Course Objectives
1. Discuss the current evidence for the use of FES for people with SCI
2. Discuss FES parameter applications and modifications to achieve optimal outcomes in individuals with neurologic disabilities
3. Discuss the opportunities and challenges of implementing FES in the clinical setting.
4. Understand multiple uses of FES from the perspectives of the consumer and clinician.
5. Assess practical applications for successful implementation in the clinic and the home environment for FES
6. Discuss lower cost alternatives to commercially available FES technologies and the financial implications of FES programs and technologies
7. Explore current technology surrounding implantable FES systems and current functional applications for implantable FES systems

Course Agenda
- Introductions
- Parameters and Evidence for Common FES Applications: Therese Johnston
- Implementing a Clinical Program for FES: Candy Tefertiller
- Short Session Break
- Implantable FES Systems: Lisa Lombardo
- Consumer & Clinical Perspectives: Panel Question & Answer

Priorities of Individuals with SCI

Parameters used in Clinical FES
- Important to understand parameters
  – To understand how units differ
  – To make best decisions for the intervention
- Read the booklets that come with the equipment!

FES Parameters and Evidence for FES in SCI
Therese E. Johnston, PT, PhD, MBA
Thomas Jefferson University
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Current (I)

- Rate of movement of charged particles in a conductor
- Involves transfer of energy that causes physiological change
- Directly related to the voltage

- Measured in amperes
- Our applications: milliamps (mA)
- On e-stim machines, often is the “intensity” dial

Resistance

- Defines the ease of movement within the conductor
- Measured in Ohms

- Ohm’s Law
  \[ I = \frac{V}{R} \]
  \[ V = I \times R \]

- Therefore, as \( R \) increases, \( V \) needs to increase to maintain a constant \( I \)

Resistance in our Applications

- Use of gels, sponges, & wet gauze decrease the resistance
- Lotions, oils, dry skin, & callus increase resistance

Alternating Current

- Uninterrupted bi-directional flow of particles
- Polarity reverses as electrons move in one direction & then reverse

Pulsed Current

- Each pulse is an isolated electrical event
- Biphasic Pulsed Current

Pulse & Pulse duration

- Pulse = isolated electrical event
- Can be uni or bi-directional
- Pulse duration = time to complete one pulse
- Our applications: usually in microseconds (\( \mu \)sec)
Other Terms

- **Interpulse interval** = time between pulses
- **Period** = pulse duration + interpulse interval duration

*Frequency

- The number of pulses each second
- Important in fatigue

This would represent 3 pulses per second (pps)

*Balance of Charge

- A waveform is balanced when:
  The area under the negative phase = the area under the positive phase

Amplitude Characteristics

- **Peak Amplitude**
- **Peak to peak amp**
- **RMS amp**: takes the shape of waveform into account. Is about 70% of peak amp for a true sinusoidal wave

Clinical Stimulators

- **Primary Parameters**
  - Pulse duration: usually less than 400 µsec
  - Amplitude: up to 100 mA
  - Frequency: up to 100 pps

- These 3 parameters together are all important in how strong the electrical stimulus is & what effects it can create
Effects of Increasing Parameters

- **Amplitude**
  - Increases force production
- **Pulse Duration**
  - Increases force production (& pain over 400µsec)
- **Frequency**
  - Increases firing rate
  - Increases force
  - Increases fatigue

FES Applications

- This talk will include
  - Walking
  - Cycling

FES as a Dorsiflexion Assist during Gait

- Electrodes are typically placed on the anterior tibialis and the peroneal nerve
- Triggered by a foot switch or external trigger
- Considered an orthotic substitute

Parameters from the Literature

- **Pulse duration:**
  - 200-400 µsec
- **Frequency:**
  - To obtain tetany
- **Amplitude:**
  - To create a 3- to 3+/5
- **On/off time:**
  - Times with person’s gait
  - Need a control source

Possible Stimulators

- Portable stimulator that can use a trigger
  - Foot/heel switch
  - Hand trigger
- Single application devices on the market
  - WalkAid
  - Bioness
  - Odstock (UK only)

Portable Stimulator

- Programmable parameters
  - Pre-set
  - Custom allows wide range
- Remote heel switch
**WalkAid**

- One-channel stimulator
- Uses a Tilt or Heel Sensor to control stimulation
- Parameters
  - 25-300 µsec
  - 16.7–33 pps
  - Up to 200 mA
  - Up to 3 sec on time (for exercise)

**Bioness L300**

- Gait Sensor
  - In shoe and attached to shoe
  - Detects speed & surface changes
- Parameters
  - 200 µsec
  - 30 pps
  - 30-35 mA

**Parastep® Walking System**

- Muscles stimulated by surface stim
  - quadriceps, peroneal reflex for stepping, and the gluteal muscles
- Parameters: 24Hz, pulse width 150 µsec, & intensity up to 300mA
- The user can chose from
  - sit/stand, stand/ful, right step & left step, and can increase or decrease the stim intensity while walking

**Evidence for Walking with FES**

Papers by Guest et al., Jacobs et al., Klose et al., Nash et al, Needham-Shropshire et al.

**Parastep®, Sigmedics, Fairborn, OH**

**FES: Incomplete SCI**

- Field-Fote et al. 2011
  - FES to peroneal nerve
  - ↑ walking speed & distance across groups (FES/OG, TM/manual A, TM/FES, TM/robotics)
  - Distance ↑ greatest in OG group who used FES

- Ladouceur et al. 2000
  - FES for peroneal nerve (swing) & quadriceps (stance)
  - With FES, saw
    - ↑ functional mobility
    - ↑ maximal overground walking speed
FES: Incomplete SCI

- Kim et al. 2004
  - FES: surface peroneal nerve stimulator
  - Results: Gait speed best with FES/hinged AFO combo, Best foot clearance with FES

- Postans et al. 2004
  - Acute SCI: FES to many muscles on TM
  - Greater ↑ in overground walking distance after FES and TM training
  - No difference in walking speed gains

FES Cycling

Parameters of FES Cycles

- Ergys
  - 0-140 mA, 400-1000 µsec; 30, 40, 50, 60 pps

- RT300
  - 0-140mA, 100-1000 µsec, 10-100 pps

- Motomed/Hasomed
  - 0-126 mA, 20-500 µsec, up to 180 pps (using doublets)

Common Intervention Times

- From the literature
  - Most studies have subjects cycle for 30 mins 3x/week
  - More recent studies have made changes to this
  - Some increased duration to 1 hour
  - Some increased frequency to 5x/week

- In practice
  - See 30-60 minutes 3-5x/week

Evidence for FES Cycling

- Bone
  - Lauer et al. 2011 (peds): hip BMD ↑ more than in kids without SCI
  - Bloomfield et al., 1996: Bone ↑ only if cycling at >18W
  - Chen et al. 2005: ↑ in distal femur, proximal tibia
  - Frotzler et al. 2008: (higher intensity): ↑ in trabecular & total BMD and CSA in distal femoral epiphysis

- Muscle
  - Demchak et al. 2005 (acute): less muscle loss
  - Johnston et al., 2011 (peds): ↑ quadriceps volume & stimulated strength
  - Scremin et al. 1999 (chronic): ↑ CSA of quadriceps, adductor magnus, ↑ muscle to adipose ratio
  - Duffell et al. 2008 (chronic): ↑ stimulated quadriceps torque, ↑ quadriceps fatigue resistance
### Evidence for FES Cycling

- **Cardiorespiratory**
  - Hettinga, et al., 2008 (review): average VO2 increase of 1.05L/min (n=264) while cycling
  - Johnston et al., 2011 (peds): ↑ greater than kids with typical development
  - Janssen et al., 2008 (chronic): Modified FES: ↑ VO2, HR, cardiac output, blood lactate
  - Zgobar et al., 2008 (chronic): ↑ small artery compliance
  - Berry et al., 2008 (chronic): ↑ peak power output, ↑ peak VO2

### Conclusions

- Understand parameters needed and rationale for decision making
- Some evidence exists for the use of FES applications in SCI

### Implementing a Clinical Program of Functional Electrical Stimulation

**Candy Tefertiller, PT, DPT, ATP, NCS**  
Director of Physical Therapy at Craig Hospital

- Focus on recovery vs. compensation
  - Retraining the neuromuscular system below the LOI for task execution
  - Development and implementation of new technologies and interventions to facilitate repetition and task specificity
  - Improvement in neuromuscular function seen even years after neurologic injury

### Intensive Activity Based Therapy

- Daly 2011: ↑ gait coordination; effects X 6 months
- Kesar 2011: ↑ AGRF, trailing limb angle, knee flexion (swing)
- Kesar 2010: ↑ muscle performance with VFT’s vs. CFT’s
- Forssberg et al. 1977: phase dependent modulation
- Fung et al. 1994: ↑ H-Reflex
- Perez et al. 2003: ↓ spasticity
- Bajd et al. 1997: ↑ vertical swing
- Barbeau et al. 2002: Therapeutic Effect
- Field-Fote et al. 2005, 2011 (RCT’s): ↑ OG speed
- Thompson 2012: SCI ↑ CST activity with 30 min PNS

### FES Research

- **Neuroplasticity** and/or
- **Improved Compensation**

Electrical Stimulation and FES may offer an important avenue to facilitate movement in an injured musculoskeletal system and facilitate improved function via...
FES in the Clinic/Home

- Available Technologies:
  - Foot Drop Systems
    - Bioness L300
    - Walkaide
  - Foot/Thigh Control
    - Bioness L300 Plus
  - FES Cycles
    - Restorative Therapies (UE and LE cycles)
    - Motomed (UE and LE cycles)
    - Ergys
  - FES Elliptical
    - Restorative Therapies

FES Cycling Classes:

- Inpatient and Wellness Classes
  - 4-5 clients/hour
  - 1PT; 1 Tech; 1-2 Volunteers
  - Creates competitive and motivating environment
  - Peer Support
  - Transition to upright posture when appropriate

ABT Program: Cycling → Elliptical

Evaluate:
- Spasticity
- Isolated Movement
- Trunk Control
Transition:
- FES Bike → RT600

Neuroprosthetics

Nerve stimulation devices designed to replace or improve function of an impaired nervous system

Commercially available for home and clinical use

FES in the Clinic:

- Combined with OG training
  - Common Peroneal/TA
  - Gastroc/soleus
  - Hip flexors/extensors
  - Trunk extensors
  - Knee flexors/extensors
  - Foot sensors reversed to control stance vs. swing phase
  - Strength training (TA vs. Gastroc/soleus) for clonic activity
  - Initiate stepping prior voluntary initiation
- Combined with developmental sequencing
- Combined with manually assisted BWS Ltng

FES in the Clinic:

- Developmental Sequencing
- Over ground training
- Core Strengthening
**FES in the Clinic**

**FES and Locomotor Training**

- Easily combined
  - Manual Assist
  - Over ground
- Reduces staff fatigue
- May reduce clonic activity
- May allow training at higher speeds including running
- Spinal Cord Assessment Tool for Spasticity (SCATS)
- Modified Ashworth

**Implantable FES Systems**

**Applications of FES for SCI**

Lisa Lombardo, MPT

Cleveland FES Center

**Conclusion**

Clinical Decision Making is the Key

- Lots of wonderful new technology in rehab to enhance our treatment plans
- They are simply the Tools…… we need to determine when, how and with whom to improve long term outcomes
- No one modality will work for everyone
- Use EBM to guide clinical decision making

**Learning Objectives**

- Discuss implanted FES research applications for spinal cord injury
- Provide benefits and limitations for each of the applications
- Discuss recommendations for the future
**Enabling technology**

- Implanted Stimulator-Telemeter (IST) “Pacemaker for the body”
  - 12 - 16 stimulus channels
  - up to 2 biosignal sensing (EMG) channels
- Intramuscular electrode
- Multicontact spiral cuffs
- Universal External Control Unit (UECU)

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**Clinical Applications for SCI**

- **Trunk Control & Posture**
  - Pressure Sore Prevention
  - Wheelchair Propulsion
- **Standing**
  - Transfers
  - Balance
- **Stepping**

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**FES Lower Extremity Research**

- **Inclusion**
  - C6-T12 SCI
  - > 6 months post-injury
  - Intact lower motor neurons
  - Absence of psychiatric problems
  - No untreated orthopaedic problems
  - No acute medical problems
  - Adequate social support
  - Willingness to comply with follow-up procedures
- **Exclusion**
  - Pacemaker
  - Cardiac arrhythmia
  - Pregnancy
  - Contractures
  - Seizure disorder
  - Obesity
  - Untreated substance abuse
  - Immunodeficiency
  - Frequent UTIs
  - Pressure sores

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**Cleveland FES Center**

Advancing Technology, Enhancing Life

Developing technology that improves the quality of life of individuals with disabilities through the use of Functional Electrical Stimulation and enabling the transfer of the technology into clinical deployment.

**Functional Electrical Stimulation (FES)** is the application of electrical stimulation to restore function. FES can be applied for therapeutic purposes or for replacement of lost function.

**Neural Prosthesis**: A device that connects directly with the nervous system and uses FES to replace or supplement function.

www.FEScenter.org
Email: Info@FEScenter.org
Standing System
Transfer & Balance

Stepping System

Lower Extremity FES Summary
- Controlling posture and balance may be feasible and clinically relevant
- Implanted systems for standing after SCI are clinically viable
- Nerve cuffs can improve system performance
- Standing balance can be addressed in new ways
- FES with EMG control can enhance walking ability after incomplete SCI

Cleveland FES Center Programs

Spinal Cord Injury
- Hand Grasp
- Arm & Shoulder Movement
- Pressure Sore Prevention
- Trunk Control & Posture
- Restoration of Cough
- Urology/Pelvic Health
- Pain & Spasticity
- Standing & Transfer
- Walking

Stroke
- Shoulder Pain Reduction
- Pain & Spasticity
- Mental Image/Upper Body
- Hand, Implanted System
- Hand, Functional Control
- Foot Drop
- Walking Stability
- Swallowing Assistance

Acknowledgements

Website: www.fescenter.org

Consumer & Clinician Perspectives
Panel Question & Answer

ALL RESEARCH VOLUNTEERS & THEIR FAMILIES
Considerations to Participating in any FES program

- Not all programs are appropriate for all populations
- Implanted vs. external
- Commitments of self, family/caregiver
- Time
- Out of pocket cost and/or reimbursement
- Potentially dangerous if not used properly use
- Peripheral nerve damage or skin damage
- Infections
- Over-stress or fatigue the stimulated muscles

References


Resources to Learn More

- "Electrotherapeutic Terminology in Physical Therapy: APTA Section on Clinical Electrophysiology." Published in 2000. Available through the APTA on line store.
- International Functional Electrical Stimulation Society Education Section. Website: http://www.ifess.org/cedu_consumereducation
- Also available on Spinal Cord Central: http://www.spinalcord.org
- Cleveland FES Center: http://www.fescenter.org

References


References