MESH-GLOVE. 1. A METHOD FOR WHOLE-HAND ELECTRICAL STIMULATION IN UPPER MOTOR NEURON DYSFUNCTION

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ABSTRACT. A newly devised method for electrical stimulation via a wired mesh-glove is described. The stimulation paradigm is novel in that a whole hand is the target of stimulation. Specific standardized stimulation modalities are reviewed. The protocol for mesh-glove stimulation for patients with and without volitional movements, but increased muscle tone is outlined. A sequenced program based on restoration of motor functions is described. The mesh-glove stimulation is well suited for home use. On the basis of our experience working with 40 patients after stroke, head and spinal cord injuries, we concluded that this procedure is beneficial and safe.

Key words: hand, electrical stimulation, stroke, brain injury, spinal cord injury (SCI).

INTRODUCTION

Impairment of volitional motor activity is common after stroke, head injury, spinal cord injury and other conditions of upper motor neuron dysfunction. This finding is particularly relevant in stroke patients who have achieved substantial recovery of speech and gait, but volitional motor activity of the hand remained incomplete or absent (7). In such conditions, restricted hand movements and muscle hypertonia markedly decrease functional performance. It has been shown that residual volitional motor activity can be enhanced by electrical stimulation of paralyzed muscles (4, 6). There have also been attempts to combine electrical stimulation with biofeedback in order to improve motor performance in stroke patients (3). Motor activity of the paralyzed hand can be restored by direct stimulation of the motor nerves in a sequence of stimulation that will generate functional movements (8), by surface stimulation of motor points of paralyzed muscles (9). Moreover, there are reports demonstrating that sensory stimulation can also be effective for the suppression of

muscle hypertonia and facilitation of volitional movements (1, 2, 4).

In order to develop a method that would primarily activate hand afferents rather than evoke contractions of the long extensors and flexors of the wrist and fingers, we use a mesh-glove made of conductive wire. This mesh-glove becomes a single stimulating electrode that allows us to stimulate cutaneous and muscle afferents, and motor fibers of intrinsic muscles.

In this report, we shall describe the technical characteristics of this new method and its potential clinical utility for the enhancement of residual motor activity of the hand and arm in patients with upper motor neuron dysfunction.

METHOD

The mesh-glove (Fig. 1) is made of conductive, flexible wire and is easily slipped over the hand. Before fitting the hand with the mesh-glove, which is available in different sizes (Prizm-Medical Inc. Norcross, Georgia 330071, USA), a conductive jelly is applied over the whole hand. The mesh-glove has a built-in socket which connects both anodes of a two-channel stimulator. The cathodes of the stimulator are separately connected to 4×3 cm koraya-padded carbon rubber electrodes placed over the dorsal and volar surfaces of the forearm proximal to the wrist. A safe distance (approximately 2 cm) between the edge of the mesh-glove (anode) and wrist electrodes (cathodes) is essential in order to avoid contact. Carbon rubber electrodes can be trimmed, if necessary. Placement of the cathodes against nerves or motor points is not required.

A two-channel stimulator (Medtronic Model 3128 Respond II) was used to deliver a train of 50 Hz stimuli (pulse width 300 μS) and amplitude adjusted to obtain the desired response. The following features of stimulation are used: synchronous two-channel stimulation with constant amplitude, reciprocal two-channel cycling with internally set duty cycle, and reciprocal stimulation with external control of duty cycle.

Based on the threshold for stimulus perception and visible motor response, we used the following standardized stimulation modalities:

1. Continuous synchronous stimulation below the sensory threshold;

Fig. 1. Two-channel stimulator with cables connecting two independent cathodes (one to be placed over the dorsal and the other over the volar aspect of the forearm), a common anode to the mesh-glove, and a bottle of conductive jelly.

2. Continuous synchronous stimulation at the sensory threshold;
3. Reciprocal stimulation at level of muscle contraction without joint movement;
4. Reciprocal stimulation which elicits finger extension and flexion;
5. Reciprocally induced finger flexion and extension synchronized with residual volitional movements (this modality can be controlled by a manual switch used by the trainer or by the patient himself).

The following goals of mesh-glove stimulation have been defined: (1) decrease in spasticity; (2) improved awareness of the hand and facilitation of volitional movements; (3) conditioning of muscle disuse; and (4) relearning and augmentation of residual volitional activity.

These goals are accomplished by the subsequent protocols:

Protocol 1. (control of spasticity): It consists of continuous stimulation below sensory threshold synchronously from both stimulator channels, once or twice a day for 20–30 minutes, followed by passive stretch of the fingers with the wrist in neutral position. Noticeable decrease in spasticity is usually observed after a few initial sessions and over the next couple of weeks this effect becomes more pronounced. The protocol is completed when sustained passive finger extension is fully obtained with the wrist in neutral position, if hand deformity was not caused by fixed contractures.

Protocol 2. (awareness of hand and facilitation of movements): It includes 20–30 minutes of continuous, synchronous two-channel sensory threshold mesh-glove stimulation, once or twice a day in order to improve awareness of the hand which in addition, commonly exhibits diminished sensory functions. In several weeks, the patient usually reports better appreciation of the affected hand. At this stage, in addition to sensory threshold stimulation, the patient is encouraged to elicit volitional finger movements assisted by passive stretch, while the wrist is in neutral position.

Protocol 3. (conditioning of muscle disuse): It consists of reciprocal two channel stimulation at motor level with the electrodes placed as before. This protocol is applied for 5–30 minutes, once or twice a day, until muscle twitches are sustained throughout the 30 minute stimulation session (approximately 12 weeks).

Protocol 4. (relearning and augmentation of residual volitional activity): It consists of reciprocally induced finger flexion and extension synchronized with residual volitional finger movements. Manual switch is used for control of duration of flexion and extension cycles. Stimulation is applied once or twice a day for 20–30 minutes, usually for 24 weeks. When this stage is reached, additional routine protocols for proximal segments of the arm are added in conjunction with other therapeutic programs for the restoration of arm motor functions.

DISCUSSION

In laboratory settings, neuromuscular and functional electrical stimulation have been widely used in patients with paralysis and paresis due to upper motor neuron dysfunction. It has been reported that this method can facilitate spontaneous recovery in stroke patients and enhance motor activity after the plateau had been reached (8). Previously, major emphasis has been given to the restoration of motor activity of the arm, forearm and wrist. When surface electrodes are applied over the forearm muscles, the anatomical and functional complexities of the muscles involved in hand control limit selective and consistent restoration of finger movements. The described method of mesh-glove whole-hand stimulation, therefore, is adding a missing link to the already

existing methods of functional electrical stimulation for the upper limb in stroke and other related conditions.

Much of our experience was gained using a Medtronic Respond II Stimulator (Model 3128), but equivalent commercial products have also been successfully used. We have found that the mesh-glove electrode is more comfortable and effective when connected as an anode. Cathode electrodes placed at the wrist are also more effective in eliciting finger movements than when positioned over the bellies of the forearm flexor and extensor muscles. It is important to keep in mind that this procedure was primarily developed for the enhancement of residual functions of the fingers, although improvement of the wrist movements may be expected, as well.

The method of mesh-glove stimulation was developed in the past two years working with 40 patients. This group included 25 stroke patients, 15 females and 10 males, with mean age of 60.8 ± 12.5 years, and onset of injury ranging from 8–96 months (mean $\pm$ SD, 33.8 ± 23.7 months). Of these, 21 patients had hemispheric lesions (12 right and 9 left hemiparesis), and brainstem lesions were found in 4 patients. All were ambulatory with the exception of 3. Five of the 40 patients suffered from head injury (1 female and 4 males; mean age 32.5 ± 5.81 years; onset range 6–18 years), of which 4 were quadriparetic (2 ambulatory) and one was with right upper monoparesis. The remaining 10 patients (9 males and 1 female) suffered cervical SCI (onset range 7—18 years) and all were wheelchair-bound. While working with all these patients we sought to determine whether mesh-glove stimulation is an acceptable and feasible method, how to standardize stimulation modalities and, lastly, what is the effect of such a procedure on muscle tone and volitional movements. All the patients complied willingly and thoroughly with the protocol for mesh-glove application. In all of those patients, it was easy to apply this procedure and to teach family members how to carry out the prescribed protocol. When spastic fingers prevented mesh-glove application, sensory subthreshold stimulation of the fingers wrapped into the glove induced relaxation. As spasticity was reduced, the mesh-glove could be fitted successfully. Reduction in muscle tone was more readily achieved in stroke patients, and facilitation of volitional movement was a finding commonly seen in most patients.

The novelty of mesh-glove stimulation lies in an attempt to depolarize larger diameter afferent fibers of the volar and dorsal aspects of the hand. It is likely that low threshold cutaneous, joint and proprioceptive afferents are simultaneously stimulated. Ascending volleys arising from those afferents may influence excitability of spinal and supraspinal mechanisms involved in the control of muscle tone.

In our experience, mesh-glove stimulation is suitable for a long-term home program. Another advantage is that stimulation does not depend upon particular positioning of the surface electrodes over the bellies of muscles or motor points, as is the case when long extensors and flexors of the wrist and fingers are stimulated. Moreover, there are no side effects and the patient complies willingly. This approach of whole hand mesh-glove stimulation can be easily combined with other sites of stimulation, particularly with more proximal muscle groups of the arm, or in conjunction with different therapeutic exercises and relearning procedures. Further clinical experience should determine the effectiveness and potential limits of this method.

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