Effects of Electrical and Electromagnetic Stimulation after Anterior Cruciate Ligament Reconstruction

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A need exists to develop new methods of neuromuscular electrical stimulation (NMES) that are both effective and relatively pain-free. The purpose of this pilot study was to determine the effects of both NMES and a new method of electromagnetic (NMES/PEMF) stimulation for reducing girth loss and for reducing pain and muscle weakness of the knee extensor muscles in patients during the first 6 weeks after reconstructive surgery of the anterior cruciate ligament (ACL). Seventeen patients receiving ACL reconstructive surgery participated as a control group (N = 3), as an NMES group (N = 7), and with combined NMES and magnetic field stimulation (NMES/PEMF) (N = 7). Patients receiving NMES/PEMF rated each type of stimulation for perceived pain and were measured for their torque. Torque results revealed a mean decrease of 13.1% for NMES/PEMF patients. The mean percent of thigh girth decreased 8.3% for controls, 0.5% for NMES, and 2.3% for NMES/PEMF patients. The NMES/PEMF patients rated NMES as causing about twice the pain intensity as NMES/PEMF during treatments. As a result of this data, the authors conclude that both NMES and NMES/PEMF are effective in reducing girth loss and that NMES/PEMF is less painful than NMES alone in treating patients after ACL reconstruction.

Key Words: *electrical stimulation therapy, magnetics*

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Muscle wasting (atrophy) is caused by specific pathological processes or surgery as well as physical inactivity (disuse) of the patient after reconstructive surgery of the anterior cruciate ligament (ACL) (16, 22, 23). Muscle wasting of the quadriceps femoris muscle interferes with rehabilitation efforts to correct knee instability (16) and improve functional performance (1, 20). Teaching patients to perform isometric exercises of the knee extensors at sufficient intensity to control muscle wasting is extremely difficult (34), and the exercises do not prevent disuse atrophy (15). Reducing or preventing muscle wasting would be beneficial for rehabilitation.

Neuromuscular electrical stimulation (NMES) has been used as a substitute for volitional exercise to reduce atrophy and weakness occurring after knee surgery (2, 13, 34). Arvidsson et al (2), using a battery-powered NMES unit with 40 pulses per second (pps) of 300 μsec duration each, 1.5 hours per day for 5.5 weeks beginning the second week after ACL reconstructive surgery, treated male and female patients as an experimental group and withheld NMES on a control group. After 6 weeks of immobilization, amounts of muscle wasting were not significant between male patients receiving NMES (13.5%) and the control group (17.2%), but were significant for female patients assigned to similar groups (15.6% and 31.4%, respectively). Cross-sectional areas were measured by computerized tomography. All patients also received isometric exercises (2).

Wigerstad-Lossing et al (34) reported that the loss of cross-sectional area of the quadriceps femoris muscle was significantly less among NMES patients (23%) than controls (29%) during the immobilization period after ACL reconstruction. These researchers used a portable, battery-powered unit delivering 30 pps and pulse durations of 300 μsec for three 40-minute sessions per week beginning the second day after surgery. All patients, who would be immobilized for 6 weeks with the affected knee flexed at 20–30°, started a similar isometric training regimen on the first postsurgical day. They also stated that the tendency toward an increase in type II over type I fiber area indicated more intense muscle contractions in the NMES patients (34).

In a single-case experiment, Delitto et al (13) reported the effects of NMES on changes in knee extension and flexion isometric torque and thigh girth in a patient 6 weeks

after ACL surgery. The NMES was begun 2 weeks after surgery using 50 pps at maximum patient tolerance. Induced contractions were sequenced for 15 seconds of stimulation and 50 seconds rest for 20 repetitions each session, with three sessions a week over 46 days. The NMES treatments resulted in increases in extension and flexion torque and thigh girth (13).

Our experiences, like those of Delitto et al (13), have shown that success or failure of induced stimulation is dependent on the amounts of pulse charge; that is, the greater the pulse charge, the less the muscle wasting and weakness. However, NMES-induced muscle contractions at sufficient intensities to prevent or reduce wasting are hindered by patient pain associated with the stimulus. Reducing pain with NMES would be beneficial in rehabilitation.

The greater the pulse charge, the less the muscle wasting and weakness.

We were aware of the possibility that high intensity muscle contractions with reduced pain could be induced by simultaneously adding a pulsed electromagnetic field (PEMF) with NMES. In 1965, Bickford and Fremming (5) reported the noninvasive use of magnetic stimulation of human and animal peripheral nerves. Polson et al (27), in 1982, recorded muscle action potentials using a single pulse magnetic field. In 1985, Barker et al (3) extended this magnetic stimulation method to deep peripheral nerves and to the human brain.

A pulsed electrical current passing through a coil (copper loop) will, in turn, induce a time-varying magnetic field. If the pulsed magnetic field is of sufficient amplitude and duration, neuromuscular tissue in its vicinity can then be stimulated (depolarized) similarly to conventional NMES that uses surface electrodes (3). This principle may be expressed by the formula:

$$E = \frac{dB}{dt} \times \frac{r}{2}$$

where E is the amplitude of the magnetic field, dB/dt is the rate of change of the magnetic field, and r is the radius of the circular coil (3). Current flow in the coil produces a magnetic field perpendicular to the skin beneath the coil, which, in turn, causes another current flow parallel to the skin without causing patient pain (Figure 1).

To test our clinical impressions that NMES and the combined NMES and PEMF (NMES/PEMF) methods under certain conditions may have beneficial effects, we devised a pilot study to gather baseline information. The purpose of this pilot study was to determine some clinical effects of NMES and NMES/PEMF when using a stimulus amplitude sufficient to produce 50% or more of maximum voluntary contraction (MVC) intensity. We believe that our purpose could be satisfied by: *1*) comparing effects of NMES/PEMF with NMES on thigh girth and pain intensity, a step that would help validate the new method of NMES/PEMF, and *2*) measuring effectiveness of NMES/PEMF on knee torque production. We expected that NMES/PEMF would compare favorably with NMES on curtailing girth loss, would be more tolerable than NMES, and would maintain knee torque production with presurgical values 6 weeks after ACL reconstruction.

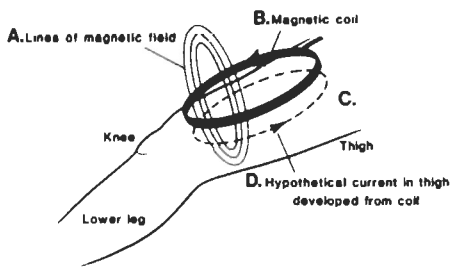

FIGURE 1. *Magnetic stimulation showing: A) magnetic field, B) flow of electrical current, C) skin surface of thigh, and D) flow of induced electrical current.*

METHOD

Patient Data

A sample of convenience, 17 patients (14 men, 3 women) ranging in age from 15 to 39 years (mean age = 24.9 years), was obtained by asking patients prior to surgery to participate. Those who agreed to participate in our study signed a written consent after they were informed of the purpose, procedure, benefits, and risks of the study. When scheduled for surgery, they were measured and then assigned sequentially to either NMES or NMES/PEMF groups. Sequential assignment was necessary because the PEMF unit was under repair when the study began. Rather than deny patients NMES treatments (standard for the University of Kentucky Sports Medicine Center), our controls agreed to participate because of inaccessibility of the appropriate NMES and NMES/PEMF units at their outreach facilities. The outpatient physical therapy facilities attended by control patients were standard referral sites that have demonstrated compliance with our rehabilitation protocols. The authors believe that the sample is a true subset of the population requiring ACL reconstruction and that the sequential assignment to either of the experimental groups in no way biased the outcome. Rigid controls throughout the study allowed the authors to draw appropriate conclusions. The small sample size was necessary to obtain baseline information promptly about the effects of NMES and NMES/PEMF. Because several studies using control subjects

not receiving NMES (2, 7, 11, 15, 24, 34) have shown that NMES is more effective at improving torque and reducing atrophy, the size of the control group was not considered essential; this also applied to the sizes of the NMES and NMES/PEMF groups for comparing the latter's effectiveness.

All patients received the same technique of arthroscopically assisted ACL reconstruction by the same surgeon, using the middle third of the patellar tendon, described in detail elsewhere (29). Postsurgically, the involved limb of each patient was protected in full extension to 5° of flexion in an orthotic device (29) for 5–6 weeks. All patients received identical physical therapy (except for NMES or NMES/PEMF), which was initiated within 24 hours after surgery and progressed weekly using a standard ACL protocol that included range of motion, muscle setting, straight leg raise, and ambulation exercises during the first 6 weeks after surgery (described in detail elsewhere) (31). Patients numbered one through three served without induced stimulation as the control group, four through 10 received NMES (NMES Group), and patients 11 through 17 received NMES/PEMF (NMES/PEMF Group).

Measurements

Torque was recorded on our experimental patients prior to surgery for the purpose of determining NMES amplitude sufficient to produce torque equivalent to 50% of MVC of the knee. While grasping the handles along the seat, the patient was seated and strapped on an isokinetic dynamometer (Biodex Corp, PO Drawer S, Shirley, NY 11967) with his or her tested knee positioned in 10° of flexion and hips flexed at 60°. The axis of rotation of the dynamometer was aligned with the tested knee. The greatest torque reading of three attempts was accepted as the MVC. Each contraction was 5 seconds in duration, with 5 seconds between contractions. After the MVC determination, while the patient remained seated and attached to the dynamometer, NMES electrodes were secured over the affected thigh. The stimulation amplitude (without volitional contraction) was then manually adjusted in a stepwise fashion until 50% of the predetermined MVC torque was produced. This peak amplitude was recorded and used after surgery as a basis to begin bedside NMES treatments (dynamometer use was restricted). The reliability of stimulating 16 healthy subjects to achieve 50% of their MVC using the same amplitude of current on different days was previously determined in our laboratory to be $r = .90$. Constraints on postsurgical measurements of torque at 6 weeks negated scores for the control and NMES groups. However, starting with the eleventh (sequentially assigned) patient, the constraints were lifted to compare pre- and posttorque scores with NMES/PEMF. The conditions for pre- and postsurgical voluntary and presurgical induced torque determinations for patients 11 through 17 were similar to those of predecessors except that magnetic stimulation was superimposed over the NMES electrodes to familiarize the patient with the forthcoming NMES/PEMF treatment procedures as described.

Thigh girths were measured by a therapist (blinded to group assignments and not the principal investigator) on all patients in this study at 12.2, 20.3, and 25.4 cm (6, 8, and 10 in) proximal to the superior patellar pole using a plastic tape measure that does not stretch. Care was taken for appropriate alignment of the tape measure in relation to the circumference of the thigh. All girth measurements were recorded to the nearest 0.1 cm with the patient in the long sitting position on a treatment table. Similar girth measurements were repeated 6 weeks after surgery. Girth measurements were obtained as a rough estimate of the amount of muscle atrophy. They correlate highly with estimates of thigh volume (12, 24) and are reliable (4).

Patients receiving the NMES/PEMF treatments were asked to rate each mode of induced stimulation separately for pain intensity (NMES only administered in the hospital, NMES/PEMF administered in the outpatient clinic) immediately after the third treatment of each. Oral pain medication was used in the hospital following epidural removal 48 hours after surgery, but no pain medication was used during outpatient treatments. The stimulus amplitude used corresponded to that which effectively induced muscle contractions at 50% of MVC prior to surgery. A 10-cm visual analog scale (VAS) displayed the descriptor of each extreme of the symptom to be assessed (0 cm = no pain, 10 cm = severe pain). The patient was asked to mark the line between the two extremes that represented his or her level of pain during each stimulation type (NMES vs. NMES/PEMF). The VAS is a valid ratio scale (28) and a reliable instrument for assessing pain intensity (17, 30).

Neuromuscular Electrical Stimulation

An Electrostim 180-2i stimulator (Electrostim USA Ltd, 1851 Black Rd, Joliet, IL 60435) was used to produce the NMES. This line-powered unit produces individual sine waves at a carrier frequency of 2,500 Hz delivered in 50 bursts per second with a 10-ms "on" time and a 10-ms "off" time. Two pairs of carbonized rubber electrodes (8 × 12.5 cm) were used and connected to the same parallel circuit. Sponges moistened with tap water and placed between the skin and the electrodes served as the conducting medium. The electrodes were placed on the skin over the femoral nerve at the femoral triangle of the thigh and over the vastus medialis muscle.

Electrodes were also located over the bellies of the biceps femoris muscle distally and over the medial hamstring muscles proximally (13). All electrodes were placed parallel to the muscle fibers for optimal torque production (8) and secured with straps circumferentially.

The patient was in the long sitting position with the affected knee fully extended for all NMES treatments with or without the orthotic device. Each induced contraction lasted 15 seconds (5-sec ramp on), followed by 50 seconds off for 10 contractions per session. The amplitudes were predetermined independently for each patient for inducing contractions equivalent to 50% of MVC. All patients were instructed to cocontract their knee extensors and flexors simultaneously with the NMES or NMES/PEMF to neutralize forces placed on the ACL graft (18). Both voluntary cocontractions and prolonged expiration patterns were encouraged to improve patient tolerance of the induced stimulation. The NMES treatments began the day after surgery at bedside in the hospital with one session each on 3 successive days. Each muscle contraction was induced by presurgically recorded stimulus amplitude that produced torque equivalent to 50% or more of MVC. Patients were encouraged to tolerate maximum stimulus amplitude with each session so that the milliamperage was increased weekly. The NMES/PEMF was administered with physical therapy in the fourth and each succeeding session as outpatient treatment, three times per week for 5 weeks (total = 6 weeks, 18 NMES and NMES/PEMF treatments, two assessments).

Combined Magnetic and Neuromuscular Electrical Stimulation

A modified Cadwell model MES-10 magnetic stimulator was used (Cadwell Laboratories Inc, 909 N Kellogg St, Kennewick, WA 99336). Its simplified operation consists of charging capacitors to specified voltages and then discharging the current through the stimulating coil at time-varying rates. The magnetic field strength and stimulating time are controlled manually. At peak amplitude, the modified Cadwell unit produces 1.5 Tesla (15,000 gauss) along the edges of the 26-cm diameter coil at 60 cosine pulses per second. Previous experience showed that this PEMF produces knee extensor torque ranging from 15 to 51% (mean = 36.6%) of MVC of healthy subjects (10). However, because of subject variation in torque produced by the peak PEMF amplitude alone, we decided to use the technique reported by Bickford et al (6). Their electromagnetic stimulation (NMES/PEMF) technique would apply the conventional NMES (producing 50% of MVC) simultaneously with the PEMF (superimposing the coil over the electrodes) to augment the ability of the time-varying magnetic field to elicit high intensity muscle contractions (producing greater than 50% of MVC) (Figure 2). The magnetic field was applied at peak amplitude simultaneously along with NMES for 10-second contractions for patients in the NMES/PEMF Group for 5.3 weeks (one outpatient treatment was given in week 1). Muscle contraction duration was reduced from 15 seconds to 10 seconds with NMES/PEMF because of intense coil heating.

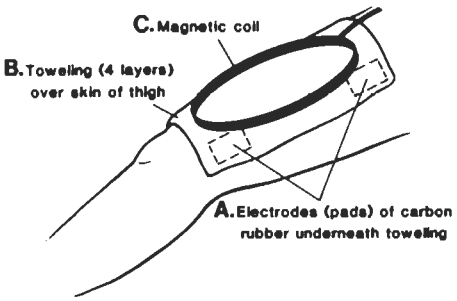

FIGURE 2. *Procedure for inducing muscle contractions: A) electrode for neuromuscular stimulation (NMES), B) four layers of toweling, and C) coil for NMES combined with magnetic stimulation (NMES/PEMF).*

Muscle wasting and weakness associated with partial denervation are neuropathic conditions that may retard rehabilitation of the knee after surgery. Irregular and less numerous muscle action potentials have been found in muscle after surgery (25). Vastus medialis muscles of patients displaying atrophy after 6 weeks of NMES/PEMF treatments were assessed by needle electromyography (6 in proximal to the superior pole of the patella).

Data Analysis

Descriptive statistics are used to reveal scores taken prior to and 6 weeks after patients received ACL reconstruction. One-way analysis of variance (ANOVA) was used to analyze data gathered on girth. The paired *t*-test was used to analyze the differences in the NMES/PEMF group between pre- and postsurgery torque means, between means of current amplitudes of the two experimental groups, and mean differences between ratings of NMES and NMES/PEMF on the Visual Analog Scale for pain intensity. The .05 alpha level was used for determining significance. The Newman-Keuls post hoc test for unequal groups was used to pairwise compare significant means of the ANOVA.

RESULTS

Mean torque values recorded from patients receiving NMES/PEMF, 54.8 ± 24.7 pre- and 47.6 ± 21.9 Nm postsurgery (40.4 and 35.1 ft-lbs, respectively), showed a decrease of 13.1%. This amount of torque loss after 6 weeks of rehabilitation and ACL reconstruction was not statistically significant ($t = 1.368$, 6 *df*).

No significant difference between mean peak stimulus amplitudes was seen between the two experimental groups ($t = 1.855$, 5 *df*). Patients receiving NMES averaged a maximum 79.7 ± 19.3 mA of cur-

rent (range = 24–96 mA), while patients receiving NMES/PEMF averaged a maximum 82.6 ± 16.2 mA over 6 weeks of treatment (range = 30–96 mA) in addition to the peak (1.5 Tesla) magnetic stimulation.

Descriptive statistics of thigh girth on the affected extremity are shown in Table 1. The mean percent of decreased girth 6 weeks after knee surgery was 8.3, for controls 0.5 for the NMES group, and 2.3 for the NMES/PEMF group.

Summary of analysis of variance for girth scores is shown in Table 2. A significant difference between means was found for the NMES/PEMF and control groups, and NMES and control groups. No significant difference was found between means of NMES/PEMF and NMES groups.

The induced stimulation duration per treatment session varied from 0.04 hours/day (150 seconds) for the NMES group to 0.03 hours/day (100 seconds) for the PEMF group.

Pain from the pulse charge of NMES is well known from our experiences and others (7, 11, 22). Patients receiving NMES/PEMF perceived significant differences between the NMES only and NMES/PEMF treatment methods (t = 7.481, 6 df, $p < .01$). The mean rating on the VAS for NMES was 7.3 ± 1.1 cm, while that for NMES/PEMF was 3.4 ± 1.6 cm.

Two patients who received NMES/PEMF and sustained a mean 1.1-cm girth loss at the distal measurement site were given needle electromyography. No action potentials were found that were suggestive of neuropathy.

DISCUSSION

Torque scores are not available for the control and NMES groups because of protocol restraints at the time of their rehabilitation. These restraints were lifted for NMES/PEMF treatments. During the rehabilitation period in which NMES/PEMF was given with weekly increases of peak current (milliamperage increases were assumed to result in increased torque production), the torque measured at the end of the 6 weeks decreased unexpectedly compared with presurgical scores. All induced stimulation treatments were delivered by a line-powered unit capable of reproducing large pulse charges with each contraction. This capability of producing large pulse charges constantly with each of the 10 contractions per session has not been our experience with battery-powered NMES units. Our experience indicates that these latter units, as used by others (33, 34), cannot sustain the pulse charge required over 10 consecutive contractions of 50% or more of MVC needed to increase muscle performance. Our NMES/PEMF patients receiving similar amounts of milliamperage as NMES patients and augmented contraction intensities with PEMF should have had an advantage, but torque scores did not reveal this. Increased patient tolerance of greater current levels than the NMES group, while producing equal (or more) torque may relate to the Hall effect. When a magnetic field is placed so that the lines of force pass vertically through the direction of the NMES current, the magnetic field will tend to deflect or drive the direction of the conventional current sideways rather than in its original direction (9). This sideways rather than horizontal flow of the conventional NMES current may reduce some effectiveness of PEMF for torque while reducing pain. The small torque loss (13%) in our patients may also be related to the 10-second induced muscle contractions.

The NMES/PEMF patients received 50 seconds less induced muscle contraction exercise per session than the patients receiving NMES (15-second contractions) because of PEMF coil heating (120°F with 10 second vs. 155°F with 15 second contractions). Isometric contractions induced in the fully extended knee by PEMF also do not offer optimization for muscle strengthening (26). Joint angle specificity may have also

Source	Site (cm)	Thigh Girth (cm)		Change (cm)	Percent
		Presurgery	Postsurgery		
Controls	12	52.8 (4.8)	47.8 (3.7)	−5.0	−9.4
($N = 3$)	20	56.7 (7.1)	52.1 (5.5)	−4.7	−8.2
	25	60.6 (7.1)	56.2 (5.4)	−4.4	−7.3
NMES*	12	48.4 (3.5)	48.2 (4.2)	−0.2	−0.4
($N = 7$)	20	53.7 (3.5)	53.6 (4.0)	−0.2	−0.3
	25	57.1 (4.2)	56.6 (3.9)	−0.4	−0.7
NMES/PEMF**	12	52.3 (5.4)	51.0 (5.9)	−1.3	−1.9
($N = 7$)	20	56.8 (6.1)	55.2 (6.7)	−1.5	−2.7
	25	59.3 (6.2)	58.0 (6.8)	−1.3	−2.3

Mean (standard deviation).
** Neuromuscular electrical stimulation.*
*** Electromagnetic stimulation.*

TABLE 1. *Descriptive statistics for thigh girth measurements.*

Source	SS	df	MS	F	p
Methods	48.77	2	24.39	7.35	<.01
Error	46.41	14	3.32		
Total	95.18	16			

TABLE 2. *Summary of analysis of variance of three groups of patients on girth loss.*

played a role since our testing required the knee to be flexed about 10°. Four of the seven NMES/PEMF patients either maintained or increased their torque during the 6 weeks of treatment, but three patients decreased torque sufficiently to influence the mean decrease of 13.1%. A major accomplishment was, however, that NMES/PEMF patients' torque loss after the first 6 weeks of rehabilitation was less than that reported by others (49%) (24, 34). Variable test conditions in the studies may, however, account for these torque differences. Our 13% decrease in isometric torque at 6 weeks postsurgery implies that affected knee extension was 87% of that recorded presurgery. The strength recorded for our NMES/PEMF patients is within the range reported by Shelbourne and Nitz for 10 weeks postsurgery (32).

Girth differences were expected based on our experiences. The mean 8.3% girth loss experienced by our control patients the first 6 weeks after having ACL reconstructive surgery represents equal or less girth loss than that reported by others for controls; for example: Wigerstad-Lossing et al = 29% (34), Arvidsson et al = 17.2% (2), Morrissey et al = 13% (24). For patients receiving NMES in these same studies, the postsurgical muscle wasting was: 23% (34), 13.5% (2), 10.3% (24), respectively. In our study, patients receiving NMES had a mean decreased girth measurement at 6 weeks postsurgery of 0.5%, and patients receiving NMES/PEMF had a measurement of 2.3%. Variable training conditions, pulse charges, and measurement error (rater reliability) may influence some of the differences between studies. Although methods of girth measurement differed between studies, the percentages indicate the relative changes between pre- and postsurgery and differences. All of our patients received the same conventional physical therapy regimen, while patients in the experimental procedures received the addition of induced stimulation. Our physical therapy regimen may be more intensive than that used by others and, therefore, account for the smaller decreases in girth among controls. We consider our girth losses to be considerably less than those reported by others using NMES treatments (2, 24, 34). No significant difference occurred between the girth means of patients in our two methods of induced muscle contractions; yet, both methods differed significantly from the mean 8.3% of the control group. We attribute the mean differences to the benefit of high intensity muscle contractions induced by line-powered stimulators in the first 6 weeks after ACL reconstruction.

Our results using the neuromuscular electrical stimulation in combination with electromagnetic stimulation are encouraging.

The induced stimulation times of our patients were considerably less than those reported by others; yet, our results merit attention when compared with studies employing longer stimulation periods. Morrissey et al (24) reported that their patients used NMES 8 hours/day, Arvidsson et al (2) stimulated their patients 1.5 hours/day, and patients of Wigerstad-Lossing et al (34) averaged 0.67 hours/day with NMES treatments. Each of these studies used battery-powered stimulators. Using line-powered stimulators, Delitto et al (13) reported using NMES 0.08 hours/day. In our study, the NMES was given 0.04 hours/day (2.5 min) and the NMES/PEMF 0.03 hours/day (1.67 min). We attribute the difference in treatment times of reported studies to our aggressive stimulation regimen consisting of a line-powered unit capable of delivering 10 fused tetanic contractions that were equivalent to or greater than 50% of MVC. Also, direct supervision of all induced stimulation treatments by a physical therapist assured patient compliance, which may be a major factor when assessing results of NMES studies. We believe that NMES and NMES/PEMF both demonstrate beneficial effects for rehabilitation and increased patient satisfaction due to the presence of visually equal thigh musculature.

Another important finding in our study was patient ratings on the VAS when using the NMES and NMES/PEMF methods of treatment. The NMES/PEMF patients not only tolerated peak currents of equal quantities to patients receiving NMES only, but were assumed to sustain intense muscle contractions which would normally create considerable pain. Data collected in our laboratory show that correlations between milliamperage used to induce torques equivalent to 50% of MVC and pain intensity ratings of subjects ranged from $r = -.13$ to .33. Data imply that little to no relationship exists between peak current and perceived pain intensity. The effectiveness of magnetic stimulation has shown considerable clinical potential because of its ability along with NMES to produce high-level muscle contractions well within patient tolerance. Pain is a limiting factor when using conventional NMES. Since magnetic stimulation bypasses the pain receptors in inducing muscle contractions, pain is thus reduced when compared with using NMES in which the greatest current density is near the surface electrodes. The combination of the two methods of inducing high current amplitude (NMES/PEMF) apparently influ-

ences the effect on pain receptors by reducing the pain when compared with NMES. The cross-over approach to assessing pain associated with the different methods of stimulation on a single group may be confounded. Although the VAS is ideal because it is difficult for subjects to remember the pain ratings of a previous trial (hospital vs. outpatient trials), conditions involving medication and time may have influenced our outcome. Factors such as electrode size and positioning, skin moisture content, and psychological profile have also been cited by others as influencing pain perceived with electrical stimulation (14, 21). Results on our few patients using the technique of combining conventional NMES with PEMF stimulation are encouraging but warrant further research for use in therapeutics.

Neuropathic muscle would retard rehabilitation of the knee after surgery because of wasting and weakness resulting from partial denervation. No tourniquet was used in surgery with our patients. Since no action potentials suggestive of neurological dysfunction were found in the vastus medialis muscle of the two patients, the cause of the mean 1.1-cm wasting at the most distal measurement site was most likely due to insufficient resistance activity (10 sec/contraction) with the fully extended knee.

CONCLUSION

Our data support the conclusion that both conventional NMES and the method of combining NMES with magnetic stimulation (NMES/PEMF) are capable of reducing girth loss during the first 6 weeks after ACL reconstruction. The augmentation method of NMES and magnetic stimulation was perceived by our ACL patients as being more tolerable than NMES alone. The NMES/PEMF method appears to be a promising and valid clinical approach to treating patients after ACL reconstruction. JOSPT

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