Electromyography (EMG), Electroencephalography (EEG), and Neurophysiology in Clinical Practice

Monday, February 23, 2015
Ritz-Carlton
Amelia Island, Florida
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**CME Activity Description**

This course is designed as a review of techniques and topics pertaining to Clinical Neurophysiology which includes: basic physiology; pathophysiology; EEG; evoked potentials; EMG; movement disorders; and intraoperative monitoring. There is a focus on clinical correlation of various neurophysiological tests used for the evaluation of patients with epilepsy, sleep disorders, movement disorders, peripheral nerve, and neuromuscular disorders. Presentations will be made by members of the staff of Mayo Clinic and faculty of the Mayo Clinic College of Medicine from the Department of Neurology in Jacksonville, Florida; Rochester, Minnesota; and Scottsdale, Arizona.

**CME Activity Objectives**

Upon conclusion of this program, participants should be able to:

- Develop a logical approach to the use of standard clinical electrophysiological techniques in the evaluation of common and uncommon neuromuscular disorders
- Identify technical pitfalls associated with NCS and needle EMG and understand methods to correct and minimize technical problems
- Interpret the findings and clinical significance of abnormalities on nerve conduction studies
- Recognize and interpret the significance of EMG waveforms on needle EMG
- Identify technical pitfalls associated with EEG and the normal and variant patterns of pediatric and adult patients
- Interpret the findings and clinical significance of abnormalities on EEG studies
- Integrate the various clinical neurophysiology studies (evoked potentials, autonomic tests, sleep studies, vestibular testing) in the evaluation of patients with disorders of the central nervous system

Attendance at this Mayo Clinic activity does not indicate nor guarantee competence or proficiency in the performance of any procedures which may be discussed or taught in this activity.

**Intended Audience**

This course is intended for neurologists and physiatrists interested in the basics of clinical EMG, EEG, and Neurophysiology. Attendance at this Mayo course does not indicate nor guarantee competence or proficiency in the performance of any procedures that may be discussed or taught in this course.

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**American Board of Psychiatry and Neurology**

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The American Board of Psychiatry and Neurology has reviewed the "EMG, EEG and Clinical Neurophysiology, Feb 22-28, 2015 course, (awarding Self-Assessment 8.0 AMA PRA Category 1 Credits™) and has approved this program as part of a comprehensive self-assessment program, which is mandated by the ABMS as a necessary component of Maintenance of Certification.

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Faculty, Planning Committee and Provider Disclosure

Summary

Electromyography (EMG), Electroencephalography (EEG), and Neurophysiology in Clinical Practice

February 22 – 28, 2015

Ritz-Carlton
Amelia Island, Florida

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</thead>
<tbody>
<tr>
<td>Katherine H. Noe, M.D.</td>
<td>Grant/Research Support</td>
<td>NeuroPace, Inc.</td>
</tr>
<tr>
<td>Gregory A. Worrell, M.D., Ph.D.</td>
<td>Grant/Research Support, Stock Shareholder (self-managed)</td>
<td>NIH, NeuroOne, Inc.</td>
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<th>Product/Device</th>
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February 22 – 28, 2015

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Electromyography (EMG), Electroencephalography (EEG), and Neurophysiology in Clinical Practice
February 22 – 28, 2015

Cadwell Laboratories
Natus
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Sunovion
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Technique of Needle Examination
(and a little golf, too)
Devon I. Rubin, M.D.
Mayo Clinic
Jacksonville, FL

Objective
• Practical points to consider in the performance of needle EMG
• Methods to improve technique
• Remind of special considerations or issues to reduce risk

DEVON I. RUBIN’S FIVE STEPS
The Modern Fundamentals of EMG Technique

1) Planning the Study
• Clinical evaluation
• Muscle selection
• Special precautions
2) Performing the needle examination
• Preparing the patient
• Needle insertion and movement
• Pain control
3) Ensuring patient relaxation & tolerance
4) Analysis of spontaneous activity
5) Analysis of MUP

Case
72 year-old woman with right back and leg pain referred by a neurologist for an EMG. Per MDs note: “Patient has predominantly pain in back and knee. Normal strength and reflexes on exam.”
The patient is afraid of needles and will only allow you to examine one muscle. Which would you choose?

a. Iliopsoas
b. Vastus medialis
c. Anterior tibialis
d. Medial gastrocnemius
e. I don’t know

Step 1: Planning the Study
Considerations
Perform your own focused neuromuscular history and examination
IN EVERY PATIENT!

• Note distribution of weak muscles and sensory deficits
  • Focal, multifocal, diffuse?
  • Symmetric or asymmetric?
• Note possible technical concerns
  • Infection precautions, Anticoagulation, Skin abnormalities

Step 1: Planning the Study
Considerations in Selection of Muscles

• Examine muscles clearly involved (weak)
  • Define pathophysiology (myopathic vs neurogenic)
  • Ideally mild-moderately weak muscles
• Examine muscles NOT likely to be involved
  • Narrows localization
• Suspected myopathy: Limit to one side
Step 2: Performing the Needle Examination

- Preparing the Patient
- Needle Insertion and Movement
- Minimizing patient discomfort
- Technical problems

Needle Insertion and Movement

- Muscle in “neutral” relaxed position
- Pull skin taut & distal
- “Quick stick”

Needle Movement

- Smoothly in short steps (0.5 to 1 mm)
- Pause 1-2 seconds to listen for slow fibs

Methods to Improve Relaxation

- Passive limb movement
- Contraction of antagonist
- Distraction
- Exceptions:
  - Tongue, diaphragm, (thoracic PSP)
  - Spasticity, rigidity, tremor

Minimizing EMG Pain

Patient Preparation

- Thoroughly explain test
- Reassure regarding discomfort
- Warn about more painful muscles
- Distract with conversation
- Analgesic or mild sedatives beforehand
### Monopolar vs Concentric Needle

<table>
<thead>
<tr>
<th></th>
<th>Monopolar</th>
<th>Concentric</th>
</tr>
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<tbody>
<tr>
<td><strong>Cost</strong></td>
<td>Less</td>
<td>More</td>
</tr>
<tr>
<td><strong>Baseline stability</strong></td>
<td>Less</td>
<td>More</td>
</tr>
<tr>
<td><strong>MUP amplitude / duration</strong></td>
<td>Slightly higher</td>
<td>Slightly lower</td>
</tr>
<tr>
<td><strong>Recording surface</strong></td>
<td>Larger</td>
<td>Smaller</td>
</tr>
<tr>
<td><strong>Pickup area</strong></td>
<td>Larger (multidirectional)</td>
<td>Smaller (directional)</td>
</tr>
<tr>
<td><strong>MUP amplitude and duration</strong></td>
<td>Longer higher</td>
<td>Shorter / lower</td>
</tr>
<tr>
<td><strong>Recorded noise</strong></td>
<td>More</td>
<td>Less</td>
</tr>
<tr>
<td><strong>Patient discomfort</strong></td>
<td>??? (Less)</td>
<td>??? (More)</td>
</tr>
</tbody>
</table>

### Monopolar vs Concentric Electrode

- Pain with needle examination (n=48)
  - 50-mm **concentric** vs 50-mm **monopolar**
  - Small (0.5-1 mm) vs **larger** steps (0.5-1 cm)


### Results: Immediate Pain

- Concentric needle
  - Small steps significantly less painful (p < 0.001) than larger steps

- Monopolar needle
  - No difference in pain with step size

- Large steps: monopolar less painful; p<.01
- Small steps: no difference in needles

### Minimizing EMG Pain

**Needle Handling Techniques**

- Needle movements less than one mm.
- Brief insertional bursts
- **Straight line** movements with pauses
- Smooth, steady movements (no jabs)
- Continuous discussion and feedback

### Endplate Activity

- Painful, move away quickly (Turn preamplifier on immediately after needle insertion)
- Small needle movements - more control

### Detecting Hematoma by MRI following EMG Paraspinals

- Caress, 1996
  - n=17
- Paraspinal Mapping
  - n=54
  - (138 aspirin), (10 warfarin)
  - Gertken, 2011
  - n=431
Risk with Anticoagulation

- US following EMG, mean 30 min following needle exam
- Hematoma found in:
  - 2/101 pts on warfarin
  - 1/57 pts on aspirin or clopidogrel
  - 0/51 pts in control group
- All small, subclinical

Lynch S, Boon A. Muscle Nerve 2008

In other “high risk” muscles . . .

- Majority with 50 mm needle, INR 1.6 – 4.0
- 2 pts with SUBCLINICAL hematomas on US
  - Tibialis posterior (9 x 1 mm) (ASA/clopidogrel)
  - FPL (16 x 3 mm) (warfarin, INR 2.3)

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Control</th>
<th>ASA/clopidogrel</th>
<th>Coumadin</th>
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<tbody>
<tr>
<td>Total</td>
<td>100</td>
<td>116</td>
<td>107</td>
</tr>
<tr>
<td>Cervical paraspinals</td>
<td>17</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>Proximal paraspinals</td>
<td>17</td>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td>Lumbar paraspinals</td>
<td>13</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>Tibialis posterior</td>
<td>7</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>Peroneus tertius</td>
<td>10</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>Peroneus longus</td>
<td>25</td>
<td>16</td>
<td>31</td>
</tr>
<tr>
<td>Iliopsoas</td>
<td>11</td>
<td>17</td>
<td>12</td>
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</tbody>
</table>

Boon AJ et al. Muscle Nerve 2012

Anticoagulation

- No defined “practice parameter” regarding “safe” level of anticoagulation
- Decision is individual
  - Most MDs will perform with INR < 3.0
  - Thrombocytopenia less than 30,000

Technique in Anticoagulated Patients

- Limit number of muscles
- Limited needle movement
- Avoid deep and higher risk muscles
  - Anterior compartment of leg (stay superficial)
  - Muscles neighboring arteries (FPL, iliopectosas)
  - Paraspinals
- Prolonged, firm pressure

Lymphedema

- Risk of persistent leaking of serous fluid
- Possible risk of infection
- AANEM Position statement (2005):
  - “reasonable caution should be exercised in performing needle examinations in lymphedematous regions.”

Cutaneous Issues
**Peri-pleural Muscles**

- Trapezius
- Cervical paraspinals
- Rhomboid
- Serratus anterior
- Intercostal & diaphragm

**Methods:**
- Slow, smooth needle movements
- Listen for short rise time MUPs
- Withdraw when rise time slows
- Listen for respiratory pattern of firing

---

**Summary**

- Remember each step of needle EMG
- Plan the study appropriately
- Minimize discomfort using SMALL needle movements
- Adjust technique in special circumstances
- Practice leads to Master-ing the technique!
Unusual Muscles and EMG

Eric J. Sorenson, MD
DISCLOSURE

Relevant Financial Relationship(s)

None

Off Label Usage

None
Learning Objectives

• Understand the indications to study uncommon muscles
• Localizing value of uncommon muscles
• Risks associated with uncommon muscles
Reference

Anatomical Guide for the Electromyographer: The limbs and trunk


Authored by: Aldo O. Perotto
Case #1

55 year old man in good health. Noticed hand weakness, numbness and pain after an assault.

On examination: weakness and atrophy of the APB and Opponens

Normal strength in FDI and adductor digiti minimi

Normal reflexes at Biceps, Triceps and brachioradialis
### Median sensory (antidromic)

<table>
<thead>
<tr>
<th>STIMULUS SITE</th>
<th>LAT1 (ms)</th>
<th>LAT2 (ms)</th>
<th>AMP (UV)</th>
<th>AREA (UVms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1: Wrist</td>
<td>2.6</td>
<td>3.3</td>
<td>8.993</td>
<td>36</td>
</tr>
<tr>
<td>A2: Elbow</td>
<td>7.9</td>
<td>9.1</td>
<td>3.649</td>
<td>26</td>
</tr>
<tr>
<td>A3: Upper Arm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A4: Supraclavi</td>
<td></td>
<td></td>
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</table>
Median Motor
Median F-wave
Needle examination summary

<table>
<thead>
<tr>
<th>MUSCLE</th>
<th>INSERTIONAL ACTIVITY</th>
<th>SPONTANEOUS</th>
<th>MUP NORMAL</th>
<th>RECRUITMENT</th>
<th>DURATION</th>
<th>AMPLITUDE</th>
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<tbody>
<tr>
<td>Abductor pollicis brevis</td>
<td>Increased</td>
<td>0</td>
<td>Normal</td>
<td>++</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>Biceps brachii</td>
<td>Normal</td>
<td>0</td>
<td>Normal</td>
<td>++</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>Deltoid</td>
<td>Normal</td>
<td>0</td>
<td>Normal</td>
<td>++</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>First dorsal interosseous</td>
<td>Normal</td>
<td>0</td>
<td>Normal</td>
<td>++</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>Triceps brachii</td>
<td>Normal</td>
<td>0</td>
<td>Normal</td>
<td>++</td>
<td>++</td>
<td></td>
</tr>
</tbody>
</table>
Needle examination of which of the following muscles would provide the most localizing value:

A) 1st Lumbrical
B) Flexor pollicis longus
C) Extensor Indices Proprius
D) Extensor Carpi Radialis
Flexor Pollicis Longus

Indications:
1. Localization of median nerve and anterior interosseous nerve lesions or C8-T1 root lesions
2. Most frequently used when the APB is abnormal in a median neuropathy at the wrist to check a distal median innervated muscle above the wrist to exclude a median nerve lesion in the forearm

Problems:
1. Proximity to the radial artery
2. Deep muscle, sometimes difficult to locate, may be painful
Indications:
1. Median nerve lesions, particularly those that involve the very distal median nerve.

Problems:
1. Proximity to the digital nerve and the tendons of other muscles
2. Incorrect activation
3. If too deep the adductor pollicis will be punctured
4. These muscles are subject to some variation in innervation
Extensor Indices Proprius

Indications:
1. Useful in C8 radiculopathies and radial nerve lesions, especially those involving the posterior interosseous nerve

Problems:
1. Small thin muscle near the extensor pollicis longus and other thumb muscles
2. Painful if enter tendons inadvertently
Extensor Carpi Radialis

Indications:
One of the last muscles innervated by the radial nerve before it becomes the posterior interosseous nerve
Indications:
1. Localization of median and anterior interosseous nerve lesions and C8-T1 root lesions

Problems:
1. Thin, deep muscle - can only be localized by activation of the muscle
2. Needle must be positioned to pass between the two bones that are close together
Traumatic Proximal Median Mononeuropathy
Case #2

57 year old man with the onset of thigh pain and weakness following inguinal hernia repair 2 months prior to presentation.

MRI of the lumbar spine was normal.
Case #2

Examination:
- Weakness in the hip adductors
- Normal strength in the vastus, rectus femoris, iliopsoas
- Reflexes normal at the knee
- No discrete sensory loss
**Recording Site:** Extensor digitorum brevis (pedis)

**Stimulus Site**
- A1: Knee
- A2: Ankle
- A3: Fibula
- A4: Lat. mall.

<table>
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<th>Segment</th>
<th>Dist mm</th>
<th>Diff ms</th>
<th>CV m/s</th>
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<td>400</td>
<td>9.0</td>
<td>44</td>
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<td>Ankle-EDB</td>
<td>70</td>
<td>4.1</td>
<td></td>
</tr>
<tr>
<td>Fibula-Ankle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lat. mall.-EDB</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
**Stimulus Site**

<table>
<thead>
<tr>
<th>Stimulus Site</th>
<th>Lat (ms)</th>
<th>Dur (ms)</th>
<th>Amp (mV)</th>
<th>Area (mVms)</th>
<th>Temp (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1: Knee</td>
<td>13.3</td>
<td>7.0</td>
<td>14.9</td>
<td>50.8</td>
<td>31.5</td>
</tr>
<tr>
<td>A2: Ankle</td>
<td>4.8</td>
<td>6.3</td>
<td>17.0</td>
<td>52.9</td>
<td>31.4</td>
</tr>
</tbody>
</table>

**Segment**

<table>
<thead>
<tr>
<th>Segment</th>
<th>Dist (mm)</th>
<th>Diff (ms)</th>
<th>CV (m/s)</th>
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</thead>
<tbody>
<tr>
<td>Knee-Ankle</td>
<td>413</td>
<td>8.5</td>
<td>49</td>
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<tr>
<td>Ankle-Abductor hallucis</td>
<td>84</td>
<td>4.8</td>
<td></td>
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</tbody>
</table>
# Needle examination summary

<table>
<thead>
<tr>
<th>Anatomy</th>
<th>Side</th>
<th>Insertional</th>
<th>Fibrillation</th>
<th>Fasciculation</th>
<th>MUP Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectus femoris</td>
<td>Left</td>
<td>Normal</td>
<td>0</td>
<td>0</td>
<td>Normal</td>
</tr>
<tr>
<td>Tibialis Anterior</td>
<td>Left</td>
<td>Normal</td>
<td>0</td>
<td>0</td>
<td>Normal</td>
</tr>
<tr>
<td>Iliopsoas</td>
<td>Left</td>
<td>Normal</td>
<td>0</td>
<td>0</td>
<td>Normal</td>
</tr>
<tr>
<td>Vastus medialis</td>
<td>Left</td>
<td>Normal</td>
<td>0</td>
<td>0</td>
<td>Normal</td>
</tr>
</tbody>
</table>
Needle examination of which of the following muscles would best localize the lesion:

A) Tensor Fascia Lata
B) Rectus Femoris
C) Gracilis
D) Sartorius
Gracilis

Indications:
1. Obturator nerve lesions and L4 radiculopathies

Problems:
1. A small, flat muscle that may be difficult to find especially in the obese and deconditioned patient
Tensor Fascia Lata

Indications:
1. L5 root lesions. Involvement of this muscle in L5 root lesions may be more obvious than the gluteus medius
2. It is often easier to obtain minimal activation of only a few units in the TFL than in other proximal L5 muscles.

Problems:
1. May be difficult to locate in the very obese patient
2. If too anterior the needle will enter the rectus femoris or sartorius.
Rectus Femoris
Sartorius
Obturator neuropathy due to metastatic disease
Case #3

55 year old man with the spontaneous onset of severe pain over his scapula 1 year prior. This lasted a few days and gradually improved over a few weeks. As his pain improved he noticed weakness in his right shoulder which has persisted.
Examination

Strength: Normal with the exception of right scapular winging

Reflexes: Normal at Biceps, Triceps and Brachioradialis

Sensory: Normal
# Needle examination summary

<table>
<thead>
<tr>
<th>Anatomy</th>
<th>Side</th>
<th>Ins. Activity</th>
<th>Fibrillation</th>
<th>Fascication</th>
<th>MUP Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Dorsal Inteross</td>
<td>Left</td>
<td>Normal</td>
<td>0</td>
<td>0</td>
<td>Normal</td>
</tr>
<tr>
<td>Pronator teres</td>
<td>Left</td>
<td>Normal</td>
<td>0</td>
<td>0</td>
<td>Normal</td>
</tr>
<tr>
<td>Biceps brachii</td>
<td>Left</td>
<td>Normal</td>
<td>0</td>
<td>0</td>
<td>Normal</td>
</tr>
<tr>
<td>Triceps brachii</td>
<td>Left</td>
<td>Normal</td>
<td>0</td>
<td>0</td>
<td>Normal</td>
</tr>
<tr>
<td>Deltoid</td>
<td>Left</td>
<td>Normal</td>
<td>0</td>
<td>0</td>
<td>Normal</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>Left</td>
<td>Normal</td>
<td>0</td>
<td>0</td>
<td>Normal</td>
</tr>
<tr>
<td>Supraspinatus</td>
<td>Left</td>
<td>Normal</td>
<td>0</td>
<td>0</td>
<td>Normal</td>
</tr>
<tr>
<td>Rhomboid major</td>
<td>Left</td>
<td>Normal</td>
<td>0</td>
<td>0</td>
<td>Normal</td>
</tr>
<tr>
<td>Trapezius</td>
<td>Left</td>
<td>Normal</td>
<td>0</td>
<td>0</td>
<td>Normal</td>
</tr>
</tbody>
</table>
Which muscle?

Which of the following unusual muscles is most likely to be abnormal?

A) Serratus Anterior
B) Levator Scapulae
C) Teres Minor
D) Latissimus dorsi
Indications:
1. Winging of the scapula
2. Unexplained shoulder pain
3. Examining the most proximal branch of the C5, C6, and C7 spinal nerves after the posterior primary rami

Problems:
1. The risk of inadvertently entering the lung especially in obese and uncooperative patients
Trapezius

Indications:
1. Scapular winging
2. Lesions of the lower cranial nerves or upper cervical spine
3. Proximal muscle weakness
4. Shoulder pain syndromes
Indications:
1. Very proximal C4 and C5 muscle that may be more easily isolated than the rhomboids
2. The dorsal scapular nerve (C5) comes off the upper trunk just distal to the long thoracic nerve, also receives innervation from the dorsal primary rami of the C4 root

Problems:
1. If needle inserted too posterior: trapezius will be entered
2. Too anterior: the sternocleidomastoid
3. If too superior: the splenius capitis
Teres Minor

Indications:
1. Axillary nerve lesions
2. Shoulder pain

Problems:
1. Entering the wrong muscles:
   - too caudally: the teres major
   - too medially: the infraspinatus
   - too rostrally: the deltoid
   - too far lateral: the triceps
Latissimus Dorsi

Indications:
1. The most proximal posterior cord muscle before the middle trunk
2. A proximal C7 muscle
3. Neurologic dysfunction after shoulder dislocation
4. Unexplained shoulder pain

Problems:
1. Muscle hard to locate in the obese and deconditioned patient, proximity to the pleural space
Traumatic long thoracic neuropathy
Case #4

58 year old man with progressive weakness and atrophy of his forearm muscles for past 10 months.

No pain
No sensory loss
Examination

Weakness of his Finger extensors and wrist extensors

No sensory loss

Preserved reflexes, including triceps and brachioradialis
Radial Motor Study

Recording Site: EDC

<table>
<thead>
<tr>
<th>STIMULUS SITE</th>
<th>LAT ms</th>
<th>DUR ms</th>
<th>AMP mV</th>
<th>AREA mVms</th>
<th>TEMP OC</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1: Elbow</td>
<td>4.4</td>
<td>9.7</td>
<td>4.891</td>
<td>27.01</td>
<td>32.4</td>
</tr>
<tr>
<td>A2: Groove</td>
<td>6.1</td>
<td>10.1</td>
<td>4.453</td>
<td>24.66</td>
<td>32.4</td>
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<tr>
<td>A3: Axilla</td>
<td>6.9</td>
<td>10.7</td>
<td>1.073</td>
<td>6.404</td>
<td>32.6</td>
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<tr>
<td>A4: Supraclavi</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
Radial Sensory

Recording Site: Dorsal Hand

<table>
<thead>
<tr>
<th>STIMULUS SITE</th>
<th>LAT1, ms</th>
<th>LAT2, ms</th>
<th>AMP, uV</th>
<th>ARVL, uV•ms</th>
<th>TEMP, °C</th>
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</thead>
<tbody>
<tr>
<td>A1: Forearm</td>
<td>1.7</td>
<td>2.3</td>
<td>22.66</td>
<td></td>
<td>66.2.5</td>
</tr>
<tr>
<td>A2: Elbow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>
# Needle examination summary

<table>
<thead>
<tr>
<th>MUSCLE</th>
<th>INSERTION ACTIVITY</th>
<th>SPONTANEOUS ACTIVITY</th>
<th>MUP NORMAL</th>
<th>RECRUITMENT</th>
<th>DURATION</th>
<th>AMPLITUDE</th>
<th>PHASES</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Activation</td>
<td>Long</td>
<td>High</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Reduced</td>
<td>Short</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Rapid</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| R. Biceps brachii       | Normal             | 0                    | Normal     | ++          | ++       | 50%       | +      |
| R. Brachioradialis      | Normal             | 0                    | Normal     | ++          | ++       |           |        |
| R. Deltoid              | Normal             | 0                    | Normal     | ++          | ++       |           |        |
| R. Extensor indicis     | Increased          | +                    | Normal     | ++          | ++       |           |        |
| proprius                |                    |                      |            |             |          |           |        |
| R. First dorsal         | Normal             | 0                    | Normal     | ++          | ++       | 25%       | +      |
| interosseous            |                    |                      |            |             |          |           |        |
| R. Latissimus dorsi     | Normal             | 0                    | Normal     |             |          |           |        |
| R. Pronator teres       | Normal             | 0                    | Normal     |             |          |           |        |
| R. Triceps             | Normal             | 0                    | Normal     |             |          |           |        |
Which muscle next?

Which of the following unusual muscles would be most informative next?

A) Extensor digitorum communis
B) Supinator
C) Flexor Carpi Radialis
D) Anconeus
Anconeus
Anconeus

**Indications:**
1. Proximal to distal localization of a radial nerve lesion

**Problems:**
1. A thin muscle that is sometimes difficult to palpate and separate from the extensor carpi ulnaris muscle
Supinator

Indications:
1. C5-C6 radiculopathies and radial nerve lesions
2. Just proximal to most lesions of the posterior interosseous nerve

Problems:
1. Deep muscle, can only be reached by passing through other muscles
Extensor Digitorum Communis

**Indications:**
1. Useful in distinguishing C6 from C7 radiculopathies and radial nerve lesions, especially those involving the posterior interosseous nerve

**Problems:**
1. Variable innervation between C7 and C8
Indications:
1. Could be used in a suspected proximal median neuropathy if pronator teres is normal

Problems:
1. If needle to deep it will be in the finger flexors
2. If too lateral will be in pronator teres
3. Very rarely examined
Intra-op recordings
Multifocal motor neuropathy with conduction block
Case #5

• 22 year old fire-fighter with 6 year history of progressive shoulder weakness, right greater than left

• Found at by primary caregiver to have a CK fluctuating between 500-1000
Examination

Strength: Weakness of his multiple shoulder girdle muscles right >> left
Mild bifacial weakness

Reflexes: Normal

Sensory: Normal
Spinal Accessory Right

Recording Site: Trapezius

<table>
<thead>
<tr>
<th>Stimulus Site</th>
<th>Lat ms</th>
<th>Dur ms</th>
<th>Amp</th>
<th>Area Vms</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1: Neck</td>
<td>4.5</td>
<td>9.6</td>
<td>3.1</td>
<td>18.4</td>
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</table>
### Spinal Accessory Left

<table>
<thead>
<tr>
<th>Stimulus Site</th>
<th>Lat (ms)</th>
<th>Dur (ms)</th>
<th>Amp (mV)</th>
<th>Area (mV·ms)</th>
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</thead>
<tbody>
<tr>
<td>A1: Neck</td>
<td>2.7</td>
<td>13.0</td>
<td>7.8</td>
<td>59.9</td>
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</table>
## Needle examination summary

<table>
<thead>
<tr>
<th>MUSCLE</th>
<th>INSERTIONAL ACTIVITY</th>
<th>SPONTANEOUS</th>
<th>MUP NORMAL</th>
<th>RECRUITMENT</th>
<th>DURATION LONG</th>
<th>AMPLITUDE</th>
<th>PHASES</th>
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<tbody>
<tr>
<td>R. Biceps brachii</td>
<td>Normal</td>
<td>0</td>
<td>Normal</td>
<td></td>
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<tr>
<td>R. Deltoid</td>
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<td>0</td>
<td>Normal</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>R. Triceps</td>
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<td>0</td>
<td>Normal</td>
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<td></td>
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<tr>
<td>R. Tibialis anterior</td>
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<td></td>
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<tr>
<td>R. Vastus lateralis</td>
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<td></td>
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<tr>
<td>R. Paraspinal, thoracic</td>
<td>Increased</td>
<td>0</td>
<td>Normal</td>
<td></td>
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</tr>
<tr>
<td>R. Sternocleidomastoid</td>
<td>Normal</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>+</td>
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<tr>
<td>R. Trapezius</td>
<td>Increased</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
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<tr>
<td>L. Trapezius</td>
<td>Normal</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>R. 1st dorsal interosseous</td>
<td>Normal</td>
<td>0</td>
<td>Normal</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Which muscle?

Which of the following unusual muscles will likely be helpful?

A) Diaphragm
B) Intercostal muscles
C) Rectus Abdominis
D) Pectoralis Major
Indications:
1. The sternal head is a rare proximal C8-T1 muscle and the medial pectoral nerve separates the lower trunk from the medial cord of the brachial plexus
2. Myopathies affecting the shoulder girdle muscles

Problems:
1. Difficult to separate the two heads, multiple root innervation, proximity to pleural space
Diaphragm

**Indications:**
- Phrenic nerve lesions
- Respiratory insufficiency, particularly ventilator dependent patients of undetermined cause
- Some myopathies and motor neuron diseases

**Problems:**
- Proximity of the liver and spleen
- Risk of pneumothorax
- In complete phrenic nerve lesions localization by activation of MUPs is not possible
- In very chronic lesions, the muscle may become very thin and thin difficult to localize
Diaphragm with US
Diaphragm with US
Intercostal Muscles

Indications:
1. Intercostal nerve lesions, thoracic radiculopathy, atypical chest pain
2. Segmental localization of intraspinal lesions
3. Respiratory failure of possible neuromuscular cause

Problems:
1. These muscles are rarely examined because of the potential for a pneumothorax
2. If they are examined the patient should be advised of the potential risk
3. You minimize the risk of pneumothorax if you do not advance the needle past the point where you encounter motor units
Rectus Abdominis

Indications:
1. Lower thoracic or upper lumbar radiculopathies, intercostal, ilioinguinal, or iliohypogastric nerve lesions
2. Patients with atypical abdominal or inguinal pain
3. May help in segmental localization of intraspinal Lesions

Problems:
1. Thin sheet like muscles: you may pass through more quickly than you expect
2. A long (70 mm) needle may be required to reach them in the obese patient
3. Careful attention to technique will make the chance of peritoneal
FSH dystrophy
Case #6

- 69 year old female with 2 year history of dysarthria and dysphagia
- Progressive for about 6 months and now stable last 18 months.
- Not fatigable
- No Diplopia
Exam

• Extra-ocular movements normal, no ptosis, no fatigability
• Normal facial sensation, normal mastication
• Normal facial strength
• Normal hearing
Exam

- Absent gag
- No palatal movement with phonation
- Normal SCM and Trapezius strength
- Mildly weak tongue, no atrophy or fasciculations
- Flaccid, hypernasal dysarthria
Facial CMAP
Stim Mode: Train / Single

Stim Freq: 2 Hz
Stim Dur: 0.1 ms
Stim Site:
Time: 13:02:36
Comment: b2

<table>
<thead>
<tr>
<th>Pot No.</th>
<th>Peak Amp (mV)</th>
<th>Amp Decr (%)</th>
<th>Area (mVms)</th>
<th>Area Decr (%)</th>
<th>Stim Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.06</td>
<td>0</td>
<td>7.75</td>
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<td>54.9mA</td>
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<td>2</td>
<td>1.98</td>
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<td>3</td>
<td>1.91</td>
<td>7</td>
<td>7.32</td>
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<td>54.9mA</td>
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<tr>
<td>4</td>
<td>1.91</td>
<td>7</td>
<td>7.21</td>
<td>7</td>
<td>54.9mA</td>
</tr>
</tbody>
</table>
Spinal Accessory CMAP
Which muscles?

Of the following muscles which would be most likely to be helpful?

A) Orbicularis Oculi
B) Frontalis
C) Masseter
D) Tongue
Indications:
1. Facial nerve or brainstem lesions, Bell's palsy, hemifacial spasm
2. Guillain-Barre syndrome
3. Facial myopathies
4. Motor neuron disease
5. Flaccid dysarthria

Problems:
1. The muscle is thin and sometimes hard to locate
Indications:
1. Similar to the orbicularis oculi but also used for single fiber studies of a facial muscle

Problems:
1. May be painful
2. Very thin muscle
3. Easy bleeding and bruising
4. Maintain pressure over the site for a short time
Masseter

Indications:
1. Lesions of the trigeminal nerve
2. Lower motor neuron lesions of the brainstem
3. Myasthenia gravis

Problems:
1. Poor relaxation.
2. Some myasthenia gravis patients may have such marked involvement that motor units are tiny and resemble fibrillation potentials
3. The muscle is covered by the platysma (facial nerve) and superficial insertion may reveal the smaller MUPs of the platysma
Tongue

Indications:
1. Lesions of the hypoglossal nerve and twelfth nerve nucleus
2. motor neuron disease
3. flaccid dysarthria
4. myasthenia gravis

Problems:
1. Relaxation often poor and difficult to see fibrillation potentials if they are infrequent
2. Small size of normal motor unit potentials may allow misinterpretation as fibrillation potentials
## Needle EMG Examination

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>First Dorsal R.</td>
<td>Normal</td>
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<td>0</td>
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<td>Normal</td>
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<td></td>
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<tr>
<td>Interosseous R.</td>
<td>Normal</td>
<td>0</td>
<td>0</td>
<td></td>
<td>Normal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Pronator teres R.</td>
<td>Normal</td>
<td>0</td>
<td>0</td>
<td></td>
<td>Normal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Triceps brachii R.</td>
<td>Normal</td>
<td>0</td>
<td>0</td>
<td></td>
<td>Normal</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Deltoid R.</td>
<td>Normal</td>
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<td>0</td>
<td></td>
<td>Normal</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Orbicularis oris R.</td>
<td>Normal</td>
<td>0</td>
<td>0</td>
<td></td>
<td>Normal</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Masseter R.</td>
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<td>0</td>
<td></td>
<td>Normal</td>
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<tr>
<td>Geniohyoid R.</td>
<td>Normal</td>
<td>0</td>
<td>0</td>
<td></td>
<td>Reduced +</td>
<td>++</td>
<td>++</td>
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<td>Genioglossus R.</td>
<td>Normal</td>
<td>0</td>
<td>0</td>
<td></td>
<td>Reduced +</td>
<td>++</td>
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<tr>
<td>Sternocleidomastoid R.</td>
<td>Normal</td>
<td>0</td>
<td>0</td>
<td></td>
<td>Reduced +</td>
<td>++</td>
<td>++</td>
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Remarks:
Collette-Sicard Syndrome
EMG Waveform Analysis

Devon I. Rubin and Elliot L. Dimberg
Mayo Clinic
Jacksonville FL
EMG Waveform Analysis Session

This Morning:
   #1 - Basics of EMG Waveform Recognition
       Review of spontaneous discharges

   #2 – Basics of MUP Analysis

This Evening:
   Rapid Quantitation of MUP
   Testing your skills with Case Examples and Quizzes

   Fun!
EMG Waveform Analysis

Recording and analyzing the electrical activity of the muscle fibers in motor units in the muscle

Unique combination of knowledge and skills
Basic Pattern Recognition

- EMG: highly complex patterns
- Existing, automatic skill
- Recognition skill is instantaneous
  - Simultaneous types and numbers
- Learn by:
  - Hearing > seeing
  - Naming
  - Comparison with others
  - Repetition
- Categorize waveform by pattern

Motor unit potential

Fibrillation potentials

Complex repetitive discharge

Myotonic discharges

End plate spikes

Myokymic discharges
EMG Potentials

Fibrillation potential
Long duration MUP
Polyphasic MUP
Short duration MUP
Complex repetitive discharge
Varying MUP
Myokymic discharge
Myotonic discharge
Neuromyotonic discharge
End plate spike
Fatiguation potential
Characterization by Origin of EMG Potentials

**Single Muscle Fibers**

**Firing Alone**
- End plate spikes
- Fibrillation potentials
- Myotonic discharges

**Firing in Groups**
- Adjacent muscle fibers -
  - Complex Repetitive Discharge
  - Insertion activity
- Motor unit potentials -Spontaneous
  - Fasciculation potentials
  - Myokymic discharges
  - Neurotonic discharges
- Motor unit potentials - Voluntary
Characterization by Signal Recognition

- **Listen:**
  - Firing pattern (Regular, Irregular, Semi-rhythmic)
  - “Sounds like . . . .”

- **Look:**
  - Configuration (Triphasic, biphasic, positive/negative)
Triphasic Muscle Action Potential
FORM OF THE ACTION POTENTIAL OF A CONDUCTED IMPULSE
RECORDED MONOPOLARLY AT VARIOUS POSITIONS IN A
VOLUME CONDUCTOR – LORENTE DE NÓ EXPERIMENT——

“Volume Conductor”

S

POLARITY

INSERTION POTENTIAL IN MYOTONIA

EH Lambert
Firing Patterns of EMG Potentials

**Regular:** linear change (1% variation) (fibrillation potential)

**Regular:** no change (complex repetitive discharge)

**Regular:** exponential change, *wax/wane* (myotonic)

**Irregular:** (random change) (end plate spike)

**Semi-Rhythmic:** (10% variation) (motor unit potential)

**Bursts:** (single or multiple MUP) – Regular or semi-rhythmic
Fibrillation Potentials

Action potentials of individual muscle fibers in the absence of innervation

FIRING PATTERN: Regular
0.5 - 15 per second

FORM:
• Spikes - Biphasic or triphasic, 50-300 microvolts “tick-tick”
• Positive waves - Biphasic, long rise time “tock-tock”
Fibrillation Potentials

Spike form

Positive wave form

Regular: steady change (fibrillation potential) (0.5-15 Hz)

Sequential Spikes

Interspike Interval (ms)
Potentials recorded from a single muscle fiber by two electrodes along the fiber

(The potentials are initiated by movement of electrode #1)
Triphasic Fibrillation Potential

Site of generation of fibrillation potential
Positive wave Fibrillation Potential

Site of generation of fibrillation potential
Grading Fibrillation Potentials

1+ Persistent single trains

2+ - Moderate numbers

3+ - Many in all areas

4+ - Completely fill baseline
Fibrillation Potentials
Associated Disorders

Neurogenic
- Anterior horn cell disorders – e.g. ALS
- Radiculopathies – “active”
- Mononeuropathies – “severe”
- Axonal peripheral neuropathies

Myopathic
- Inflammatory (e.g. polymyositis, IBM)
- Toxic myopathies (e.g. statin myopathy)
- Muscular dystrophies
- Rhabdomyolysis

Severe NMJ disorders
- Myasthenia gravis (severe)
- LEMS
- Botulism

Fiber necrosis
Fiber splitting
Vacuolar damage
Fibrillation Potential Origin and Cessation in Myopathies

Muscle fiber necrosis
Vacuolar destruction
Muscle fiber splitting

Muscle fiber reinnervation
Endplate spikes and noise

**Irregular** (end plate spike)

Firing pattern: _irregular, rapid_
Biphasic - _initial negativity_

Miniature end plate potentials
Firing pattern: _irregular, rapid_
Myotonic Discharges

Regular: exponential change, wax/wane (myotonic)

Spike

Decreasing rate & amplitude

Positive waveform

Increasing rate & amplitude
# Myotonic Discharges

## Associated Disorders

<table>
<thead>
<tr>
<th>Myopathic - Prominent</th>
<th>** with clinical myotonia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myotonic dystrophy**</td>
<td></td>
</tr>
<tr>
<td>- DM1</td>
<td></td>
</tr>
<tr>
<td>- DM2 (PROMM)</td>
<td></td>
</tr>
<tr>
<td>Myotonia congenita**</td>
<td></td>
</tr>
<tr>
<td>Paramyotonia congenita**</td>
<td></td>
</tr>
<tr>
<td>Hyperkalemic periodic paralysis</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Myopathic – Occasional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymyositis</td>
</tr>
<tr>
<td>Acid maltase deficiency</td>
</tr>
<tr>
<td>Drug - induced myotonia</td>
</tr>
<tr>
<td>- cholesterol lower agents, colchicine</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Neurogenic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axonal peripheral neuropathies – RARELY</td>
</tr>
<tr>
<td>Severe, old neurogenic disorders - RARELY</td>
</tr>
</tbody>
</table>
Complex Repetitive Discharges

- Fast or slow (3 – 40 Hz)
- **Configuration**: (3-10 spikes, stable or unstable)

**Regular**: fixed intervals (abrupt onset, cessation, change)
Complex Repetitive Discharge
Ephaptic transmission from neighboring muscle fibers
Complex Repetitive Discharges
Associated Disorders

**Neurogenic – CHRONIC DISORDERS**
- Anterior horn cell disorders – e.g. ALS, SMA
- Radiculopathies – “chronic, old”
- Axonal peripheral neuropathies - longstanding

**Myopathic - CHRONIC**
- Inflammatory (e.g. IBM)
- Muscular dystrophies

**Normal**
- Iliopsoas
- Biceps
Fasciculation Potentials

Origin - AHC, axon, nerve terminal

FIRING PATTERN
• Single, random, irregular
• 1 - 100 per minute

FORM
• No standard configuration
• Resemble motor unit potentials
• Often distant

Sound: “rain on a roof”
Fasciculation Potentials
Associated Disorders

**Neurogenic**
- Anterior horn cell disorders – e.g. ALS, SMA
- Radiculopathies
- Axonal peripheral neuropathies

**Other**
- Hyperexciteable nerve syndromes (“cramp-fasciculation syndrome”)
- Tetany
- Hyperthyroidism
- Anti-cholinesterase medication (e.g. Mestinon)

**Pearl:**
Long duration, polyphasic (complex) fasciculation – more suggestive of a neurogenic disorder

**Normal**
- Benign fasciculations
Myokymic Discharges

- 1 or few MUP firing repetitively in bursts
- Burst Pattern: Regular or Semi-rhythmic
Myokymic Discharges
Associated Disorders

### Facial
- Multiple sclerosis
- Brainstem glioma
- Polyradiculopathy
- Facial palsy
- ALS
- Tuberculoma
- Sarcoidosis
- Meningeal carcinomatosis
- Syringobulbia

### Extremities
- Radiation
- Chronic nerve compression (CTS)
- AIDP, CIDP
- Gold therapy
- Rattlesnake venom
Neuromyotonic Discharges

- Spontaneous MUP
- Regular (wane)
- Very high frequency (200-300 Hz)
  - Continuous single MUP firing or
  - Discontinuous bursts
- “Indy (NASCAR) racecar”
Neuromyotonic Discharges
Associated Disorders

• Voltage-gated, potassium channel disorders
  – “Continuous muscle fiber activity”
  – “Isaac’s syndrome”
• Anticholinesterase poisoning
• Tetany
• Chronic spinal muscular atrophies
• Intra-operative nerve irritation
Voluntary Motor Unit Potential
Gastrocnemius medialis

200 uV
30-20 kHz

Trig: -175 uV↑
Switch: Collect / Analyze

Trig: 6.7 Hz

200 uV
4 div

QMUP Data
Duration ms 10.5  10.5  0.0  10.5  0.0
Amplitude uV 735  735  0.0  735  0.0
Phases 2.9  3.0  0.0  2.9  0.0
Spike Dur ms 0.6  0.6  0.0  0.6  0.0
Risetime ms 1105  1105  0.0  1105  0.0
Area uVms 1.24  1.24  0.0  1.24  0.0
Size Index 1.24  1.24  0.0  1.24  0.0
Voluntary Motor Unit Potentials

- **Configuration**: Triphasic, initial positive (occasionally negative), 6-15 msec duration
- **Sound**: “ataxic clock”

**Semi-Rhythmic** (5-40 Hz) – Limited (10%) variation
What is the best way to recognize motor unit potentials?

Semi-rhythmic firing pattern
Motor Unit Potentials

Motor neuron
Branches of motor neurons
Myofibrils

Muscle fiber
A Single Motor Unit

All the muscle fiber innervated by the AHC.
Motor Unit
Recording **Multiple** A Single Muscle Fiber Action Potential
Motor Unit

Recording Multiple (2-15) Muscle Fiber Action Potentials
Factors Affecting MUP Morphology

**Technical**
- Electrode type
  - Recording surface area
- Filter settings
- Amplifier characteristics

**Physiologic**
- Muscle
- Subject’s age
- Temperature
Technical Factors
Needle Electrode Types

Concentric
Monopolar
Single Fiber

Pick Up Area
Pick Up Area
Effect of Needle Electrode Position
Same Motor Unit, Different Muscle Fiber Locations
Filters

Reduction in MUP duration by low frequency filtering
First Dorsal Interoseous M.

LLF:
1.6
8.0
32.0

200 μV
10 ms

LFF 30 Hz
Duration 11.3 ms

LFF 2 Hz
Duration 13.5 ms
Physiologic Factors Affecting MUP

- **Low Temperature (or fiber diameter)**
  - Slows muscle fiber action potential CV, increase temporal dispersion
    - MORE COMPLEXITY
    - LONGER DURATION
  - Increases muscle fiber action potential amplitude

- **Age** – MUP amplitude, duration, and turns increases with age (distal leg muscles)

- **Muscle**
  - Frontalis < Biceps < Anterior tibialis
MUP Parameter Determinants

Muscle Configuration

- Number of motor units: 50-600 motor units per muscle
- Innervation ratio: 5-2000 muscle fibers per motor unit
- Fiber density: 25-200 per square millimeter
- Motor unit area: 2-15 mm diameter
MUP Parameters Assessed

- **Rise time**  
  - Distance from muscle fibers
- **Spikes, turns, phases**  
  - Fiber number, synchrony
- **Duration**  
  - Fiber size, density, synchrony
- **Stability**  
  - NMJ and nerve terminal
- **Recruitment**  
  - Number of motor units
## Temporal Course of EMG changes in acute neurogenic disorders (severity dependent)

<table>
<thead>
<tr>
<th></th>
<th>1 week</th>
<th>2 weeks</th>
<th>6 weeks</th>
<th>6 months</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fibrillation Potentials</strong></td>
<td>None</td>
<td>Some</td>
<td>Many</td>
<td>None (Tiny)</td>
</tr>
<tr>
<td><strong>Recruitment</strong></td>
<td>Reduced</td>
<td>Reduced</td>
<td>Reduced</td>
<td>Reduced</td>
</tr>
<tr>
<td><strong>Phases</strong></td>
<td>Normal</td>
<td>Polyphasic</td>
<td>Polyphasic</td>
<td>Normal (polyphasic)</td>
</tr>
<tr>
<td><strong>Duration</strong></td>
<td>Normal</td>
<td>(Long)</td>
<td>Long</td>
<td>Long</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>None</td>
<td>Unstable</td>
<td>Unstable</td>
<td>CRD Fascics</td>
</tr>
</tbody>
</table>
Neurogenic Disorders
MUP Changes

**Loss of axons**
- Reduced number of MUP
- Reduced recruitment

**Collateral sprouting**
- Loss of synchrony of fibers
- Change in appearance
Temporal Course of MUP Changes
Acute Neurogenic Injury

Normal

Immediate
Reduced Recruitment

1 months post
Unstable MUP, turns

2-6 months
Polyphasic, long duration

> 6 mo
Long duration
MUP Parameters

- **Rise time**
  - Distance from muscle fibers
- **Spikes, turns, phases**
  - Fiber number, synchrony
- **Duration**
  - Fiber size, density, synchrony
- **Stability**
  - NMJ and nerve terminal
- **Recruitment**
  - Number of motor units
## Temporal Course of MUP Changes
### Acute Neurogenic Injury

<table>
<thead>
<tr>
<th>Time</th>
<th>Description</th>
<th>Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>[Normal MUP diagram]</td>
<td>[Normal MUP waveform]</td>
</tr>
<tr>
<td>Immediate</td>
<td>Reduced Recruitment</td>
<td>[Immediate MUP diagram]</td>
</tr>
<tr>
<td>1 months post</td>
<td>Unstable MUP, turns</td>
<td>[1 month MUP diagram]</td>
</tr>
<tr>
<td>2-6 months</td>
<td>Polyphasic, long duration</td>
<td>[2-6 month MUP diagram]</td>
</tr>
<tr>
<td>&gt; 6 mo</td>
<td>Long duration</td>
<td>[&gt; 6 month MUP diagram]</td>
</tr>
</tbody>
</table>
MUP Recruitment
MUP Firing Rate with Effort

![Graph showing MUP Firing Rate with Effort](image)
Reduced Recruitment
Reduced Recruitment

MUP1

MUP2

MUP3

MUP Firing Rate

Force

Mild

Moderate

Strong

0

5

10

15

20

25
“Poor Activation”

- MUP1
- MUP2
- Force: Mild (Strong)
- MUP Firing Rate: 0, 5, 10, 15, 20, 25
- Effort
- Pain
- Central Disorder: Stroke
- Myelopathy

Graph showing MUP firing rates against force. MUP1 and MUP2 are plotted on the graph with corresponding effort levels.
Rapid Recruitment

Assessment is Effort-Dependent!

Recruitment frequency is normal

Ratio of rate: number ≤ 5

Multiple MUP with minimal effort ("all or none pattern")
Recognizing Reduced Recruitment

- Compare ratio of rate: number with normal for that muscle

- Most limb muscles have ratio of rate: number of ≤ 5
  - 15 Hz: 3 MUP
  - 20 Hz: 4 MUP

- Learn more tonight
Disorders With Reduced Recruitment

**Neurogenic**
- Axon destruction (e.g. nerve laceration, radiculopathies, neuropathies)
- Loss of anterior horn cells (e.g. ALS)
- Conduction block (e.g. Saturday night palsy)

**Myopathies**
- Severe myopathy with loss of all muscle fibers in some motor units (e.g. end-stage muscular dystrophy)

*Hallmark of a neurogenic process*
Proportional to loss of axons
Stages of Reinnervation
Collateral Sprouting

a) UNSTABLE NMJ TRANSMISSION
   Decrement on repetitive stimulation
   Motor unit potential variation

b) ALTERED FIBER NUMBER AND SYNCHRONY
   MUP configuration change
   MUP size change
Recognizing MUP Changes
Neurogenic Diseases

<table>
<thead>
<tr>
<th>Normal</th>
<th>Immediate</th>
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</thead>
<tbody>
<tr>
<td>Reduced Recruitment</td>
<td></td>
</tr>
<tr>
<td>1 months post</td>
<td>Unstable MUP</td>
</tr>
<tr>
<td>2-6 months</td>
<td>Polyphasic</td>
</tr>
<tr>
<td>6 mo - 2 yrs</td>
<td>Long duration</td>
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</tbody>
</table>
Motor Unit Potential Stability

Stable

Unstable (varying)
Motor Unit Potential Variation
Blocking of Muscle Fibers
Disorders with Motor Unit Potential Variation

**Neurogenic**
- Ongoing reinnervation after axonal loss
  - e.g. ALS, recovering radiculopathy or mononeuropathy, reinnervating neuropathy

**NMJ disorders**
- Myasthenia gravis (severe)
- LEMS
- Botulism

**Myopathies**
- Reinnervating muscle fibers

Often NOT recognized!
Need to think about it!
Look / listen for it!
Temporal Course of MUP Changes
Acute Neurogenic Injury

<table>
<thead>
<tr>
<th>Time Period</th>
<th>MUP Changes</th>
<th>Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>Normal</td>
<td><img src="image" alt="Normal MUP" /></td>
</tr>
<tr>
<td>Immediate</td>
<td>Reduced Recruitment</td>
<td><img src="image" alt="Reduced Recruitment" /></td>
</tr>
<tr>
<td>1 months post</td>
<td>Unstable MUP, turns</td>
<td><img src="image" alt="Unstable MUP" /></td>
</tr>
<tr>
<td>2-6 months</td>
<td>Polyphasic, long duration</td>
<td><img src="image" alt="Polyphasic MUP" /></td>
</tr>
<tr>
<td>&gt; 6 mo</td>
<td>Long duration</td>
<td><img src="image" alt="Long Duration MUP" /></td>
</tr>
</tbody>
</table>
Polyphasic MUP
Neurogenic - Asynchronous Firing
Polyphasic MUP Myopathy
“Nascent” MUPs

- Reinnervation after severe axon loss
  - Atrophic muscle fibers
  - Temporally dispersed
    - immature myelination
    - small muscle fibers
  - Asynchronous summation of only few fibers
  - Unstable NMJ transmission

- Low amplitude, polyphasic, varying MUP
  - Short, normal, or long duration

& REDUCED RECRUITMENT
## Recognizing MUP Changes

### Neurogenic Diseases

<table>
<thead>
<tr>
<th>Time Period</th>
<th>MUP Characteristics</th>
</tr>
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<tr>
<td>Normal</td>
<td></td>
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<tr>
<td>Immediate</td>
<td>Reduced Recruitment</td>
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<tr>
<td>1-2 months post</td>
<td>Unstable MUP</td>
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<td>Polyphasic</td>
</tr>
<tr>
<td>6 mo - 2 yrs</td>
<td>Long duration</td>
</tr>
</tbody>
</table>

- **Normal**: Normal MUP activity without any changes.
- **Immediate**: Reduced recruitment of MUP fibers immediately after nerve injury.
- **1-2 months post**: Unstable MUP activity, indicating incomplete recovery.
- **2-6 months**: Polyphasic MUP, with multiple phases and increased variability.
- **6 mo - 2 yrs**: Long duration polyphasic MUP, persistent nerve damage.

*Diagram with corresponding MUP waveforms for each stage.*
Normal Motor Unit Potential
“Neurogenic” Motor Unit Potential
Motor Unit Potential Changes in Myopathies

- Reduced motor unit territory
  - Reduction of # of muscles fibers / motor unit
  - Reduction in muscle fiber size
- Decreased duration of MUP
- Decreased amplitude of MUP
- Increased phases of MUP (desynchrony)
Normal Motor Unit Potential
“Myopathic” Motor Unit Potential
Disorders with Short Duration MUPs
*(not necessarily “myopathic”)*

**Neurogenic**
- Early reinnervation from severe nerve damage (“nascent MUP”)

**Myopathic**
- Inflammatory (e.g. polymyositis, IBM)
- Toxic myopathies
- Muscular dystrophies
- Myotonic dystrophy
- Congenital myopathies

**NMJ disorders**
- Myasthenia gravis
- LEMS
- Botulism
EMG Waveform Analysis Session

This Evening:

Practice assessment of recruitment and other MUP parameters

Testing your skills with Quizzes and Case Examples

Questions and Answers this Evening
Crafting the EMG Report

Benn E. Smith, M.D.
Department of Neurology
February 2015
Disclosure

Relevant Financial Relationship(s)
None

Off Label Usage
None
What is all the fuss?

1) Why discuss this topic at all?
2) Isn’t it obvious how to write an EMG report?
3) Shouldn’t we be spending more time on learning the technical nuances of EMG?
4) Did we have trouble finding useful topics to fill the EMG course program?
Problems with EMG Reporting

1) The topic is not well covered in most training programs
2) We have difficulty summarizing EMG/NCS data
3) We are preoccupied by the electrical
4) We neglect the non-electrical clinical
5) We have problems writing clearly and accurately
6) It is easier not to take responsibility in writing an EMG report
What do we mean by “craft”?

Craft (\ 'kraft \) vt: to make or produce with care, skill, or ingenuity (a carefully \~ed story)
There is a hole in our training

1) EMG reports have a reputation of being difficult to understanding and of marginal clinical utility
2) Even though a physician may be a masterful electromyographer, she may have not done so well in English composition
3) There is so much to learn on the technical side of doing EMG/NCS, skills in putting together an excellent report are sometimes neglected
Our difficulty summarizing electrophysiologic data

1) There is a widespread tendency to repeat all data in the interpretation (and present little -- if any -- synthesis)
2) EMGers often are meticulous about identifying every “tree,” while doing poorly at succinctly describing the affected “glen” or “forest”
Our difficulty summarizing electrophysiologic data

3) EMGers often focus too narrowly on the details of electrophysiologic values and miss “the elephant in the room,” that is, the historical clues and physical findings that clearly point to an alternative diagnosis.
EMG #1 referral indication: “paresthesia and pain”

Summary: The left median antidromic sensory response amplitude was 10 µV (nl > 15 µV) with a conduction velocity of 53 m/s (nl > 54 m/s) and a distal latency of 4.5 ms (nl < 3.6 ms). The left ulnar antidromic sensory response was 5 µV in amplitude (nl > 10 µV) with a conduction velocity of 51 m/s (nl > 53 m/s) and a distal latency of 3.3 ms (nl < 3.2 ms). The left median/APB motor amplitude was the 4.2 mV (nl > 4 mV) with conduction velocity of 49 m/s (nl > 48 m/s) and a motor distal latency of 5.2 msec and an F wave latency of 30 ms (nl < 32 ms). The left ulnar/ADM motor amplitude was 6.1 mV (nl > 6 mV) with a conduction velocity of 47 m/s (nl > 51 m/s) and a motor distal latency of 3.4 ms (nl < 3.6 ms) and an F wave latency of 29.7 ms (nl < 33 ms). The left fibular/EDB motor response was 1.0 mV in amplitude (nl > 2.0 mV) with a conduction velocity of 38 m/s (nl > 41 m/s), a motor distal latency of 5.0 ms (nl < 6.6 ms) and no elicitable F waves. The left sural sensory response was 2.2 µV in amplitude (nl > 6 µV) with a distal latency of 4.6 ms (nl < 4.5 ms). Concentric needle examination showed large motor unit potentials in the left first dorsal interosseous, abductor pollicis brevis, tibialis anterior, and medial gastrocnemius muscles with fibrillation potentials in the abductor hallucis muscles on both sides and a single train of positive sharp waves in the left low lumbar paraspinal muscles.

Interpretation: The EMG findings suggest either median, ulnar, fibular, and tibial mononeuropathies (multiple mononeuropathies), polyneuropathy with superimposed carpal tunnel syndrome, polyradiculoneuropathy, or motor neuron disease with an additional sensory neuropathy. Multilevel cervical and lumbosacral radiculopathy or plexopathy cannot be completely excluded. Suggest clinical correlation.
The cluttered noncommittal report

Comment: Regurgitation of detailed individual data elements with no useful summary or pattern recognition. Noncommittal interpretation with no attempt at correlating the findings with the patient’s symptoms and signs.
EMG #2 referral indication: “paresthesia and pain”

**Summary:** NCS showed low amplitude sensory and motor responses with borderline NCVs and disproportionate prolongation of the left median sensory and motor distal latencies. Concentric needle examination demonstrated mild distal MUP enlargement accompanied by low-grade irritability and fibrillation potentials limited to intrinsic foot muscles. The patient reported no hand symptoms whatsoever. Tinel sign was absent over the median nerves at the wrists. Mild left thenar atrophy noted of which the patient was unaware.

**Interpretation:** The EMG findings suggest electrophysiologically mild to moderate predominantly axonal sensorimotor peripheral neuropathy with superimposed asymptomatic left median neuropathy at the wrist.
The tailored “nickel on the table” report

Comment: Summarized individual data elements with findings presented in a cohesive clinically pertinent pattern. Interpretation commits to a particular diagnostic formulation (polyneuropathy and subclinical median neuropathy at the wrist) correlating the findings with the patient’s symptoms and signs.
Our preoccupation with the electrical

1) We reduce impedance, attach wires, turn dials, and administer current pulses
2) We collect waveforms, analyze responses, move cursors, record detailed numbers
3) We report nerve conduction values to 2 decimal places, list muscles with long Latin names, describe MUP morphology, and obsess over charts with myriad pluses and minuses
Our neglect of the non-electrical clinical

1) Time is short, patients are many, face-to-face physician-patient interactions are brief
2) We rarely take the time to review key elements of the presenting complaints, the pace of development of symptoms, or exacerbating and ameliorating factors
3) We tend to rely heavily on the referral indications and the history taken by the referring physician
“Typical” EMG Referral Indications

1) **Pain**
   - Dysparenuia
   - Charcot joint, check anal EMG
   - Pain in the neck

2) **Sensory**
   - EMG for worms crawling in leg
   - Thing numbness
3) **Incomplete understanding of EMG**
   - lower limb numbness, r/o CTS
   - r/o lower extremities
   - carpool tunnel
   - reptile dysfunction

4) **??????**
   - EMG for mental stenosis
   - my apathy
   - patient leaving town
EMG #3 referral indication: “unsteadiness”

**Summary:** NCS and concentric needle examination of the lower limbs were normal.

**Interpretation:** Normal EMG. This study provides no evidence for peripheral neuropathy or any other neuromuscular explanation for the patient’s unsteadiness.
Failure to Make Pertinent Clinical Observations during EMG Testing

Comment: Focus is purely on the electrophysiology, ignoring obvious clinical signs and symptoms at the time of the examination (see below)
Summary: NCS and concentric needle examination of the lower limbs were normal. Every needle insertion below the knee on either side resulted in either an extensor plantar response or triple flexion. Physical examination showed no upper limb deep tendon reflexes, markedly hyperactive lower limb reflexes, sustained bilateral ankle clonus, and bilateral extensor plantar responses. No sensory level to pin prick could be demonstrated on the torso either anteriorly or posteriorly.

Interpretation: Normal EMG. Although this study does not suggest a peripheral process, the physical findings described above are those of a bilateral central nervous system disorder affecting upper motor neuron pathways. Neurologic consultation is recommended. Results discussed by telephone with Dr. Jones.
Report Assessment?

Pertinent Clinical Observations during EMG Testing Help the Referring Clinician

Comment: while electrophysiological findings are presented, the emphasis is put on clinical observations which re-direct the neurologic evaluation
4) Patients often “change their tune” between the initial H and P and their EMG visit

5) Patients often use medical terms (“paresthesia”, “sciatica”, etc.) during their initial H and P which have not been explored further by the referring physician

6) Limb pain is often equated with a neurogenic etiology, leading to low yield referrals for “radicular” or “neurogenic” pain
EMG #5 referral indication: “Right hip/leg pain”

**Summary:** NCS showed a low amplitude right fibular/EDB compound muscle action potential and absent right fibular/EDB F waves. Concentric needle examination demonstrated large motor unit potentials in the right L5 territory both distally and proximally, unaccompanied by irritability or fibrillation potentials in the leg, hip girdle, or lumbar paraspinal muscles.

**Interpretation:** The EMG findings are those of right L5 radiculopathy.
Report Assessment?

Failure to Discount the EMG Findings as Being Clinically Insignificant

Comment: although the EMG and NCS findings are correctly described and interpreted, the electromyographer does not “go to the next level” and weave them into the prior clinical history, taking into account other possible explanations for the current symptoms.
EMG #6 referral indication: “Right hip/leg pain”

**Summary:** NCS showed a low amplitude right fibular /EDB compound muscle action potential and absent right fibular/EDB F waves. Concentric needle examination demonstrated large motor unit potentials in the right L5 territory both distally and proximally, unaccompanied by irritability or fibrillation potentials in the leg, hip girdle, or lumbar paraspinal muscles. The patient reported having an episode of severe low back and radiating right lower limb pain twelve years ago associated with a transient right foot drop. The problem resolved spontaneously over 3-4 months. Physical examination currently shows normal lower extremity strength and marked pain on flexion, abduction, and external rotation of the right hip.

**Interpretation:** Although the EMG findings provide evidence of electrophysiologically old inactive right L5 radiculopathy, the current symptoms are perhaps more likely to be due to mechanical disease of the right hip joint.
This Report Looks Beyond the “Tree” to see the Forest

Comment: the same NCS and EMG observations are made, but this time with the added depth of relevant past medical history and current physical examination abnormalities which lead to the correct diagnosis.
1) The EMG report often presents findings in isolation without an attempt to comment on clinical relevance.

2) The EMG report which recommends "clinical correlation" gives the impression that the EMGer is somehow absolved of integrating the EMG results into the clinical context.

3) The EMG report should not only rely on electrophysiologic findings, but instead should incorporate all clinically relevant data available to the EMGer.
Conclusions

1) The referring physician is looking for help in coming up with a valid explanation for the patient’s symptoms
2) Try to develop a “big picture” approach to framing results of the EMG (“tell the story”)

- leave minutia in the data section
- “What would I want from the report if this were my patient?”
- don’t be afraid of expressing uncertainty or doubt in the report
Conclusions

3) Performing a brief history and physical examination is time well spent in the EMG Laboratory – we are physicians
Craft (\'kraft\) n: an occupation or trade requiring manual (or mental) dexterity or artistic skill (the sculptor’s ~)
EMG Waveform Analysis

Evening Workshop

Evening Workshop Outline

#1 – Unknown quiz

#2 – Learn Rapid Auditory Quantitation of MUP parameters

#3 – “Who Wants to be an Electromyographer?”

#4 - Bedtime (or breakfast)

EMG Waveform Analysis – Skills to Master

- Pattern Recognition
- Semi-quantitation

Analysis of Motor Unit Potentials

42 year old with arm pain - Needle EMG of Deltoid

Is this potential normal or abnormal? How do you know?

How much time (on average) do you spend analyzing MUP in a muscle?

1. >10 minutes
2. 5 – 9 minutes
3. 1 – 4 minutes
4. < 1 minute

Motor Unit Potential Configuration

Recording Multiple (2-15) Muscle Fiber Action Potentials
Quantitation In Electrodiagnosis

NCS

- Repetitive stimulation

- Voluntary needle EMG activity
  - Limited use in USA
  - More common in Europe
  - New programs

MUP Quantitation - Single MUP method
Effective but still time consuming

What is “Rapid Quantitation”?
Obtain a numerical value without measurement

MAYO MUP ABNORMALITY GRADING BY MEAN VALUE IN MSEC AT AGE 20
Lower and upper limit of normal (from Buchthal 1955)

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Grade</th>
<th>Lower</th>
<th>Upper</th>
<th>Lower</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st dorsal interos.</td>
<td>0</td>
<td>8.0</td>
<td>12.2</td>
<td>6.0</td>
<td>14.1</td>
</tr>
<tr>
<td>Deltoid</td>
<td>±</td>
<td>7.0</td>
<td>13.1</td>
<td>5.0</td>
<td>15.0</td>
</tr>
<tr>
<td>Triceps</td>
<td>*</td>
<td>6.1</td>
<td>14.3</td>
<td>4.1</td>
<td>16.3</td>
</tr>
<tr>
<td>Biceps</td>
<td>**</td>
<td>6.0</td>
<td>14.0</td>
<td>4.0</td>
<td>16.0</td>
</tr>
<tr>
<td>Anterior tibial</td>
<td>***</td>
<td>5.0</td>
<td>15.0</td>
<td>3.5</td>
<td>15.0</td>
</tr>
<tr>
<td>Vastus medialis</td>
<td>****</td>
<td>4.0</td>
<td>15.0</td>
<td>2.5</td>
<td>15.0</td>
</tr>
<tr>
<td>Opponens pollicis</td>
<td>+++++</td>
<td>3.0</td>
<td>15.0</td>
<td>2.0</td>
<td>15.0</td>
</tr>
</tbody>
</table>

Automated MUP Analysis
Computer does all the work

- Averaged MUP quantitation (AMUP) *McGill & Dorfman 1989
- Multiple MUP quantitation (MMUP) *Stalberg 1995
- Decomposition EMG (DQEMG) *Stashuk & Doherty 2003
- Rapid MUP quantitation *Lambert - back to the future

Estimate Your Pulse Rate (Per minute)

1. Under 56
2. 56 – 60
3. 61 – 65
4. 66 – 70
5. 71 – 75
6. 76 – 80
7. 81 – 85
8. 86 – 90
9. Over 90
Let's Learn Rapid Quantitation

1. Identify the waveform by pattern recognition
2. Learn rapid quantitation (train your ears)
3. Test your rapid quantitation

MUP Parameters to Learn

- **Rise time**
  Distance from muscle fibers
- **Recruitment**
  Number of motor units
- **Stability**
  NMJ and nerve terminal
- **Spikes, turns, phases**
  Fiber number, synchrony
- **Duration**
  Fiber size, density, synchrony

MUP Changes to Quantitate in Neurogenic Diseases

<table>
<thead>
<tr>
<th>Normal</th>
<th>Immediate</th>
<th>Reduced Recruitment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 months</td>
<td>Unstable MUP</td>
</tr>
<tr>
<td></td>
<td>2-6 months</td>
<td>Phases</td>
</tr>
<tr>
<td></td>
<td>6 mo - 2 yrs</td>
<td>Duration increase</td>
</tr>
</tbody>
</table>

How Close is the Potential?
Your ear will tell you!
Based on slew rate/rise time

Your ear hears the slew rate = rate of rise (mV/msec)

Rise time = time (msec) from peak positivity to peak negativity

Rise time depends on slew rate and amplitude

Practice Rise Time with EMG Simulator

Normal Recruitment

Orderly addition of potentials from different motor units with increase in discharge rate
MUP Recruitment
MUP Firing Rate with Effort

Reduced Recruitment
Too few MUP for rate of firing

"Poor Activation"

Recognizing Reduced Recruitment
EMG Simulator Exercise

- Step 1 - What is the firing rate of any individual MUP?
- Step 2 - How many different MUP?
- Step 3 - What is the ratio of rate to number?

- Compare ratio of rate: number (most limb muscles < 5)
  - 15 Hz: 3 MUP, 20 Hz: 4 MUP
  - Grading based on rate of firing of 1st MUP when 2nd MUP recruited:
    1+ for >10 Hz
    2+ for >15 Hz
    3+ for > 20 Hz
Methods to Confirm Firing Rate

1. Rate counter
2. 50 msec/div – 20 div sweep – count the number of MUP in 1 sec
3. 10 msec/div sweep – count the interspike interval and divide into 1000 msec

<table>
<thead>
<tr>
<th>INTERVAL (msec)</th>
<th>FREQUENCY, Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>6.5</td>
</tr>
<tr>
<td>125</td>
<td>8.0</td>
</tr>
<tr>
<td>100</td>
<td>10.0</td>
</tr>
<tr>
<td>75</td>
<td>13.3</td>
</tr>
<tr>
<td>60</td>
<td>16.6</td>
</tr>
<tr>
<td>50</td>
<td>20.0</td>
</tr>
</tbody>
</table>

Recognizing Reduced Recruitment

EMG Simulator Exercise

- **Step 1** - What is the firing rate of any individual MUP?
- **Step 2** - How many different MUP?
- **Step 3** - What is the ratio of rate to number?

- Compare ratio of rate: number (most limb muscles ≤ 5)
  - 15 Hz: 3 MUP, 20 Hz: 4 MUP

- Grading based on rate of firing of 1st MUP when 2nd MUP recruited:
  - 1+ for >10 Hz
  - 2+ for >15 Hz
  - 3+ for >20 Hz

MUP Parameters to Learn

- **Rise time**
  - Distance from muscle fibers
- **Recruitment**
  - Number of motor units
- **Stability**
  - NMJ and nerve terminal
- **Spikes, turns, phases**
  - Fiber number, synchrony
- **Duration**
  - Fiber size, density, synchrony

Recognizing MUP Changes

Early Reinnervation

<table>
<thead>
<tr>
<th>Time</th>
<th>Appearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td><img src="image" alt="Normal MUP" /></td>
</tr>
<tr>
<td>Immediate Reduced Recruitment</td>
<td><img src="image" alt="Immediate Reduced MUP" /></td>
</tr>
<tr>
<td>1 months post</td>
<td><img src="image" alt="1 Months MUP" /></td>
</tr>
<tr>
<td>Unstable MUP</td>
<td><img src="image" alt="Unstable MUP" /></td>
</tr>
<tr>
<td>2-6 months</td>
<td>Polyphasic</td>
</tr>
<tr>
<td>6 mo - 2 yrs</td>
<td>Long duration</td>
</tr>
</tbody>
</table>

Motor Unit Potential Variation

Blocking of Muscle Fibers

![Motor Unit Potential Variation Diagram](image)
MUP Variation
Blocking of muscle fibers

MUP Parameters to Learn
• Rise time
  • Distance from muscle fibers
• Recruitment
  • Number of motor units
• Stability
  • NMJ and nerve terminal
• Spikes, turns, phases
  • Fiber number, synchrony
• Duration
  • Fiber size, density, synchrony

Recognizing MUP Changes
Remodeling

Normal
Immediate
Reduced Recruitment
1 months
Unstable MUP
2-6 months
Polyphasic
6 mo - 2 yrs
Long duration

MUP Parameters to Learn
• Rise time
  • Distance from muscle fibers
• Recruitment
  • Number of motor units
• Stability
  • NMJ and nerve terminal
• Spikes, turns, phases
  • Fiber number, synchrony
• Duration
  • Fiber size, density, synchrony

Motor Unit “Remodeling”

Normal
Immediate
1 months post
2-6 months
6 mo - 2 yrs

Normal MUP
Long Duration MUP
Increased # fibers, fiber density

Disorders with Short Duration MUPs
- Myopathies
- Myasthenia gravis / LEMS
- Early reinnervation after nerve damage (nascent MUP)
- Late stage neurogenic atrophy
- Periodic paralysis

Normal MUP

Short Duration MUP (Myopathy)