Functional Electrical Stimulation
– Use in Neurological populations

Dr. Sean Dukelow MD, PhD
Stuart Miller BScPT, CHT

Adapted from talks by
Kristin Musselman and others
(with permission)
Objectives for session

1) Knowledge translation – train the trainer
2) Define FES
3) Applications of FES – who is appropriate?
4) The Basics of FES
5) ↑ Functional activity – UE and LE
6) Problems with FES – contraindications / precautions…
Knowledge translation

Knowing better
(high quality knowledge)
+
doing better
(using what we know)

Mrklas 2015
Train the trainer approach (T3)

Group led course:
Lead instructors
Facilitators

Red guy was initially a group of people – not just the organizer

FES work group → External course → In-house course
Participants → Facilitators → ~ 200 clinicians → Advanced course
**FES**: what is it?

Defn: use of electrical stimulation of the peripheral nervous system to contract muscles during functional activities (e.g. standing, walking, reaching, and grasping etc.)
Neuro Clients

FES can be used with:

- Stroke
- Brain injury
- Spinal cord injury (lesions above T12)
- Cerebral palsy
- Multiple sclerosis
- Parkinson’s Disease
- Familial/hereditary spastic paraparesis
Neuro Clients

FES *not* to be used with:

- Complete peripheral nerve damage
- Polio*
- Motor neuron disease*
- Guillain-Barre syndrome*
- Spinal cord lesions above T6 – needs close monitoring - autonomic dysreflexia

* In minority of cases FES can be useful
Why FES?

- **Increased functional activity**
  currents depolarize nerves → sensory & motor responses → ↑ muscle strength & control

- **Increase intensity of rehab**
  Train at higher contraction intensities

- **Strong evidence to support its use**
  ‘Another tool in your tool bag’
How does FES work?

I feel great!
‘Magic of Neuroplasticity’: Neural reorganization and plasticity

Ascending afferent input from sensory organs in joints, muscles, tendons and skin as well as the direct effect of stimulation on the afferent nerves act upon the nervous system encouraging new synaptic connections.
Neural reorganization with FES

- At the spinal level
  - Improved recruitment by voluntary descending activity
  - Subroutines – synergies / pattern generators

- Within the brain
  - increasing motor and sensory cortex expression
Neural control of movement
Classification of movement

Reflexive
Most Automatic
Repetitive

Postural Balance

Volitional
Least Automatic
Muscle Facilitation & Re-education

- Goal: re-establish voluntary control of body position & movement after disruption of motor control mechanisms

- Needs to be applied in context of motor learning
  - Functionally relevant activities
  - Intermittent feedback
  - Client must be an active participant
FES Paradigms

- FES Independent Application
  - Use of FES for a finite time period to minimize impairments and to encourage motor relearning in context of function
  - The expectation is that the patient will be weaned off FES

- FES Dependent Application
  - This enables the patient to perform functional activities that wouldn’t otherwise be possible (e.g., picking up and carrying a bag) – ‘neuroprosthesis’
THINGS TO REMEMBER:

Active involvement in task performance leads to a substantial increase in cortical excitability compared to non-skillful or passive training  

Perez et al. 2004, *Exp Brain Res*
Regaining functional use
‘Practice makes permanent’ - patterns

- **Intensity**: neuroplasticity: 900 reach and grasp reps/day – less you use the paretic arm, the more the unaffected hemisphere activates (Neurorehab Neurol Repair 2009)

- **Patterns**: Central patterns Synergies…

  **STRETCHING** will it reanimate?

Sensible Not so sensible

Suggested reading: www.ebsr.com (re stretching – moderate evidence)
Active involvement in task performance leads to a substantial increase in cortical excitability compared to non-skillful or passive training  

Perez et al. 2004, Exp Brain Res
Stimulation Parameters

FES Parameters

- Waveform
- Amplitude
- Pulse duration
- Frequency
- Ramp up/down
- On/off time
- Polarity
Do parameters matter?

- Recent literature review found no relationship between stimulus parameters, duration of treatment, subject characteristics and clinical outcome!

- “Triggered or volitionally activated ES more likely to yield improvements in motor control than non-triggered ES”

- Use parameters that encourage active participation of client

(de Kroon et al. 2005)
Where do we apply FES?
Nerve or Motor Point Stimulation

Nerve Stim

Motorpoint Stim
Motor point – what is it?
Motor nerve innervation for upper extremity frameworks
REDUCTION OF SHOULDER SUBLUXATION

Active—axillary nerve (post deltoid)
Indifferent—suprascapular nerve (supraspinatus)

Reduce subluxation
(‘stable platform’)

Treatment goal – joint protection

Parameters – endurance

Targeted motor points -
Posterior deltoid and supraspinatus
(Baker & Parker 1986, Kobayashi et al 1999)

Use minimum amplitude to raise humeral head into glenoid fossa
(avoid shoulder elevation)

STRONG EVIDENCE for FES

www.ebrsr.com
Upper Extremity – Shoulder Subluxation / Pain in Stroke

- **6 studies showing decreased pain**

- **3 studies showing decreased subluxation**
  (various study designs – Baker and Parker 1986, Kobayshi et al. 1999, Koyuncu et al. 2010, Fil et al. 2011)

- **1 study (Church et al. 2006)** – (largest RCT) that shows FES might worsen arm function in patients with severe paresis

Suggested Reading: pp. 28-34, Module 11, www.ebrsr.com
FES in the Upper Extremity

- Upper extremity movements are complex
- Require precise timing of many muscles acting over more than one joint
- Rarely are “normal” movement patterns attained with stimulation alone
Evidence – Stroke Upper Extremity

- > 30 studies examining the effects in the upper extremity
- There is strong (Level 1a) evidence that FES treatment improves upper extremity function in acute and chronic stroke (www.ebrsr.com)
- There are a number of studies showing FES can decrease shoulder pain and subluxation
Evidence – Spinal Cord Injury

- 13 studies with implantable FES systems (many use the “Freehand” device) – almost entirely positive
- 2 studies on the NESS-H200 – mainly positive results for increasing strength and ADL function
- 2 studies on the Bionic Glove – positive results for UE function
- 1 study on the Complex Motion FES system – positive results

Suggested Reading: www.scireproject.com, Upper Extremity Chapter, pp. 40 - 53
Upper extremity – reach and grasp

- What’s driving the process?
  - Successful transport of the limb in order that an object might be captured by the hand and manipulated by it...
  - sensorimotor integration...
Radial nerve

‘OPENERS’ (extrinsics):
Elbow extension
Supinator
Wrist extension
FANNING OF HAND
MCP extension
Thumb abduction extension
Median nerve

‘CLOSERS’:
Pronators (teres / quadratus)
Flexors: FCR, FDS

‘OPPOSERS’
Some thenars
1\textsuperscript{st} and 2\textsuperscript{nd} lumbricals
Ulnar nerve

**MAIN WRIST FLEXOR:**
FCU – dart thrower’s arc

Ulnar FDP

**INTRINSICS:**
Interossei and Ulnar Lumbricals
Example – what does it all mean?

Increased functional activity
Remember…

- Stimulation parameters must be tailored to treatment goal and client
  - **Post Stroke** – facilitating voluntary control and wrist ROM – not a problem if finger extensors are activated
  - **Post-SCI** – development/maintenance of tenodesis grip – MUST avoid finger extension with wrist extension to avoid overstretching flexors
FES for the Lower Extremity

Remember:

- Combine ES with active exercise or functional tasks
Evidence – Stroke Lower Extremity

- To date ~ 17 Good quality RCT’s
- From EBRSR: strong (Level 1a) evidence that FES and gait retraining results in improvements in hemiplegic gait
There is level 4 evidence that FES assisted walking (Thrasher et al. 2006; Ladouceur and Barbeau 2000a; 2000b; Wieler et al. 1999; Klose et al. 1997; Granat et al. 1993; Stein et al. 1993; Granat et al. 1992) that FES-assisted walking can enhance walking speed and distance in complete and incomplete SCI.

There is level 4 evidence from 2 independent laboratories (Ladouceur and Barbeau 2000a,b; Wieler et al. 1999) that regular use of FES in gait training or activities of daily living leads to persistent improvement in walking function that is observed even when the stimulator is not in use.

FES-assisted walking can enable walking or enhance walking speed in incomplete SCI or complete (T4-T11) SCI. Regular use of FES in gait training or activities of daily living can lead to improvement in walking even when the stimulator is not in use.

Suggested Reading: www.scireproject.com, pp21-24, Lower Limb Chapter
FES for Gait

Appropriate for clients with some walking ability
Treatment tailored to client & his/her deficits
Multiple channels may be needed, but increases complexity

Wieler et al. 1999

- For foot drop:
  - FES to fibular nerve to elicit ankle dorsiflexion
  - If dorsiflexion not sufficient, stim increased to elicit flexor reflex (activates hip & knee flexors)

- For knee or ankle instability during stance:
  - Add FES to femoral or tibial nerve

- For instability of hip/pelvis:
  - Add FES of superior gluteal nerve (gluteus medius)
Lower extremity nerves

- Sciatic nerve and branches
- Femoral nerve
- Tibial nerve
- Common Fibular nerve (new name)
Foot drop

- Common fibular nerve
- Tibial artery
- Superficial fibular nerve
- Cutaneous branches of the superficial fibular nerve
- Deep fibular nerve

Old terminology
FES for Foot Drop

- Commercial devices available:

- Walkaide

- Odstock Pace

- Can also use a FES device with accessory jack for foot switch

- NESS L300
Abnormal Tone in Neuro Clients

Observed changes in tone due to pathological conditions

- Depends on remaining input (reduced &/or altered) to muscle’s alpha motor neuron
- **Low muscle tone** (hypotonicity)
  - results from loss of normal input to alpha motor neuron or damage to alpha motor neurons → loss of input to muscle fibers
- **High muscle tone** (hypertonicity)
  - Results from abnormally high excitatory input compared to inhibitory input to intact alpha motor neuron
  - *Spasticity* = velocity-dependent resistance to passive muscle stretch
Spasticity – in stroke
Spasticity – what is role of FES?

- **Effects of Electrical Stimulation in Spastic Muscles After Stroke: Systematic Review and Meta-Analysis of Randomized Controlled Trials**
  - Cinara Stein, MSc; Carolina Gassen Fritsch, Ft; Caroline Robinson, MSc; Graciele Sbruzzi, DSc; Rodrigo Della Méa Plentz, DSc

- **Conclusions** — FES combined with other intervention modalities can be considered as a treatment option that provides improvements in spasticity and range of motion in patients after stroke
There is *strong* evidence that ES decreases spasticity in chronic stroke.

(Teasell et al. 2014)

Similar conclusions in:
- Canadian Stroke Strategy Best Practices and Standards
  (www.strokebestpractices.ca)
- Canadian Stroke Network
  (http://strokengine.ca/intervention/index.php)
Problems with FES

- Risk of raising unrealistic expectations
- Difficulty in predicting outcome
- Insufficient evidence for duration and dosage of treatment
- Electrodes:

Health Professions Strategy and Practice: Professional Practice Notice:

Clinical Electrotherapy – Safety Considerations for Electrode and Coupling Agent Usage:
https://insite.albertahealthservices.ca/assets/hpsp/tms-hpsp-ppn-clinical-electrotherapy.pdf
Provincial Partnerships

1) **STROKE** – Strategic Clinical Network

2) **SCI** - FES Steering Committee
   - Provincial steering committee to guide development of FES cycling program provincially, using uniform standards and approach – teleconferences every 2 – 3 months – provincial meeting in October / November – looking at standard outcomes / assessment

   - Edmonton and Calgary (Red Deer/Lacombe) FES cycling programs will be utilizing similar approach for enrolment and data collection

   - Spinal Cord Alberta
RT300 – FES cycle - SCI
(Jackie Kilgour presentation from FMC)

RT300 is an upper or lower extremity functional electrical stimulation cycle which uses surface electrodes and specific parameters designed to stimulate alpha motor neurons.

*The RT300 was made possible by donations from the Calgary Health Trust and community philanthropy.
RT300 is intended for general rehabilitation for:

- Relaxation of muscle spasms
- Prevention or reduction of disuse atrophy
- Increasing local blood circulation
- Maintaining or increasing range of motion
RT300 at work

- http://www.rtilink.com/
Lower Extremity FES – Cycling

- There is level 2 evidence (Baldi et al. 1998) that FES-assisted cycling exercise prevents and reverses lower limb muscle atrophy in individuals with recent (~10 weeks post-injury) motor complete SCI and to a greater extent than PES.

- There is level 4 evidence (Scremin et al. 1999; Crameri et al. 2002) that FES may partially reverse the lower limb muscle atrophy found in individuals with long-standing (>1 year post-injury) motor complete SCI.

- There is level 4 evidence (Gerrits et al. 2000) that FES-assisted cycle exercise may increase lower limb muscular endurance.

Suggested Reading: www.scireproject.com, Lower Limb Chapter
Absolute Contraindications/Exclusion Criteria

- Client has lower motor neuron damage or denervated muscle (ie. cauda equina, peripheral neuropathies, polyneuropathies, GBS)
- Presence of ANY of the contraindications to FES use
  - cardiac demand pacemaker – may interfere with sensing portion of pacemaker
  - Pregnancy – effects of FES on unborn child are unknown
  - unhealed fracture in the area – may displace fracture
  - Near another stimulator (eg. Phrenic nerve/bladder stim)
  - Near arterial/venous thrombus
  - Over carotid sinus
  - Over areas of skin breakdown
Relative Contraindications

- Severe spasticity
- Heterotopic ossification
- Severe osteoporosis
- Dysaesthetic pain syndrome
- Open sores in the area of treatment
- Malignancy in the area of treatment
- Spastic response to electrical stimulation
- Uncontrolled autonomic dysreflexia
- Obesity
Precautions

Prevention:
• Keep skin clean
• Clean electrodes with water after each use
• Do not shave legs - trim hairs with scissors
• Replace electrodes as recommended
  • carbon rubber electrodes – if dull
  • adhesive – if dry

Clinical Electrotherapy – Safety Considerations for Electrode and Coupling Agent Usage: Health Professions Strategy and Practice – Professional Practice Notice
https://insite.albertahealthservices.ca/assets/hpsp/tms-hpsp-ppn-clinical-electrotherapy.pdf

Cure:
• Stop stimulation until marks clear
• Change to ‘better’ electrodes
• Change to symmetrical biphasic output
• Re-educate your patient about skin / electrode hygiene
Summary

1. FES is easy to apply if you understand basics
2. FES contributes to neural reorganization & plasticity
3. FES should be combined with active movement
4. Best practice guidelines support use of FES for hemiplegic shoulder, gait & UE function – apply FES to hemiplegic shoulder early as preventative.

Patient Education Sheet for FES developed in 2015

https://myhealth.alberta.ca/Alberta/Pages/functional-electrical-stimulation.aspx
WHEN WE ASKED YOU TO TURN OFF ALL ELECTRONIC DEVICES, WE DIDN'T MEAN YOUR HUSBAND'S PACEMAKER...
Contact Info:

stuart.miller@albertahealthservices.ca

kristin.musselman@uoft.ca
References

- *Functional Electrical Stimulation for Neurological Populations*. Kristin Musselman PhD P Ther 546 Sept 23, 2010 presentation
- www.ebrsr.com; www.strokebestpractices.ca; www.strokeengine.ca
Questions?

Thanks for listening – feedback?