

# Electrical Stimulation Versus Voluntary Exercise in Strengthening Thigh Musculature After Anterior Cruciate Ligament Surgery

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Twenty patients who had undergone anterior cruciate ligament reconstructive surgery were placed randomly and independently in an Electrical Stimulation Group ( $n = 10$ ) or Voluntary Exercise Group ( $n = 10$ ) to compare the effectiveness of these two muscle-strengthening protocols. Patients in both groups used simultaneous contraction of quadriceps femoris and hamstring muscles during a training regimen that consisted of either voluntary exercise or electrical stimulation trials five days a week for a three-week period within the first six postoperative weeks. After patients completed the training regimen, bilateral maximal isometric measurements of gravity-corrected knee extension and flexion torque were obtained for both groups and percentages were calculated. Results showed that patients in the Electrical Stimulation Group finished the three-week training regimen with higher percentages of both extension and flexion torque when compared with patients in the Voluntary Exercise Group (extension:  $t = 4.35$ ,  $p < .05$ ; flexion:  $t = 6.64$ ,  $p < .05$ ). These results indicate that patients in an electrical stimulation regimen can achieve higher individual thigh musculature strength gains than patients in a voluntary exercise regimen when simultaneous contraction of thigh muscles is prescribed during an early phase of postoperative rehabilitation.

**Key Words:** *Electrotherapy, electrical stimulation; Knee; Ligaments; Muscle performance, lower extremity.*

During rehabilitation of patients after anterior cruciate ligament (ACL) reconstructive surgery, a large part of a clinician's effort focuses on strengthening patients' quadriceps femoris and hamstring muscles.<sup>1,2</sup> Terminal knee extension exercises (eg, free weights and isokinetics) commonly used to strengthen weakened quadriceps femoris muscles are believed to be detrimental to traditional intra-articular repairs and reconstructions.<sup>3,4</sup> Thus, clinicians face a difficult dilemma, because patients with ACL reconstruction have been reported to demonstrate a disproportionate loss of strength of the

quadriceps femoris muscles.<sup>9,10</sup> but commonly used knee extensor muscle strengthening strategies are contraindicated.

Researchers have theorized for humans<sup>11,12</sup> and directly measured in nonhuman primates<sup>13</sup> that simultaneous contraction of the quadriceps femoris and hamstring muscles can decrease the amount of stress on the ACL when compared with isolated quadriceps femoris musculature contractions. Alternative methods that use the concept of co-contraction of the hamstring musculature to safely strengthen the quadriceps femoris muscles in patients with ACL deficiencies are believed to be safe, regardless of knee-joint position. These methods include both voluntary and electrically elicited co-contraction of the thigh musculature, and their use has become more prominent in the last 10 years.<sup>14</sup>

The comparative effectiveness of electrical stimulation (ES) and voluntary exercise (VE) as treatments to increase quadriceps femoris musculature strength is well established in healthy subjects.<sup>14-17</sup> In these studies, ES has been shown to be effective in increasing strength of the quadriceps femoris muscles when compared with nonexercise control groups. In addition, these results using ES to augment strength have been shown to be equivalent to the results of both VE and combined VE and ES regimens. All of these studies, however, were performed on individuals without strength deficits at the start of the studies. Clinicians, therefore, cannot infer these

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results to patient groups who exhibit quadriceps femoris musculature weakness.

In the immediate postoperative phase of ACL reconstruction, ES and VE isometric contractions are frequently prescribed to decrease disuse atrophy of patients' thigh muscles. No reports in the literature compare VE with ES in patients after ACL reconstructive surgery. The purpose of this study was to investigate the comparable strengthening effects of voluntary versus electrically elicited co-contractions of thigh musculature in patients soon after ACL reconstructive surgery.

## METHOD

### Subjects

Twenty patients, ranging in age from 19 to 44 years ( $\bar{X}$  = 29 years), who had recently undergone ACL reconstructive surgery were randomly and independently assigned to an ES Group ( $n$  = 10) or VE Group ( $n$  = 10). All patients were familiarized with the study and gave their informed consent before admission to the study. The investigative design and informed consent procedures were approved by an institutional human studies committee.

### Procedure

Patients in the ES Group were treated five times a week for three weeks. Treatment consisted of 15 electrically elicited co-contractions of the quadriceps femoris and hamstring musculature. The patient's postoperative orthotic device was removed before electrical stimulation, and four gelled electrodes connected to the same circuit of the muscle stimulator\* were placed over the patient's quadriceps and hamstring muscles as described previously.<sup>18</sup> We taped the electrodes to the patient's skin and replaced the postoperative orthotic device. Patients sat at a Cybex<sup>†</sup> II isokinetic dynamometer<sup>†</sup> with their knee in the maximal amount of flexion tolerable postoperatively. A mechanical flexion stop was placed on the dynamometer in this position of maximally tolerable flexion.

Before each application of electrical stimulation, the patients obtained a position of maximal hip flexion by bending their trunk forward to increase the passive elastic component of the hamstring musculature. The isokinetic dynamometer was then set in the isometric mode, and current (2,500 Hz carrier wave, 50 pulses per second, sawtooth waveform) from the muscle stimulator was increased to the patient's maximally tolerated level. Isometric torque was visually monitored on a strip chart recorder throughout the electrically elicited contraction to ensure that no net extension torque during the electrical stimulation occurred. Co-contractions were of 15-second duration with a 50-second rest period between contractions. During each co-contraction, patients were instructed to increase the intensity of the muscle stimulator to their maximally tolerable level.

We verbally instructed patients in the VE Group in isometric co-contraction of their thigh muscles. Patients in the VE Group were directed to assume a position of maximal knee flexion and to perform at least 15 co-contractions five days a week, using a 15-second duration and a 50-second rest period between contractions. We instructed the patients to

unfasten the straps of the postoperative orthotic device so that their quadriceps femoris muscles could be visualized. With their knee in as much flexion as allowable, they were then instructed to simultaneously contract their quadriceps femoris and hamstring muscles "as hard as you can." We told the patients to visualize and palpate their quadriceps femoris muscles to elicit a firm contraction and to perform each co-contraction at maximal effort. A physical therapist (A.D., J.M.M., or J.A.T.) instructed patients during the initial session (an average of 15 minutes) and met with patients weekly until the three-week regimen was concluded.

All patients were treated for a three-week period immediately before postoperative orthotic device removal. Depending on the referring surgeon, treatment was usually initiated at the start of the second or third postoperative week. All treatment periods were concluded before the end of the sixth postoperative week. After the treatment period, we obtained maximal isometric measurements of patients' extension and flexion torque bilaterally with the knee in 65 degrees of flexion. All posttreatment measurements were made by an observer blinded to patients' group assignment.

### Data Analysis

Gravity-corrected percentages were calculated for knee extension and flexion torque measurements using the following formulas:

$$\frac{\text{Involved limb extension torque} + \text{torque from weight of limb}}{\text{Uninvolved limb extension torque} + \text{torque from weight of limb}} \times 100 \quad (1)$$

$$\frac{\text{Involved limb flexion torque} - \text{torque from weight of limb}}{\text{Uninvolved limb flexion torque} - \text{torque from weight of limb}} \times 100 \quad (2)$$

We used a posttest design because we were uncertain whether patients could perform at least 60 degrees of knee flexion for pretest measurements. In addition, the posttest design decreases sources of secondary variance (ie, history, maturation, pretest sensitization) when compared with the traditional pretest-posttest design.<sup>19</sup> Independent  $t$  tests ( $df$  = 18, alpha level = .05) were used to compare percentages of knee extension and flexion torque ratios between the ES and VE Groups. Adjustment of the alpha level because of multiple  $t$  tests was made using a Bonferroni correction factor.<sup>20</sup>

## RESULTS

Raw values for gravity-corrected isometric knee flexion and extension torques for each group are summarized in Table 1. The mean percentage of both extension and flexion torque ratios on the involved side of patients in the ES Group were significantly different than the comparable values of patients in the VE Group (Tab. 2).

## DISCUSSION

Simultaneous contraction of the knee extensor and flexor muscles has become popular in early rehabilitation of patients with ACL injuries because of the protection offered to the intra-articular graft. Although ES and VE are common strategies used to co-contrast thigh musculature, the results of this study provide evidence that ES can provide greater isometric strength gains than VE soon after ACL reconstructive surgery.

\* VersaSum 380<sup>®</sup>, Electro-Med Health Industries, Inc. 6240 NE 4th Ct. Miami, FL 33138.

† Cybex, Div of Lumex, Inc. 2100 Smithtown Ave, Ronkonkoma, NY 11779.

TABLE 1

Raw Isometric Knee Torque Values (in Foot-pounds)\* for Electrical Stimulation (ES) and Voluntary Exercise (VE) Groups for Involved and Uninvolved Extremities

Group	Uninvolved Extremity Torque				Involved Extremity Torque			
	Extension		Flexion		Extension		Flexion	
	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s
ES (n = 10)	144	39	88	19	114	41	84	21
VE (n = 10)	170	33	103	19	84	20	72	12

\* 1 ft·lb = 1.356 N·m.

TABLE 2

Gravity-corrected Mean Isometric Knee Torque Ratios (Involved vs Uninvolved Extremities) of Electrical Stimulation and Voluntary Exercise Groups

	Electrical Stimulation (%) (n = 10)		Voluntary Exercise (%) (n = 10)		t
	$\bar{X}$	s	$\bar{X}$	s	
	Knee extension	78.8	14.0	51.7	
Knee flexion	94.1	4.0	70.0	11.0	6.64*

\*  $df = 18, p < .05$ .

This finding contrasts with those of previous studies conducted on healthy individuals<sup>4-17</sup> showing that ES and VE have equivalent potential to increase quadriceps femoris musculature strength. The discrepancy between the results of this study and other studies may be because of the difference between co-contracting two antagonistic muscles versus contracting one set of muscles. We felt that training patients to co-contract muscles required more time and greater involvement on the physical therapist's part than training patients to isometrically contract one set of muscles. In the isometric contraction of one set of muscles, a patient usually receives a force or torque feedback, whether it be quantitative (from an instrument) or a qualitative sensation (eg, pressure on the inside of a cast), in response to the muscle contraction. As effort increases, the patient receives useful feedback concerning the magnitude of muscle contraction. We could not use these feedback techniques with patients who were training to use co-contractions, because no net torque was produced. In most cases, we had to rely on the supposition that patients in the VE Group were following our instructions to co-contract "as hard as you can."

Addition of an electromyographic biofeedback device to the VE regimen may have provided useful feedback to patients and investigators about the intensity of muscle contractions. We decided against using a biofeedback device in this study because we were interested in testing the effectiveness of the VE treatment regimen as it usually is administered in a clinical setting. In our experience, isometric VE is most commonly administered without an EMG biofeedback device. Future studies that use EMG biofeedback in voluntary co-contractions, however, would be interesting.

The inability to monitor the forcefulness of muscle contractions was equally evident, however, in the ES Group. We relied on patients in the ES Group to increase the intensity of stimulation to their highest tolerable level, but we did not know the forcefulness of the muscle contractions elicited. In contrast to voluntary co-contraction of the thigh muscles,

however, use of the electrical stimulator may have reduced the cognitive component of the motor task of simultaneously contracting the thigh muscles to a point where patients could concentrate on increasing the current level (and thus the forcefulness of the muscle contractions) to a greater degree and more effectively overload the muscles while training.

In addition, patients in the VE Group did not come to the clinic for every treatment as did patients in the ES Group. Patients in the VE Group demonstrated co-contraction proficiently (assessed visually and through palpation) during follow-up visits, leading us to believe that this mode of training was successful. Noncompliance with the prescribed exercise regimen in the VE Group, however, may have been a factor that was not completely controlled for. This lack of control contrasts with the ES Group, where patients came to the clinic for each treatment session and we were certain that the treatment was performed as prescribed.

We retrospectively compared the raw isometric torque values of the VE Group with those of the ES Group and found the mean difference of the knee flexor and extensor muscles to be nonsignificant. We recognize, however, the great deal of variability in the raw torque values and suggest caution in interpreting this result as evidence that the groups initially were equivalent. In a posttest design, the best assurance of equivalent groups is random and independent assignment.

Another possible explanation for the discrepant results between the ES and VE Groups may be the physiological differences between the two forms of exercise. The order of recruitment and synchrony of motor unit firing during ES is the reverse of that in voluntary contractions.<sup>21-23</sup> In disuse atrophy, a notable type II muscle fiber atrophy occurs.<sup>24</sup> Electrical stimulation may have been more effective than VE in eliciting type II muscle fiber activity and, therefore, better able to retard atrophy of these fibers. If type II muscle fiber atrophy is primarily responsible for the weakness in postsurgical patients with ACL reconstruction, then preferential elicitation of type II muscle fibers by ES may explain the difference between the two treatment regimens in this study. This speculation requires verification of appropriate investigative designs.

Although ES use has the potential for greater isometric muscle strength gains than VE in patients with ACL reconstruction, will isometric strength gains correspond to faster functional gains? Can rehabilitation of patients with ACL reconstruction be shortened by using ES postoperatively? These questions are the focus of our future research.

## SUMMARY

Using co-contraction of thigh musculature, we compared ES and VE muscle-strengthening regimens in patients during

the initial phase of post-operative ACL reconstruction. Using a posttest group design, we randomly placed 20 patients in either an ES Group (n = 10) or a VE Group (n = 10). We found significantly greater isometric strength gains of both

knee extensor and flexor muscles of patients in the ES Group compared with patients in the VE Group. Possible reasons for this disparate result and functional considerations are discussed.

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