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The Value of Electrical Stimulation as an Exercise Training Modality

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Introduction

Voluntary exercise is the traditional way of improving performance of the human body in both the healthy and unhealthy states. Physiological responses to voluntary exercise are well documented. It benefits the functions of bone, joints, connective tissue, and muscle.

In recent years, research has shown that neuromuscular electrical stimulation (NMES) simulates voluntary exercise in many ways. Generically, NMES can perform three major functions: (1) suppression of pain, (2) improve healing of soft tissues, and (3) produce muscle contractions. Low frequency NMES may gate or disrupt the sensory input to the central nervous system which results in masking or control of pain. At the same time NMES may contribute to the activation of endorphins, serotonin, vasoactive intestinal polypeptides, and ACTH which control pain and may even cause improved athletic performances [1]. Soft tissue conditions such as wounds and inflammations have responded very favorably to NMES. NMES of various amplitudes can induce muscle contractions ranging from weak to intense levels.

NMES seems to have made its greatest gains in rehabilitation where directed muscle contractions may improve joint ranges of motion [2]; correct joint contractures that result from shortening muscles [3]; control abnormal movements through facilitating recruitment or excitation into the alpha motoneuron in orthopedically, neurologically, or healthy subjects with intense sensory, kinesthetic, and proprioceptive information [4]; provide a conservative approach to management of spasticity in neurological patients [5]; by stimulation of the antagonist muscle to a spastic muscle [6], stimulation of the agonist muscle [7], and sensory habituation [8]; serve as an orthotic substitute to conventional bracing used with stroke patients in lieu of dorsiflexor muscles in preventing steppage gait and for shoulder muscles to maintain glenohumeral alignment to prevent subluxation [5]; and of course NMES is used in maintaining or improving the performance or torque producing capability of muscle [9-11]. NMES in exercise training is our major concern in this presentation.

Muscle Strengthening by Neuromuscular Electrical Stimulation

Maintaining or improving the performance or torque producing capability of muscle is our major concern. Although resistance voluntary exercise has been the traditional method of improving muscle performance (strengthen or increase torque), NMES has also been demonstrated to strengthen muscle [9-11]. The object in strengthening muscle with NMES is to induce very intense contractions with little or no discomfort. Pulse charge and frequency are stimulus characteristics that need to be considered to meet the objective of strong contractions with little or no discomfort. Pulse charge is comprised of pulse duration and amplitude. The optimal pulse duration that feels comfortable ranges from 0.02 to 0.2 msec, while safe amplitudes range from 0 to 100 mA. Because electrical pulses are very short lasting, they are comfortable and their shape does not seem to be a critical factor if symmetrical biphasic (rectangular or sine). Intense muscle contractions that produce the greatest torque are induced at pulse frequencies between 50 and 90 per second. Subject variation exists and therefore no definite single type of stimulator, other than line powered, or set of stimulus characteristics are associated with the least discomfort. Level of contraction for muscle strengthening in any program has been reported to be 50 to 80 percent of maximum voluntary contraction (MVC) effort. [9-11]. Strength gains are directly related to the training amplitude of NMES. Strength training programs using NMES have usually employed ten contractions per session ranging from 10 to 40 sessions.

The difference between success and failure using NMES for maintaining or augmenting muscle mass and muscle torque during periods of joint immobilization or minimum exercise may be related to the selection of specific stimulus characteristics. Experience at the University of Kentucky confirms that. We hypothesize that a pulse or burst frequency and charge sufficient to induce fused tetanic contractions equivalent to 50 percent of isometric MVC delivered for ten contractions per session, three sessions per week for 6 weeks will improve muscle performance. Our hypothesis should also be appropriate for work with astronauts and problems that they encounter in zero-g conditions.

Our recent pilot study that assessed the ability of electrically induced contractions for preventing muscle wasting and weakness during the first 6 weeks after reconstructive surgery for anterior cruciate ligaments should serve as support for using electrically induced muscle contractions.

Method

Patient Data

Sixteen patients were treated sequentially after surgery. Patients numbered 1 through 3 served as controls (n=3) and did not receive electrically induced contractions because of inaccessibility of treatments as outpatients at out-reach facilities. Patients numbered 4 through 10 received conventional NMES only (n=7), and patients 11 through 16 received the simultaneous combination of NMES and magnetic stimulation (n=6).

All patients were operated on with the same arthroscopic assisted reconstruction technique of the anterior cruciate ligament using the middle third of the patellar tendon. An orthotic device maintained the postoperative limb in full extension to 5 degrees of flexion. All patients in this study received physical therapy which progressed with each succeeding week.

Measurements

Torque measurements on patients 4 through 16 were made preoperatively to determine amplitude of NMES for producing torque equivalent to 50 percent of isometric MVC. Torque was determined by a Biodex dynamometer system. Starting with the ninth patient the protocol was altered to accommodate comparisons between pre- and postoperative torque scores at 6 weeks, and use of magnetic stimulation (a new mode of clinical therapy).

Thigh girths were measured on all patients in this pilot study at 12.24, 20.32, and 25.40 cm (6, 8, and 10 in) proximal to the superior patellar pole using a plastic tape measure.

Patients receiving the combined NMES and magnetic stimulation were asked to rate each mode of induced stimulation with 10 cm visual analog scale (VAS).

Treatment

Patients 4 through 10 were treated with NMES only in the conventional manner. Patients 11 through 16 were treated by the combined NMES and magnetic stimulation (MES). A modified Cadwell MES-10 magnetic stimulator (used for peripheral and cerebral nerve conduction studies) with a 26 cm copper coil (designed for the thigh) was used in the study, and delivered a peak amplitude of 1.5 tesla (15000 gauss) along the coil edges with a single cosine pulse form at 60 pulses per second. From previous experience this magnetic field is sufficient to produce torque ranging from 8 to 82 percent of MVC of healthy subjects' quadriceps femoris muscle [12]. However, because of the subject variation in torque response to the peak amplitude of the magnetic field, we decided to use magnetic field augmentation by combined magnetoelectric technique reported by Bickford and co-workers [13]. This technique applies the conventional NMES simultaneously with the magnetic stimulation to elicit contractions sufficient to produce 50 or more percent of MVC. The magnetic field was superimposed and applied at peak amplitude simultaneously with NMES for 10 seconds per contraction. A 10-second muscle contraction time was used with the magnetoelectric stimulation rather than the previous 15 seconds with conventional NMES only because of the coil heating (120 to 150 °F, 48.9 to 65.6 °C).

Results

The two NMES patients measured for torque at pre- and postoperative increased their knee torque by a mean 24.7 percent during 6 weeks of treatment, while those receiving MES showed a mean 15.1 percent decrease. The mean torque loss among patients not in the study measured in our clinic is 50 percent of preoperative MVC.

The mean percent of decreased girth 6 weeks after knee surgery for controls was 8.3 percent, 0.5 percent for patients receiving NMES only, and 0.0 percent for patients having MES.

The induced stimulation duration per treatment session varied from 0.04 hours/day (150 seconds) for NMES only patients, to 0.03 hours/day (100 seconds) for MES patients. All patients receiving induced stimulation were treated under the supervision of a physical therapist.

Patients receiving MES perceived differences between the NMES given during the hospital stay (three sessions) and MES given during outpatient visits (15 sessions). The mean rating on the VAS for NMES patients was 7.1 cm and that for MES patients was 3.7 cm.

Discussion

Patients from the NMES only treatment increased muscle torque during the 6 weeks postoperative. Until the success of a few patients receiving NMES was demonstrated, postoperative torque measurements at 6 weeks were believed to result in deleterious forces to the graft [14]. No torque for the controls is available because of postoperative restrictions at the time of their rehabilitation. Patients receiving MES lost torque as a group, although three of six patients contributed to the loss. The torque loss in MES patients may have been attributed to the 10-second contraction duration or 33 percent less induced contraction time than NMES patients, and the full knee extension position used in treatment of MES patients. The torque was tested with 10 degrees of knee flexion, thus contributing to loss of torque-angle specificity.

Findings on girth measurements among our patients were within expected limits based on previous experiences. Patients receiving NMES averaged far less muscle wasting than that reported by others [15-17], while our MES patients displayed no muscle wasting 6 weeks after having major knee surgery. The induced stimulation times of our patients were considerably less than reported by others, yet our results merit attention when compared with other studies ranging from 1.5 [16] to 17.7 [15] hours per day. The difference in results obtained in our pilot study and that of others may be attributed to our aggressive stimulation regimen consisting of line powered units capable of delivering ten-fused tetanic contractions that were equivalent to our greater than 50 percent of MVC.

Another important finding in our study was the patient tolerance for intense induced muscle contractions when using the magnetoelectric method of treatment. The patients' ratings on the VAS showed that the MES method is more acceptable to their comfort than that of the conventional NMES.

Conclusion

The data of this pilot study support the conclusion that both conventional NMES and the augmented method of combining NMES with magnetic stimulation are capable of preventing muscle wasting and reducing muscle weakness during the first 6 weeks after major knee ligament surgery. The MES method is tolerated better by patients than the conventional NMES. Data are encouraging to date for the MES method but our goal is the development and improved clinical application of magnetic stimulation to replace the conventional NMES.

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