Action potentials in nerve and muscle

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<table>
<thead>
<tr>
<th>Intracellular</th>
<th>Extracellular</th>
</tr>
</thead>
<tbody>
<tr>
<td>K⁺</td>
<td>K⁺</td>
</tr>
<tr>
<td>-90 mV</td>
<td>0 mV</td>
</tr>
<tr>
<td>Active influx of Na⁺</td>
<td>Active efflux of Na⁺</td>
</tr>
<tr>
<td>Na⁺</td>
<td>Na⁺</td>
</tr>
<tr>
<td>0 mV</td>
<td>90 mV</td>
</tr>
<tr>
<td>Cl⁻</td>
<td>Cl⁻</td>
</tr>
<tr>
<td>-80 mV</td>
<td>0 mV</td>
</tr>
</tbody>
</table>

Figure 8.2. Simplified scheme of voltage and possible fluxes of potassium (K⁺) and sodium (Na⁺) into and out of the muscle fiber with opening and closing of the respective channels. When the voltage is close to the threshold, the sodium and potassium gradients are high, thus driving the influx of sodium and efflux of potassium. The sodium pump, the SERT, and the ATPase pump generate the membrane potential.

Intracellular recording

Kimura, 2001
Muscle recordings; EMG

Technical factors determining the recording

Electrode size
Reference electrode
Amplifier filter
The electrical field around a muscle recorded with a small (S) and a large (L) electrode surface.

Various EMG electrodes, from focal to global:
- **Wire electrodes** (IOM, pelvic muscles, kinesiology)
- **Needle electrodes**
  - SFEMG
  - Concentric
  - Monopolar
  - Macro
- **Surface electrodes**

Wire electrode
- Cannula with wires inserted into the muscle
- When in place, the cannula is pulled out, leaving the wires connected to the amplifier.
Electrodes

A
B
C
D
E

Reference electrode

SFEMG cannula
Monopolar remote el
Conc cannula
Macro remote surface el
Surface close or remote surface el

Concentric electrode

this activity is cancelled
Monopolar electrode recording

Technical factors determining the recording

- Electrode size
- Reference electrode
- Amplifier filter
Concentric needle electrode
Field disappears in electrode shadow (1 mm)
Conc el has 360° view for early and late MUP comp.
but 180° view for the central MUP complex (± 250 µsec)

Concentric needle electrode
Uptake area for approaching field
Concentric needle electrode
Uptake area for when the signals pass the electrode

Concentric needle electrode
Uptake area for disappearing field

Normal, slightest contraction
Active MU
Active MU
Normal, slight contraction

Normal, moderate contraction

Conc electrode
Distant MU
Electrode moved to "focus"

Conc electrode

New MU with increasing force

Conc electrode

New MUs with increasing force, one close to the electrode
New MU over the cannula

Conc electrode

New MU with increasing force, should be seen repeated, otherwise possible summation

Conc electrode
Effective uptake area of different electrodes –

In Summary
Structure of peripheral nerves

Myelinated axon

Displacement of nodes with compression
Physiology of myelinated axons

- saltatory conduction
- sodium channels at Ranvier’s node
- potassium channels in the internodal region
- internodal conduction time 20 us
- thicker axons have faster CV (5 m/s per um)
- fastest human motor axons conduct at 65-70 m/s
- slowest around 25-35 m/s

Conduction in abnormal nerves

- Saltatory nerve conduction depends on the innermost myelin layers
- prolonged internodal conduction time from 20 us to 500 us
- conduction blocks arise due to local inexcitability
- non-saltatory conduction requires reorganization of the axolemma
Generation of sensory potentials

Phase cancellation

Phase cancellation
Sensory conduction studies; some factors to consider

- Type of electrode; needle, surface
- Inter-electrode distance
- Stimulus strength
- Antidromic-orthodromic direction
- Temperature

Types of sensory recording electrodes

Near nerve sensory recordings; Plantar digital nerves

Reference values for healthy subjects
CV(m/s)=45.6-0.22*age(years) sd=3.3  diff <8 m/s
Simulation of sensory surface recordings

Simulation: effect of pathology for different electrodes (17 and 45 mm) distance

Effect of interelectrode distance
Orthodromic sensory neurography

Antidromic sensory neurography

Antidromic and orthodromic neurography

Median nerve: wrist to forefinger

<table>
<thead>
<tr>
<th>BEST</th>
<th>SAT</th>
<th>CD</th>
<th>APP</th>
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<tbody>
<tr>
<td>3.9</td>
<td>57.6</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3.2</td>
<td>57.3</td>
<td>0</td>
<td></td>
</tr>
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</table>
Orthodromic vs. antidromic

<table>
<thead>
<tr>
<th>Antidromic</th>
<th>Orthodromic</th>
</tr>
</thead>
<tbody>
<tr>
<td>less painful</td>
<td>no muscle artifact</td>
</tr>
<tr>
<td>larger amplitude</td>
<td>more painful</td>
</tr>
<tr>
<td>muscle artifact in mixed nerves</td>
<td>lower amplitude</td>
</tr>
</tbody>
</table>

Motor conduction studies; some factors to consider
- Placement of electrodes
- Electrode size
- Stimulus strength
- Muscle length
- Temperature

Motor conduction studies; “belly-tendon”

- bell vs ref other hand
- tendon vs ref other hand
- belly vs tendon

10.5mv

12 mV
Motor conduction studies; "belly-remote"

- Motor conduction studies; "belly-remote"

Effect of electrode size and placement

- Effect of electrode size and placement


Effect of electrode size and placement

- Effect of electrode size and placement

Effect of electrode type

<table>
<thead>
<tr>
<th>Stimulation electrode</th>
<th>Median nerve</th>
<th>Thenar muscles</th>
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</thead>
<tbody>
<tr>
<td>Currents</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Threshold</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supraliminal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subliminal</td>
<td></td>
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</table>

Effect of muscle length on the M wave

<table>
<thead>
<tr>
<th>Muscle Length</th>
<th>M wave</th>
<th>Median nerve</th>
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<tbody>
<tr>
<td>15 cm</td>
<td>27.9</td>
<td></td>
</tr>
<tr>
<td>10 cm</td>
<td>-6.3</td>
<td></td>
</tr>
<tr>
<td>5 cm</td>
<td>-1.5</td>
<td></td>
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<tr>
<td>2 cm</td>
<td>-7.2</td>
<td></td>
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<tr>
<td>1 cm</td>
<td>-18.5</td>
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Recording from thenar muscles - median nerve

Stimulation electrode currents

subliminal  threshold  liminal  supraliminal
Stimulus intensity

- Too high (cathodal escape) 3.8 8.9
- Recommended (10-15% suprom.) 3.9 9.9
- Maximal response 3.9 9.9
- Submaximal -26 7.3
- Threshold 4.2 8.7

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