including a series of balancing and truncal exercises to inpatient treatments [35] or as part of an outpatient telerehabilitation intervention [36] may prove to be a cost-effective strategy for preventing future impairment.

c. Treadmill Training Using Body Weight

Body weight-supported treadmill training (BWSTT) provides supervised, repeated practice of walking for task-related purposes. Patients with poor motor control are fitted with a chest harness attached to an overhead hoist to avoid fully loading a paretic limb. The treadmill promotes rhythmic striding. However, therapists are frequently required to aid with the paretic leg and trunk. BWSTT was expected to enhance practice while permitting more normalized sensory inputs to better drive motor output for stepping, based on animal research. However, the Locomotor Experience Applied Post Stroke (LEAPS) study failed to demonstrate any extra therapeutic effect of BWSTT compared to a similar intensity and duration home exercise program [20]. Although previously considered as a promising solution for impaired walkers, BWSTT may not accurately replicate the task-related environment of over-ground motor learning training [37]. Due to the high expense of equipment and skill required to administer BWSTT, it is an intervention that should be considered only for patients who have some motor control but are not progressing with rigorous over-ground training.

d. Gait Assist Robots

Electromechanical assistance technologies, such as robotic steppers and exoskeletons, guide patients' lower limbs entirely or partially through the gait cycle stages [38]. In comparison to BWSTT, these devices can deliver automatic gait training on a treadmill or elliptical-like device without the need for therapist monitoring. To present, the devices have not consistently resulted in more significant overall increases in over-ground walking metrics than more conventional physical treatment at the same intensity [39]. In addition, robotic devices are being developed to assist patients in developing motor skills by allowing them to make kinematic mistakes during practice. Wearable, lightweight, motorized exoskeletons have recently been available that aid with hip or knee flexion and weight-bearing when stepping overground. Although costly, they may permit delayed ambulation in situations where it would be impossible otherwise; controlled research will be necessary to establish whether their usage may supplement traditional rehabilitation practices. Seven randomized controlled trials that compared robot assisted therapy that uses end-effector devices with conven- tional therapies for improving gait function after stroke were selected for review.

Authors	Robotic device	Number of participants	Stroke stage	Intensity	Concomitant therapy	Summary of results in comparison with conventional therapies
End-effector-type devices						
Werner et al., 2002	Gait trainer	30	Subacute	20 minutes, 5 times per week for 4 weeks	No	No difference
Peurala et al., 2005	Gait trainer	45	Chronic	20 minutes, 5 times per week for 3 weeks	No	No difference
Tong et al., 2006	Gait trainer	54	Subacute	20 minutes, 5 times per week for 4 weeks	Yes	More effective
Dias et al., 2007	Gait trainer	40	Chronic	40 minutes, 5 times per week for 4 weeks	No	No difference
Pohl et al., 2007	Gait trainer	155	Subacute	20 minutes, 5 times per week for 4 weeks	No	More effective
Peurala et al., 2009	Gait trainer	56	Subacute	20 minutes, 5 times per week for 3 weeks	Yes	More effective
Morone et al., 2011	Gait trainer	48	Subacute	20 minutes, 5 times per week for 4 weeks	No	More effective
Exoskeleton devices						
Mayr et al., 2007	Lokomat	16	Subacute	30 minutes, 5 times per week for 4.5 weeks	No	More effective
Husemann et al., 2007	Lokomat	32	Subacute	30 minutes, 5 times per week for 4 weeks	Yes	More effective
Hornby et al., 2008	Lokomat	62	Chronic	30 minutes, 12 sessions total	No	Less effective
Jung et al., 2008	Lokomat	25	Chronic	30 minutes, 3 times per week for 4 weeks	Yes	More effective
Hidler et al., 2009	Lokomat	72	Subacute	1 hour, 12 sessions total	No	Less effective
Westlake & Patten, 2009	Lokomat	16	Chronic	30 minutes, 3 times per week for 4 weeks	Yes	More effective
Schwartz et al., 2010	Lokomat	67	Subacute	30 minutes, 3 times per week for 6 weeks	Yes	More effective
Chang et al., 2012	Lokomat	37	Subacute	40 minutes, 5 times per week for 2 weeks	Yes	No difference

Table 1. Robot-assisted therapy for gait function

Figure 1: Examples of robotic devices for motor training

e. Electrical Stimulation With A Purpose

FES is a method that uses peripheral nerves and muscles that remain untouched by central nervous system injury. Electrical stimulation is used to cause certain muscle groups to contract and relax. For example, when the common peroneal nerve is stimulated externally, dorsiflexion of the ankle occurs to help with paretic foot clearance. External [40] and implanted [41] electrodes have improved gait for at least six months following the operation. While numerous commercial devices are available in the United States, attempts to demonstrate their potential cost-effectiveness have recently begun [42].

5. CONCLUSION

The majority of stroke survivors are left with persistent impairments. Rehabilitation efforts should optimize patients' physical, communicative, and cognitive performance within the first three to six months following stroke. Consistent, incremental skill practice of goal-directed tasks in the home can result in continued improvement during the chronic period after stroke [12]. Numerous new rehabilitation techniques, founded on using technology advancements to magnify the benefits of the practice, provide novel pathways for amplifying performance improvements at any point following stroke. Stroke rehabilitation's future remains both promising and challenging in addressing residual impairments, particularly in terms of trying biological treatments for brain repair in the most severely afflicted patients.

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