Objectives

- Brief summary of FES cycling literature
- FES cycling for children
  - Study completed at Shriner Hospitals for Children
- FES cycling for adults
  - Current study funded by Craig H. Neilsen Foundation

Evidence for FES Cycling in SCI
FES Cycling

- FES Cycling studies have primarily addressed
  - Bone
  - Muscle
    - Metabolic syndrome
  - Cardiovascular
  - Respiratory
  - Metabolic

FES Cycling: Bone

- Bone Measures
  - Bone mineral density
    - DXA
  - Bone microarchitecture
    - MRI/pQCT/CT
  - Bone markers

FES Cycling: Bone Overview

- Overview
  - Mixed results
  - The role of intensity needs to be understood
  - Measurement techniques need re-evaluation
- Future
  - Low cadence cycling
  - Calcium and/or vitamin D supplements
  - Other ways to increase intensity to load bone
FES Cycling: Muscle
- CSA/volume
  - MRI, CT, girth
- Strength
  - Volitional
  - Stimulated

FES Cycling: Muscle Overview
- Muscle Size
  - ↑ muscle and muscle fiber CSA and muscle volume
  - May attenuate muscle loss with acute SCI
- Muscle strength
  - ↑ stimulated & volitional strength
- Muscle properties
  - Possible fiber change (mixed results)
  - ↑ capillaries around fibers but may be proportional to gain
- Future
  - Low cadence cycling or sprints at high resistance
  - Other ways to increase intensity

FES Cycling: Cardiovascular/Respiratory
- Acute effects
- Effects over time with intervention
FES Cycling: Overview
Cardiovascular/Respiratory

• Overview
  • Oxygen uptake can increase with FES cycling training
    (acutely and as outcome)
  • We may not be training subjects hard enough for
    greatest benefit

• Future
  • Examine ways to continue gains after 6 months
  • Optimize training strategies to allow greatest benefits
    with reasonable time commitment

FES Cycling: Metabolic/Body Comp

• Body Composition
  • Lean tissue
  • Adipose tissue
  • Muscle to adipose ratios
  • Lipids
  • Inflammatory markers

FES Cycling: Metabolic/Body Comp
Overview

• Body composition
  • ↑ lean tissue without ↓ in adipose
  • Need ways to impact adipose

• Metabolic
  • No impact on lipids
  • Some evidence for impact on inflammatory
    markers/glucose
  • More research needed
FES Cycling: Motor Learning/Recovery

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

Cycling with FES for Children with SCI

This work was conducted at Shriners Hospitals for Children, Philadelphia, PA

Subjects

- Thirty children, ages 5 to 13 years
- AIS A, B, or C SCI
- At least 1 year post SCI
**Intervention Groups**

- Children were randomized to:
  - FES cycling (FESC)
  - Passive cycling (PC)
  - E-stim exercise (ES)
- Exercise performed for 60 minutes 3x/wk for 6 months

**Data Collected**

- Progressive upper extremity ergometer test until fatigue
  - Resting and peak HR
  - Peak VO2/kg
- Fasting lipid profile

**Data Collected**

- Bone
  - DXA to assess BMD of hip, distal femur and proximal tibia
- Muscle: Quadriceps and Hamstrings
  - Stimulated strength
  - Muscle volume via MRI
Results

- Intervention adherence (accounting for allowed missed sessions)
  - FESC: 95.2 ± 18.1%
  - PC: 107.2 ± 16.2%
  - ES: 105.5 ± 19.6%

Results: Oxygen Uptake

Discussion: Oxygen Uptake

- Clinically significant change in FES group (p=0.057)
- VO2 in children after an exercise program
  - 12 week aerobic exercise program for 10 to 12 year old children with typical development showed average VO2 max increases of 6.5% (Rowland TW, Pediatrics, 1995)
  - Our FES cycling group improved on average 21.9%
Results: Lipids

Discussion: Lipids

- Positive lipid changes in children post exercise (Kelley GA. Atherosclerosis, 2007)
  - Triglycerides: >22.8 mg/dL decrease
  - Cholesterol: >4.4 mg/dL decrease
  - HDL: >4.8 mg/dL increase
  - LDL: >4.3 mg/dL decrease

- Our subjects did not have changes by these guidelines

Results: Bone

- No differences between or within groups
**Results: Bone/Possible Threshold**

![Graph showing Bone/Possible Threshold](image)

**Discussion: Bone**
- BMD changes observed were greater than the reported 0.9 to 10% gains after exercise for children with and without disability
- Cycling with and without FES may be beneficial for skeletal health in pediatric SCI

**Results: Muscle Strength**
- Between groups: Differences for quadriceps strength but not hamstrings
  - Post hoc: FESC gained more strength than PC and ES
- Within group
  - FESC: ↑ quadriceps but not hamstrings
  - PC: no change in quadriceps or hamstrings
  - ES: no change in quadriceps or hamstrings
Results: Muscle Strength

- Baseline vs 6 months
- FES: Quadriceps (p=0.011) and Hamstrings (p=0.421)

Results: Muscle Volume

- Between groups: Differences for quadriceps volume but not hamstrings
  - Post hoc: ES gained more in muscle volume compared to the FES and ES
- Within group:
  - FESC: ↑ quadriceps but not hamstrings
  - PC: no changes in quadriceps or hamstrings
  - ES: ↑ quadriceps but not hamstrings
Discussion: Muscle

- Children receiving either electrically stimulated exercise ↑ in muscle size and/or stimulated strength
  - FESC: ↑ quad strength & volume
  - ES: ↑ quad volume but not strength

- These changes may decrease their risk of cardiovascular disease, insulin resistance, glucose intolerance, and type II diabetes

Overall Conclusions

- Changes seen
  - Clinical change in oxygen uptake with FES cycling
  - No impact on lipids
  - Clinical change in bone with FES and passive cycling
  - Muscle gains using electrical stimulation

- Implications
  - May need to increase exercise intensity

FES Cycling in Adults with SCI

Current study funded by the Craig H. Neilsen Foundation
Current FES Cycling Study

- **The overall objective** is to compare the effects of two different FES cycling paradigms for adults with SCI
  - novel low cadence, high resistance cycling paradigm
  - more traditional high cadence, low resistance cycling paradigm

It is hypothesized that the low cadence, high resistance group will experience greater musculoskeletal and cardiovascular improvements.

Inclusion/Exclusion

- **Inclusion**
  - AIS A or B SCI
  - Intact lower motor neurons
  - 18-65 years old (pre-menopausal for women)

- **Exclusion**
  - Current fracture or pressure sore
  - Presence of contraindications to MRI
  - Other medical issues
  - Vent dependent

FES Cycling Intervention

- Subjects cycle for 1 hour, 3x/week for 6 months
  - Restorative Therapies, Inc. RT300

- Cycling paradigms
  - 50 rpm
  - 20 rpm
Data Collection

- Musculoskeletal Measures
  - Distal femur and proximal tibia trabecular bone microarchitecture
  - Cortical bone structure
  - Areal bone mineral density
  - Bone-related histochemical values
  - Stimulated lower extremity muscle strength
  - Muscle volume

Data Collection

- Cardiovascular related measures
  - Fat-free tissue
  - Blood lipid and metabolic profiles
  - Muscle volume

  - Collected at baseline, 3 months (limited set), & 6 months

Subjects

- 11 have been enrolled in cycling phase
  - 5 completed study
  - 1 withdrew
  - 2 taking calcium and vitamin D supplements in preparation for cycling
  - More being screened
Preliminary results

- Imbalance across groups in data have currently due to withdrawal and adverse event

- Maximal resistance cycled
  - 1.0 to 1.6 Nm (1.2 ± 0.3) for the high cadence group
  - 1.1 to 5.2 Nm (3.0 ± 1.7) for the low cadence group

Bone

Distal femur trabecular bone

[Images of pre- and post-bone images]

Trabecular Bone Spacing

<table>
<thead>
<tr>
<th>Group</th>
<th>Baseline</th>
<th>6 months</th>
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<tbody>
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<td>High 1</td>
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<tr>
<td>High 2</td>
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<tr>
<td>Low</td>
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Muscle and Fat Mass

Results to Date Summary

- Some trends are present
  - Trabecular spacing
  - Bone resorption
  - Muscle mass
- Re-evaluate once have more subjects completed
Next Steps

- FES cycling future research
  - Dosing questions
    - Load, duration, frequency
  - Optimizing cardiorespiratory outcomes
  - Studies with higher power
    - Multisite RCT
  - Longer term benefits and feasibility
  - Other exercise modes