NEUROMUSCULAR ELECTRICAL STIMULATION TO ENHANCE QUADRICEPS RECOVERY: AN EVIDENCE BASED APPROACH

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NMES
“Stimulation of weak Inhibited muscles”

- NMES (Neuromuscular Electrical Stimulation)
  - Stimulation through intact peripheral motor nerves
  - Treatment goals:
    - Retard Atrophy
    - Strengthen
    - Recover motor control
Review of Electrotherapy Currents

Electrotherapy Currents

- Pulsed Current
- Alternating Current
- Direct Current
Alternating Current

Phase

Note: The term cycle is the AC term for a “pulse”

Cycle is comprised of two phases deviating in opposite direction from baseline. Note: there is no space between the end of one cycle and the beginning of the next. This is why it can not be called a pulse.
Direct Current
Selecting Electrotherapy Parameters

“Electrotherapy is about building pulses or cycles (AC)”

The Ht (amplitude), width (phase or cycle duration), and frequency are manipulated to create a desired physiologic response.
Pulse (PC) and Cycle (AC) characteristics

- Amplitude: (intensity) mA = “how tall”
- Width: microseconds
  - Pulse duration (pulsed current)
  - Cycle duration (alternating current):
- “Carrier Freq Indirectly describes the cycle duration”
  - Carrier frequency of 2500 Hz = 400 µsec
  - Carrier frequency of 5000 Hz = 200 µsec
Pulse Current: Pulse Characteristics

Phase

Interphase Interval

Phase

Amplitude

300 microseconds

100 microseconds

Pulse duration
Alternating Current: Cycle Characteristics

Phase

Amplitude

300 µsec

Phase

Cycle Duration

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Alternating Current
(Russian Waveform)

- Sinusoidal waveform
- Carrier freq: 2,500 Hz
- Bursts of 10ms each
- Burst interval 10ms
- Duty cycle 50%

- Burst frequency 50Hz
- On:Off ratio 10:50 (10 secs on, 50 secs off)
Demystifying Alternating Current Waveforms (Cycle Duration = 1/freq)

<table>
<thead>
<tr>
<th>Carrier frequency</th>
<th>Cycle duration (AC term for pulse duration)</th>
<th>Phase duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000 Hz</td>
<td>500 µSec</td>
<td>250 µSec</td>
</tr>
<tr>
<td>2500 Hz</td>
<td>400 µSec</td>
<td>200 µSec</td>
</tr>
<tr>
<td>4000 HZ</td>
<td>250 µSec</td>
<td>125 µSec</td>
</tr>
<tr>
<td>5000 HZ</td>
<td>200 µSec</td>
<td>100 µSec</td>
</tr>
</tbody>
</table>

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Frequency

- Refers to how many times per second the pulse or cycle is delivered
- Expressed as pulses/sec or hertz (Hz)
- Termed beat frequency when AC is used
Frequency: clinical implications

- Frequency Determines which neurons are stimulated most **effectively**
  - Large neurons: 50-150Hz
    - $\alpha$ sensory
    - Fast twitch motor
  - Slow twitch motor neurons: 25-35Hz
  - Small myelinated $\delta$ sensory neurons: 1-10Hz
Pulse frequency in high intensity NMES procedure

- High pulse frequencies increase the rate of motor unit discharge (rate coding): resulting in increase force output.
- Disadvantage: Fatigue

Solution: do not exceed 50-75 pps or bps. Instead use large pulse or cycle durations and high amplitudes to recruit more MU’s
High Intensity NMES

- Majority of research is in the area of strength augmentation to the quadriceps S/P ACL reconstruction.
- High Intensity NMES in combination with a volitional exercise program has been shown to be superior to volitional exercise alone (Snyder-Mackler et al)

Problem of persistent quadriceps weakness s/p ACL reconstruction

Wilk et al reported that only 7% of subjects at 6 months S/P ACL reconstruction achieved 90% of uninvolved quad strength on isokinetic testing at 180 deg/sec.

Quad strength recovery 1 yr S/P ACL recon 61%- 91%.

Arangio, et al JOSPT 1997
Quadriceps Weakness S/P TKA

- Quad Strength = Primary impairment both Pre and post TKA
- 1st month post-op quad strength measure is affected more severely than other clinical measures such as ROM and Pain - 62% decline from pre-op strength
- High correlation between quad strength and improved functional performance

Contributing factors to Persistent quad weakness

- Knee joint effusion\(^1\) (Spencer 1984)
- Reflex inhibition due to pain
- Selective atrophy of fast twitch MM fibers (type IIb)
- Development of substitution patterns
- Selection of rehab interventions
  - Lack of specificity of exercise
  - Incorrect dosage of exercise

## Muscle fiber types

<table>
<thead>
<tr>
<th></th>
<th>Type I ‘Slow twitch’</th>
<th>Type II ‘Fast twitch’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contraction speed</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>Endurance</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Fatigue</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>Strength</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Function</td>
<td>Static, postural</td>
<td>Dynamic, explosive</td>
</tr>
</tbody>
</table>

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Muscle fiber types

Normal muscle – note that size of Type II is approximately 2x the size of Type I
Disuse atrophy

Atrophied muscle – note that size of type II is now almost half of size Type I.
Strength decreases associated with Immobilization

Muscle can lose 6 - 40% of its ability to generate force over a 4-6 wk period of immobilization.¹

CKC Approach

- Shelbourne and Nitz protocol for accelerated ACL rehab (1990)
- Emphasis on:
  - Early wt. Bearing
  - Early full passive knee extension
  - CKC strengthening

De Carlo, Shelbourne et al. JOSPT 1992;309-316
Ernst et al demonstrated that hip and ankle extensors compensate for a knee extensor moment deficit in the lateral step-down and vertical hop at 9 months S/P ACL recon.

OKC Interventions to Address Persistent Quad Weakness

- Priority = protection of graft and prevention of extensor mechanism dysfunction.
- OKC interventions in early rehab
  - Isometric knee extension at 60-90 deg
  - Isotonic knee extension between 60-90 deg
  - High intensity NMES isometric at 65 deg

Ross MD, Denegar CR. J Strength And Cond Research. 2001; 466-473
110 subject randomized multicenter study of patients S/P ACL reconstruction

Volitional EX only group – 4wk intervention attained 57% quad strength of uninvolved.

NMES/vol EX group – 4wk interv attained 70% or greater quad strength of uninvolved

A positive correlation between high intensity NMES group and improved knee flexion extension excursions during gait was identified on two dimensional motion analysis.

A separate low intensity NMES/volitional Ex group (portable battery powered) attained only 51% of the uninvolved quad strength.
Lyons et al Phys Ther 2005

- Found comparable results when quadriceps torque production of Empi 300PV was compared to force production elicited by clinical line powered unit (Russian Waveform)

- Supports the efficacy of using this model portable device for in clinic and home use

High Intensity NMES Procedure

- Selecting the appropriate NMES device
  - Clinical line powered model
  - Proven portable device
  - Large pulse or cycle durations (AC)
  - Sufficient amplitude capabilities
  - On/off time capabilities
Rationale for electrode size

- Small electrode
  - Increases current density
  - Recruits fewer motor units
  - More uncomfortable

- Large electrode (4x5 inches)
  - Recommended for this procedure
Patient position/set-up

- Knee isometrically braced at 65 deg using an electromechanical dynamometer.
- Dynamometer is used both for isometric baseline test of uninvolved and to monitor % of MVC achieved during each NMES contraction.
- Remember dosage of NMES is measured via MVIC.
Electrode placement

- Proximally: upper portion of VL mm belly
- Distally: mm belly of VMO
Fitzgerald et al research
JOSPT 2003

- Modified Snyder-Mackler approach: supine position with knee in full extension – no dynamometer
- Current dose:
  - Max tolerable full tetanic contraction
  - Visible and/or palpable superior glide of patella
- Not as great of gains as Snyder-Mackler protocol but still good. At 12 wks s/p ACL recon 75.9% quad recovery in NMES group compared to 67.0% in ex only group.

Fitzgerald et al. JOSPT. 2003;33:492-501
NMES parameters using AC

- Waveform: Russian
- Carrier frequency: 2500 Hz
- Frequency: 75 Bursts/sec
- On time: 10-15 sec
- Off time: 50-120 sec
- Ramp: 2 sec up: 2 sec down
- Amplitude: max tolerable, > 50% MVIC
- # of contractions: 10-15
- Sessions/wk: 3
NMES parameters (pulsed)

- Pulse duration: 400 microseconds or greater
- Frequency: 75 pulses/sec
- On time: 10-15 second contraction
- Off time: 50-120 second rest
- Ramp: 2 sec up: 2 sec down
- Amplitude: max tolerable, > 50% MVC
- # of contractions: 10-15
- # of sessions/wk: 3
Theoretical Mechanisms for NMES induced Strength Adaptations

- Over-riding of reflex inhibition
- SAID principle (overload)
Quadiceps Femoris Muscle Recovery (Involved/Uninvolved × 100) vs. Training Intensity (%MVC Uninvolved)
Contraindications

- Musculotendinous lesion, in which tension on the tissue would create further damage
- Absence of a secure bony attachment of the muscle e.g. avulsion fx
- Superficial metal (staples, pins, external fixators)
- Over the upper thoracic region
- Cardiac pacemaker
- Over the carotid sinus in the neck
- Uncontrolled hypertension or hypotension
CONTRAINDICATIONS CONT...

- DVT / thrombophlebitis
- Abdominal, lumbosacral/pelvic region, during Pregnancy
- Neoplasm or infection
- Phrenic nerve or urinary bladder stimulator
- Patients prone to seizures
- Transcranial stimulation
- Stimulation over the eyes
Thank You