FES therapy for spasticity in stroke patients with upper extremity impairments: state of art.

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INTRODUCTION.

Upper-limb impairment and rehabilitation approach.

Although many stroke patients are able to recover some walking function during initial rehabilitation, the majority of stroke patients are unable to user their upper extremity (UE) in their activities of daily living (ADL) after months of standard occupational therapy and physiotherapy[1]. Recovery of function in the hemiparetic upper limb is noted in fewer than 15% of patients after stroke[2]. Kwakkel et al.[3] have reported that most patients scoring fewer than 11 points on the Fugl–Meyer upper-extremity test 2 weeks after stroke have little chance to recover measurable hand dexterity and are even less likely to recover upper-extremity functional ability.

In the UE of patients who have had a stroke, a common course of hemiparetic recovery reveals the development of uncontrolled flexion synergy. This pathological synergy in induced in the hemiparectic limb during efforts to use it for a particular task[4]. Often the individual can close the fingers into a first, which is part of the flexion synergy, but is unable to open the fingers. Patients who continue to recover may regain the ability to produce movements outside of synergy patterns and, finally, to make isolated movements. Abnormal synergies constitute a significant impairment that needs to be addressed by rehabilitation[5].

Improving the rehabilitation outcome of the UE in stroke patients has been an ongoing challenge to the rehabilitation specialty. Several promising therapeutic approaches have emerged in the field of stroke rehabilitation. Some of these therapies are intended for the acute phase and others for the chronic phase. Examples of restorative therapies include cell-based approaches, selective serotonin reuptake inhibitors, catecholaminergics, brain stimulation, robotic and other device-based interventions, mental-imagery based protocols, and constraint-induced movement therapy plus other intensive physical therapy regimens. None of these therapies has been universally accepted for enhancing outcomes after central nervous system injury, such as stroke. Most approaches are now being studied in preclinical trials or early-phase human trials.

Electrical stimulation: backgrounds.

Electrical stimulation of the upper limb has been receiving increasing attention as a therapeutic modality in post-stroke rehabilitation[6]. Functional electrical stimulation (FES) is a technology that activates paretic muscles using short duration electrical pulses applied through the skin[1]. Since the 1960s, the primary focus of FES development was to produce assistive devices that could be worn or implanted and used in ADLs. More recently, evidence has emerged that FES can be applied as part of a clinical intervention for training[1].

Electrically induced contraction of the muscles that move the wrist and finger joints has shown both statistical and clinical improvement in minimizing upper-extremity impairment[7-9]. More recent investigations have focused on regaining upper-extremity function rather than simply minimizing impairment, in particular the recovery of the ability to grasp, hold, move, and release objects[6,8-22]. However, these studies varied considerably in their training protocols. Several investigators applied the stimulation without asking the patients to add volitional activation and limited the stimulation-dependent training period to 3–6 wks[7-9,14,16,18,21-27]. Studies have demonstrated modest improvements in functional measures using EMG as a trigger to initiate stimulation to produce wrist extension. A literature review of 19 clinical trials evaluating the effect of electrical stimulation on motor control concluded that triggered stimulation may be more effective than cyclical stimulation but that its effect was not influenced by specific parameters of stimulation[28]. However, a more recent study by the same authors comparing cyclic with EMG-triggered stimulation found no significant difference between the 2 methods with respect to improvement in motor function[29]. EMG-triggered stimulation, however, may increase spasticity in the antagonist muscle group to that being stimulated, due to the effort required to produce a signal[30]. EMG-triggered neuromuscular electrical stimulators cannot control electrical stimulation in proportion to voluntary EMG, because it stops monitoring EMG after the stimulation.

Other researchers combined the stimulation with task-specific or functional exercises[6,12-14,31-35]. These studies showed improvements in hand function and spasticity.

One of the main challenges in applying FES therapy is to achieve effective, synergistic muscle activity that results in functional movement, and the generation of useful forces. For this, the appropriate sequence of electrical pulses must be provided. Upper limb neuroprostheses are able to facilitate 2 common grasping styles: the palmar grasp and the lateral grasp[7]. The palmar grasp is used to hold large, heavy objects such as cans and bottles, and is achieved by flexion of the 4 fingers against the palm of the hand. The lateral grasp is used to hold small, thin objects such as keys and paper between the thumb and the fully flexed index finger. Reaching is assisted by stimulating the anterior and posterior deltoid muscles, biceps, and triceps. Proper sequencing of contractions of these muscles facilitates a large variety of reaching and retrieving movements of the upper limb.

Motor cortical plasticity and relearning of function is encouraged by functional practice of meaningful tasks aimed at acquiring a practical skill rather than constant repetition of movement that lacks purpose and context[36,37]. FES combined with task-specific practice could be effective in improving outcomes in patients with moderate to severe dysfunction[38].

A home based FES modalities for stroke.

Several reviews, which have studied FES therapy for hemiparetic UE in stroke patients, have supported the conclusion that FES may be effective as a home-based modality in the rehabilitation of the hemiparetic UE after stroke[4,39-41].

New power-assisted FES system is a portable, 2-channel neuromuscular stimulator that promotes wrist or finger extension or shoulder flexion movement during coordinate movement but will not work when the target muscles cannot contract. This device induces greater muscle contraction by electrical stimulation in proportion to the voluntary integrated EMG signal picked up. Daily power-assisted FES home-program therapy with novel equipment has been shown to effectively improve wrist, finger extension and shoulder flexion. Combined modulation of voluntary movement, propioceptive sensory feedback, and electrical stimulation might play an important role in improving impaired sensory-motor integration by power-assisted FES therapy[41].

FES believed to inhibit antagonist muscle activity, but the effect is sometimes insufficient to control antagonist spasticity[42]. Hara Y et al[43] examined the effect on spastic hemiparesis of a hybrid therapy consisting of FES on extensor wrist and fingers muscles and motor point block with phenol at the spastic finger flexor muscles (Hybrid power-assisted FES) for 4 months. Modified Ashworth Scale showed marked improvement in all patients as compared with the control subjects after training. This study is the first report of functional rehabilitation that uses an EMG-controlled stimulator equipped with a pair of surface electrodes that both records the EMG and delivers electrical stimulation. The EMG-triggered neuromuscular electrical stimulation system cannot control electrical stimulation in proportion to voluntary EMG after onset of preprogrammed electrical stimulation.

Currently, FES systems are changing in order to improve the functionality of patients with disabilities. Mann et al[44] investigated the feasibility of using accelerometer-controlled electrical stimulation for the elbow, wrist and finger extensors to enable functional task practice in patients with chronic hemiparesis. An accelerometer is a means of controlling electrical stimulation in which the trigger for stimulation is directly associated with initiation of forward reach and grasp[45]. In this case series study, fifteen volunteers who had at least 45º of forward shoulder flexion and could initiate elbow extension and grasp, received 2 weeks of cyclic stimulation exercise to elbow and forearm extensor muscles, followed by 10 weeks of triggered stimulation to practice functional reaching. The Action Research Arm Test score improved from 19 to 32, and the Modified Ashworth Scale score for elbow, wrist and finger flexor spasticity was reduced from 2 each to 1, 0 and 1. The reduction in spasticity throughout the hemiplegic limb demonstrated in this study was maintained in the wrist and fingers and had reduced further at the elbow, 3-months follow up. These findings are supported by a number of other studies, but none conducted a follow-up assessment to establish how long that improvement was maintained. In Chan et al[46]. the participants used a self-trigger mechanism, with an accelerometer as a motion detector, for generating an electric stimulation pattern that was synchronized with the bilateral upper limb activities during the training. Twenty patients were recruited 6 months after the onset of stroke and completed 15 training sessions. Participants were randomly assigned to the FES group or to the control group. After 15 training sessions, the FES group had significant improvement in Fulg Meyer Assesment, Functional Test for the Hemiplegic Upper

Extremity, and active range of motion of wrist extension when compared with the control group.

Neuroplasticity and FES.

In Fujiwara et al[47] the authors devised a therapeutic approach to facilitate the use of the hemiparetic UE in daily life by combining integrated volitional control electrical stimulation (IVES) with a wrist splint, called hybrid assistive neuromuscular dynamic stimulation (HANDS). IVES can automatically change its stimulation intensity in direct proportion to the changes in voluntary generated electromyography (EMG) amplitude recorded with surface electrodes placed on the target muscle. Twenty patients with chronic hemiparetic stroke were included. They used the HANDS over 3 weeks, 5 days a week and 8 hours each day. The intervention resulted in both clinical improvement of the paretic UE and corticospinal modulation in patients with chronic stroke. The improvement may be attributed to reduction of wrist and finger flexor spasticity as is evidenced by decreased co-contraction during the finger extension task. Partial restoration of reciprocal inhibition might explain this improvement. The authors assessed reciprocal inhibition with H reflex. The change of intracortical circuitry in the motor cortex was assessed with paired pulse paradigm, and it was demonstrated that the paretic hemisphere short intracortical inhibition (SICI) was reduced after intervention. The desinhibition of intracortical interneurons is supposed to play an important role in motor learning, reorganization, and recovery after brain[48]. Decreases in inhibition as well as increases in synaptic efficacy of neural circuits are some of the proposed mechanism for rapid neuronal plasticity of sensoriomotor areas during skill acquisition, learning, and memory[49]. The IVES used in this study can control electrical stimulation continually in direct proportion to voluntary EMG. Patients can therefore use this stimulator at their will in daily life as long as 8 hours a day.

The mechanism of the new FES therapy is that alternative motor pathways are recruited and activated to assist impaired efferent pathways[50]. This explanation is based on the sensory-motor integration theory that sensory input from movement of an affected limb directly influences subsequent motor output[51]. Movements induced by EMG-stimulation may result in the enhancement or reinstatement of proprioceptive biofeedback physiologically time-linked to each attempted movement. The voluntary initiation of the electrical activity in the wrist and finger extensor muscles served as a stimulus for the onset of the electrical stimulation. The sensorimotor aspects of this combined movement are closely intertwined and the movements might produce proprioceptive feedback, an afferent signal that returns to the somatosensory cortex, completing the cycle[50].

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