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Electrical Stimulation for Recovery of Function in Neurorehabilitation

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Objectives

As a result of this course, participants will be able to:

1. identify at least three mechanisms for therapeutic benefit of interventions with electrical stimulation.
2. select patients and therapeutic targets appropriate for interventions with electrical stimulation.
3. describe the current best evidence for interventions with electrical stimulation in neurorehabilitation.
Evidence

Why Electrical Stimulation?

- Neural restoration is possible.

- Regular, near normal input optimizes the nervous system for recovery.

- Achieving significant, incremental improvements at any time following injury is possible.
Benefits of Activity

- Establishment and maintenance of synapses
- Myelination: formation and maintenance
- Birth of new neural cells from stem cells
- Promotion of functional recovery
- Promote generation of tripotential progenitor cells
- Stimulate remyelination
- Promoting sprouting of collateral axons

Hami, Hayek (2008); Sadowsky McDonald (2009); Li, et al. (2010); Becker, et al. (2010).

NMES Assisted Grasp Training and Restoration of Function in the Tetraplegic Hand: A Case Study Series

Martin, Johnston, Sadowsky
Objective

- To determine the influence of repetitive NMES assisted grasp and release activities on the paretic tetraplegic hand.

Participant #1

- 21 y.o., female
- C5 ASIA A
- 21 mos. post injury
Participant #2

- 17 y.o., male
- C5 ASIA C
- 6 mos. post injury

Participant #3

- 18 y.o., male
- C4 ASIA A
- 12 mos. post injury
Intervention

Outcomes

- Jebsen Hand Function Test
- Box and Blocks Test
- Semi-structured Interview
NMES Improves Grip Speed

Blocks transferred in 1 minute

Baseline | 1st post-test | Final post-test

NMES Improves Grip and Prehension Patterns

Time

all subtests | grasp | prehension
Subjective Patient Report

- “The treatment reminded me I have fingers.”

- “My fingers feel much looser, like I can use them now.”

- “This weekend I picked up a full soda can, and did not spill it!”
Conclusions

- Improvements were observed in all main outcome measures.

- Most significant improvements were seen in grasp functions.

- Participants reported reduction of spasticity, more effective hand grasp, and greater endurance in functional tasks of the trained hand.

Indications and Precautions
Types of ES

<table>
<thead>
<tr>
<th>TES</th>
<th>NMES</th>
<th>FES</th>
<th>TENS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Therapeutic Electrical Stimulation</td>
<td>Neuromuscular Electrical Stimulation</td>
<td>Functional Electrical Stimulation</td>
<td>Transcutaneous Electrical Nerve Stimulation</td>
</tr>
</tbody>
</table>
| Use of electricity to drive a desired nerve response for therapy. | Electricity applied across the surface of the skin over intact peripheral nerve evokes an action potential in the nerve fiber which causes an exchange of ions to drive the muscle to contract. | Application of electrical stimulus to a paralyzed nerve or muscle to restore or achieve function. Also refers to orthotic substitution (Bioness L300). | Pain modulation by exciting peripheral nerves. Common Types:  
  • Sensory  
  • Motor  
  • Noxious |

Therapeutic Indications

- Increase circulation
- Reduce muscle spasm
- Promote healing of fracture or tissue
- Reduce edema
- Strengthening
- Improve and maintain muscle mass during or following periods of inactivity
Therapeutic Indications

- Maintain/ gain ROM
- Re-educate/ facilitate voluntary contraction
- Reduce effects of spasticity
- Prevent/ reverse disuse atrophy
- Orthotic substitution

Contraindications/ Precautions
(at the discretion of the treating team)

- Implanted electrical device
- Active metastases
- Evidence of osteomyelitis
- Decreased sensation
- Thrombosis/ hemorrhage
- Pregnancy
- Epilepsy
- Cognitive status
Neuroanatomy: A quick review
Upper Motor Neuron (UMN)

- Nerve entirely in central nervous system
  - Cell body in brain
  - Axon in spinal cord
- Damage results in
  - Loss of movement and sensation
  - Hyperreflexia
  - Increased muscle tone
  - Disuse atrophy
  - Contracture secondary to increased tone
- Recovery is attributed to plasticity/redundancy, but is probably a combination of factors (remyelination, endogenous stem cells, sprouting to other intact tracts)

Lower Motor Neuron (LMN)

- Nerve which originates in the central nervous system, ends in the peripheral nervous system
  - Cell body in spinal cord
  - Axon outside the spinal cord (runs to a muscle)
- Damage results in
  - Loss of movement and sensation
  - Hyporeflexia
  - Low to no muscle tone
  - Dennervation atrophy
  - Contracture secondary to soft tissue shortening
- Damage to the axon only (in the extremity) regrows at the rate of 1cm/month
- Damage to the cell body (in the cord) does not regrow, may impact response to ES
Basic Electrophysiology

Mechanism for Contraction

- Electricity applied across the surface of the skin over an intact peripheral nerve evokes an action potential in the nerve fiber (like physiologically generated potentials) causing muscle to contract.

- AP travels in both directions
  - To neuromuscular junction for contraction
  - To motor neuron in ventral horn

- Different from physiologic contraction
All or nothing contractions

- *Electrically* elicited contractions lack smooth, gradual onset of voluntary contraction, reflecting biased and synchronous motor unit recruitment.

- *Voluntary* contractions allow for asynchronous activation of varied motor units which allows for smooth switching between active and inactive motor units to maintain muscle activity, while allowing recovery time for individual motor units.

Recruitment of motor units

- Axons of the largest diameter are the easiest to activate and are recruited before axons of smaller diameter.

- Recruitment of motor units by electrical stimulation progresses from large to small, the reverse order of voluntary contractions.

- Recruitment is also a function of electrode proximity

- A greater proportion of fatigable motor units is necessary for a given contraction. *Fatigue occurs more rapidly in ES contraction.*
Stimulation Current & Parameters

Minimize Current

Primary goal is to get motor action or neurological benefit with as little external input as necessary, while minimizing fatigue.
Electrodes and Placement

- Use as small electrode as possible
  - One that will recruit entire muscle
  - Minimizes fatigue and bleed
- Larger electrode will be more comfortable
- Electrodes should encompass motor point of targeted muscle
  - Largest cross sectional area
- Consider skin health, factors of impedance

Alterable Parameters

- **Waveform**: biphasic (symmetrical or asymmetrical), monopolar
- **Frequency**: hertz (pulses per second)
- **Amplitude**: milliamperes
- **Ramp** (surging): time to maximum amplitude
- **Duration**: total treatment time and individual pulse (microseconds)
Waveforms

Monophasic
- One phase each pulse
- Also known as pulsating DC
- Unidirectional flow
- One electrode is positive and the other is negative

Biphasic
- 2 opposing phases are contained in a single pulse
- Asymmetric and Symmetric
- Symmetric is preferred to asymmetric if motor neurons are the target

Waveforms

Biphasic symmetrical
Biphasic Asymmetrical
Monophasic
Amplitude

- Magnitude of a current (or voltage)

- Peak amplitude: maximum current during a phase

- Measured in milliamps (mA)
Frequency

- The number of pulses repeated at regular intervals
- Referred to as pulses per second (pps) or Hertz (Hz)
- Inverse relationship between pulse frequency and tissue resistance

FREQUENCY 2 pulses per second (2Hz)
Pulse Duration

- The total time elapsed from the beginning to the end of one pulse

- Includes the phase duration of all phases and the interphase interval
Biased Parameters

Sensory (TENS)  
- High frequency (80-100Hz)  
- Low pulse duration (80-100μsec)  
- Amplitude sub-motor

Motor (NMES, FES)  
- Low frequency (20-60Hz)  
- Longer pulse duration (100 μsec-1millisecond)  
- Amplitude to tolerance

Starting Parameters

- Ex: 20Hz, 200μsec, timing based on condition/activity

- Pick a place to start. Adjust based on what you see.
  - Can the pt. tolerate it?
  - Can you reach tetany?
  - Are you getting capture of the whole muscle?
  - Are you getting the action you wanted?
  - Are you getting bleed into other muscles?
**Altering Parameters**

<table>
<thead>
<tr>
<th>Goal</th>
<th>Frequency</th>
<th>Pulse Width</th>
<th>Intensity</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase comfort</td>
<td>Increase</td>
<td>Decrease</td>
<td>Decrease</td>
<td>Can also try using larger electrodes</td>
</tr>
<tr>
<td>(if reporting pins and needles)</td>
<td></td>
<td></td>
<td>(only enough to get tetany)</td>
<td></td>
</tr>
<tr>
<td>Decrease electrical bleed</td>
<td>Increase or decrease</td>
<td>Decrease</td>
<td>Decrease</td>
<td>Can also try using smaller electrodes</td>
</tr>
<tr>
<td>Minimize fatigue</td>
<td>Decrease</td>
<td>Decrease</td>
<td>Decrease</td>
<td>Overall, aim to minimize current, consider variable waveform</td>
</tr>
<tr>
<td>To improve quality of tetany</td>
<td>Increase</td>
<td>Increase or decrease</td>
<td>Increase</td>
<td>Look for smooth fused contraction</td>
</tr>
</tbody>
</table>

**Spasticity Management**

- E-stim also helps to strengthen muscles and has analgesic properties which both help to decrease spasticity.

- Successful clinical applications include long ramp times, to minimize stretch reflex, and variable pulse frequency and duration, to reduce summation and accommodation.
E-stim for spasticity management

1. Sensory settings to spastic muscle
   - Applied prior to activity
   - Applied during to activity
   - Examples: Sensory e-stim to quadriceps either in the car on the way to therapy, or during gait, to increase knee flexion during swing

2. Motor settings to spastic muscle
   - Applied prior to activity (fatigue)
   - Example: Motor e-stim to quadriceps while standing in standing frame to fatigue quads, done prior to gait training, to increase knee flexion during swing

3. Motor settings to antagonist
   - Applied during activity
   - Example: Motor e-stim to hamstrings during gait training to increase knee flexion during swing

Case: E-stim
Special Patient Populations

SCI

- Spinal stability
  - ES to LE while in traction/halo to provide input without motion
  - ES to LE to lower risk for DVT
- Medical fragility
  - ES to LE and trunk before getting out of bed or during upright to offset orthostasis
- Bedrest
  - ES to dorsiflexors or wrist extensors to offset ortho complications
- In ICU: ES early and often!

Needham, Truong, Fan 2009
SCI

- Retrospective cohort to examine the effect of long-term lower extremity FES cycling on the physical integrity and functional recovery in people with chronic SCI.
- FES during cycling in chronic SCI may provide substantial physical integrity benefits, including enhanced neurological and functional performance, increased muscle size and force-generation potential, reduced spasticity, and improved quality of life.

Sadowsky et al 2013

MS

Several studies involving ES for foot drop:
- ↓effort in walking
- ↑walking speed
  - Improved stair negotiation, increased ankle DF
- ↑quality of life

Taylor et al 1999; Sheffler et al 2009
MS and FES Cycling

- 5 patients with primary or secondary progressive MS
- Cycled in the home for 6 months
- Results:
  - Improvements in 2 minute walk test, timed 25 foot walk, and TUG
  - Strength improved in muscles stimulated by FES cycle
  - Multiple Sclerosis Functional Composite (MSFC) and physical and mental health sub-scores and total SF-36 improved
- Conclusions: FES cycling was reasonably well tolerated by progressive MS patients

Ratchford et al.

CVA

- Cognitive limitation
  - Ensure pt has a way to express discomfort
- ES improves uptake of Botox
- ES as compliment to splint program

Hesse, et al., 2001
Cardiac

- ES increases cardiovascular demand
- Pacemakers v. Defibrillator
  - Depends on type
  - Location of stimulation

Ortho

- No ES close to external fixator
- OK around internal hardware
- Respect surgical precautions
- ES offset atrophy associated with immobilization
- TENS
- Sensitive skin electrodes for fragile or irritable skin

Crevenna, et al., 2003
Pediatric

- Start slow
  - Decorate electrodes
  - Wear electrodes only
  - Demo on Mom/Dad
- Minimize current
- Can cut down electrode
- Distraction!

Functional Applications
Coupling ES with effort is important for muscle recruitment and cortical representation.
FES to paraspinals during seated play
FES to gluteals during half kneeling

FES to hip flexors using trigger switch during crawling
Case Study

Things to think about?

1. List active muscles.
2. List possible muscles that may be responsive.
3. What are the goals?
4. Would you use e-stim?
5. Thought process of e-stim parameters.
6. What activities would you pair with e-stim.
Sam

- 20-year-old boy with C5 tetraplegia
- Full PROM all joints and all planes, except -20° dorsiflexion—not fixed.
- S/p biceps to triceps tendon transfer. Has completed post-operative rehab protocol.
- Has limited trunk function, fine motor skills, shoulder pain, and scapular instability.
- Working on transfers, bed mobility, and manual w/c propulsion.
QUESTIONS?

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