OBJECTIVES
<table>
<thead>
<tr>
<th>Outlines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle contraction in innervated muscles</td>
</tr>
<tr>
<td>Parameters for electrical stimulation of denervated muscles</td>
</tr>
<tr>
<td>Parameters for electrical stimulation of innervated muscles</td>
</tr>
<tr>
<td>indications for use of electrical stimulation for muscle contraction</td>
</tr>
<tr>
<td>Contraindications/ precautions for use of electrical stimulation for muscle contraction</td>
</tr>
<tr>
<td>Clinical case study</td>
</tr>
</tbody>
</table>
Neuromuscular electrical nerve stimulation (NMES) is electrical stimulation of innervated/partial innervated muscles using surface electrodes to induce muscle contraction aiming for:

- Muscle re-education
- Prevention/Retardation of disuse atrophy
- Muscle strength and/or endurance
- Reduce edema (Muscle pump contraction)
Motor point

- Superficial located on the surface of the skin
- Usually located at muscles belly between the proximal one third & distal 2/3 fleshy part of the muscle fibers.
- Point of great density of terminal motor end plates
- Point of great excitability to E-stim.
**WHAT IS THE MOTOR UNIT?**

**Motor unit**

- **Single motor neuron** (alpha motor neuron) from anterior horn cell and all the muscle fibers it stimulate.
- Each motor unit supplies from 4-100 muscles fibers.
- Dependent on movement precisions e.g. Gastrocnemius 2,000 muscle fibers per motor neuron
- Motor neuron determines fiber type

<table>
<thead>
<tr>
<th>Motor unit classification</th>
<th>Muscle fiber classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow</td>
<td>Type I slow oxidative (SO)</td>
</tr>
<tr>
<td>Fast fatigue resistance</td>
<td>Type II a fast oxidative glycolytic (FOG)</td>
</tr>
<tr>
<td>Fast fatigue</td>
<td>Type IIb fast glycolytic (FG)</td>
</tr>
</tbody>
</table>
POSITION OF THE MP OF QUADRICEPS MUSCLES
POSITION OF THE MP OF HAMSTRING MUSCLES
POSITION OF THE MP OF LEG MUSCLES
POSITION OF THE MP OF FACIAL NERVE
LOCATIONS OF THE MOTOR POINTS

[Diagram showing hand and arm muscles with labeled points]
To trace motor point

1. Interrupted direct current at 0.1ms (100µs) for **innervated muscle**
2. Interrupted direct current at 10ms for **denervated muscle**

- **ES parameters**
- F(1-20Hz)
- Intensity (start 1mA)
- Pulse duration 100-1000µseconds
- Pen electrodes (active)
- Dispersive electrode
- Alcohol swap (cotton) and markers
- A, B, C, D,

http://www.youtube.com/watch?v=ltQTB5ekhf4
## VOLUNTARY VERSUS E-STIMULATION CONTRACTION

<table>
<thead>
<tr>
<th></th>
<th>E-stimulation contraction</th>
<th>Voluntary MS contraction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Order of recruitment</strong></td>
<td>Fast twitch type II, then slow twitch type I</td>
<td>Slow twitch type, followed by fast twitch Type I MU fire first, then Type II. Type IIb brought in last of</td>
</tr>
<tr>
<td><strong>Pattern of recruitment</strong></td>
<td>Synchronize</td>
<td>A Synchronize</td>
</tr>
<tr>
<td><strong>Pattern of AP propagation</strong></td>
<td>Two direction</td>
<td>Ortho-dromic</td>
</tr>
<tr>
<td><strong>Fatigability</strong></td>
<td>Easy and rapid</td>
<td>Resistance &amp; delayed</td>
</tr>
<tr>
<td><strong>Force of contraction</strong></td>
<td>Quicker &amp; Strongest</td>
<td>Slower and low force</td>
</tr>
<tr>
<td><strong>Onset of contraction</strong></td>
<td>Rapid &amp; jerky</td>
<td>Slow and smooth</td>
</tr>
</tbody>
</table>
How To Differentiate Between innervated /denervated muscles

- History
- Physical examination
- S-D curve
- NCV
- EMG
DENERVATED MUSCLES

Loss of its peripheral nerve secondary to disease, chemical toxicity, physical injury, or intentional surgical interruption of a nerve causes muscles denervation

- Complete denervation (CD), all motor unit loses all innervation
- Partial denervation (PD) some of motor unit in the muscles lose its innervation

- Loss of voluntary and reflex activity,
- Muscle atrophy (Decrease size, and diameter of individual muscles fibers)
- Changes in muscle excitability:
  - (Decrease amount of tension and Increase time required for contraction)
- Muscles fibrosis (within 2 years)
CLASSIFICATION OF THE PERIPHERAL NERVE INJURY

**Neuropraxia**
Compression on nerve
100ms, rectangular

**Axonotmesis**: partial denervation
100-600ms,
triangular, trapezoidal

**Neurotmesis**
Complete denervation
100-2000ms /triangular, saw-tooth
The *Strength Duration Curve* (SD-curve) is a graph representation of non-liner relationship between intensity and duration of current.

The purpose of S-D curve is to know whether the stimulated muscle is *innervated, denervated (CD and/or PD)*

**It depends on:**
- Numbers of motor units recruitment
- Intensity and frequency of current.
- Placement of electrodes.
- Degree of injuries

**Optimum timing of SDC:**
- 10 – 14 days post injury
STRENGTH DURATION CURVE (SDC)

Methods of SDC:

E-stim unit with rectangular waveform with pulse duration i.e. 0.2, 0.4, 0.6, 0.8, 1, 1.2, 10, 30, 100, 300ms and constant current.

Put the active electrode over the fleshy belly of the muscle.

First apply current having longest duration and look for minimal perceptible contraction.

Gradually shorten the impulse duration and note the corresponding increase in current strength.

The electrode placement should not be changed throughout the test. Plot of SD graph.
**Rheobase** is a minimal current intensity (amplitude) required to produce a minimal visually perceptible muscle contraction (giving a long duration; 300ms).

- Normal values are (2-18mA)

**Chronaxie** is the length/duration of pulse in milliseconds with the two-fold intensity of the rheobase to produce muscle contraction

- **Chronaxie** of innervated muscles is less than 1ms (range 0.05-0.5ms).

- **Chronaxie of fully denervated** muscle may be 30 to 50ms
FIGURE 4–3. Plot of strength duration test values recorded in Figure 4–2 with chronaxie marked by arrows. (A) Normal abductor digiti minimi muscle on right hand, chronaxie 0.3 ms; (B) denervated muscle on left hand 2 weeks after injury, chronaxie 20 ms; and (C) partial reinnervated muscle on left hand 6 weeks after injury, chronaxie 10 ms.
STIMULATION OF DENERVATED MUSCLES
LONG DURATION INTERRUPTED DIRECT CURRENT

Unidirectional, interrupted direct current with following characteristic:

- **Pulse duration**
  - Long pulse duration (100ms-600ms)
  - 100-300ms PD
  - ≥ 300ms CD

- **Inter-pulse interval**
  - 3-5 times of pulse duration.

- **Frequency**
  - Depends on pulse duration e.g. If Pulse duration = 100ms
    - Frequency of 30 Hz

- **Waveforms**
  - Pulsed monophasic
    - Saw-tooth,
    - Triangular,
    - Trapezoid

---

**Graphs:**
- Interrupted DC
- Ramped DC
STIMULATING DENERVATED MUSCLE

- **First 2 weeks.**
  - Use asymmetric, biphasic waveform and pulse duration < 1mSec

- **After 2-3 weeks,**
  - Interrupted long duration DC of square/triangular waveform with a pulse duration of 200-500mSec, and inter-pulse interval 3 to 5 times longer
  - Use monopolar or bipolar electrode setup with small diameter active electrode (negative) placed over most electrically active point.
  - Stimulation using 3 sets of 5-20 repetitions, 3/ per week
Parameters of E-Stim of Denervated Muscles

- Retardation of denervated atrophy
- Utilization of substrates
- Prevent venous & lymphatic stasis
- Working hypertrophy
- Maintenance of muscle extensibility
NMES- FARADIC CURRENT
Faradic current is biphasic unevenly alternating current, with frequency 1-150Hz. Each pulse consists of two unequal phases

**B-Negative:** Low intensity long duration

**A-Positive:** High intensity short duration
Faradic current

Interrupted direct current (why?)
pulse duration of 0.1 to 1ms,
frequency of 30 - 100Hz
Surged form of current (why?)
FC-stimulation Parameters

- Frequency
- Waveforms
- Amplitude
- Pulse duration
- Pulse interval
Types of muscles contraction is frequency dependence. So Frequency range (10, 50, 75, 100 Hz).

In order to achieve a constant contraction, the stimulus must be applied at rate of 30-80Hz.

- For small muscles (20-30pps).
- For large muscles (50-80pps).
Pulsed biphasic
Asymmetrical biphasic usually used

**Normal muscle:**
Rectangular waveform is more comfortable than triangular pulse

**In disuse atrophy:**
triangular waveform can be used.
**FARADIC CURRENT STIMULATION**

**Pulse duration**

Therapeutic selection 0.02, 0.05, 0.1 & 1ms.

*Normal muscles*: recommended PD is 0.15-0.35Msec.

**Pulse duration** > 10msec is indicated to neurological disorders.

As the pulse duration is shortened, the higher current amplitude is required to achieve the same strength of contraction produced by longer pulse duration,
The current must be interrupted (off-time) to allow the muscles to relax following period of contraction (on-time), to prevent muscle fatigue.

The recommended on: of ration as following

- In case of muscle strength 1:3 - 1:5
- In case of muscle spasm 1:1
- In case of muscle pump (edema) 1:1 or 1:2
The strength of muscles contraction is amplitude dependence.

The recommended amplitude as following:

- Normal muscles: Strength
- Muscles Recovery form injury/disuse: Strength Muscles functional recovery
- Muscle reeducation: Functional recovery
- Muscle spasm/edema: Decrease spasm, Decreased edema

- 50% of MVIC
- 10% of MVIC
- Sensory higher motor, Lower motor
- Visible MS. contraction
### Recommended Parameter Settings For Electrically Stimulated Muscle Contractions

<table>
<thead>
<tr>
<th>Parameter Settings/Treatment Goal</th>
<th>Pulse Frequency</th>
<th>Pulse Duration</th>
<th>Amplitude</th>
<th>On:Off Times and Ratio</th>
<th>Ramp Time</th>
<th>Treatment Time</th>
<th>Times per Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle strengthening</td>
<td>35-80 pps</td>
<td>150-200 µs for small muscles, 200-350 µs for large muscles</td>
<td>To &gt;10% of MVC in injured, &gt;50% MVC in uninjured</td>
<td>6-10 seconds on, 50-120 seconds off, ratio of 1:5, initially. May reduce the off time with repeated treatments</td>
<td>At least 2 seconds</td>
<td>10-20 min to produce 10-20 repetitions</td>
<td>Every 2-3 hours when awake</td>
</tr>
<tr>
<td>Muscle reeducation</td>
<td>35-50 pps</td>
<td>150-200 µs for small muscles, 200-350 µs for large muscles</td>
<td>Sufficient for functional activity</td>
<td>Depends on functional activity</td>
<td>At least 2 seconds</td>
<td>Depends on functional activity</td>
<td>NA</td>
</tr>
<tr>
<td>Muscle spasm reduction</td>
<td>35-50 pps</td>
<td>150-200 µs for small muscles, 200-350 µs for large muscles</td>
<td>To visible contraction</td>
<td>2-5 seconds on: 2.5 seconds off. Equal on:off times</td>
<td>At least 1 second</td>
<td>10-30 min</td>
<td>Every 2-3 hours until spasm relieved</td>
</tr>
<tr>
<td>Edema reduction using muscle pump</td>
<td>35-50 pps</td>
<td>150-200 µs for small muscles, 200-350 µs for large muscles</td>
<td>To visible contraction</td>
<td>2-5 seconds on: 2.5 seconds off. Equal on:off times</td>
<td>At least 1 second</td>
<td>30 min</td>
<td>Twice a day</td>
</tr>
</tbody>
</table>
To be effective 2 & 3 treatments per week for the first 8-12 weeks.

Treatments last 15-20 minutes but no longer than 30 minutes.

It is better to have 3 short treatments per week than 1 long treatment.

For muscle strength several time/day for short time 10 minutes is effective.
EFFECTS OF FARADIC STIMULATION

**Sensory nerves**

- **Mild prickling** due to stimulation of sensory nerve.
- **Mild erythema** due to local reflex vasodilatation of superficial blood vessels, which causes slight reddening of the superficial tissues.

**Motor nerves**

- Faradic current stimulates the motor nerves/muscle, causes contraction of the muscles.
- Because the stimuli repeated 50 times (50Hz) or more, the contraction is tetanic.
- To avoid muscle fatigue secondary to this contraction the current becomes surged.

E-stimulation causes MS-strength through Overload principle and specificity mechanisms.
EFFECTS OF MUSCLE CONTRACTION

- Increased muscle metabolism.
- Increase oxygen demand by the muscles.
- Increase output of waste product & metabolites (carbon dioxide, lactic acid).
- Dilatation of capillaries and arterioles
- Increased blood flow
- Increase local temperature.
- Increase venous and lymphatic drainage
- Changes in muscle structure (fast twitch to slow twitch)
- Increase joint range of motion.
CLINICAL APPLICATION OF ELECTRICAL STIMULATION INDUCED MUSCLES CONTRACTION
FACILITATION OF MUSCLE CONTRACTION & RE-EDUCATION

- Pain & muscle spasm,
  - Quadriceps e.g. vastus medialis after knee injury & diseases

- Prolonged disuse, wasting and imbalance
  - Following knee surgery (e.g. ACL, TKR)
  - Scoliosis.
  - Prolonged period of immobilization (following fracture)

- Muscle and nerve repair and transplantation.

- Peripheral Nerve injury

- Pelvic floor Muscle (stress incontinence)
Electrical stimulation of the muscle causes increase venous and lymphatic return, increase blood velocity and flow, alter cell membrane permeability, these causes reduction of edema.

The treatment is most effective if the current is applied by the method, termed faradism under pressure.

**Faradism under pressure** is stimulation of the muscle that generally act as the pump muscles and is combined with compression and elevation of the limb to increase venous and lymphatic drainage and hence relive edema.
E-STIMULATION FOR NEUROLOGICAL DISORDERED

Stroke: E-stim of weakened lower limb agonist muscles can improve

- Voluntary recruitment of motor units
- Improve gait
- Increase ankle dorsiflexion torque
- Assist or support joint position during movement
- Can substitute for ankle foot orthosis
- Can substitute for hand function in ADL (e.g. NESS hand rehabilitation system)

https://www.youtube.com/watch?v=Px6CJUfZOoQ
RETARDATION OF MUSCLE ATROPHY

Maintenance of muscle tissue after injury that prevent normal muscle contraction can be achieved through using an electrical stimulated muscle contraction, which produce the physical and chemical events associated with normal voluntary muscle contraction and helps to maintain normal muscle function.

INCREASING RANGE OF MOTION

Muscle contraction pulls the joint through limited range. The continued contraction of this muscle group over an extended time make the contracted joint and muscle tissues modify and lengthen.
The person with foot drop is unable to dorsiflex their foot.

The right quad has atrophied or wasted. Stimulation of the quad can prevent atrophy and increase strength.

Placement for quad weakness/atrophy.

The approximate electrode placements for foot drop. The negative is placed over the peroneal nerve.
Post op ACL

- Problem: Quadriceps atrophy
- Goal: Decrease atrophy, increase strength.
- Waveform: Symmetric
- Duty cycle: 25% (4:12)
- Placements:

Rotator cuff repair

- Problem: Rotator cuff atrophy, poor scapular stability
- Goal: Decrease/ reverse atrophy, scapular stabilizer re-ed.
- Waveform: Symmetric/ asymmetric
- Duty cycle: 25%, hand switch
- Placements:

Isometric Abduction  Scapular depression
CONTRAINDICATION FOR FARADIC CURRENT STIMULATION

- Skin lesion & dermatological conditions such as eczema.
- Infection such as osteomyelitis.
- Vascular diseases such as thrombosis, & thrombophlebitis.
- Marked loss of skin sensation (chemical burn).
- Unreliable patients.
- Superficial metal (concentration of electricity).
- Metal and cardiac pacemaker
- Over recent or non-union fractures
- Over potential malignancies
Electrodes Placement For Muscles Contraction

tibialis Anterior muscles

Rectus femoris

Vastus medialis

Wrist extensor