Evidence for Health and Fitness Benefits of Functional Electrical Stimulation for People with Spinal Cord Injury

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Objectives
Following this session, attendees will be able to
1) Discuss the current literature on the benefits of FES cycling, walking and resistance training on cardiovascular, metabolic, and musculoskeletal health for people with various levels and classifications of SCI.
2) Discuss the current gaps in the literature in regard to these FES applications and potential ways to address these gaps.
3) Discuss new techniques and strategies that are on the horizon for FES applications to improve their effectiveness.

Course Outline
FES Introduction (Dr. Bickel, 20 minutes)
• History of FES
• Terminology
  o Confusion with names
  o Symmetrical Biphasic Pulsed Current
  o Parameters (pulse duration, amplitude, frequency)
• Force production
  o Increases by increasing the number of motor units recruited and the frequency at which these recruited motor units fire.
  o Strength/duration
  o Force frequency relationships
    ▪ At 50-60 Hz – force levels off
• Motor Unit Recruitment
  o differs with NMES and volitional contractions
    ▪ NMES: Non-selective, spatially fixed, temporally synchronous
    ▪ Volitional: Selective, orderly, temporally asynchronous
  o Increased Fatigue with NMES with inability to decrease this with NMES
    ▪ There is a need to optimize NMES to reduce the inherent muscle fatigue that occurs
  o Intensity

FES cycling (Dr. Johnston, 20 minutes)
• Level of Injury
  o Use of FES cycling requires an upper motor neuron lesion

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- Bone
  - Bone Measures: DXA, MRI/pQCT/CT, Bone markers
  - Mixed results
    - The role of intensity needs to be understood
    - Measurement techniques need re-evaluation
  - Future
    - Calcium and/or vitamin D supplements
    - Other ways to increase intensity to load bone

- Muscle
  - Measures: CSA/volume (MRI, CT, girth), strength (volitional or stimulated)
  - Results
    - Increased muscle and muscle fiber CSA and muscle volume
    - May attenuate muscle loss with acute SCI
    - Increased stimulated & volitional strength
  - Future
    - Other ways to increase intensity

- Cardiovascular/Respiratory
  - Measures: Acute effects vs. effects over time with intervention
  - Results
    - Oxygen uptake can increase with FES cycling training (acutely and as outcome)
    - We may not be training subjects hard enough for greatest benefit
    - Differences between paraplegia and tetraplegia
  - Future
    - Examine ways to continue gains after 6 months
    - Optimize training strategies to allow greatest benefits with reasonable time commitment

- Metabolic/Body Comp
  - Increased lean tissue without a decreased in adipose
    - Need ways to impact adipose
  - Metabolic
    - No impact on lipids
    - Some evidence for impact on inflammatory markers/glucose
    - More research needed

- Motor Learning/Recovery
  - Some reports of increased volitional strength and/or sensation
  - More research needed with incomplete SCI to understand effects
  - Possible complement to gait/locomotor training?

FES walking (Dr. Johnston, 10 minutes)
- Types of Systems
  - Surface
  - Percutaneous
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**Implanted**
- Combined with over ground walking or BWS treadmill walking

**Complete SCI: Parastep**
- Surface FES system
  - Quadriceps, peroneal reflex for stepping, gluteal or lumbar spine muscles
  - Controlled through a box on the walker
- Series of 5 papers published on its effects (1997): Miami Project
  - 13 men, 3 women, thoracic motor complete chronic SCI
  - 32 training sessions, 3 walking trials per session with 15-20 mins rest in between

**Results**
- ↑ distance, standing duration, & pace
- ↑ thigh and calf girth
- ↑ time to fatigue, ↑ workload, ↑ VO2 (14.9%) during peak UE ergometry
- ↓ HR at workloads > 20 W (subpeak test)
- No change in UE strength
- No change in BMD
- Overall improved blood flow
- Training effects: resting CSA, HR, FVI (flow velocity interval), PV (pulse volume), and AIV (arterial inflow volume)
- Augmentation of hyperemic response to vascular occlusion

**Summary**
- Some positive effects with Parastep
- Clinically available and approved by CMS
- Limited health benefits as used in these studies

**Incomplete SCI (surface and percutaneous systems)**
- Different muscles stimulated
  - Common ones are peroneal nerve and withdrawal reflex, quadriceps
- Results (small sample sizes)
  - ↑ LE strength, ↓ energy cost, ↑ distance, ↑ speed, ↑ step length, improved kinematics with FES off

**FES resistance training (Dr. McCully, 20 minutes)**
- Weight training
  - Goal is to increase weight lifted, under the same or lower current levels
  - Following 4 months of resistance training, women had approx. a 50% increase in quadriceps muscle mass while men had approx. a 30% increase.
  - Subjects with the greater mass increase had largest change in oral glucose tolerance test
- Metabolism and recovery
  - PCR recovery time constant is doubled in SCI compared to healthy adults
    - Declines after weight training in some subject with SCI
  - Muscle metabolism via near infrared spectroscopy
    - Shows that people with SCI have decreased mitochondrial capacity
SCI had about 1/3 the mitochondrial function of AB group
  - Improvements were seen in mitochondrial function following resistance training

**Stimulation strategies to maximize muscle performance during FES (Dr. Lee, 10 minutes)**
- Applying principals of the Force-Frequency relationship to FES applications
- Applying the Force-Intensity relationship to FES applications
- “Smarter” systems attempt to mimic natural neuromotor strategies for motor control
  - Use of Feedback
  - Frequency modulation
    - Variable vs. constant activation frequencies
    - Rate coding vs. constant activation frequencies
  - Intensity modulation
    - Motor unit recruitment/de-recruitment vs. intensity modulation
  - Combined techniques

**Summary of health benefits, cardiovascular, metabolic, and musculoskeletal health (Dr. Backus, 20 minutes)**
- Translating Evidence: Why Be Concerned with Health in People with SCI?
  - Average life expectancy of persons with spinal cord injury (SCI) has increased
    - 69.14% (20 year survival)
    - 51.97% (30 year survival)
  - Longevity Poses Health-Related Problems
    - Increased risk of same problems in the general population
    - Cardiovascular disease (CVD) is the leading cause of death in the able-bodied American population
    - Accounted for 36.3% (871,517) of all 2,398,000 deaths in the United States in 2004 (Rosamond et al, 2007)
  - CVD
    - Associated with level & extent of SCI
    - Increased Risk of Mortality: Some reports suggest is leading cause of mortality in SCI
- Question: Do interventions using functional electrical stimulation interventions improve variables related to health in people with SCI?
  - FES Cycling
    - The following may experience cardiorespiratory benefits:
      - Adults & children with complete tetraplegia or paraplegia between C4 and T11
      - Adults & children with incomplete tetraplegia or paraplegia between C4 and T11
      - Adults with acute or chronic SCI
      - Children with chronic SCI
    - The following may experience muscle benefits:
• Adults with acute or chronic complete or incomplete tetraplegia or paraplegia;
• Children with chronic SCI
• Adults with acute or chronic, complete or incomplete SCI may experience positive changes in vascular function that may improve cardiac health

- Changes in cardiorespiratory, vascular and muscle function are meaningful
  • May lead to a decrease in the risk factors associated with CVD
  • May increase longevity after SCI
  • May lead to greater health and quality of life in persons with SCI

- Impact on bone
  • More variable outcomes
  • Those who may experience benefits:
    o Children with chronic, motor complete SCI C4-T11
    o Adults with chronic SCI C5-T9
    o Location of changes varies

- Safety considerations:
  • Changes in heart rate and blood pressure appear to vary based on level of injury, and not intensity of the exercise
  • Those with tetraplegia do not demonstrate the same response to exercise as those with paraplegia
  • Caution should be taken to prevent cardiac disturbances or breakdown due to the training

- Considerations for future study
  • Variable responses in vascular responses and lipid profiles require further study
  • FES cycling and passive cycling have not been compared in relation to the exercise and health-related benefits
  • Include cost-benefit analyses to allow persons with SCI, and their payers, to make well-informed choices about which intervention would be most productive and cost-efficient for that person
  • Final recommendations related to training with FES cycling
  • Persons with SCI who desire pursuing FES cycling for improving health and wellness should discuss with their health care provider the intensity and duration of the program required to effect a change in cardiorespiratory, muscle, vascular, or metabolic variables based on the level, extent and chronicity of their SCI.

  o FES Walking Interventions
    • Clinical application:
      • No surprise – if they exercise, people with SCI can achieve health-related benefits
      • May take several sessions to obtain benefits
• With complete injury may need to continue long term
• Cost benefit analysis?
• What is impact on secondary complications?

  o FES Resistance Training
    ▪ Some people with SCI can progress in training
    ▪ Muscle metabolism
    ▪ Resistance training may be best to increase muscle girth
    ▪ Endurance training may be better for improving muscle metabolic function

Panel Questions and Answers (all, 20 minutes)

Select References

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