Functional Electrical Stimulation

Presented by:
Scott Truong & Phil Chrapka
Functional Electrical Stimulation (FES)

- Method of using low electrical currents to restore body functions by stimulating nerves

- Can be used to help patients with many conditions especially **Spinal Cord Injury (SCI)**
Basic FES System

A Basic Electrical Stimulation System

Controller

Instructions

Stimulator

Stimulation Unit

Electrodes

Leads

Pulse
Overview

- Nervous & Muscular system
- Complications
- History
- FES Principles
- FES System Components
- Applications
- Future Directions
The Nerve

- The foundation of FES relies on stimulating motor nerves
Action Potential

- 100’s to 10,000’s of neurons, along with connective tissue and blood vessels compose nerves
- Nerves run throughout body to muscles
- Traveling electric gradient
Motor Nerve
Motor Nerve

- Neurotransmission at the end of action potential to muscle
Nervous System

- CNS: consists of the brain and spinal cord
- Spinal cord sends signals to motors nerves of the PNS
- PNS runs throughout body
- CNS and PNS are continuous
Spinal Cord Injury (SCI)
- Complete paraplegia
  - T–1 to T–12
- Complete tetraplegia
  - C–1 to C–8
**Damages**

- CNS damage = spinal cord damage
- PNS damage = nerve damage
- CNS damage vs PNS damage
- FES functions on the basis of CNS damage not PNS damage
- A break in neurotransmission
- Common results of damages: paraplegics, foot drop, paralysis, etc.
First solution using FES

- First developed in 1961 by Liberson and colleagues
- Coined term “functional electrotherapy
- Corrected drop foot in hemiplegic patients using electrical stimulation
FES Principles

- FES: a technique that uses short electrical pulses to activate nerves affected in paralysis
- Restores function to people with disabilities
- Basic components:
  - Electrodes
  - Stimulator
  - Controller

![A Basic Electrical Stimulation System]
FES Principles

- There are 2 types of Electrodes:
  - Surface (transcutaneous) electrodes
  - Implanted (percutaneous) electrodes
Surface Electrodes

- Placed on patient’s skin over target nerves
- Adhesive or non-adhesive
- Electric signals passed through skin to stimulate nerves
Surface Electrodes

- Not permanent
- Good for short-term use
- Reuseable
- Good for nerves that aren’t deep
- Non-invasive

- Hard to place exactly over correct area
- A hassle to put on all the time
- Difficult to stimulate deep nerves
- Can stimulate pain feedback nerves
- Precision is low
- Can cause skin burns
Implanted Electrodes

- Electrode attached to nerves or to muscles close to nerves
- Invasive
- Leads exiting skin for external controller or none for remote controller
Implanted Electrodes

- Does not require reapplication
- Very precise muscle stimulation
- Good for long-term use

- Invasive
- Difficult to replace if required
- Permanent
FES Principles

- Pulses create an electric field near the target nerve and depolarize it → action potential
- Action potentials spread down axon and stimulate target muscle
- Tetanization (muscle contraction) requires at least 20 pulses per second
FES Principles

(a) Single twitch     (b) Wave summation     (c) Unfused tetanus     (d) Fused tetanus

Action potential

Time (msec)
FES Principles

- Typical pulse parameters:
  - Biphasic (monophasic causes burns)
  - 20–30 pulses/sec
  - Duration of primary signal: 100–200 μsec
  - Current: 25 – 35 mA
  - Amplitudes: 25 – 35V

- Pulse determines strength of contraction
- Main condition – motor nerves need to be intact (not “denervated”)
Stimulator

- Implanted stimulator receives signals from controller via radio waves
- External stimulator can receive radio waves or be directly connected to the controller via wires
- Connected to electrodes via leads wrapped in an “insulated conducting” material
Controller

- **Stationary version**
  - Usually large and bulky
  - A computer
  - Controlled by another person or automated
  - Often used for short term rehabilitation

- **Portable version**
  - Often worn on hip
  - Convenient for long term use
  - Manual and automated versions available
FES Today

- Spinal Cord Injury (SCI)
- Foot drop
- Walking
- Cardiac pacemakers
- Bladder voiding
- Pain suppression

FES Applications in Spinal Cord Dysfunction

1. Cardiovascular Exercise
2. Breathing Assistance
3. Cough Assistance
4. Grasping & Reaching
5. Bladder & Bowel Control
6. Transfers & Standing
7. Stepping and walking
8. Erection & Electroejaculation
9. Improving Circulation
10. Preventing Pressure Sores
11. Treating Pressure Sores
12. Controlling Spasticity
13. Preventing / Treating Contractures
14. Preventing / Treating Osteoporosis
15. Treating Weak Muscles
16. Regaining Voluntary Function / Improving Movement Control
17. Restoring Sensation
18. Controlling Tremor
FES Today

- Hand Grasp
  - Surface electrode versions
    - Bionic Glove
    - Handmaster
  - Implanted electrode versions
    - Freehand System
    - NEC–FES System
2-way depolarization

Ulnar and Median nerve control fingers

Electrodes should be implanted or cuffed in/on the forearm
Hand Grasping
Hand Grasping

- Flexor carpi radialis, palmaris longus, flexor digitorum superficialis, and flexor pollicis longus = median nerve
- Flexor carpi ulnaris = ulnar nerve
- Flexor digitorum profundus = median and ulnar nerves
- Extensor carpi radialis longus, extensor carpi radialis brevis, and extensor digitorum = radial nerve
- Extensor digiti minimi, extensor carpi ulnaris, and deep posterior muscles = deep radial nerve
FES For Hand Grasping

- Holding and manipulation
- Two main objectives:
  - Reliable and long lasting power grasp
    - Adjustable
  - Smooth pinch grasp to manipulate small objects
    - Easily controllable
- Should not interfere with existing function
- Should be normal physiological movement
- Usually C–5 to C–7 tetraplegia
Freehand System
Freehand System

- Opening and closing of hand controlled by position sensor on shoulder of patient’s opposite arm
- Front (protraction), back (retraction) – for opening and closing
- Up (elevation), down (depression) – for logic commands and freezing the grasp
Freehand System

- 8 implanted epimysial electrodes and implanted stimulator
- Electrodes generate flexion and extension of fingers and thumb
- Position sensor and controller are not implanted
Freehand System

- First neuroprostheses approved by the USA FDA
- 130 patients currently using this system
- Commercially available
- Time required to take on or off is quick
- 18–24 month wait after injury is needed
Bionic Glove
Bionic Glove

- Designed to enhance tenodesis grasp in patients that have control of wrist flexion and extension
- Uses position transducer on wrist to detect wrist flexion and extension
- 3 adhesive surface electrodes, placed over motor points of target muscles
- 1 anodic electrode placed proximal to the wrist crease

Fig 2. Electrode contact. When the glove is donned and tightened, a contact panel between the inner surface of the glove and an inner lining presses onto a metallic stud on the back of a self-adhesive gel electrode. The contact panel is connected to the circuitry in the control/stimulator box.
Bionic Glove

Fig 3. Hysteresis. Wrist angle is used to switch stimulation on and off. In this example, when the wrist flexes to 20°, stimulation causing hand opening is initiated. Hand-open stimulation is turned OFF by re-extending the wrist to 10° flexion. This mismatch in the ON and OFF trigger angles is termed hysteresis.
Bionic Glove

Fig 1. The Bionic Glove. (A) Self-adhesive electrodes are placed over motor points of the muscles to be stimulated. (B) The glove is donned and tightened onto the electrodes, making electrical contact with them (Fig 2). (C) Voluntary flexion of the wrist to a preset trigger angle initiates stimulation of the muscles that open the hand. (D) Extending the wrist to another trigger angle directs stimulation to the muscles that produce grasp.

A adhesive electrodes over motor points

B wrist position sensor control/stimulator box conductive panels inside glove automatically connect control box to electrodes

C wrist flexes, triggers hand opening sensor control box

D wrist extends, triggers pinch grip D-ring
Bionic Glove

OFF
Bionic Glove
Bionic Glove

- Can be used early in rehabilitation
- Shortcomings:
  - Stimulator on forearm is subjected to abuse
  - Position transducer is delicate
  - Contacts between electrodes and mesh are disrupted due to arm movements
  - Electrode on thumb slips off with use
Summary

- FES has had promising progress
- Limited use
  - Highly technical
  - High expectations from family
- After FES treatment, some patients recovered grasping functions
Future directions

- BIONs (Biological Neurons)

- “Thought” – control FES
Any Questions?
References

- Hambrecht, FT, “FES: How and when it started?”, IFESS organization, volume 1 number 2, Last updated: Jan 19, 2007
  http://www.ifess.org/Services/News%20and%20Views/Volume_1/Number_2/number_2.htm
  http://fescenter.case.edu/site2/GRFX/FESRG.pdf