An update on the use of clinical electrical stimulation – Protocols and applications

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Today’s talk

- Brief review of electrical stimulation applications
- New protocols in muscle stimulation
- New applications in pain relief
- New technology and applications in iontophoresis
Review of electrical stimulation

• External currents are applied to the appropriate tissues (typically nerves)
Basics

- 2 connections to complete circuit
- **Anode** - the positive terminal or lead
  - Red
- **Cathode** - the negative terminal or lead
  - Black
More basics

• Resistance
  – Resistance to flow of particles
  – High = fat, dry skin
  – Low = muscle, clean and moist skin

• Capacitance
  – Ability to store particles – does us no good
  – Must be overcome
Control resistance

- Dry skin or oily skin – 3000 ohms
- Clean moist skin – 100 ohms
- Hydrate electrodes
Types of Current

- **Direct current** (DC, Galvanic current, monophasic)
- **Alternating current** (AC, biphasic)
- **Pulsatile current**

Pulses are separated by a period of time without current flow.
Electrodes

- Types
  - Self adhesive
  - Carbonized
  - Sponge
Effects of electrical current

Na Gate opens

+40 mV

OCC
• The nerve fibers are depolarized by the electrical stimulation.
• The negative lead will pull the positive ions toward it causing an AP.
• This is the reason the negative electrode is considered more “active” in NMES.
Motor Stimulation

- The largest, most superficial nerve fibers in the nerve bundle will be stimulated by NMES first.
- As the intensity of the NMES increases, more motor fibers and thus more motor units (and muscle fibers) will be stimulated.

This is a cross section of a peripheral nerve with its many nerve fibers enclosed. The largest and most superficial fibers will be stimulated first.
NMES vs. voluntary

- **Voluntary**
  - Slow twitch
  - Fire at increasing frequency up to 50/sec
  - Asynchronous recruitment

- **NMES**
  - Fast twitch
  - Fire at 35-50 pps
  - Synchronous recruitment
Ab stomper
Keep in mind with NMES

- 2 way street
  - Efferent (motor nerve) activation obviously
  - Afferent activity also (spindles, GTOs)
- This feedback loop may be as important as the actual muscle activation
Lower extremity – knee scope

- Wilk et al 2010, Cartilage 1(2):96-107
Effects of Neuromuscular Electrical Stimulation After Anterior Cruciate Ligament Reconstruction on Quadriceps Strength, Function, and Patient-Oriented Outcomes: A Systematic Review

Kyung-Min Kim, Ted Croy, Jay Hertel, Susan Saliba*
Effects of Neuromuscular Electrical Stimulation After Anterior Cruciate Ligament Reconstruction on Quadriceps Strength, Function, and Patient-Oriented Outcomes: A Systematic Review

![Diagram of study selection process]

**FIGURE 1:** Study selection. Abbreviations: CPG, clinical practice guideline; RCT, randomized clinical trial; SD, standard deviation.

**Literature Review:**

*Effects of Neuromuscular Electrical Stimulation After Anterior Cruciate Ligament Reconstruction on Quadriceps Strength, Function, and Patient-Oriented Outcomes: A Systematic Review*

| VOLUME 40 | NUMBER 7 | JULY 2010 | © 2010 JOURNAL OF ORTHOPAEDIC & SPORTS PHYSICAL THERAPY |
### TABLE 1

<table>
<thead>
<tr>
<th>Author</th>
<th>PEDro Scores</th>
<th>NMES</th>
<th>Control</th>
<th>NMES Intervention</th>
<th>Control Intervention</th>
<th>Outcome Measure</th>
<th>NMES (Mean ± SD)</th>
<th>Control (Mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sisk</td>
<td>4</td>
<td>10</td>
<td>9</td>
<td>NMES + EX</td>
<td>EX</td>
<td>Isometric (Nm)</td>
<td>0.73 ± 0.41*</td>
<td>0.70 ± 0.30*</td>
</tr>
<tr>
<td>Delitto</td>
<td>4</td>
<td>10</td>
<td>10</td>
<td>NMES</td>
<td>EX</td>
<td>Isometric (ft-lb)</td>
<td>114.0 ± 41.0*</td>
<td>84.0 ± 20.0*</td>
</tr>
<tr>
<td>Wigerstad-Lossing</td>
<td>4</td>
<td>13</td>
<td>10</td>
<td>NMES + EX</td>
<td>EX</td>
<td>Isometric (Nm)</td>
<td>900.0 ± 90.0*</td>
<td>570.0 ± 90.0*</td>
</tr>
<tr>
<td>Draper</td>
<td>4</td>
<td>15</td>
<td>15</td>
<td>NMES + EX</td>
<td>EMG Biofeedback + EX</td>
<td>Isometric (ft-lb)</td>
<td>379.0 ± 12.4*</td>
<td>46.4 ± 10.5*</td>
</tr>
<tr>
<td>Snyder-Mackler</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>NMES + EX</td>
<td>EX</td>
<td>Isokinetic (Nm)</td>
<td>210°/s (avg torque)</td>
<td>46.8 ± 6.0*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>90°/s (avg torque)</td>
<td>65.8 ± 10.8*</td>
<td>36.8 ± 6.5*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>210°/s (peak torque)</td>
<td>114.8 ± 21.0*</td>
<td>63.6 ± 11.3*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>90°/s (peak torque)</td>
<td>95.2 ± 14.4*</td>
<td>56.4 ± 11.4*</td>
</tr>
<tr>
<td>Paternostro</td>
<td>4</td>
<td>16</td>
<td>17</td>
<td>NMES + EX</td>
<td>TENS + EX, EX only</td>
<td>Isokinetic (Nm)</td>
<td>108.8 ± 55.3*</td>
<td>81.4 ± 32.2*</td>
</tr>
<tr>
<td>Ross</td>
<td>3</td>
<td>10</td>
<td>10</td>
<td>WB EX + NMES</td>
<td>WB EX</td>
<td>Lateral step-up test</td>
<td>1765.0 ± 5.36</td>
<td>14.35 ± 4.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Anterior reach</td>
<td>58.75 ± 7.38</td>
<td>58.3 ± 4.78</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Unilateral squat</td>
<td>70.55 ± 18.46</td>
<td>64.48 ± 15.36</td>
</tr>
<tr>
<td>Fitzgerald</td>
<td>6</td>
<td>21</td>
<td>22</td>
<td>NMES</td>
<td>EX</td>
<td>Isokinetic (Quad index)</td>
<td>7.59 ± 16.8*</td>
<td>670.0 ± 193*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Self-reported function (12 wk)</td>
<td>892.0 ± 89.3*</td>
<td>82.2 ± 10.4*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Self-reported function (16 wk)</td>
<td>91.05 ± 7.3*</td>
<td>86.4 ± 8.2*</td>
</tr>
</tbody>
</table>

**Abbreviations:** Avg, average; EMG, electromyography; EX, therapeutic exercises; ft-lb, foot-pounds; Nm, Newton meter; NMES, neuromuscular electrical stimulation; PEDro, Physiotherapy Evidence Database scale; Quad Index, quadriceps index; TENS, transcutaneous electrical nerve stimulation; WB, weight bearing.

* Isometric knee extension torque.
* Isokinetic knee extension torque at various testing angular velocities.
* Self-reported measures of knee function at 12 and 16 weeks following ACL reconstruction.
### TABLE 2

**Summary of Neuromuscular Electrical Stimulation Treatment Parameters**

<table>
<thead>
<tr>
<th>Author</th>
<th>Frequency</th>
<th>Pulse Width</th>
<th>Duty Cycle</th>
<th>Intensity</th>
<th>Treatment Course (Duration)</th>
<th>Treatment Sessions</th>
<th>Follow-up Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sisk⁵</td>
<td>40 Hz</td>
<td>300 μs</td>
<td>10 s on, 30 s off</td>
<td>MTL</td>
<td>1st-6th wk (6 wk)</td>
<td>38</td>
<td>7th wk</td>
</tr>
<tr>
<td>Delitto⁶</td>
<td>50 Hz</td>
<td>400 μs</td>
<td>15 s on, 50 s off</td>
<td>MTL</td>
<td>2nd or 3rd-6th wk (3 wk)</td>
<td>15</td>
<td>6th wk</td>
</tr>
<tr>
<td>Wigerstad-Lossing¹¹</td>
<td>30 Hz</td>
<td>300 μs</td>
<td>6 s on, 10 s off</td>
<td>65-100 mA</td>
<td>1st-6th wk (6 wk)</td>
<td>18</td>
<td>6th wk</td>
</tr>
<tr>
<td>Draper⁷</td>
<td>35 Hz</td>
<td>N/A</td>
<td>10 s on, 20 s off</td>
<td>MTL &lt;50 mA</td>
<td>1st-6th wk (6 wk)</td>
<td>105</td>
<td>6th wk</td>
</tr>
<tr>
<td>Snyder-Mackler²⁸</td>
<td>75 Hz</td>
<td>400 μs</td>
<td>15 s on, 50 s off</td>
<td>MTL</td>
<td>3rd-6th wk (4 wk)</td>
<td>12</td>
<td>6th wk</td>
</tr>
<tr>
<td>Paternostro²⁰</td>
<td>30 Hz</td>
<td>200 μs</td>
<td>5 s on, 15 s off</td>
<td>MTL</td>
<td>1st-6th wk (6 wk)</td>
<td>38</td>
<td>6th wk</td>
</tr>
<tr>
<td>Ross²⁴</td>
<td>50 Hz</td>
<td>200 μs</td>
<td>15 s on, 35 s off</td>
<td>MTL</td>
<td>1st-6th wk (6 wk)</td>
<td>26</td>
<td>6th wk</td>
</tr>
<tr>
<td>Fitzgerald⁶</td>
<td>75 Hz</td>
<td>400 μs</td>
<td>10 s on, 50 s off</td>
<td>MTL</td>
<td>3rd-14th wk (11 wk)</td>
<td>21</td>
<td>12th-16th wk</td>
</tr>
</tbody>
</table>

**Abbreviations:** Hz, hertz; MTL, maximally tolerated level; N/A, not available.

* Start and end of treatment in the postoperative weeks.

¹ Estimated number of treatment sessions (treatments a week multiplied by the number of weeks).

² Time point after anterior cruciate ligament reconstruction when outcome measures were taken.

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**Literature Review:**

*Effects of Neuromuscular Electrical Stimulation After Anterior Cruciate Ligament Reconstruction on Quadriceps Strength, Function, and Patient-Oriented Outcomes: A Systematic Review*
FIGURE 2. Isometric and isokinetic knee extension strength outcomes. Data are effect sizes calculated from group differences, and their 95% confidence intervals in parentheses. The corresponding study reference number is indicated next to the parentheses. Abbreviation: NMES, neuromuscular electrical stimulation.

Literature Review:
Effects of Neuromuscular Electrical Stimulation After Anterior Cruciate Ligament Reconstruction on Quadriceps Strength, Function, and Patient-Oriented Outcomes: A Systematic Review
FIGURE 3. Functional performance test outcomes. Data are effect sizes calculated from group differences and corresponding 95% confidence intervals from Ross et al. Abbreviation: NMES, neuromuscular electrical stimulation.
FIGURE 4. Self-reported function outcomes (Knee Outcome Survey activities of daily living scale). Data are effect sizes calculated from group differences and corresponding 95% confidence intervals from Fitzgerald et al. Abbreviation: NMES, neuromuscular electrical stimulation.
Some NMES quad activities

- Squats using switch
- Gait using switch or heel switch
- TENS during ther ex and ADLs
  – Pietrosimone et al, JOSPT 2011; 41(1):4-12
NEXT TOPIC – EDEMA MANAGEMENT and TISSUE HEALING

- Red blood cells
  - Slightly negative
- Albumin proteins
  - Slightly negative
- Attraction/repulsion?
- Injury current
Chronic edema

- Twitchy contraction to activate calf pump, move skin and lymphatic tissue
- 5-15 pps
- Twitchy, tolerable contractions
- 200-300 microsecond duration
- Any waveform
LE treatment protocol

- 2 channels
- 5 pps, 250 microsecond pulse duration
- 30 seconds on, 0 seconds off
- Synchronous
- Top/bottom of foot – channel 1
- Ant tib/calf – channel 2
Chronic edema evidence

- Man et al – “Effect of neuromuscular electrical stimulation on foot/ankle volume during standing “
- 20 healthy subjects – standing vs. standing with stim to gastroc and ant tib
Man cont

• Volumetric measurements
  – Stim group = 12+/- 39 ml gain
  – Control group = 51+/- 32 ml gain
  – Significant at p=0.001
Chronic edema evidence

- 10 post stroke subjects with LE edema
- Stim vs. sequential compression vs control
Faghri cont

• Measured girth and volume pre, after standing, and post intervention
• Stim comparable to SCD
Chronic edema evidence


• 10 healthy volunteers
• Vol, stim, vol+stim
• Multiple venous and cardiac measures
Faghri cont

• Comparable venous return in standing with stim and voluntary
• Best return with combination
Acute edema

- Use soon post injury/post therapy
- Typically uses HVPC
Acute edema

- Can use electrodes or sock/glove (with large dispersive)
- 100 pps
- Cathode on edema prone area
- Intensity as tolerated
- Maybe some pain relief too
Mechanisms

HISTAMINE

Endothelial cell

Ca+ Stores

Ca+

Ca+

Ca+

Endothelial cell
Mechanisms

Contraction of the Myofibrils cause the cell to shrink
Dipoles at
- Histamine binding site
- Gate on calcium storage vesicle
- Binding site on endothelial cells
Animal models


- Hamster cheeks injected with histamine
Karnes et al

- Measured leakage of albumin proteins
- Less leakage with HVPC and sub motor levels
- Proposed mechanisms
Acute Edema protocol

- HiVolt waveform in 300PV
- 100 pps
- Positive polarity (red wire is +)
- Black wire (with splitter) on ankle
- Red wire – large electrode on low back
- 30 seconds on, 0 seconds off
Pulsed US and cartilage

• Loyola-Sanchez et al, APMR Jan 2012
• 27 adults with medial knee joint space narrowing
• 24 sessions of US (n=14)
  – 20% duty cycle
  – 1 MHz, .2 W/cm²
  – Compared to sham US group
• Measured cartilage volume, thickness on MRI
Pulsed US and cartilage

- Difference in cartilage thickness and volume between groups approached significance ($p=.09$)