Mission:

• Promote high quality FES research and evidence-based clinical applications of FES for people with SCI.
• Our target audience includes health professionals and consumers.

Contact:
Ashraf S. Gorgey, MPT, PhD, FACSM
ashraf.gorgey@va.gov or agorgey@gmail.com
Electrical Stimulation from Exercise to Locomotion after Spinal Cord Injury

Ashraf S. Gorgey, MPT, PhD, FACSM, FACRM
Director of Spinal Cord Injury Research
Hunter Holmes McGuire VA Medical Center
Associate Professor, PM&R
Virginia Commonwealth
Disclosure Statement

I am currently the Chair of the FES and Technology Task Force Committee-ACRM

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Learning Objectives

➢ Review previous/current knowledge about the use of electrical stimulation in training muscles after SCI.

➢ Introduce the concept of long pulse width stimulation (LPWS) to stimulate denervated muscles after SCI.

➢ Briefly summarize the current evidence about the use of trans-spinal/epidural stimulation in muscle activation and restoration of locomotion after SCI.
Pulse Durations (150 vs. 450 µs)

Gorgey et al. 2006; EJAP
Amplitude of the current (mA) and SCI

Figure 2

Gorgey et al. 2013; NeuroRehab.
Evoked NMES Resistance Training (RT) (12 weeks RT+ diet vs. diet control)

Gorgey A et al. 2012; MSSE
Skeletal muscle CSA

Gorgey A et al. 2012; MSSE
Carbohydrate Profile following 12 weeks NMES-RT

Gorgey et al. 2012
Resistance Training & TRT in motor complete SCI
TRT+ Resistance Training for 16 weeks
Skeletal muscle CSA-measured by MRI (n=10/group)

Delta Changes in muscle CSA (cm$^2$)

-5.0  0.0  5.0  10.0  15.0  20.0  25.0  30.0

16-week interventions

TRT+RT  TRT

Whole thigh

Whole muscle CSA

Absolute muscle CSA

Gorgey et al. In Press, NT
Home Based NMES-RT for 8 weeks
NMES-RT for 8 weeks

Gorgey et al. 2017; SCSC
Functional Electrical Stimulation - Lower Extremity Cycling

Gorgey et al. 2017; JoVE
Pulse Duration and SCI-tetra (n=10)

Gorgey et al. 2014; JRRD
Functional Electrical Stimulation and Substrate Utilization (n=10)

Gorgey AS & Lawrence J, 2016; PMR
FES for 10 weeks on Metabolic Profile (n=18; Griffin et al. 2009)

**Metabolic factors**

<table>
<thead>
<tr>
<th>Metabolic Factor</th>
<th>Pre Value</th>
<th>Post Value</th>
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<tbody>
<tr>
<td>CRP (mg/L)</td>
<td>15.92 ± 1.57</td>
<td>12.94 ± 0.78 *</td>
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<tr>
<td>IL-6 (pg/ml)</td>
<td>4.91 ± 1.10</td>
<td>3.79 ± 0.52 *</td>
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<tr>
<td>TNF-α (pg/ml)</td>
<td>11.82 ± 0.63</td>
<td>11.31 ± 0.62</td>
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SCI with Lower motor neuron injury

Recruitment

450 Persons with motor complete (AIS A or B) SCI were contacted

155 expressed interest

115 Phone Screen Failure

40 qualified

8 did not respond to NMES

6 no show

26 enrolled

22 completed

4 withdrew
Stimulation of Denervated Muscle

- Denervated muscle has lost its peripheral nerve supply
  - Results in a decrease in size, diameter, and weight of muscle fibers
  - Decrease in amount of tension which can be generated
  - Increase the time required for contraction

- Electrical currents may be used to produce a muscle contraction in denervated muscle to minimize atrophy
MRI of mid-thigh muscles following innervation and denervation in persons with SCI
Strength-Duration Curve of Denervated Muscle

Normal Innervated Muscle

Denervated Muscle
Long Pulse Width Stimulation & Denervated Muscle
Long Pulse Width Stimulation (LPWS)
LONG PULSE WIDTH STIMULATION (LPWS)

- Home based functional electrical stimulation (FES) using a LPWS (120-150 ms) at an intensity of 250 mA for 5 days/week has been studied in 25 SCI persons with complete LMN denervation.

- There is an increase (24%) in knee extensor cross-sectional area (CSA) following the first year.

Denervated muscle following 1-2 years of training
Automaticity of Spinal Cord Circuitry

- Central Pattern Generator (Lumbar circuitry processing complex proprioceptive and cutaneous information to generate cyclic motor pattern).

- Central Pattern Generator is demonstrating the significance of automaticity in mammalian spinal cord.

- Fictive locomotion (stepping in the absence of supra-spinal control or peripheral afferent input).

- As a result, spinal cord can learn and modulate task specific by practice.
Transcutaneous electrical spinal cord stimulation (SCS) - Gerasimenko et al. 2015

Carrier frequency at 10 KHz
Pulse duration: 0.3 ms - 1.0 ms (300 µs - 1000 µs)
Frequency: 5 to 40 Hz
Intensity: 30 to 200 mA
Stimulation intensity during Trans-spinal stimulation

- Orthodromic excitation of motor axons
- Anti-dromic excitations of muscle spindles (Ia, II, Ib)
Epidural Stimulation

Epidural Stimulation in Rehabilitation after SCI
Moraud et al. 2018-Trunk Control During Locomotor training + EpiSCS
How does Epidural Stimulation Continuous vs. Pulsed Stimulation (to reduce antidromic collision) using high frequency and low stimulation amplitude

Formento et al. 2018
Epidural Stimulation pattern

a

- EES artifact
- Proximal tibial nerve
- Soleus muscle
- Distal tibial nerve
- Sural nerve
- Surface electrodes
- Needle electrodes

Subject #2

- Sensory antidromic activity
- Motor orthodromic activity

Time (ms)
Progression of SCS-enabled stepping performance on a treadmill (Gill et al. 2018)
Single vs. Interleaved SCES (Gill et al. 2018)
Summary/Conclusions

- NMES or FES training increases skeletal muscle size and soft tissue LM as well as helping carbohydrate metabolism.
  - Modest improvement in Body Composition parameters
  - Robust increase in Basal Metabolic Rate

- Long pulse width stimulation is a potential technique to stimulate denervated muscles and may help to restore muscle size in those with T10 or below level of injury or those with Quada equina injury.

- Trans-spinal/ Epidural stimulation may be potential rehabilitation tool to increase muscle activity, facilitate standing and stepping as well as over ground ambulation after SCI.
Research Team
Thank You!