Functional Electrical Stimulation (FES)

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FES – What is it?

- FES stand for Functional Electric Stimulation
- It can restore the lost functions of the nervous system by means of the electrical stimulation
FES – *Why* we need that?

- Research in the control of body movements
- Important from the perspective of the therapeutic and diagnostic medicine
  - Spinal Cord Injury
  - Stroke
  - Abnormal Body Systems
Background Information

- Review of Anatomy
- Electrical stimulation
Background Information

- Review of Anatomy
  - Membrane Potential
  - Nerve System
  - Skeletal Muscle Tissue
  - Nervous excitation
Membrane Potential

There are different concentrations of cations (charged particles like Na++, K, Ca2+) and anions (charged particles like Cl-) inside and outside of the plasma membrane. More negative charged particles (anions) are on the inside of the plasma membrane. The voltage potential is lower in the cytoplasm than to the extracellular space.
Membrane Potential

Extracellular fluid

+ + + + + + + + + + + + + +

Plasma membrane

- - - - - - - - - - - - - -

Cytoplasm

Cell

Cytoplasm

Plasma Membrane

Voltmeter of Science
-40 to -70 mV
Membrane Potential

Membrane of the cell effectively forms a capacitor

Extracellular fluid

+ + + + + + + + + + + + +

Plasma membrane

- - - - - - - - - - - - -

Cytoplasm
Nerve System

- The structure and function of a nerve tissue
Nerve System

Key:
- Graded potential
- Nerve action potential
- Muscle action potential
Skeletal Muscle Tissue

(a) Fusion of myoblasts into skeletal muscle fiber

(b) Details of several myofibrils

10.03
Mechanism of Nervous Fiber Excitation

- Transmembrane potential of the axon varies widely from the resting potential (~-70mV)
- As the $K^+$ enter the plasma membrane, the membrane potential increases steadily.
- When the membrane potential reaches to threshold voltage (~50mV), the Na+ gate opens, and membrane potential will then rise rapidly.
Mechanism of Nervous Fiber Excitation Con’t

- Once the membrane potential reaches 30mV, there is a positive feedback on the cell, Na⁺ gate closed, and membrane potential decrease to its resting potential

\[
E_m = \frac{RT}{F} \ln \left( \frac{[K^+]_o + b[Na^+]_o + c[Cl^-]_i}{[K^+]_i + b[Na^+]_i + c[Cl^-]_o} \right)
\]
Mechanism of Nervous Fiber Excitation Con’t

Voltage threshold for opening of voltage sensitive Na\(^+\) channels. Since increasing voltage is caused by Na\(^+\) entry and this entry causes increased voltage; this is a positive feedback loop.
Background Information

- Physiological recruitment of a neuron
- Artificial electrical recruitment of nerves
Physiological recruitment of a neuron
Artificial electrical recruitment of nerves

Different from Physiological recruitment.

I. Anatomical location of recruitment
II. It does not involve synapses or connections with the neuron.
III. It is determined by the amount of electrical stimulation has been applied.
Electrical Stimulation

- Equivalent Circuit Model of the Nerve Axon

\[ \frac{dV_c(n,t)}{dt} + G_c V_c(n,t) = -G_c \{V_c(n-1,t) - 2V_c(n,t) + V_c(n+1,t)\} = I_c(n,t) \]

Equivalent circuit model of a section of myelinated nerve axon.
Electrical Stimulation
Applications

The FES technology can apply to different area to restore the lost functions of the nervous system:

- Hand disabilities – reaching and grasping
- Phrenic stimulation
- Drop-foot stimulator
Hand disabilities

Hand disabilities – reaching and grasping

- 3 best known grasping FES apparatus
  - Freehand system
  - Bionic Glove
  - Handmaster NMS
Freehand system

What is it look like?

- attach electrodes to muscle in patient’s hand (wrist) and forearms
- a "joystick" controller implanted in the opposite shoulder
- a pacemaker-type stimulator is surgically implanted into patient’s chest
Freehand system

- Electrodes
- Electrode Leads
- Implant Stimulator
- Transmitter Coil
- Shoulder Position Sensor
- External Controller
Freehand system

How it works?

- "joystick" controller – a shoulder position sensor
- sensor placed on the chest relaxes and tightens the hand as the shoulder moves back and forth
- stimulator sends electrical signals through the electrodes
Freehand system

- these signals cause the muscle to contract and the hand to open and close

X-Rays show the location of the stimulator, the electrodes and leads
Freehand system

- Through the shoulder movements to open and close the hand

- 2 important grasp movement
  - Pamlar Prehension
  - Lateral Prehension
Freehand system

- Palmar Prehension
  - cupping the hand like the letter "C" for activities like drinking from a cup and picking up larger objects

*holding cups, ball or a game piece*
Freehand system

- Lateral Prehension
  - pressing your thumb against your forefingers for activities such as writing and brushing your teeth

for writing, eating and grasping
Hand disabilities

- Bionic Glove
  - a hybrid system that utilizes a glove with FES electrodes
  - detection of wrist extension stimulates finger flexion
  - only patients who have sufficient wrist extension strength can use
Hand disabilities

- Handmaster NMS
  - three pairs of surface stimulation electrodes
  - envisioned as an exercise and rehabilitation tool
  - also used as a permanent prosthetic system
  - it is easy to put on and to take off
Phrenic stimulation

What apparatus we use?
- Diaphragm pacing device/system

Include 3 main parts
- a controller box outside the body
- electrical wire (connection)
- an electrode which implant into the muscle of diaphragm
Phrenic stimulation

diaphragm pacing device/system
Phrenic stimulation

How it works?

- apply the electricity from the controller box
- stimulate the diaphragm muscle to contract through the electrode (diaphragm move down)
- the muscle relax after the stimulation (get back to original position)
- repeat this electrical stimulation periodically
Phrenic stimulation

- Relationship between contraction of diaphragm and breathing
Phrenic stimulation

- Suitable patient (requirement)
  - with an intact phrenic nerve motor neuron pool in their cervical spinal cord on both sides
  - need to implant an electrode into the muscle of diaphragm through the surgery
Drop-foot stimulator

- What problem is it?
  - diminished ability to use the muscles that lift the foot
- surface stimulation device/system
  - Odstock 2
  - WalkAide
  - MikroFES
Odstock 2

- an assisting aid or as a training device to strengthen muscles and improve voluntary control

- allowing isolated components of the gait cycle to be practiced under therapist control
What is it look like?

- a pocket-sized main unit
- a foot switch (one or two)
- two adhesive surface electrodes connected with wires
Odstock 2

Overview of the device
Odstock 2

- pocket-sized main unit
Different situation of drop foot

- Bilateral dropped foot
- Dropped foot with gluteal muscles
- Dropped foot with quadriceps
- Dropped foot with hamstrings
- Dropped foot and calf
- Bilateral Gluteal muscles for correction of trandalanberg gate
- Dropped foot with triceps
Bilateral dropped foot
- single foot switch is used under the heel
- weight is taken off the switch, channel 1 is active
- weight is returned to the switch, channel 2 is active
- both common peroneal nerves are prevented from being active at once
Dropped foot with gluteal muscles

- gluteal muscles are stimulated through the stance phase to extend the hip
Dropped foot with quadriceps

- quadriceps are stimulated throughout the stance phase to allow weight bearing
References


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Questions & Concerns?

Thank you for listening