Preventing Acute Atrophied Muscles by Therapeutic Magnetic Stimulation


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Introduction

Many patients with upper motoneuron lesion have difficulty in making useful muscle contractions due to weak and atrophied muscles. The feasibility of using functional electrical stimulation (FES) for muscle activation to restore gait in these patients has been demonstrated. This is possible because most of these patients have intact peripheral nerves below their level of injury that can be stimulated to provide muscle contractions. Therapeutic electrical stimulation (TES) has been performed to increase muscle force, and to prevent muscle atrophy.

However, it requires general anesthesia to place the electrodes for the intramuscular TES and this method sometimes has risks of infection at the penetrating portion for the migration of electrodes. On the other hand, the method with percutaneous TES can be painful to patients with the preserved sensation.

Functional magnetic stimulation (FMS) does not require surgery, thus avoiding complications associated with surgery or chronic implants, such as infection and haemorrhage. The magnetic fields generated from the magnetic coil are able to pass through high-resistance structures such as bone, fat, and skin without harm to the body. FMS has been used effectively to stimulate the spinal nerves below the level of spinal cord injury (SCI), resulting in restored vital functions such as the ability to cough [2], to empty the bladder, to improve the bowel movement [3], and to produce lower-limb muscle contractions.

The purpose of this study is to evaluate the effects of magnetic stimulation in preventing acute muscle atrophy in rats.

Methods

Forty adult male Wister ST rats with an average body weight of 236g (range 210-249g) were used in these experiments. The animals were assigned to 2 groups: the stimulated group (n=20), and the non-stimulated group (n=20). All rats were suspended by their tails through the silks, and their hindlimbs were unweighted to make their muscles atrophy. For the hindlimbs suspension, the rats were deeply anaesthetized with an intraperitoneal injection of pentobarbital sodium (40mg/kg). The rats in the non-stimulated groups served as a control.

A commercially available magnetic stimulator (Daiya Industry Co. Japan) was used for FMS, and the average of diameter of the magnetic coil (MC) was 30mm. This stimulator can generate a maximum field strength of 1.0 Tesla near the MC. A computer with an interactive program written specifically for activating the stimulator was used to control the frequency and length of the stimulation. The continuous stimulation parameters were set up to 750V (about 93% of maximum intensity of this system) and 20Hz. The MC was supported by an adjustable frame, making it was possible to keep the center of the coil placed on L3-L5 beside the midline initially for lumbosacral stimulation, which was varied to obtain the maximal movement of their hindlimbs (Fig 1.).
This stimulation of rats was performed for 60 min/day, for 10 days. The animal care protocol for this study was approved by our university’s institutional animal care, and uses committee and followed the guidelines of the US National Institutes of Health (NIH).

Magnetic stimulation for the rats of the stimulated group was started 1 day after the operation. The day after the stimulation period ended, the rats were anaesthetized, and tibialis anterior and extensor digitorum longus muscles were surgically removed from both legs. Muscle samples were taken from the maximum circumference part of each muscle in a 10-mm thick cross-section. Subsequent samples were obtained by slicing cross-sections of the samples perpendicularly. The muscles were then rapidly frozen in 2-methylbutane (isopentan) and cooled in liquid nitrogen. Each sample was stored at -80°C until it was analyzed. Samples were then cut into 10-µm thick serial sections, with the cryostat maintained at -15°C.

Transverse serial sections were stained by a histochemical method (adenosinetriphosphatase) with preincubation at pH 4.4. Type 1, type 2A, and type 2B fibers were identified according to the criteria of Brooke, Kaiser and Dubowitz, Brooke [4]. The lesser fiber diameters of 150 fibers from each muscle fiber type were measured with Mac SCOPE ((MITANI Co. Japan). We analyzed the distribution of the muscle types, and then we measured muscle fibers. This method of measurement was designed to overcome the distortion that produces an oval shape when the muscle fiber is being cut obliquely [3]. The data are reported as mean ± standard deviation (SD). The differences in the lesser diameters in each muscle type were statistically evaluated by student t-test. This criterion for significance was p-value less than .01.

Results

Tibialis anterior. The mean lesser diameter of type 1, type 2A, and type 2B muscle fibers were, respectively, 35.0±7.9µm (Mean ± SD), 30.2±6.8µm, and 35.0±7.9µm in the stimulated group, 25.7±3.9µm, 22.9±2.9µm, and 25.7±3.9µm in nonstimulated group. There was a significant difference in the size of the muscle fiber diameter between the stimulated and nonstimulated muscles all type. (type 1; p = 0.001, type 2A and type2B; p < 0.001).

Extensor digitorum longus. The mean lesser diameter of type 1, type 2A, and type 2B muscle fibers were, respectively, 31.4±9.7µm (Mean ± SD), 28.9±7.2µm, and 33.0±7.2µm in the stimulated group, 24.8±4.7µm, 24.6±4.1µm, and 28.7±6.8µm in nonstimulated group. There was a significant difference in the size of the muscle fiber diameter between the stimulated and nonstimulated muscles in all types (type1, type2A, and type2B p<0.001)(Fig.2).
Discussion

Very few evidence has been provided in the electrophysiological detection of pathology affecting lumbosacral nerve roots because of their deep, relatively inaccessible location. Electrical stimulation of these roots can only be performed using high voltage techniques or by using needle electrodes inserted to the depth of the vertebral lamina. Both methods are painful, and the latter is also invasive.

The recent development of surface magnetic coil system has allowed deeply situated nerve fibers to be stimulated less painfully. It can be used in various cervical, thoracic, lumbar, or sacral motor nerve-conduction studies. Magnetic stimulation applies Faraday’s law, which states that an electric field is induced whenever a magnetic field changes. This induced electric field, if of adequate amplitude and duration, may generate sufficient current to stimulate nerves. Additionally, it can stimulate the spinal nerves even when applied outside the clothing, and produce contraction of the innervated musculature. FMS is a noninvasive, painless, and simple strategy.

Animal studies show that immobilization of the lower limbs for different periods result in muscle atrophy ranging from 15% to 70%, in which the most muscle atrophy occurred in the first 7 days of immobilization. TES or FMS can be helpful for preventing the muscle from atrophy after SCI, thus it should be performed during the acute phase. In animal models of disuse, such as in spaceflight, after spinal cord transaction, and hindlimb suspension, muscle atrophy occurs at an extremely high rate during first several months. A recent study has shown that thigh girth decreased to 50% within 3 weeks after SCI, suggesting that atrophy was virtually complete within the first month after SCI.

The muscle atrophy in patients with SCI has been demonstrated as a progressive decrease in the fiber diameter and changes in the fiber type distribution [5]. Once the muscle atrophy has occurred before the stimulation started and developed, it then requires a longer period of time before the muscles return to near normal condition. In order to restore paralyzed muscles by TES, an increase in muscle fiber diameter is required. It is important to maintain muscle power by TES, as well as an increase in the size of muscle fiber. Our preliminary experiments indicate that there are significant differences in the size of muscle fiber diameter between non-stimulated and stimulated muscles. As a result of using magnetic stimulation, all types of muscle growth in the acute phase of hindlimb suspension outpaces fast muscle atrophy. These results suggest that magnetic
stimulation for acute atrophied muscles is effective in reducing muscle atrophy. We believe that SCI patients can receive FMS earlier as long as the muscle atrophy does not develop.

This preliminary finding corresponds well to results obtained in rats, which showed that FMS improved the muscle fibers in acute stage. The most interesting application of magnetic stimulation to peripheral nerve, however, would be in the rehabilitation area, where tetanic stimulation would be required to produce useful movement of the innervated muscles.

Conclusions

The functional magnetic stimulation of acute atrophied muscles is effective for reducing muscle atrophy and might be an alternative method for electrical stimulation. The comparison of the clinical effects of TES and FMS for acute SCI patients should be further investigated.

References


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