NEUROMUSCULAR ELECTRICAL stimulation (NMES) is the application of electrical current to the neuromuscular junction and surrounding muscle fibers to elicit a muscle contraction. In the 1970s, Yadov Kots reported that NMES was superior to volitional exercise in developing muscle-strength gains in Olympic athletes. Kots suggested that when current intensities creating muscle contractions of greater than 100% maximum voluntary contraction (MVC) were used, increases of up to 40% above the MVC were realized. Because these reports did not include details of procedures or references and were never peer-reviewed, they should not be highly regarded in terms of evidence quality; however, they spawned an interest in the use of NMES to augment muscle strength in clinical populations with muscle weakness. Since that time, NMES has been suggested to be an effective tool to augment muscle strength in athletes receiving rehabilitation for orthopedic injuries. The purpose of this column is to review current evidence regarding the efficacy of NMES treatment parameters used to augment muscle strength in athletic patients with various pathologies.

Current Waveform

NMES typically utilizes an alternating current. The modifiable characteristics of the current waveform are frequency (pulses or bursts per second) and pulse or burst duration. Frequency partially determines the force of an NMES-induced muscle contraction. As frequency increases, so does the force of the muscle contraction, until a smooth, tetanic contraction is achieved. Frequencies of 50, 70, and 90 bursts per second have been reported to have no influence on pain perception, and studies that have utilized NMES effectively for strengthening have used frequencies of 50–75 bursts or pulses per second. Pulse duration is the length of time the current is depolarizing the nerve and must be sufficient to activate motor units. Some stimulators have a setting for carrier frequency rather than pulse duration. Pulse duration may still be calculated (1 divided by the carrier frequency), and either parameter is acceptable to control the effect of the current on motor-unit recruitment. Carrier frequencies of 10,000 Hz (100-µs pulse duration) have been reported to be more painful than carrier frequencies of 2,500 (400-µs) or 5,000 Hz (200-µs). When examining torque-producing capability, one study reported no difference between pulse durations of 200 µs (0.2 ms) and 5.6 ms, but pulse durations typically used in effective NMES protocols range from 200 to 400 µs. Hence, a frequency of 50–75 pulses or bursts per second, with a pulse duration between 200 and 400 µs, is sufficient to achieve a smooth contraction while minimizing pain.

Current Intensity, Time Properties, and Repetitions

Once appropriate current characteristics have been selected, other considerations arise. The current intensity should be sufficient to elicit a strong, tetanic muscle contraction. Studies that have used NMES effectively recommend the maximum tolerable intensity that elicits a muscle contraction that is at least 50% of...
the maximum volitional isometric contraction (MVIC) of the muscle being stimulated. If an MVIC of the involved muscle is contraindicated, 30% of the MVIC of the uninvolved muscle is appropriate. It is also recommended that the intensity be ramped up over 2–3 s, with a rest between contractions to maximize comfort and limit fatigue. Current studies have utilized on/off cycles with a ratio of 1:5 (usually 10–15 s on and 50–120 s of rest) for a total of 10–15 contractions. Three treatments per week are reported to be more beneficial in improving strength than two.

Electrode Considerations

Electrodes influence the effectiveness of the contractions and pain perception. A bipolar electrode configuration should be used, and the electrodes should be placed over the motor points of the muscles to be stimulated with an interelectrode distance proportionate to the size and depth of the muscle. Ohm’s law dictates that current intensity is directly proportional to the voltage generated by the stimulator and inversely proportional to the resistance of the electrode–tissue interface, therefore, to minimize the resistance of current flow to the muscle, adequate electrode–skin contact, clean electrodes, and clean and shaven skin are critical. The current is then delivered at a density, which dictates patient perception, that is the current intensity divided by area of the electrode. Hence, it is best to use a pad size that is as large as possible to reduce the pain caused by the stimulus. Pad sizes used in the treatment of quadriceps weakness after ACL reconstruction have been reported to be 3 × 5 cm, 2.9 3.5 in. in diameter, 3.5 × 4 in., or 4 × 5 in. 12

Measuring Effectiveness of Treatments

To determine the effectiveness of an NMES treatment, one must quantify baseline strength and track the subsequent improvements in strength. Suggested protocols include measurement of the MVIC of the uninjured and involved muscle groups prior to the first treatment of each week for comparison. If the necessary equipment is available, such as an isokinetic dynamometer, the strength of the contraction may be measured during the treatment to quantify the relationship between volitional contractions and electrically induced contractions. Treatments should continue until the involved muscle reaches 80% of the uninvolved muscle.

Clinical Populations

Few randomized clinical trials have been published that directly evaluate the efficacy of NMES as a treatment for muscle weakness in clinical populations. Reports suggest NMES may be effective in restoring strength to the lumbar extensors in ice skaters with low back pain, improving thenar-eminence strength in a recreational athlete who sustained forearm fracture with median nerve injury, and treating quadriceps weakness in patients with patellofemoral dysfunction. However, the first two reports are only case studies, and the third did not have a control group. Hence, more research is needed to determine if these treatments are worthwhile, as these studies do not rank high on the evidence-based-medicine scale for evidence quality.

Although there is little evidence for the preceding treatments, the overwhelming majority of high-quality research has focused on augmentation of quadriceps strength in patients who have sustained ACL injury and subsequent ACL reconstruction. These patients exhibit elevated risk for quadriceps inhibition and weakness, both of which result in gait alterations during the stance phase. Hence, quadriceps strength recovery is paramount in restoring full function. Several studies have shown NMES to be an effective treatment for quadriceps strength after surgery in these patients. All four of these studies were randomized clinical trials. One concluded that NMES treatments alone are superior to volitional exercise alone in restoring quadriceps strength. The others demonstrated that NMES combined with volitional exercise was more effective than volitional exercise alone in restoring quadriceps strength. The importance of this effectiveness is broad, given that those who received NMES treatments regained normal gait patterns earlier and scored higher on the ADLS, a measure of the impact of knee dysfunction on activities of daily living, than those who did not receive NMES. The rigor of randomized clinical trials and their value on the evidence-based-medicine scale suggests that the results of these four studies be highly regarded. The parameters utilized for NMES in these studies are summarized in Table 1.

Two randomized clinical trials reported no difference in quadriceps strength between those who received NMES combined with volitional exercise and those who only participated in volitional exercise, and between those who received NMES treatments alone and those who completed only volitional exercise. The