Effectiveness of electrical stimulation on rehabilitation after ligament and meniscal injuries: a systematic review
Efetividade da estimulação elétrica na reabilitação pós-lesões ligamentares e meniscais: uma revisão sistemática

Aline Mizusaki Imoto¹, Stella Peccin², Gustavo Jerônimo Melo Almeida³, Humberto Saconato⁴, Álvaro Nagib Atallah⁵

Brazilian Cochrane Centre, São Paulo, Brazil

ABSTRACT

CONTEXT AND OBJECTIVE: Electrical stimulation (ES) is widely used to strengthen muscles following ligament and meniscal injuries. The aim of this study was to evaluate the effectiveness of ES for rehabilitation after soft tissue injuries of the knee treated surgically or conservatively.

DESIGN AND SETTING: Systematic review at the Brazilian Cochrane Center.

METHODS: We searched the Cochrane Central Register of Controlled Trials (2010, Issue 12), Medline (Medical Analysis and Retrieval System Online) via PubMed (1966 to December 2010), Embase (Excerpta Medica database, 1980 to December 2010), Lilacs (Literatura Latino-Americana e do Caribe em Ciências da Saúde, 1982 to December 2010), and PEDro (Physiotherapy Evidence Database, 1929 to December 2010). The studies included were randomized controlled trials using ES to increase muscle strength for rehabilitation of patients with soft tissue injuries of the knee. Two authors independently evaluated studies for inclusion and performed data extraction and methodological quality assessment.

RESULTS: Seventeen studies evaluating ES after anterior cruciate ligament reconstruction and two studies evaluating ES after meniscectomy were included. There was a statistically significant improvement in quadriceps strength through ES (mean difference, MD: -32.7; 95% confidence interval, CI: -39.92 to -25.48; n = 56) and in functional outcomes (MD -7; -12.78 to -1.22; n = 43) six to eight weeks after surgical reconstruction of the anterior cruciate ligament.

CONCLUSION: There is evidence that ES coupled with conventional rehabilitation exercises may be effective in improving muscle strength and function two months after surgery.

KEYWORDS:
Electric stimulation therapy.
Rehabilitation.
Knee joint.
Knee injuries.
Physical therapy modalities.

PALAVRAS-CHAVE:
Terapia por estimulação elétrica.
Reabilitação.
Articulação do joelho.
Traumatismos do joelho.
Modalidades de fisioterapia.
INTRODUCTION
Knee injuries can be considered to be a modern epidemic. They are more common among people between 10 and 29 years of age and occur more often among men (57%). Soft tissue injuries of the knee most frequently involve the menisci or knee ligaments. The incidences of these injuries are 0.3 and 0.7 per 1000 individuals/year, respectively. The anterior cruciate ligament (ACL) is the ligament most frequently damaged, and the medial meniscus is the most frequently damaged meniscus. One study investigating associations between ACL and meniscal injury found that 86% of the patients with ACL insufficiency had an associated meniscal injury, while 58% presented this association in another study.

In general, knee soft tissue injuries occur when the knee twists while bearing weight. The injury severity depends on the excess movement and force on the knee joint.

Muscle wasting and weakness are well-known effects following joint surgery and immobilization. Improvement of muscle strength is a major goal to be achieved early during rehabilitation. For example, atrophy and weakness quickly develop in the quadriceps muscle after ACL reconstructive surgery. Five to six weeks of immobilization following serious ligament injury or surgery induces significant changes in type 1 muscle fibers in the quadriceps and 60% to 80% reduction in isometric quadriceps strength. Muscle strength is important for recovering physical function, and compromised thigh muscle strength has been shown to be associated with abnormalities of walking velocity, stride length and pace.

Avoidance of isolated use of the knee extensor muscle, in order to protect the newly made ligament, and time are the two main requirements in the rehabilitation process. Rehabilitation may include exercises and electrostimulation (ES) to improve quadriceps strength. ES is recommended as an adjunct treatment for quadriceps strengthening after anterior cruciate ligament reconstruction and has also been shown to improve quadriceps femoral torque produced after ligament knee surgery. The most frequently used currents are: alternating current (2500 Hz) and pulsed biphasic asymmetric rectangular current. The choice of electrical current must be based on the capacity of electrical stimulation to produce an effective contraction. ES is widely used to strengthen muscles after soft tissue injuries of the knee such as ligament and meniscal injuries, and after surgery to treat these conditions, such as anterior cruciate ligament reconstruction. It is therefore important to conduct a systematic review to assess the effectiveness of electrical stimulation for improving the strength of muscles following soft tissue injuries of the knee, treated conservatively or surgically.

OBJECTIVES
To assess the effectiveness of ES for rehabilitation after soft tissue injuries of the knee (anterior cruciate, posterior cruciate, lateral and medial ligament and meniscal injuries), treated surgically or conservatively.

METHODS
Types of studies included: This review included randomized or quasi-randomized controlled trials.

Types of participants: The patients included in this review were 14 years old or over, with soft tissue injuries of the knee (acute or chronic injury of the anterior or posterior cruciate ligament, medial or lateral collateral ligament, menisci, alone or in combination), treated surgically or conservatively.

Types of interventions: The rehabilitation protocols that were assessed involved ES as a component of a rehabilitation program after soft tissue injuries of the knee.

Controls: The controls received no treatment, placebo, other physical intervention or conventional rehabilitation.

Types of outcome measurements
Primary outcomes: The primary outcomes were muscle strength; functional outcomes (e.g. self-selected walking speed, number of participants using crutches or number of participants who did not progress to the treadmill); pain, as measured using a visual analogue scale; and functional scales, e.g. the activities of daily living (ADL) scale and Lysholm score.

Secondary outcomes: The secondary outcomes were range of motion; KT-1000 arthrometer results; subjective and objective laxity/instability of the knee; swelling; and time taken to return to work, at pre-injury level of activity.

Search strategy to identify studies
We searched the Cochrane Central Register of Controlled Trials (Cochrane Library 2010, Issue 12); Medline (Medical Analysis and Retrieval System Online) via PubMed (1966 to December 2010); Embase (Excerpta Medica Database; 1980 to December 2010); Lilacs (Literatura Latino-Americana e do Caribe em Ciências da Saúde; available at http://bases.bvs.br, from 1982 to December 2010); Cumulative Index to Nursing and Allied Health Literature (CINAHL; 1982 to December 2010); PEDro (Physiotherapy Evidence Database, 1992 to December 2010), at http://www.pedro.fhs.usyd.edu.au/index.html); and the reference lists of studies. We also contacted study authors and experts in order to identify unpublished data. No language restrictions were applied.

The search strategies for randomized controlled trials in PubMed, Embase and Lilacs were combined with subject-specific search terms (electrical stimulation terms and knee injury terms). The strategies of Medline via PubMed were adapted for other databases. The PubMed search strategy was the following: (knee AND (injur* OR ligament* OR tendon* OR (soft tissue OR menisc*)) AND ((electric* AND stimulation) OR (neuro...})

**Methods**

Two authors independently selected trials for inclusion. Any disagreements were resolved through consultation with a third author.

Two authors independently extracted the data. Data relating to methodological issues, participants’ characteristics, interventions and outcome measurements were extracted using a standard extraction form.

Two authors independently assessed trial quality using the Delphi list18 (Table 1). The numbers of positive answers to the questions in the questionnaire were expressed as percentages.

**Data analysis**

For dichotomous data, the relative risk (RR) and 95% confidence interval (CI) were calculated. Continuous outcomes were analyzed using the mean and standard deviation of endpoint measurements, in order to generate the mean difference (MD) and 95% CI. The Rev Man 5 statistical package supplied by the Cochrane Collaboration was used to perform meta-analyses.

The presence of heterogeneity was investigated by means of the chi-square test and the I² test. The heterogeneity was considered statistically significant when I² was greater than 50% and the P-value was less than <0.10 (<10%).

**Table 1. Delphi list**

<table>
<thead>
<tr>
<th>Delphi list</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Allocation</strong></td>
</tr>
<tr>
<td>a) Was the method of randomization performed? Yes/No/Don’t know</td>
</tr>
<tr>
<td>b) Was the method of random allocation concealed? Yes/No/Don’t know</td>
</tr>
<tr>
<td><strong>2. Were the groups similar at baseline regarding the most important prognostic characteristics?</strong> Yes/No/Don’t know</td>
</tr>
<tr>
<td><strong>3. Were both inclusion and exclusion criteria specified?</strong> Yes/No/Don’t know</td>
</tr>
<tr>
<td><strong>4. Was the outcome assessor blinded?</strong> Yes/No/Don’t know</td>
</tr>
<tr>
<td><strong>5. Was the care provider blinded?</strong> Yes/No/Don’t know</td>
</tr>
<tr>
<td><strong>6. Was the patient blinded?</strong> Yes/No/Don’t know</td>
</tr>
<tr>
<td><strong>7. Were point estimates and measures of variability presented for primary outcome measure(s)?</strong> Yes/No/Don’t know</td>
</tr>
<tr>
<td><strong>8. Did the analysis include an ‘intention-to-treat’ analysis?</strong> Yes/No/Don’t know</td>
</tr>
</tbody>
</table>

**Results**

The results from the search were that the following were identified: 177 studies in Medline, of which 21 were selected for evaluation; 145 studies in Embase, of which 18 were selected for evaluation; 51 in PEDro, of which three were selected for evaluation; 33 in the Cochrane Controlled Trials Register, of which 21 were selected for evaluation; and five in Lilacs, of which none were selected. After taking into account the duplicated references in different databases, 19 studies were included and two were excluded.

**Description of the studies included**

The sample sizes ranged from eight to 110 patients. Participants’ ages ranged from 14 to 44 years. Most of the studies included (described in Table 2) involved patients undergoing ACL reconstruction. Two involved patients undergoing partial meniscectomy. These studies assessed the effectiveness of ES alongside rehabilitation programs to increase muscle strength, and ES was compared with: conventional exercises without ES and with different frequencies of ES; pulsed electromagnetic stimulation; and biofeedback therapy. The main outcome was muscle strength, which was assessed using an isokinetic dynamometer. Other outcomes assessed included: knee function questionnaires, KT-1000 arthrometer results, number of participants using crutches, number of participants whose rehabilitation did not progress to the use of a treadmill, walking velocity and stand time for the leg involved. Outcome measurements (isokinetic evaluation) were made between 1 and 52 weeks after surgery, and the isokinetic protocol involved differences in muscle contraction (isometric or isokinetic), test velocity and knee isometric test angle.

**Excluded studies**

The studies that were excluded19,20 are presented in Table 3.

**Methodological quality of the studies included (Table 4)**

The studies that were included presented some methodological flaws. None of the studies described concealment of allocation at the time of randomization. Among the studies with drop outs,13,15,21,22 only Fitzgerald et al.15 mentioned intention-to-treat analysis. The baseline participant characteristics were well described and the groups were comparable. The interventions and outcomes were well defined and described. Blinded outcome assessment was reported in four studies.15,21,23,24 None of the studies included reported sample size calculations.

**Results from comparisons**

**Comparison 1: conventional rehabilitation with and without ES**

**Isometric quadriceps peak torque**

At four weeks after surgery, according to Lieber et al.,25 the magnitude of the increase in isometric quadriceps torque was not
<table>
<thead>
<tr>
<th>Study</th>
<th>Setting</th>
<th>Inclusion criteria</th>
<th>Exclusion criteria</th>
<th>ES parameters</th>
<th>ES group characteristics</th>
<th>Control group characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anderson et al.</td>
<td>Nashville, Tennessee, USA</td>
<td>Patients with cruciate ruptures after surgery</td>
<td>Age (mean) and sex:</td>
<td>Group 1: knee immobilizer in extension + quadriceps exercise</td>
<td>1. ES (n = 17): F: 2500 Hz/50 Hz. 5 days a week, for 3 weeks.</td>
<td>1. ES (n = 17): F: 2500 Hz, pulsed at 50 Hz, 5 days a week, for 3 weeks.</td>
</tr>
<tr>
<td>Buhmann et al.</td>
<td>Göttingen, Germany</td>
<td>Patients with cruciate ruptures after surgery</td>
<td>Age:</td>
<td>Group 2: knee immobilizer in extension + quadriceps exercise + TENS</td>
<td>1. ES (n = 17): F: 2500 Hz/50 Hz. 5 days a week, for 3 weeks.</td>
<td>1. ES (n = 17): F: 2500 Hz, pulsed at 50 Hz, 5 days a week, for 3 weeks.</td>
</tr>
<tr>
<td>Delitto et al.</td>
<td>Washington University Medical School, USA</td>
<td>Anterior cruciate ligament reconstruction and age between 19 to 44 years.</td>
<td>Sample:</td>
<td>Group 4: knee immobilizer in 60° flexion+ quadriceps exercise + ES 10 hrs. a day</td>
<td>2. Biofeedback (n = 15)</td>
<td>2. Biofeedback (n = 15)</td>
</tr>
<tr>
<td>Draper and Ballard</td>
<td>Knoxville Orthopaedic Clinic, USA</td>
<td>Between 15 and 44 years. ACL reconstruction.</td>
<td>Exclusion criteria: collateral ligament, posterior cruciate ligament injury or osteotomy.</td>
<td>Group 5: knee immobilizer in 60° flexion+ quadriceps exercise + TENS + CPM (35-70°)</td>
<td>1. ES (n = 10): F: 50 Hz, time on: 10 sec and time off: 70 sec, 30 minutes</td>
<td>1. Control Group (n = 10): conventional rehabilitation. Intervention: 6 weeks after surgery</td>
</tr>
<tr>
<td>Eriksson and Häggmark</td>
<td>Stockholm, Sweden</td>
<td>Patients with cruciate ruptures after surgery, with age between 20 and 40 years</td>
<td>All patients underwent isometric quadriceps training.</td>
<td>Group 1 (n = 4):</td>
<td>1. ES (n = 10): F: 200 Hz, time on: 5-6 sec and time off: 5 sec, for 1 hr, 5 days a week for 4 weeks</td>
<td>1. ES (n = 10): F: 200 Hz, time on: 5-6 sec and time off: 5 sec, for 1 hr, 5 days a week for 4 weeks</td>
</tr>
<tr>
<td>Fitzgerald et al.</td>
<td>USA</td>
<td>14 years and above.</td>
<td>Sample: 31, underwent anterior cruciate ligament reconstruction.</td>
<td>Group 2 (n = 4):</td>
<td>1. ES (n = 10): F: 2500 Hz, pulsed at 75 Hz, time on: 10 sec, time off: 50 sec, 2 days a week</td>
<td>1. ES (n = 10): F: 2500 Hz, pulsed at 75 Hz, time on: 10 sec, time off: 50 sec, 2 days a week</td>
</tr>
<tr>
<td>Lainey et al.</td>
<td>General and Marine Hospital, Owen Sound, Canada</td>
<td>Patients underwent meniscectomy surgery</td>
<td>All patients underwent isometric quadriceps training.</td>
<td>Group 3 (n = 4):</td>
<td>1. ES (n = 10): F: 2500 Hz, pulsed at 75 Hz, time on: 10 sec, time off: 50 sec, 2 days a week</td>
<td>1. ES (n = 10): F: 2500 Hz, pulsed at 75 Hz, time on: 10 sec, time off: 50 sec, 2 days a week</td>
</tr>
<tr>
<td>Lieber et al.</td>
<td>San Diego, California, USA</td>
<td>Surgical reconstruction of the anterior cruciate ligament within previous 2-6 weeks and the ability to position the knee in 90° flexion.</td>
<td>Sample: 40 men and women, 15-44 years</td>
<td>Group 4: knee immobilizer in 60° flexion+ quadriceps exercise + TENS</td>
<td>1. ES + exercises</td>
<td>1. ES + exercises</td>
</tr>
<tr>
<td>Rebai et al.</td>
<td>France</td>
<td>Sportsmen, aged between 22 and 35 years, ACL reconstruction.</td>
<td>Exclusion criteria: collateral ligament or meniscal injuries.</td>
<td>Group 6: as group 5 and additionally, isokinetic training for week 9 onwards after surgery.</td>
<td>1. ES (different frequency): F: 80 Hz, time on: 15 sec, time off: 75 sec, total time: 60 min.</td>
<td>1. ES (different frequency): F: 80 Hz, time on: 15 sec, time off: 75 sec, total time: 60 min.</td>
</tr>
</tbody>
</table>
Ross et al. Inclusion criteria: underwent ACL reconstruction; Age: 27.1 ± 4.89 (CK chain) and 28.4 ± 5.91 (ES group); exclusion criteria: meniscal and ligament injuries associated. All patients performed isometric quadriceps training for 1 week postoperatively.

Siebert et al. Inclusion criteria: underwent ACL reconstruction. Sample: 52 (34 men and 18 women); Age: 27.4. Group 1: Daily standardized postoperative exercise program. Group 2: ES: 25 Hz or 1100 Hz 6 times a day, 30 min. CT scan. Assessment: Before operation and 2 weeks, 6 weeks and 12 weeks afterwards.

Sisk et al. Inclusion criteria: ACL reconstruction. Sample: 10, age: 18 to 28 years. All patients were managed three times a week, from the first to sixth postoperative week. Group 1: High-intensity ES: f: 2500 Hz at a burst rate of 75 bursts per second, Time on: 11 s, Time off: 120 s, number of contractions: 15. Group 2: High volitional exercise, three times a week, number of contractions: 15 positioned sitting with the knee in 60° of flexion on isokinetic dynamometer. Group 3: Low-intensity ES four times a day, five days a week. Time on: 15 s, time off: 50 s, frequency: 55 Hz. Group 4: The patients received the treatment of groups 1 and 3. They did a combination of high and low-intensity ES.


Snyder-Mackler et al. Inclusion criteria: age: 15 to 43 years; diagnosis: ACL reconstruction with Achilles tendon allograft (n = 18), patellar-ligament allograft (n = 10), semitendinosus and gracilis tendons (n = 7), autologous patellar-ligament (n = 75). Exclusion criteria: none reported.

Williams et al. Inclusion criteria: post-arthroscopic meniscectomy patients. Sex: 3 females and 18 males; Age: range 18 to 45 years, mean 33 years. ES group: ES to the quadriceps 10 minutes, 5 times a week, frequency: 2500 Hz, pulsed at 50 Hz, 15 sec of contraction and 50 sec of resting. Control group: quadriceps and hamstring isometrics and an isotonic progressive resistance program 3 times a week.


Table 3. Excluded studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frankie et al.</td>
<td>Retrospective</td>
<td>All patients performed isometric quadriceps training for 1 week postoperatively. CK chain group: Rehabilitation with CK chain exercises. ES group: F: 50 Hz, time on: 15 s, time off: 35 s, for 6 weeks. Group 2: instruction in isometric co-contraction of the thigh muscles. Duration: 6 postoperative weeks.</td>
</tr>
<tr>
<td>Hörster et al.</td>
<td>Only electromyography (EMG) assessment</td>
<td>Paternostro-Sluga et al. assessed the quadriceps isometric peak torque at 12 weeks (MD -14.2 Nm; 95% CI: -16.55 to 44.95) and 52 weeks (MD -20.5 Nm; 95% CI: -5.49 to 46.49) after surgery. There was no statistically significant difference between the groups with and without ES. After one year, Lieber et al. did not find any significant difference between the groups. Isokinetic quadriceps peak torque. At six and eight weeks after surgery, the isokinetic peak torque was assessed at test velocities of 60 °/s and 90 °/s and 210 °/s. There was a statistically significant difference in favor of ES at test velocities of 90 °/s (MD -51.00 Nm; 95% CI: -26.80 Nm; 95% CI: -10.2) and 52 weeks (MD -38.8 Nm; 95% CI: -54.9 to -22.7), but not at a test velocity of 60 °/s. At 12 weeks (MD -51.00 Nm; 95% CI: -50.00 Nm; 95% CI: -51.00 Nm; 95% CI: -10.2) and 52 weeks (MD -26.80 Nm; 95% CI: -54.51 to 0.91) after surgery, Paternostro-Sluga et al. found that there was no statistical significant difference in quadriceps isokinetic peak torque between the groups. It was not possible to pool the data for this outcome because of the different isokinetic test velocities used and the different assessment times. Buhmann et al. found that the greatest increase in the group that received ES occurred over the final four weeks of the study. Staub et al. did not find...</td>
</tr>
</tbody>
</table>
any statistical significance between the ES group and the control group regarding increases and decreases in isometric peak torque at either 12 weeks or nine months after the operation. At 18 weeks, Anderson and Lipscomb\textsuperscript{28} found a statistically significant difference favoring the ES group.

**Isometric quadriceps index**

Two studies\textsuperscript{15,23} assessed the effectiveness of ES using the isometric quadriceps index at six, 12 and 16 weeks after surgery. There was a statistically significant difference in favor of ES six weeks after surgery (MD -27.10%; 95% CI: -39.37 to -14.83), whereas there was no statistically significant difference at 12 weeks (MD -8.9 Nm; 95% CI: -19.89 to 2.09) and 16 weeks (MD -8.10 Nm; 95% CI: -18.09 to 1.89) after surgery. It was not possible to do a meta-analysis because of the different evaluation dates. Snyder-Mackler et al.\textsuperscript{24} found at six weeks after surgery that the quadriceps had achieved 70% recovery with high-intensity exercise and 57% with volitional exercise.

**Isokinetic quadriceps index**

At eight weeks after surgery, Snyder-Mackler et al.\textsuperscript{16} assessed the isokinetic quadriceps index at two test velocities. There was a statistically significant difference in favor of ES at the test velocities of 90 °/s (MD -23.4%; 95% CI: -29.32 to -17.48) and 210 °/s (MD -25.2 Nm; 95% CI: -30.07 to -20.33).

**Functional outcomes**

**ADL questionnaire**

At 12 and 16 weeks after surgery, Fitzgerald et al.\textsuperscript{15} showed that there was a statistically significant difference in favor of ES in relation to the ADL questionnaire on both occasions (MD -7 Nm; 95% CI: -12.78 to -1.22; and MD -5.1 Nm; 95% CI: -9.74 to 0.46).

**Lysholm score (without correlatable data)**

At 12 weeks and nine months, there was no statistical significance between the ES and control group regarding Lysholm and Tegner scores in the study by Staub et al.\textsuperscript{27}
Range of motion
At 18 weeks, Anderson and Lipscomb\(^2\) found a greater range of motion in the ES group (without correlatable data).

Number of participants using crutches
At four and eight weeks after surgery, Fitzgerald et al.\(^1\) found that there were no statistically significant differences in the number of participants using crutches.

Number of participants who did not progress to treadmill running
Fitzgerald et al.\(^1\) assessed the number of participants who did not progress to treadmill running and found that there were no statistically significant differences at 12 weeks (RR 0.7; 95% CI: 0.36 to 1.36) or 16 weeks (RR 0.45; 95% CI: 0.13 to 1.51) after surgery.

Gait analysis
Gait was assessed in one study.\(^3\) There were statistically significant differences in favor of ES regarding gait velocity (MD -0.28 m/s; 95% CI: -0.34 to -0.22), standing time on the side involved (MD -6.80 s; 95% CI: -8.92 to -4.68) and cadence (MD -6.10; 95% CI: -8.22 to -3.98).

Fastex test (gait step test, stabilization step test and quick feet test)
At 12 weeks and nine months after surgery, Staub et al.\(^2\) did not find any statistically significant difference between the ES and control group (without correlatable data) in the Fastex test.

Unilateral squat test, lateral step test and forward reach test
At six weeks after the operation, Ross\(^2\) did not find any statistical significance between the groups in the unilateral squat test (MD 6.07; 95% CI: -8.81 to 20.95), lateral step test (MD -3.30 s; 95% CI: -1.20 to 7.80) or forward reach test (MD 58.75 s; 95% CI: 0.45 to 5.90).

Knee pain
Fitzgerald et al.\(^1\) found that there were no statistically significant differences in knee pain at 12 weeks (MD -0.3; 95% CI: -0.7 to 1.3) or 16 weeks (MD -0.2; 95% CI: -0.89 to 0.49) after the surgery.

Muscle strength (manual muscle test)
Patients who underwent ES performed better in the manual muscle test than did the control group.\(^3\)

KT-1000 (instrumental stability test)
Buhmann et al.\(^2\) did not find any significant differences between the treatment groups (no data presented).

Computed tomography scan
Siebert et al.\(^2\) studied patients who underwent knee ligament surgery. At six weeks after the operation, the quadriceps area had become significantly reduced in the control and physical exercise group, in comparison with the group that had exercise combined with electrical stimulation.

Comparison 2: Conventional rehabilitation with ES versus conventional rehabilitation with biofeedback
One study made this comparison. At six weeks after surgery, Draper and Ballard\(^3\) found a statistically significant difference in favor of biofeedback regarding the isometric quadriceps index (MD -8.5 Nm; 95% CI: -16.72 to -0.28).

Range of motion
There was no difference in the range of motion between the two groups at one week (MD 0.4; 95% CI: -2.12 to 2.92), two weeks (MD -0.6; 95% CI: -4.43 to 3.23) or four weeks (MD 1.0; 95% CI: -2.55 to 4.55) after surgery.

Comparison 3: Conventional rehabilitation with ES of 20 Hz versus conventional rehabilitation with ES of 80 Hz
Isometric quadriceps peak torque
At 12 weeks after surgery, Rebai et al.\(^1\) found that there was no statistically significant difference between using ES of 20 Hz and using ES of 80 Hz. After 12 weeks of rehabilitation, the quadriceps peak torque deficit was less than 30%, except for two patients in the 20 Hz stimulated group (without correlatable data).

Volume deficit
The thigh muscle volume deficit in the operated limb was between 3% and 9% in the 20 Hz stimulated group and between 1% and 2% in the 80 Hz stimulated group, in the study by Rebai et al.\(^1\) (without correlatable data).

Comparison 4: Conventional rehabilitation with high-intensity ES of 2500 Hz at a burst rate of 75 Hz versus conventional rehabilitation with low-intensity ES of 55 Hz
Isometric quadriceps index
Snyder-Mackler et al.\(^2\) found at six weeks after surgery that the degree of quadriceps recovery was 70% with high-intensity training and 51% with low-intensity training (without correlatable data).

Comparison 5: ES versus ES plus pulsed electromagnetic field
Thigh girth
In the study by Currier et al.,\(^3\) at six weeks after surgery, there was no difference between the groups regarding thigh girth measured at 12 cm (MD -2.8 cm; 95% CI: -8.17 to 2.57), 20 cm (MD -1.6 cm; 95% CI: -7.38 to 4.18) and 25 cm (MD -1.4 cm; 95% CI: -7.21 to 4.41) proximally to the superior patellar pole.

Results for meniscectomy patients
Comparison: Conventional rehabilitation with ES versus conventional rehabilitation
**Isometric quadriceps peak torque**

There was no significant difference between the groups in the study by Williams et al.,34 at three weeks after meniscectomy (MD 22.3 Nm; 95% CI: -0.1 to 4.47). At six weeks, no differences were found between the groups in the study by Lainey et al.35 (without correlatable data).

**DISCUSSION**

The studies included did not address all of our objectives. Heterogeneous strength assessment protocols (evaluation data, test position and test speed) need to be standardized in order to compare results from ES studies. The participants in the studies included in this review were patients who underwent surgical reconstruction of the anterior cruciate ligament and meniscectomy, so the results from this review should not be generalized to people with collateral or posterior cruciate ligament injuries.

This review found that muscle strength was higher six weeks after surgery with ES. This finding can be explained by two theories: firstly, a combination of ES and voluntary exercise results in more exercise for the muscle; and secondly, there is preferential activation of type II fibers through ES. Activation of both types of fibers may result in an improvement of strength. Better results from ES over the initial rehabilitation period may be associated with weaker muscles over this period (six to eight weeks after surgery), and an additional stimulus (ES) makes a strong difference. We recommend that ES should be used over the first six weeks after surgery. Based on the studies included, we recommend that the ideal low frequency for increasing muscle strength ranges from 35 to 80 Hz. For cases of medium frequency, the modulation should be at 2500 Hz/50-75 Hz. The pulse duration should be around 200 to 350 microseconds and it is recommended that the relationship between contraction and resting times should be about 1:5 during the early rehabilitation phase.

Functional assessment is extremely important because returning to normal activities is the main goal of rehabilitation. Functional improvements were achieved through the use of ES, in relation to the following outcomes: activities of daily living scale, walking velocity and time spent standing on the injured leg.

One possible limitation of our study is that we carried out just one meta-analysis with only three studies, because of data heterogeneity. For the studies without correlatable data, we made a description of the results.

We carried out a literature search in which we placed importance on the quality aspects of the studies. The Consolidated Standards for Reporting Trials (CONSORT) Statement is a checklist of items that the reports on clinical trials must follow. The CONSORT Statement,36 which was created in 1999 and updated in 2010, aims to improve reports on randomized clinical trials, help authors to recognize suitable study designs and assess study validity. Most of the studies included in this review did not follow the precepts of the CONSORT Statement: there was no reporting of allocation concealment in any study; none of them reported sample size calculation; and, of the studies with drop-outs, only one mentioned intention-to-treat analysis. Using the Delphi list to assess the studies, the studies were found to fulfill at least half of the items: the groups of patients were similar at the baseline; all the inclusion criteria were well described; all the studies were randomized; and, in three studies, the assessor was blinded.

A systematic review published in 200557 assessed the effectiveness of ES on the quadriceps muscles of both healthy and injured individuals. The present study focused only on injured individuals and, in addition to strength, we reported knee function outcomes. In contrast to Bax et al.,37 we included only randomized controlled clinical trials. One of the conclusions of the previous systematic review was that ES might be more effective than voluntary exercises on weakened muscles. Our review agrees with another systematic review published in 2010,38 which included eight studies and concluded that ES combined with exercise might be more effective in improving quadriceps strength than exercise alone and that inconsistencies were noted in the ES parameters and their application.

**CONCLUSION**

The evidence available from randomized clinical trials of limited quality shows that electrical stimulation, in combination with a conventional rehabilitation program, might be more effective for improving muscle strength and function for up to two months after ACL reconstruction than conventional rehabilitation alone.

**Implications for research**

Randomized controlled trials of better methodological quality, with adequate sample size and with at least 12 months of follow-up are necessary to ascertain the effectiveness of ES for increasing the muscle strength of patients with soft tissue injuries of the knee.

**REFERENCES**


28. Ross M. The effect of neuromuscular electrical stimulation during closed kinetic chain exercise on lower extremity performance...


Sources of funding: None
Conflict of interest: None

Date of first submission: December 23, 2010
Last received: May 9, 2011
Accepted: May 23, 2011

Address for correspondence:
Aline Mizusaki Imoto de Oliveira
Rua Pedro de Toledo, 598
Vila Clementino — São Paulo (SP) — Brasil
CEP 04039-001
Tel. (+55 11) 5575-2970
E-mail: aline.mizusaki@globo.com