Current Technical Study on Functional Electrical Simulation for Stroke Patients

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Abstract. Stroke is a disease caused by sudden rupture or blockage of cerebral blood vessels, resulting in damage to brain tissue. And it has become a high fatality rate disease. Safe and effective treatments are urgently needed. FES can improve upper and lower limb movement and increase mobility in stroke patients, which is an effective physical therapy to stimulate the recovery of muscle activity. FES releases low-frequency pulses through surface or subcutaneous electrodes to stimulate the contraction of the target muscle to generate movement and reestablish the connection of motor pathways. FES treatment alone is no longer sufficient. Based on 8 studies in the last 5 years, the therapeutic effects of transcranial direct current stimulation and VR combined with functional electrical simulation were reviewed. Both combinations have achieved quite satisfactory therapeutic effects, but the therapeutic effect of VR still needs further research, and more combinations of treatment programs are more worthy of expectation.

Keywords: Brain-computer interface; functional electrical simulation; stroke; transcranial direct current stimulation; VR.

1. Introduction

In the 21st century, people have made progress in many fields such as artificial intelligence and quantum computing. At the same time, medical treatment developing fast, human living standards and life expectancy are also constantly improving. People can survive and recover from all kinds of diseases and accidents, but even as survival rates increase, so do disability rates, because many diseases and accidents are often serious and fatal, and the current medical means are not yet able to fully recover patients. Stroke is a cerebrovascular disease characterized by sudden fainting, lopsided speech, hemiplegia and poor speech. According to data from the 2019 Global Burden of Disease Report, stroke is the top cause of disability or loss of life for people over the age of 50 [1]. In China, the number of stroke patients was over 17.8 million in 2022 [2]. With the decline of fertility rate and the accelerated progress of aging society, the incidence and mortality of stroke in China have risen sharply [3], which has become one of the problems that society needs to face. In stroke, many patients may have sequelae, and only some patients will fully recover. According to statistics, only 20% of stroke patients will fully recover, 70% will become disabled, including 40% of severe disability and 10% of bed rest [4]. Recovering from a stroke is often a lifelong process, which takes a heavy toll not only on the individual, but also on his entire family, impacting their life. Therefore, so as to make stroke families can enjoy life better, a safe, convenient, non-invasive rehabilitation treatment program is particularly important. This can make a big improvement in their quality of life.

Functional electrical stimulation (FES) is a type of neuromuscular electrical stimulation (NES). It employs an intense low-frequency pulse current. To cause muscular movement, generate muscle contractions, or mimic naturally occurring movement in order to stimulate one or more groups of muscles with the goal of enhancing or regaining muscle group function [5]. FES can increase muscle strength, improve joint range of motion or reduce spasticity, and increase proprioception and trunk control to maintain a stable posture [6]. However, medical technology is advancing rapidly and many new types of treatments are being developed, and this is also true for FES. FES treatment alone has been shown to be very good, but the effect of rehabilitation in combination with other treatment

options is still being studied. Therefore, this study will be combined with the recent 5 years of FES-related research reports to discuss the technical status and development of FES.

2. Transcranial direct current stimulation

A continuous, weak direct current (1-2 mA) is used in transcranial direct current stimulation (tDCS) to control neuronal activity in the cerebral cortex. The technique tDCS involves inserting electrodes through the scalp to deliver current into particular brain regions. Depending on the polarity of the input current, the intracranial current will either increase or decrease the excitability of neurons, which can result in changes in brain function that can be used to study or treat diseases. [7]. This is another effective rehabilitation protocol for stroke. A double-blind trial [8] selects 75 stroke patients. By selecting a random number table, 38 patients were assigned to the stimulation group as the observation group and 37 patients were assigned to the non-stimulation group as the control group. The healthy group received clinical observation only. Both groups of patients received a comprehensive rehabilitation training program in the experiment, and the training was completed by the supervisor therapist. In the control group, false stimulation was applied only within 60 s after the start and end of tDCS stimulation. The current intensity increased from 0 mA to 2 mA and then dropped back to 0 mA. The observation group received tDCS stimulation therapy, the current intensity was set to 2 mA, each treatment was 20 min, 5 times a week treatment. Both groups were treated for 4 weeks. Montreal Cognitive Assessment Scale (MoCA), Stroop color word test (SCWT), connection test (TMT) and Wisconsin Card Test System (WCST) were used to evaluate the executive function of the two groups of patients. And the result of SCWT is shown in Table 1. It can be seen from the data that the observation group is better than the control group in various indicators. tDCS can affects cerebral blood flow velocity and cerebrovascular reactivity, resulting in faster cerebral blood flow velocity and higher oxygen saturation of cerebral blood, thereby improving the overall functional activity state of the brain and promoting functional recovery of stroke patients.

Table 1. Comparison of correct SCWT number and time before, 2 weeks after and 4 weeks after treatment between control group and observation group (x ± s)

Group	n	Correct number			Time (s)		
		pre-treatment	after 2 weeks	after 4 weeks	pre-treatment	after 2 weeks	after 4 weeks
Control group	35	38.22±3.18	39.96±3.22a	41.85±3.36ab	111.48±11.67	102.53±10.11a	94.85±9.89ab
Observation group	35	38.64±3.02	43.35±3.25a	45.67±3.42ab	110.34±10.24	91.36±9.33a	83.35±9.13ab
t-value		0.567	4.384	4.714	0.434	34.803	5.055
P-value		0.573	0.000	0.000	0.665	0.000	0.000

According to [9], tDCS can make a great lasting effect on the regulation of the excitatory properties of the cerebral cortex. In a placebo-controlled trial designed to promote upper limb movement recovery in approximately 1000 stroke subjects. Low-frequency repetitive stimulation (rTMS) tries to diminish excitability of the contralateral ipsilateral cortex while high-frequency repetitive stimulation (rTMS) (> 3Hz) aims to enhance excitability of the ischemic cortex. Combination treatment is another option, demonstrating a range of positive impacts on the neurological scales and dysfunction scores of the treated patients, as well as on the length of therapy.

The synergistic treatment of tDCS and FES can also achieve better therapeutic effect. According to [10], The hemiplegic walking disorder patients were split into 20 individuals who underwent transcranial direct current stimulation (tDCS) and 18 patients who did not. A 1-1 tDCS treatment device was employed in the tDCS group. The cathode was placed in the prefrontal area of a healthy brain, whereas the anode was placed in the primary motor cortex, which corresponds to the lower limbs of hemiplegics. The amount of current was 2mA. The electrodes in the pseudo-TDCS group

were in the same location, but there was only a 30-second current output prior to and after treatment. FES was given to both groups concurrently. 20 minutes per session, once day, five days per week for two weeks. They found that tDCS simultaneous FES treatment can improve balance function in stroke patients with hemiplegia, and can significantly improve their walking function. And in study [11], Sixty-six stroke hemiplegia patients eligible for inclusion were divided into three groups after stratification: synchronous, tDCS and FES group. The tDCS group received FES for the lower limb and tDCS for the head treatment. The synchronous group received tDCS therapy for the head and FES treatment for the lower limb whereas the FES group received placebo tDCS in the head and FES in the lower extremities. The therapy lasted for 12 days at a rate of 20 minutes per time, once every day. The results showed that for various assessment markers, tDCS and FES therapy was superior to tDCS or FES treatment alone.

In study [12], Thirty patients with severe stroke were randomly divided into two group A and B. Group A was treated with active tDCS and FES. Group B was treated with inactive tDCS and FES. The researchers scored patients before and after treatment using a variety of scales, as well as surface electromyography and transcranial stimulation. Active or sham tDCS intervention for 20 minutes, FES treatment for 1 hour, five times a week for four weeks. group A have a greater therapeutic effect on improving muscle activation level. Thus, the suggested regimen is better than the protocol with FES treatment alone in helping severe chronic stroke patients improve their upper extremity motor skills.

For the order of use of the two treatments, this study used functional near-infrared spectroscopy to dynamically observe the immediate effect of different time combinations of tDCS and FES on primary motor cortex functional connectivity in stroke hemiplegic patients [13]. The results showed that there was statistical significance in the activation of brain regions after FES treatment alone, tDCS simultaneous FES treatment, tDCS followed by FES treatment, and tDCS treatment alone. Brain activation of FES after tDCS is superior to FES alone and tDCS combined with FES. The increase course of motor cortex excitability was from high to low, in order of tDCS followed by FES treatment, FES treatment alone, tDCS concurrent FES treatment, and tDCS treatment alone. In addition, tDCS simultaneous FES treatment was superior to electrical stimulation alone in improving the connectivity efficiency of brain regions, and tDCS followed by FES treatment was the most obvious. In many studies, compared with tDCS or FES treatment alone, tDCS combined with FES treatment has a considerable effect, so in the future medical rehabilitation treatment means, this treatment will bring faster and more efficient rehabilitation effects for patients.

3. Virtual Reality

VR is a new technology with the emergence of three-dimensional imaging technology in recent years. Its multi-perception performance allows people to obtain more information in the virtual world. Immersion and interaction allow users to have a more real experience [14]. Although it was originally intended for the video and gaming industries. But in the medical industry, stroke rehabilitation has been complemented by interactive video games and virtual reality. In study [15], three different studies were conducted on 29 stroke patients to discuss the impact of VR technology on stroke rehabilitation, and all stroke subjects showed positive responses to VR activity stations. When patients were exposed to VR, significant attitude changes were observed. And study used a system for stroke rehabilitation called TRAVEE [16]. It contains a stimulation device, a monitoring device, a VR headset, and a computer that runs two of them. The study involved seven patients between the ages of 52 and 79 and focused on the movement of the hands. The VR device presents this movement process to the patient, and combined with FES treatment helps the patient to perform motor imagination to achieve the specified task. In terms of results, this alleviated the patient's passive or bored attitude while being able to reduce the number of exercise training sessions, and Patients can see encouraging hope in this treatment plan.

Study evaluated the biomechanics of 13 patients with hemiplegia after stroke before and after two months of rehabilitation [17]. There are 16 rehabilitation sessions, two days a week, in which subjects first anesthetized their upper limbs for 30 minutes with multichannel FES, which are synchronized IMU sensors, followed by 30 minutes of "practice" with a VR headset. Table 2 demonstrates how using virtual reality and FES as supplementary tools for post-stroke rehabilitation can increase a patient's moving range, maximum angle, angular velocity. It can be seen that the patient's various motor functions have been significantly improved. It can be seen that VR technology has a place in the medical field, and its combination with FES can not only save patients' costs, but also allow patients to obtain greater treatment effects in a shorter period of time, but also increase the interest of the treatment process.

Table 2. The maximum angle of the patient's maximum limb extension test prior to and during rehabilitation treatment (RT)

Position	Movement	Maximum Angle Prior to RT (◦)	Maximum Angle during RT (◦)
Shoulder	Extension	9.98 ± 6.48	12.68 ± 7.31
	Flexion	52.17 ± 14.01	60.65 ± 12.79
	Adduction	94.16 ± 46.67	110.60 ± 33.48
	Abduction	22.69 ± 20.07	16.58 ± 8.01
	Int. Rotation	29.59 ± 53.78	48.38 ± 8.73
	Ext. Rotation	63.12 ± 57.59	61.14 ± 46.61
Elbow	Flexion	84.69 ± 19.39	79.85 ± 13.38
	Extension	39.44 ± 15.91	38.02 ± 20.29
Wrist	Flexion	44.33 ± 18.97	39.14 ± 11.58
	Extension	13.44 ± 11.13	12.37 ± 10.06
Forearm	Supination	79.19 ± 88.11	110.98 ± 14.97
	Pronation	143.51 ± 21.11	146.67 ± 18.25

130 patients were divided into a control group and 130 patients were placed in an observation group in research [18]. The observation group got dual task rehabilitation training using virtual reality, whereas the control group received normal rehabilitation instruction. The observation group outperformed the control group in terms of reflexes, fall risk, lower limb function, balance, and gait metrics. This situational somatosensory engagement system aids in many rehabilitation objectives by enhancing patients' coping mechanisms and requiring them to react to shifting situations while they are being trained. 86 stroke patients were divided into the control group and the observation group in the research [19]. The control group received treatment using the MPI lower limb rehabilitation robot and was required to complete VR training in addition to the observation group's instruction. Prior to and following therapy, the functional scores of the two groups were compared. For 30 minutes each day, twice a day, both groups engaged in routine physical activity, daily living skills training, and other exercises. The observation group outperformed the control group in terms of functional walking scale scores. This shows that VR technology can put patients in a virtual environment, and through highly repetitive visual reinforcement of patients, can help patients feel the strength required for normal movement, so as to better help therapists obtain patient related rehabilitation information and develop better training programs. This adds to the fun of rehabilitation training, but also helps to improve the patient's attention and understanding.

4. Conclusion

FES has obvious therapeutic effect on stroke, and has great help in muscle strength and movement. tDCS and VR, as optional rehabilitation treatment for stroke, also have a better rehabilitation treatment for patients. But the selected study found that FES combined with tDCS or VR treatment

is better, especially in upper limb functional rehabilitation, and users are more satisfied with this method. The use of rehabilitation combination therapy can have better results for patients, and it is necessary to discuss which rehabilitation combination therapy is better. This article reviews some current rehabilitation combination therapies, including randomized controlled trials with different variables and their results, and analyzes the effectiveness and usability of these approaches. However, the extent to which the combination of FES and tDCS is relevant as a rehabilitation combination therapy is unclear, and whether the two produce a therapeutic effect on patients independently or in combination requires further testing. At the same time, as a new technology, the impact of VR on patients is still unclear, its role in sports imagination needs to be further explored, and its character in medical rehabilitation needs more and further experiments. At present, only a small number of studies are included in this review, and the perspectives involved are not comprehensive enough. More literature will be read in the future to improve the review of FES rehabilitation combination therapy.

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