Introduction and Update on the Use of Neuromuscular Electrical Stimulation for Neurologic Populations

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Objectives

- By the end of the session, participants will be able to:
  - Describe how neuromuscular electrical stimulation (NMES) is used in the practice of occupational therapy and articulate the theoretical and regulatory issues associated with the use of NMES;
  - Explain the essential elements of electrotherapy and define the individual NMES parameters used in treatment regimens;
  - Summarize the effects of electrotherapy on muscle tissue and demonstrate an understanding of the conditions that could benefit from NMES application;
  - Objectively evaluate the current scientific evidence supporting the use of NMES in occupational therapy practice;
  - Administer an NMES program to a partner, evaluate the response, and reciprocate by having the program applied to themselves;

Definition: PAMs

- Physical Agent Modalities (PAMs) are those procedures and interventions that are systematically applied to modify specific client factors when neurological, musculoskeletal, or skin conditions are present that may be limiting occupational performance.

Bracciano, 2008

Categories of PAMs

- Superficial thermal agents
- Deep thermal agents
- Electrotherapeutic agents
- Mechanical devices

Definition: PAMs

- PAMs use various forms of energy to modulate pain, modify tissue healing, increase tissue extensibility, modify skin and scar tissue, and decrease edema/inflammation.
- PAMs are used in preparation for or concurrently with purposeful and occupation-based activities.

Bracciano, 2008

Electrotherapeutic Agent Definitions

- NMES: Neuromuscular Electrical Stimulation
- FES: Functional Electrical Stimulation
- ES: Electrical Stimulation
- TENS: Transcutaneous Electrical Nerve Stimulation
- TMS: Transcranial Magnetic Stimulation
NMES

- **What it isn’t**
  - Superficial
  - Topical
  - Non-invasive

- **What it is**
  - INVASIVE!!!
  - Subcutaneous
  - Altering process

ACOTE Standards: OT

- OT education to include
  - Explain the use of *superficial* thermal and mechanical modalities as a preparatory measure to improve OP, including foundational knowledge, underlying principles, indications, contraindications, & precautions. *Demonstrate safe and effective application of same.*
  - Explain the use of *deep* thermal and electrotherapeutic modalities as a preparatory measure to improve OP, including indications, contraindications & precautions.

Philosophical Issues - History

- PAM use said to be inconsistent with the basic philosophy of OT (the use of purposeful activity for health/healing)
- Incorporating into profession will open it up to criticism, public confusion, political issues, and redundancy with PT
- Not intrinsic or unique to our profession and not “occupational” in nature

 McGuire, 1991; West & Weimer, 1991

AOTA’s Position Paper

- PAMs are categorized as *preparatory methods*
- “Preparatory methods support & promote the acquisition of performance skills necessary to enable an individual to resume or assume habits, routines and roles for engagement in occupation.” (AOTA, 2008)

Current AOTA Status on PAMs

- …PAMs may be applied only by OTs and OTAs who have documented evidence of possessing the theoretical background and technical skills for safe and competent integration of the modality into an OT intervention plan

AOTA, 2012

Current Status

- The foundational knowledge necessary for proper use of these modalities requires appropriate, documented professional education, which includes *continuing education courses, institutes at conferences, and accredited higher education courses or programs.*

AOTA, 2012
OT and OTA Application

- When an OT delegates the use of a PAM to an OTA, both must comply with appropriate supervision and state regulatory requirements and ensure that preparation, application, and documentation are based on service competency and institutional rules.
- Only OTs with service competency in this area may supervise the use of PAMs by OTAs. Occupational therapy assistants may gain competency only in those modalities allowed by state and laws and regulations.

IMPORTANT!!!!!!

“The exclusive use of PAMs as a therapeutic intervention without application to occupational performance is NOT considered occupational therapy.”

Discussion

- Do you currently use PAMs in your practice? With which diagnoses?
- Do you feel the use of PAMs in practice is in opposition to the philosophical and theoretical basis of OT?

Current Trends

- Greater use and acceptance of PAMs in OT practice
- Evidence-based practice
- Some states have drafted licensing guidelines to ensure competency and safe use of PAMs

Certification in PAMs

- Some states have moved to specific licensing/certification or documented evidence of proficiency in PAMs before allowing application
- AOTA approved certification course
  - www.pampca.org
- Tennessee
- Oregon
- Nebraska
- Minnesota
- Georgia
- Massachusetts
- California
- Ohio
- Maryland
- Montana
Continuing Education

- AOTA directive
- Important to directly experience NMES before applying to patient
- Knowledge base needed for correct application
- Continued use and experience with different methods leads to expertise

Discussion

- What specific knowledge do you hope to take home with you today from this workshop?

Principles of Electrotherapy

- Late 1700s: Luigi Galvani
- Used in therapeutic applications for over 40 years

Definitions

- NMES: use of pulsed alternating current (AC) to stimulate a motor response by depolarizing intact peripheral nerves
- Used to reduce muscle spasm, spasticity, increase muscle strength, facilitate muscle re-education, reduce edema, tissue/wound healing

Long History of Electrotherapy

Definitions

- HVGS: High-voltage galvanic stimulation;
  - used for tissue repair and pain control
  - Stimulator uses an interrupted monophasic twin-peak waveform
  - Output > 150 volts
- Iontophoresis: Induction of topically applied pharmaceuticals into bodily tissue by application of a low-voltage direct galvanic electrical current.
  - Used for inflammatory conditions such as tendonitis bursitis, myositis and scar tissue modification
Nerve & Muscle: Excitable Tissue

- Can maintain an electrical potential across cell membrane
- Can respond with alteration in potential
- APs occur when a stimulus excites the nerve cell causing membrane depolarization
- Can be caused by thermal, mechanical, chemical, or electrical stimuli

Bracciano, 2008

Nerve Fiber Resting State

Na
-70mv
K

Adapted from Baker et al., 2000

Generation of Action Potential

Stimulus
Na
40mv
K

Adapted from Baker et al., 2000

Basic Electrical Principles

- Electrical Current: flow or movement of electrons or charged particles from one point to another with a purpose to re-establish balance between negative and positive charges
- Electricity: energy that produces magnetic, chemical, mechanical, and thermal effects
- Current always takes a path of least resistance
- Characteristic flow is from an area of high concentration (cathode) to an area with less concentration (anode)

Bracciano, 2008

The Path of Least Resistance

Surface Tissue
Interstitial Tissue

Adapted from Baker et al., 2000

Electrical Current Propagation

- Current is best carried through the water in tissues
- Thus, structures with high water content will have lower impedance and better electrical conductance
- Rate of propagation dependent on diameter of nerve fiber and degree of myelination
- Larger diameter fibers = lower resistance to current

Bracciano, 2008
Impedance & Resistance

- **Impedance**: the opposition to the flow of electrons in tissue;
  - Characterized as the "resistance" to the current
- **Resistance**: the property of a substance that opposes or resists the flow of current
- The greater the impedance or resistance in an electrical circuit, the lower the rate of flow

### Tissue Impedance

<table>
<thead>
<tr>
<th>Tissue</th>
<th>Water Content</th>
<th>Electrical Impedance</th>
<th>Electrical Conductance</th>
</tr>
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<tbody>
<tr>
<td>Bone</td>
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</tr>
<tr>
<td>Skin</td>
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<tr>
<td>Nerve</td>
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<td></td>
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<tr>
<td>Blood</td>
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</tbody>
</table>

Adapted from Bracciano, 2008

Electrical Currents in the Clinical Setting

- **Direct current (DC)**
  - Unidirectional flow of either (+) to (−) or (−) to (+) electrons
  - "Galvanic"
  - Can cause chemical reactions in body or burns to skin
  - Used often for scar modification or medication administration
  - Can be used to directly stimulate denervated muscle

Electrical Currents in the Clinical Setting

- **Alternating current (AC)**
  - Continuous change in direction of electron flow
  - Typically supplies electricity for household items
  - Bidirectional flow that can be interrupted or not interrupted
  - Absence of net charge (no concentration of positive or negative at one pole)
  - Also described as “biphasic waveform” or bidirectional current
  - Minimal damage due to lack of accumulation of (+) or (−) electrons

Electrical Currents in the Clinical Setting

- **Pulsed Current**
  - Most stimulators deliver pulsed current using one of three pulsed waveforms:
    - 1/ Monophasic
      - One phase to each pulse
      - Unidirectional flow of ions
      - Direct stimulation of denervated muscle; transmission of meds

Pulsed Current

- 2/ Biphasic
  - Consists of two opposing electrical phases in a single pulse (positive and negative)
  - Can have symmetrical, asymmetrical, balanced or unbalanced phases
  - Asymmetry or imbalance creates a build up of electrons
  - Symmetrical biphasic more comfortable for NMES patient use
  - Asymmetrical sometimes used for smaller muscles under negative electrode
  - Symmetrical better for large muscles or for combined movement
Pulsed Current

- 3/Polyphasic
  - Burst of three or more pulses
  - Series of pulses delivered as a single charge (perception is of a single pulse)
  - Uses “medium” frequencies
  - Used in:
    - Interferential: pain relief, increase blood flow, muscle stimulation
    - Russian stimulation: increases muscle mass and strength gains; high frequency, 1:5 duty cycle

Direct Current

- Alternating Current
- Pulsatile Current
- Interrupted Direct Current

Adapted from Bracciano, 2008

Discussion

- Have you ever felt electrical stimulation?
- If not, what do you anticipate it will feel like?
- How do you think your patients will respond with the first use?

Sensory Perception

INTENSITY OF STIMULATION

- Type A sensory fibers, Group A, II beta, III; C fibers, Group IV
- Type A motor fibers
- Motor
- Sensory
- Pain

Parameters of Electrical Stimulation

- Amplitude
- Duration
- Rate/Frequency
- Pulse Train
- Pulse Pattern
- Duty Cycle
- Ramp Time

Amplitude

- Amount of current/voltage delivered during a single phase of a pulse
- Also known as Intensity or Pulse Intensity
- Measured in mA or μA
- Begin at 0 for best results and increase in gradual increments (0.5 mA)
Duration
- Pulse duration is the amount of time that elapses between the onset of one phase in a pulse to the end-point of the second phase in the same pulse.
- Typically measured in μs or ms.
- As phase duration increases, depth of penetration will increase.
- As phase duration increases, more discomfort is present, greater chemical changes can occur, more impedance present.

Rate/Frequency
- Number of pulse cycles being delivered to body tissues.
- Typically measured in pulses per second (pps).
- Frequency of current being delivered as Hertz (Hz).
- E.g., Slower rate (1-5 pps) acts as a pumping mechanism; Faster rate will recruit more muscle fibers.

Frequency
- Higher vs. Lower?
- Rightward shift of force-frequency relationship after fatigue:
  - Thomas et al., 1991
  - Fuglevand et al., 1999
- "Low Frequency Fatigue" (LFF)
  - Edwards, 1977
- LFF possibly more prevalent in older adults
  - Allman & Rice, 2002
- Paralyzed muscle generally weak and fatigable; higher frequencies needed
  - Griffin et al., 2002
  - Thomas et al., 2003

Force-Frequency Relationship
- Graph showing the relationship between force and stimulus rate (Hz).

Pulse Train
- Intermittent vs. Continuous

<table>
<thead>
<tr>
<th>20 Hz Continuous</th>
<th>20 Hz Intermittent</th>
</tr>
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<tbody>
<tr>
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</tbody>
</table>

Duty Cycle
- Ratio of time on to time off; expressed as ratio (1:3, 1:5, etc.).
- Can be expressed as on/off time.
- Percentage:
  - (total on time/total on+off time) X 100
- Important in determining amount of fatigue.
- Shorter off-time = greater fatigue.
- Typically used: 1:3.
Ramp Time
- Amount of change in pulse intensity or duration from zero to a point of maximum (ramp up)
- Amount of change in pulse intensity or duration from maximum back down (ramp down)
- Amount of current can be adjusted to gradually increase over a time period (1-8s; typical: 2s)
- Used for patient comfort during initial stimulation
- Reproduces a normal contraction sensation
- E.g., longer ramp time for spastic tissue
- Ramp time is calculated as part of total “on” time

Depth of Penetration
- High-voltage unit: up to 500 V; more current delivered
- Low-voltage unit: 0-150 V; less current delivered
- Conductivity of tissue will determine depth of penetration

Parameter Selection Guidelines

<table>
<thead>
<tr>
<th>GOAL</th>
<th>FREQ</th>
<th>PULSE WIDTH</th>
<th>INTENS</th>
<th>Notes</th>
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<tbody>
<tr>
<td>Increase comfort</td>
<td></td>
<td></td>
<td></td>
<td>Larger electrodes</td>
</tr>
<tr>
<td>Decrease electrical spread</td>
<td></td>
<td></td>
<td></td>
<td>Increase pulse width will penetrate deeper</td>
</tr>
<tr>
<td>Minimize fatigue</td>
<td></td>
<td></td>
<td></td>
<td>Maximize current, variable waveform</td>
</tr>
<tr>
<td>Improve quality of tetany</td>
<td></td>
<td></td>
<td></td>
<td>Look for smooth fused contraction</td>
</tr>
</tbody>
</table>

NMES for Spasticity
- Three primary methods
  - Stimulation of the antagonist muscle to the spastic muscle; 30 min, 3X/day; expected relief of 10 min to 2 hrs
  - Stimulation of the spastic muscle directly in order to achieve muscle fatigue. Same parameters, higher frequencies can be used as tolerated
  - Stimulating the antagonist and spastic muscle alternately. Similar to protocol used to increase AROM

Background
- Neuromuscular Electrical Stimulation (NMES) imparts fatigue
- Challenge is to obtain effective muscle contraction to enable participation in strengthening regimens
- Large area of current research related to determining the optimal parameters of NMES that will delay onset of fatigue and maximize force output over time, especially in paralyzed populations

Discussion
- Do you think you will get similar smooth, efficient muscle contractions (as we see in voluntary movement) with NMES? Why or why not?
Recruitment Order

- Size principle: MU smaller to largest
- Fiber type recruitment: slow twitch (less fatigable) to fast twitch (more fatigable)

Mechanism for Contraction

- Electricity applied on skin surface over an intact peripheral nerve
- AP evoked
- Similar to physiological AP, causing muscle to contract
- But VERY different in several ways
- Location of nerve fiber to electrode

Adapted from Cameron & Martin, 2008

Voluntary vs. Evoked Stimulation

Voluntary
- Asynchronous recruitment
- Small MUs recruited first (size principle)
- Smooth recruitment to tetany
- Less fatigue
- More efficient
- MU fire at lower rate

Evoked
- Synchronous recruitment
- Large MUs recruited first (more superficial; reversal of size principle)
- Irregular/pulsed recruitment to tetany
- Sensory fibers activated first
- Greater fatigue
- Less efficient
- Higher intensity & frequency needed to replicate voluntary firing rate

Adapted from Cameron & Martin, 2008

Factors Affecting Electrode Conduction

- Resistance from skin surface: dirt, sweat, lotions
- Excessive adipose tissue
- Dry skin
- Skin Irritation or Breakdown
- Hair
- Poor electrode contact
- Electrode spacing (too closely together or too far apart)

Electrode Size

- Current density: concentrated in smaller electrodes; dispersed in larger
- Smaller electrodes = increased risk for burns or irritation
- Constant current stimulator: consistent current density
- Larger muscle = larger electrode; smaller muscle = smaller electrode
- Crosstalk consideration

Bracciano, 2008
Physiologic Effects

- Stimulation directly effects nerve more than muscle
- Intensity determines effects
- Modifies activities of osteoblasts & fibroblasts
- Increased microcirculation
- Increased metabolic rate
- Muscle contractions stimulate lymphatic, arterial and venous blood flow
- Stimulate neurotransmitters; production of opiates

General Indications for NMES

- Range of Motion (ROM)
- Inhibition of spasticity or muscle spasm
- Muscle strengthening or disuse atrophy
- Improving endurance
- Muscle re-education or neuromuscular facilitation
- Orthotic substitution
- Edema control in acute and chronic conditions

Contraindications!

- Implanted electronics!!! (e.g. pacemakers, defibrillators, transcerebral, cardiac or spinal electrodes, etc.)
  - Safety with pregnant females has not been established
  - Electronic monitoring equipment (ECG) monitors/alarms may not work properly

- Placement over heart, thorax, mouth/pharynx/larynx areas
- Over swollen, infected, inflamed areas or skin eruptions
- In cases of phlebitis, thrombophlebitis, varicose veins or cancerous lesions
  - Safety depends on PROPER USE and HANDLING of the device

Proceed with Caution...

- Use caution with patients who have suspected or diagnosed heart problems or epilepsy
- Hemmorhagic issues following acute trauma or fracture
- Recent surgical procedure where muscle contraction may disrupt healing
- Over skin areas that lack adequate sensation
  - Persons who have an adverse effect with NMES should discontinue use.

Common Issues

- Skin irritation or hypersensitivity due to conduction medium or electrode
- Use recommended accessories for device
- Should not be used while driving, operating machinery, in bath or shower
- Should not be used for any other means than which it was designed

Empi, 2002
### Evidence for the Use of ES

#### EMG-Triggered ES
- EMG-triggered electrical stimulation (Neuromove, Zynex Medical)

#### Meta-Analysis of ES Effectiveness
- Analysis generated according to randomized clinical trial (RCT) criteria; specifically as compared to a control group
- Implies that treatment is more effective than the control to which it was compared
- Taken from strokeengine.ca
- Fourteen studies examined the efficacy of ES as a means to improve hemiplegic UE function post-stroke.

### ACUTE PHASE OF RECOVERY

<table>
<thead>
<tr>
<th>PURPOSE</th>
<th>FINDING</th>
<th>LEVEL OF EVIDENCE</th>
</tr>
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<tbody>
<tr>
<td>Functional Independence</td>
<td>NE</td>
<td>1</td>
</tr>
<tr>
<td>Hand function</td>
<td>NE</td>
<td>2</td>
</tr>
<tr>
<td>Hand function &amp; dexterity</td>
<td>E</td>
<td>1</td>
</tr>
<tr>
<td>Motor control</td>
<td>NE</td>
<td>2</td>
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<tr>
<td>Motor function of UE</td>
<td>Conflicting</td>
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<tr>
<td>ROM</td>
<td>NE</td>
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</tr>
<tr>
<td>Reaction time</td>
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<td>1</td>
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<tr>
<td>Spasticity</td>
<td>NE</td>
<td>1</td>
</tr>
<tr>
<td>Strength and sustained motor function</td>
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<td>4</td>
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</table>

### SUBACUTE PHASE OF RECOVERY

<table>
<thead>
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<th>PURPOSE</th>
<th>FINDING</th>
<th>LEVEL OF EVIDENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arm &amp; Hand function</td>
<td>NE</td>
<td>2</td>
</tr>
<tr>
<td>Functional Independence</td>
<td>E</td>
<td>1</td>
</tr>
<tr>
<td>Motor function of UE</td>
<td>E</td>
<td>1</td>
</tr>
<tr>
<td>ROM</td>
<td>E</td>
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strokengine.ca, 2013
CHRONIC PHASE OF RECOVERY

<table>
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<th>PURPOSE</th>
<th>FINDING</th>
<th>LEVEL OF EVIDENCE</th>
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<tr>
<td>10s vs. 5s stimulation for hand function &amp; dexterity</td>
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<td>EMG Measures</td>
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<tr>
<td>Hand function &amp; dexterity</td>
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<tr>
<td>Motor function of UE</td>
<td>E</td>
<td>2</td>
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<tr>
<td>NMES or EMG-triggered ES for hand function &amp; dexterity</td>
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<td>1</td>
</tr>
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<td>ROM</td>
<td>E</td>
<td>2</td>
</tr>
<tr>
<td>Reaction time</td>
<td>E</td>
<td>1</td>
</tr>
<tr>
<td>Spasticity</td>
<td>E</td>
<td>2</td>
</tr>
<tr>
<td>Strength and sustained muscular contractions</td>
<td>Conflicting</td>
<td>4</td>
</tr>
</tbody>
</table>

Efficacy per ebrsr.com

- There is strong (1a) evidence that FES treatment improves upper extremity function in acute stroke.
- There is moderate (1b) evidence that NMES can reduce spasticity and improve motor function in the upper extremity.

Transcranial Magnetic Stimulation

- 10 Chronic post-CVA patients with mod to severe UE dysfunction showed increased ROM and improved Fugl-Meyer scores following 5 days of TMS + OT (Nair, et al. 2007)

Realistic Considerations

- No clinically viable system that provides broad functional benefit currently available

  - Must provide
    - bilateral abilities and/or significant assistance to affected limb
    - Proximal and distal function
    - Ease of use by stroke survivor
    - Reduction of associated reactions or hypertonia
    - Reduction of overactive muscle activity (spasticity, co-contraction, etc.) (Chae, 2008)
**Anterior Shoulder**
- Deltoid, Pectoralis

**Anterior Shoulder: Deep**
- Pectoralis minor, Serratus anterior

**Posterior Shoulder**
- Supraspinatus, Infraspinatus, Teres Major & Minor, Triceps

**Back**
- Trapezius, Rhomboid Minor & Major, Levator scapulae, Infraspinatus, Latissimus Dorsi

**Volar Forearm: Superficial**
- Brachioradialis, Triceps, Pronator teres, Flexor Digitorum Superficialis, Flexor Carpi Ulnaris

**Volar Forearm: Deep**
- Flexor Digitorum Profundus, Flexor Pollicis Longus, Supinator
Dorsal Forearm: Superficial

- Brachioradialis, Extensor Carpi Radialis Longus & Brevis, Extensor Digitorum Communis, Extensor Carpi Ulnaris, Extensor Pollicis Longus & Brevis, Abductor Pollicis Longus, Extensor Digiti Minimi

Dorsal Forearm: Deep

- Abductor Pollicis Longus, Extensor Pollicis Brevis & Longus, Extensor Indices, Flexor digitorum profundus, Flexor carpi ulnaris

Shoulder Subluxation

Elbow Extension

Elbow Flexion

Wrist Extension

Taken from Baker et al., 2000