Neuromuscular Electrical Stimulation in Stroke Rehabilitation

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Introduction

Stroke is the No. 1 cause of disability in this country. The American Heart Association reports that approximately 600,000 people suffer a first or recurrent stroke each year in the United States.1 One significant determinant of post-stroke disability and quality of life is motor dysfunction in hemiplegia.2 Thus, interventions that maximize the recovery of motor function following stroke are of great importance. Electrical stimulation is one such intervention for which there is an increasing amount of scientific support.

Electricity has a long history in medicine. Pliny, Aristotle, and Plutarch all knew that electric eels, rays, and catfish could produce numbness when touched to human skin.3 Many early treatments for various maladies were developed empirically, without scientific basis, and have faded from use.4 However, with improved technology, electrical agents are now used for diverse types of treatments including analgesia, strengthening, wound healing, iontophoresis, and neuromuscular electrical stimulation (ES).5 This article focuses on ES as a treatment in stroke recovery and particularly on its use in motor relearning.

Electrical Stimulation

Although the stroke insult adversely affects the central nervous system, the peripheral nervous system generally remains intact. As a result, peripheral nerves, such as the peroneal nerve supplying the ankle dorsiflexor muscles, remain responsive to electrical stimulus. In the 1960s, Liberson et al. used an electrical stimulator to evoke contractions in the ankle dorsiflexor muscles so that patients did not need a brace to prevent the common problem of footdrop during the swing phase of the paretic limb during gait.6 The electrical stimulator effectively substituted for the voluntary control of the ankle, and, remarkably, some subjects acquired the ability to dorsiflex the ankle independently, although this effect was transitory. The stimulator appeared to have a beneficial effect on the neuromuscular system that continued for a short while after cessation of the stimulation.

Since Liberson et al.'s work, many researchers have reported similar qualitative and quantitative observations with respect to ES of the lower extremity in stroke survivors.7-14 The treatment used in these studies has been cyclic ES, in which stimulation is delivered automatically at a set duty cycle for a preset time period. For example, Bogataj et al. studied 20 inpatients with lower extremity hemiparesis in a single-blinded, controlled, cross-over design.12 Subjects received ES to the peroneal nerve for one-half to 1 hour per day for 3 weeks. The intensity of the stimulation was sufficient to produce dorsiflexion. They found significant improvement in gait parameters with ES and conventional physical therapy compared with conventional therapy alone. The greatest degree of improvement occurred in those subjects who were classified as mild to moderately impaired.

ES also has been traditionally used in treating the pervasive condition of shoulder subluxation in stroke patients. Although a strong correlation between shoulder subluxation and shoulder pain has not been established,15 there is evidence that subluxation plays a role in development of other painful shoulder conditions.16,17 Evidence suggests that ES can be successful in minimizing shoulder subluxation, but reduction in pain is inconsistent across studies.18-20

Motor Relearning

A newer form of electrical stimulation involves electromyographic triggered electrical stimulation (EMG–ES). Rather than electrically evoking a specific movement, EMG-ES promotes motor relearning with the goal of retraining voluntary control of the movement. Like cyclic ES, this treatment is commonly used to train foot dorsiflexion and wrist extension. In this treatment, volitional movement is required to initiate the electrical stimulation. Unlike cyclic ES, this treatment requires cognitive effort, which may be a crucial ingredient for cortical neuroplasticity.21

With this device, electrodes applied to the skin receive EMG output from the target muscle during a voluntary contraction. Once a predetermined threshold is reached, the electrical stimulation is delivered via these same electrodes, thereby allowing a larger contraction in the target muscle than could be produced independently. Thus, with EMG-ES there is a volitionally initiated but electrically reinforced repetitive movement of the affected limb that provides greater cutaneous and proprioceptive input time-locked to each attempted movement. This augmented sensory feedback is thought to be helpful in facilitating voluntary recruitment of a larger pool of motor neurons in subsequent movement attempted without the ES.22 With a larger pool of neurons firing, it is possible to produce a stronger voluntary muscular contraction. Although this augmented sensory feedback elicited by the electrical stimulation occurs with either cyclic ES or EMG-ES, the latter has been found to be superior in facilitating motor recovery,23 which again may be related to its inclusion of a cognitive component.

In a recent study using EMG-ES, Cauraugh et al. randomly assigned 11 individuals with chronic stroke (>1 year) to an EMG-ES or a control group.24 One group of subjects received 60 minutes of EMG-ES treatment 3 days per week for 2 weeks applied to their hemiplegic wrist extensor muscles in the forearm. The control group exerted volitional effort, similar to that required to trigger the stimulation in the EMG-ES group, but with no EMG-ES attached and thus, no electrical reinforcement of the contraction. The group receiving EMG-ES showed significantly greater improvement than did the control group as measured by tests of isometric wrist extension force and finger grasp-and-release function. Five other controlled trials have been published using EMG-ES or another method of biofeedback that uses joint position to trigger the ES.24-29 Although these studies either had methodological limitations or lacked long-term follow-up, the consistency of positive effects of the experimental treatment on objective measures of motor impairment does suggest that this type of treatment may be an effective option for stroke patients.

A related technique in stroke rehabilitation is mesh-glove electrical stimulation. In this protocol, the focus is entirely on afferent feedback at both the sensory (perceived) and subsensory (below perception) level. Dimitrijevic et al. reported improvements in EMG wrist extensor output and amplitudes of active wrist extension immediately after such stimulation.30,31 They noted that the treatment was most effective in subjects who had some level of active movement before treatment. The increased afferent feedback produced by this increased movement and electrical stimulation is considered to be fundamental to the mechanism of action by which electrical stimulation can improve motor performance.

Mechanism of Improvement

Investigators have suggested that the benefit in these studies stems from the proprioceptive afferent feedback that accompanies the motor stimulation.24,27,31 That is, even though it is the stimulation of the motor nerves that produces the joint movement, the sensory nerves are also excited during the stimulation, and this excitation may elicit central nervous system effects important for voluntary recruitment of motor pathways.

It is well known that afferent input affects motor centers at the spinal and supraspinal levels through short-loop and long-loop pathways. Long-term potentiation (LTP) is a term that refers to alterations in a synapse’s excitability due to repeated stimulation and has primarily been demonstrated in the hippocampus, which is the part of the mammalian brain that plays a crucial role in learning and short-term memory. However, evidence is accumulating that LTP may also affect the excitability of cortical motor neurons and, thereby, may be an important part of motor learning.32

Stefan et al. studied the excitability of cortical motor areas in humans with transcranial magnetic stimulation (TMS), a procedure in which a coil electrode is strategically positioned on the scalp and a magnetic stimulus is delivered noninvasively to the underlying cortex. 33 Depending on the excitability of the cortical motor neurons and the strength of the stimulus, a motor evoked potential (MEP) may be recorded remotely, such as in a thumb muscle, to which EMG electrodes are attached. Stefan et al. recorded MEPs before and after an intervention involving magnetic stimulation paired with ES to the median nerve. They found the postintervention MEPs to be greater than the preintervention MEPs. This, in combination with other findings, led them to conclude that the human motor cortex excitability is modifiable by external stimulation. This is an important finding because it invites exploration into the possibility that the motor cortex of individuals with stroke may also be modifiable with proper external stimulation, which may help these individuals recover effective but latent motor pathways.

Possibly related, Golaszewski et al., using functional magnetic resonance imaging (fMRI), demonstrated increased cortical activity during a finger-tapping task in healthy subjects as a result of 20 minutes of subsensory conditioning mesh-glove electrical stimulation.34 Thus, there appears to be growing evidence of the potential for electrical stimulation to affect not just muscle, which is most obvious, but also the central nervous system. Perhaps it is through the latter that improvements in voluntary function, similar to those reported by Liberson et al., occur.6

Currently, our laboratory is investigating whether intensive home use of EMG-ES in subjects with stroke can elicit behavioral improvements accompanied by changes in brain organization. Using functional magnetic resonance imaging, we recently have demonstrated changes in brain reorganization in subjects with chronic stroke following forced-use, finger-tracking training as the intervention.35 We found that with such training the side of the brain controlling the paretic hand could be switched from the ipsilateral hemisphere to the contralateral hemisphere. Currently, we are conducting a randomized, blinded investigation of whether EMG-ES, used to facilitate wrist extension and hand opening in chronic stroke patients, can produce functional improvements and brain reorganization.

Summary

Although quality of life for stroke patients with hemiplegia is clearly influenced by multiple factors, functional independence is an important one. Electrical stimulation, particularly EMG-ES, appears to be one tool that can positively affect the functional abilities of many stroke survivors. Further research is needed to determine the mechanism of action of EMG-ES and which subsets of stroke victims will most likely respond favorably. MM

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