MEDS Clinical Medicine (2024)
Clausius Scientific Press, Canada

DOI: 10.23977/medsc.2024.050522
ISSN 2616-1907 Vol. 5 Num. 5

A Literature Review on the Application of Limb Rehabilitation Techniques for Stroke Patients

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Keywords: Stroke; Patients; Rehabilitation techniques; Physical training

Abstract: Stroke is a leading cause of disability, and post-stroke rehabilitation is critical for restoring physical function. Elderly patients, due to age-related decline, impaired immune function, chronic comorbidities, and polypharmacy, often require additional support through specialized rehabilitation techniques. This review outlines commonly used limb rehabilitation techniques for stroke patients, evaluating their advantages and limitations. Recommendations are provided to enhance rehabilitation training for stroke patients and to offer evidence-based guidance for clinical practice.

1. Introduction

Stroke, also known as cerebrovascular accident, is an acute condition caused by brain tissue damage. In China, the prevalence, incidence, and mortality rates of stroke among adults aged 40 and above in 2020 were approximately 2.6%, 0.505%, and 0.343%, respectively, posing a significant challenge to the healthcare system [1]. Between 55% and 75% of stroke survivors experience varying degrees of motor impairment, with up to 80% suffering from balance and gait disturbances [2]. The incidence of stroke increases with age, particularly among elderly patients with comorbidities such as hypertension and diabetes, leading to higher rates of disability and mortality [3].

Rehabilitation, which includes physical and occupational therapies, is crucial for restoring motor function, accelerating recovery, and reducing long-term care costs [4]. Stroke severely affects patients' motor abilities, such as knee hyperextension and spastic paralysis, limiting their activities of daily living [5]. Common abnormal movement patterns include upper limb claw hand and lower limb circumduction gait [6]. Effective rehabilitation is essential to reduce limb disability, improve quality of life, and lessen the socioeconomic burden [7]. This review aims to explore the current advancements in limb rehabilitation techniques for stroke patients, providing evidence-based recommendations for optimizing rehabilitation care.

Stroke rehabilitation techniques are based on neurophysiological and developmental principles, promoting recovery of central nervous system functions through repetitive movements and training. Limb rehabilitation post-stroke is a staged process where muscle tone progresses from flaccidity to spasticity, and motor function improves from synergies to isolated and coordinated movements. Periodic assessments help provide targeted and specialized rehabilitation care, preventing irreversible limb damage [8]. Limb rehabilitation training is effective in restoring hemiplegic limb function [9], enhancing motor ability, improving joint range of motion, balance, and coordination, and promoting neurological recovery [10]. In addition to restoring physical function, these techniques enhance social skills and quality of life, positively contributing to patients' overall well-being and social participation [9].

2. Application of physical rehabilitation techniques in stroke patient

2.1. Hydrotherapy

2.1.1. Classification and Mechanisms of Hydrotherapy in Rehabilitation

Hydrotherapy techniques can be broadly categorized into three methods: shower therapy, immersion therapy, and aquatic exercise therapy. Shower therapy involves directing water at a specified pressure and temperature onto the body, either over the whole body or localized areas, using a showerhead or nozzle. Immersion therapy refers to the treatment of the whole body or specific areas by submerging the patient in water at a controlled temperature. Aquatic exercise therapy encompasses various exercises performed in water to alleviate pain or enhance physical function. These include general aquatic exercises (e.g., aquatic strength training, range of motion exercises, balance training, and water walking), aquatic aerobic training, aquatic Tai Chi, aquatic yoga, specialized hydrotherapy techniques, and therapeutic swimming [11].

Hydrotherapy mainly works through the physical properties of water, such as density, specific gravity, hydrostatic pressure, buoyancy, viscosity, and fluid dynamics, to target muscles and joints, promoting muscle relaxation and reducing spasms [12]. Buoyancy provides a weight-relief environment, aiding movement and reducing stress on the body. Hydrostatic pressure strengthens the respiratory muscles by applying pressure to the thorax, improving cardiopulmonary endurance. The viscosity of water provides resistance, cushioning movements and enhancing the safety of rehabilitation exercises by minimizing injury risk.

2.1.2. Efficacy of Hydrotherapy in Limb Rehabilitation for Stroke Patients

Hydrotherapy is rapidly advancing in China and holds a significant place in modern rehabilitation medicine. Studies suggest that hydrotherapy strengthens paralyzed muscles, improves muscle tone, and enhances walking and balance abilities in stroke patients [13]. A systematic review found that hydrotherapy positively affects gait, balance, spasticity, and other physiological indicators in stroke patients, as well as improves emotional well-being and quality of life. The effectiveness of hydrotherapy can vary depending on the specific techniques used. For example, compared to land-based interventions, water-based therapies have demonstrated superior outcomes in balance, walking ability, muscle strength, proprioception, health-related quality of life, physiological metrics, and cardiopulmonary fitness. However, the use of aquatic treadmills showed less favorable results compared to standardized hydrotherapy techniques (e.g., Halliwick, Ai Chi, Watsu, and Bad Ragaz Ring methods) and other underwater treatments like aquatic walking, balance training, strengthening, and stretching exercises [14]. Despite strong evidence supporting the efficacy of hydrotherapy in limb rehabilitation, there is a notable shortage of qualified professionals, resulting in inconsistent practitioner quality. This underscores the need to establish standardized education and training systems for professional hydrotherapists [15].

2.2. Non-invasive Brain Stimulation Therapy

2.2.1. Classification and Mechanisms of Non-invasive Brain Stimulation Therapy

Non-invasive brain stimulation (NIBS) includes repetitive transcranial magnetic stimulation (rTMS) and transcranial direct current stimulation (tDCS). rTMS works through electromagnetic induction, detecting cortical circuits and inducing excitability changes in cortical neurons, thus regulating neural plasticity and cortical excitability [16]. tDCS involves the application of low-intensity, constant direct current to the cerebral cortex, modulating cortical excitability, enhancing synaptic plasticity, balancing interhemispheric activity, and improving cerebral blood flow to optimize brain function [17]. NIBS has been shown to significantly improve neurological function, as well as motor and sensory recovery in elderly stroke patients. rTMS is painless, offers high spatial and temporal resolution, and can be applied while patients are awake. However, it requires large and expensive equipment (e.g., magnetic stimulators or electrical stimulators). tDCS, on the other hand, is simpler to administer, utilizing two electrodes placed on the scalp to deliver weak direct current. Anodal stimulation increases cortical excitability, while cathodal stimulation decreases it. tDCS is easier to integrate into behavioral tasks or during physical or occupational therapy sessions due to its compact equipment requirements [18].

2.2.2. Efficacy of Non-invasive Brain Stimulation Therapy in Stroke Rehabilitation

A systematic review [19] reported that rTMS treatment in stroke patients enhances excitability in the affected hemisphere and reduces hyperactivity in the unaffected hemisphere, effectively improving balance. Other studies have shown that tDCS aids in improving motor function and movement quality, accelerating upper limb recovery, and enhancing daily living activities in stroke patients [20]. Among the stimulation approaches, bilateral tDCS has been found to be the least effective, while cathodal tDCS has demonstrated superior results in improving upper limb function and daily activities, making it the preferred choice [21]. However, some studies have found that tDCS does not significantly improve motor, emotional, or cognitive outcomes in stroke patients undergoing motor and cognitive rehabilitation. Furthermore, no randomized controlled trials have demonstrated that tDCS during motor rehabilitation is more effective than tDCS applied during rest. Given the lack of long-term data on tDCS outcomes, these findings should be interpreted with caution. Nonetheless, they provide important directions for future research [22].

2.3. Virtual Reality Therapy

2.3.1. Classification and Mechanisms of Virtual Reality Therapy

Virtual reality (VR) therapy provides patients with a realistic virtual experience through devices such as haptic feedback systems, large screens, head-mounted displays, and motion controllers. It is categorized into immersive and non-immersive virtual reality therapy. Immersive VR uses various interactive devices to create a controlled virtual environment, engaging the patient's visual, auditory, and sensory systems, allowing them to perform therapeutic tasks within the simulated space. Non-immersive VR therapy, on the other hand, provides an encouraging environment with external feedback or gamified scenarios to promote recovery, particularly in upper limb rehabilitation post-stroke [23]. Overall, VR therapy offers users an experience akin to interacting with real-world environments, providing stroke patients with realistic motor-sensory and contextual training that enhances engagement and interest, thereby facilitating rehabilitation.

2.3.2. Efficacy of Virtual Reality Therapy in Stroke Rehabilitation

Fully immersive VR has been shown to reduce upper limb complications, enhance cognitive abilities, and promote recovery of upper limb function and daily living skills in stroke patients [24]. It also motivates patients by increasing their confidence and willingness to participate in rehabilitation, thereby improving their self-efficacy [24]. Non-immersive VR therapy has been found to improve balance and gait performance, helping stroke patients maintain a more natural gait pattern and enhancing functional mobility [25]. Medium to large effect sizes in VR interventions are particularly beneficial for improving motor abilities, especially upper limb function and balance. VR gaming technologies, such as the Wii, have demonstrated potential in promoting motor recovery and rehabilitation after stroke, offering hope for improved motor function and quality of life [26]. However, the optimal frequency, intensity, and evaluation standards for virtual reality-based lower limb rehabilitation remain unclear. Future research should focus on integrating traditional rehabilitation methods with innovative VR systems based on the principles of "individualization, adaptability, safety, effectiveness, and feasibility" to continuously improve functional recovery.

2.4. Robotic Rehabilitation Therapy

2.4.1. Classification and Mechanisms of Robotic Rehabilitation Technology

Robotic rehabilitation stimulates and rebuilds the neural pathways that control limb movements through repetitive motion, helping stroke patients establish correct sensory-motor circuits. Rehabilitation robots are generally classified into two types: those with rigid structural designs, such as Lokomat, Rewalk, Ekso, and HAL; and those with flexible structural designs, such as Myosuit exoskeleton, XoSoft, and PVC-exoskeletons [27]. Exoskeleton robots can also be categorized based on training modalities: treadmill-based exoskeletons and overground walking exoskeletons. These robots provide patients with task-specific, high-intensity training, improving lower limb strength and motor coordination. Lower limb exoskeletons are designed based on motor relearning theory, facilitating progressive, active, and repetitive movements that induce neuroplastic changes in the nervous system through motor control and learning. Flexible robots, made from textiles and pneumatic muscles, offer a more comfortable and safer wearable experience [28].

2.4.2. Efficacy of Robotic Rehabilitation in Stroke Recovery

Robotic therapy assists healthcare providers in managing patients more effectively by providing precise diagnostic data and facilitating the development of specialized rehabilitation programs, significantly improving clinical outcomes [29]. Exoskeleton robots enhance walking ability, correct abnormal gait, improve balance, and reduce spasticity in the lower limbs while improving cardiopulmonary function in stroke patients. Compared to conventional rehabilitation techniques (e.g., Rood, Bobath, Brunnstrom, and PNF methods), multi-position intelligent rehabilitation robots have shown higher recovery rates in stroke patients with hemiplegia [30]. However, studies have also indicated potential risks associated with wearable exoskeletons, such as falls and mechanical injuries like skin abrasions. Additionally, the high cost and technological complexity of robotic systems pose challenges to their widespread adoption globally.

2.5. Music Therapy

2.5.1. Classification and Mechanisms of Music Therapy

Music therapy leverages unique physiological and psychological effects to influence brain waves and the neuroplasticity process. It can be classified into passive and active interventions. Passive intervention involves listening to music under the guidance of a skilled therapist, aimed at relaxing tense and spastic muscles in patients [31]. Active intervention, on the other hand, involves creating music, such as playing instruments, where patients engage both physically and mentally without the need for formal musical training. Simple rhythm exercises using instruments can enhance motor skills, cognitive function, and memory through song discussions, music recall, and rhythm-based activities [32]. However, there is a lack of studies investigating the specific effects of music therapy on different brain regions. Advanced neuroimaging techniques such as functional MRI, near-infrared spectroscopy, and electroencephalography are needed to explore the impact of music therapy on brain function.

2.5.2. Efficacy of Music Therapy in Stroke Rehabilitation

Music therapy has demonstrated positive effects in improving upper limb motor parameters, such as movement time, speed, and smoothness, which contribute to better motor coordination and efficiency [33]. Combining music therapy with mirror therapy has been shown to significantly enhance upper limb motor function, self-care abilities, and muscle tone, while increasing excitability in damaged brain regions. Some studies have found no significant difference in motor outcomes between music-supported therapy and traditional rehabilitation (e.g., passive exercises, stretching, progressive resistance training) when training duration is matched, suggesting that music therapy may offer equivalent benefits to conventional approaches. Music therapy also enhances patient adherence and motivation, making it a valuable tool in clinical rehabilitation [34].

2.6. Traditional Chinese Medicine (TCM) Therapy

2.6.1. Classification and Mechanisms of TCM Therapy

TCM therapy employs traditional Chinese medical theories, following a holistic approach to balance the body's qi and blood circulation, aiming to enhance motor function. Techniques include acupuncture, moxibustion, herbal decoctions, massage, and exercises like Tai Chi. Acupuncture stimulates specific acupoints to regulate meridian pathways, improve blood circulation, and restore physiological function by modulating neurotransmitter expression and correcting free radical metabolism. Herbal compresses and fumigation use the combined effects of heat and medicinal properties to promote local blood circulation. Tai Chi focuses on stabilizing movements and controlling breathing, improving limb strength, coordination, and balance [35]. Early TCM rehabilitation protocols can reduce complications, promote motor recovery, and improve speech and neurological function, thereby enhancing overall patient quality of life.

2.6.2. Efficacy of TCM in Stroke Rehabilitation

Early rehabilitation combined with TCM can improve neurological function, motor recovery, and activities of daily living, offering enhanced recovery for stroke patients with hemiplegia. Studies have shown that Tai Chi improves daily functioning, motor skills, balance, and walking ability in stroke survivors [35,36]. TCM-directed therapy combined with rehabilitation, including exercises like strength training, static-dynamic balance training, and task-oriented activities (e.g., towel tasks, single-hand activities), reduces disability rates and enhances quality of life. Moxibustion at key points, such as acupoints on the limbs and tender points on tendons, effectively reduces muscle spasms and improves strength. TCM moxibustion, combined with physical therapy (e.g., guiding patients to stretch their limbs and perform active tasks), significantly improves limb function and patient quality of life [37].

2.7. Other Limb Rehabilitation Techniques

2.7.1. Neuromuscular Electrical Stimulation (NMES)

NMES combines biofeedback with electrical stimulation to enhance motor function in stroke patients. Electrodes are placed on the wrist extensor muscles of the affected side to measure electromyographic (EMG) signals and deliver electrical stimuli to the muscles. The process involves analyzing EMG signals, determining threshold values, and providing stimulation based on voluntary muscle contraction. Patients can visually observe muscle contractions during treatment, enhancing their engagement and motivation [38]. NMES has been shown to improve upper limb somatosensory evoked potentials (SEP), motor function, and daily living abilities, reducing neurological deficits in stroke patients [39].

2.7.2. Constraint-Induced Movement Therapy (CIMT)

CIMT is based on intensive repetitive training, where the unaffected limb is restricted to force the use of the affected limb, promoting neuroplasticity and improving sensory-motor function. While effective, CIMT requires careful coordination and balance training to prevent complications such as joint contractures or disuse atrophy, which can result from patients avoiding the use of the affected limb even after recovery. CIMT is particularly effective when combined with NMES, where the former enhances motor function and the latter promotes muscle contraction, offering synergistic benefits for limb recovery [40]. However, CIMT is not suitable for patients with high muscle tone during the acute phase of stroke, as forced use of the affected limb may cause irreversible damage [41]. There is a need for standardized guidelines to ensure the reliable and stable application of CIMT in clinical settings.

2.7.3. Core Stability Training

Many rehabilitation exercises focus on superficial muscles, neglecting deep core muscles around the trunk, pelvis, and hips. Core stability training targets these deep muscles, improving coordination, strength, and control of the core muscle groups, such as the rectus abdominis, leading to enhanced motor function and quicker recovery [2]. NMES combined with core stability training can significantly improve neurological deficits, motor function, and overall prognosis in stroke patients [40]. Virtual reality (VR) technology, when combined with core stability training, has been shown to further improve balance, lower limb function, walking ability, and daily activities [42]. Research suggests that core stability training is highly effective in enhancing balance and walking function in stroke patients and should be prioritized in rehabilitation programs [2].

3. Challenges and Sustainable Strategies in Linb Rehabilitation for Stroke Patents

The application of current post-stroke limb rehabilitation technologies faces challenges related to workforce, funding, technology, and management: i) A shortage of specialized rehabilitation professionals persists, with nurses primarily working under the guidance of physicians and rehabilitation therapists. ii) Limb rehabilitation requires substantial financial support for equipment procurement, maintenance, and the training of rehabilitation therapists or specialized nurses. iii) Rehabilitation during the stroke recovery phase predominantly relies on conventional Western medical approaches, such as dietary guidance and functional exercises, which, while beneficial, yield limited overall outcomes. iv) Some technologies, like rehabilitation robots, remain at the research stage with low clinical application and adoption rates. v) Many stroke patients are discharged following neurological treatment and undertake home-based rehabilitation without professional guidance. Key factors affecting recovery include the accuracy of exercises, the duration and intensity of rehabilitation, patient safety, and adherence to daily rehabilitation routines. vi) Limited availability of long-term outcomes or large-scale, multicenter data necessitates cautious interpretation and application of research findings.

4. Sustainable Strategies for Limb Rehabilitation in Stroke Patientss

Stroke rehabilitation plays a critical role in reducing disability rates and improving patients' quality of life. In the future, this field will become increasingly multidisciplinary, yet creating individualized rehabilitation plans remains a challenge. The following strategies warrant attention: i) Strengthen the training of specialized nurses and optimize the allocation of medical resources, especially in settings with high patient volumes and limited rehabilitation professionals. ii) Enhance support for rehabilitation institutions, regulate private rehabilitation facilities, promote resource sharing, and develop optimal rehabilitation plans. iii) Integrate traditional Chinese and Western medicine to reduce costs and improve efficacy. iv) Foster collaboration between medical education institutions and industry to develop rehabilitation products tailored to clinical needs. v) Utilize follow-ups and social media platforms to continuously monitor patients' rehabilitation progress and encourage adherence to home-based training. vi) Conduct comprehensive evaluations to select the most suitable rehabilitation methods for patients and expand remote tracking to validate long-term outcomes.

This article reviews the current status of limb rehabilitation techniques for stroke patients, including their classifications, mechanisms of action, and therapeutic effects. While each technique has its advantages, limitations such as small sample sizes, unclear mechanisms, and conflicting research results remain. Further validation is needed to establish their rationality. Healthcare professionals should design individualized rehabilitation plans based on patients' specific conditions to maximize functional recovery.

Acknowledgements

Funding: This study was supported by the Hunan Provincial Health Commission Scientific Research Plan Project (grant no. 202214055133).

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