Manual of Nerve Conduction Studies

Second Edition
This page intentionally left blank
To
Lois
Michael
Peter
John
Walter

To
Julie
Joshua
Caleb
Contents

Introduction xi

1. Upper Limb/Brachial Plexus Motor Nerve Studies

Axillary motor nerve to the deltoid 2
Long thoracic motor nerve to the serratus anterior 6
Median Nerve
  Median motor nerve to the abductor pollicis brevis 10
  Median motor nerve to the flexor carpi radialis 18
  Median motor nerve (anterior interosseous branch)
    to the flexor pollicis longus 22
  Median motor nerve (antterior interosseous branch)
    to the pronator quadratus 26
  Median motor nerve to the pronator teres 30
  Median motor nerve to the 1st lumbrical 34
  Median motor nerve to the 2nd lumbrical 38
  H-reflex to the flexor carpi radialis 42
Musculocutaneous motor nerve to the biceps brachii 46
Phrenic motor nerve to the diaphragm 50
Radial Nerve
  Radial motor nerve to the extensor carpi ulnaris
    and brachioradialis 56
  Radial motor nerve to the extensor digitorum communis 60
2. **Upper Limb Sensory and Mixed Nerve Studies**

- Lateral antebrachial cutaneous sensory nerve 102
- Medial antebrachial cutaneous sensory nerve 106

- **Median Nerve**
  - Median sensory nerve to 2nd and 3rd digits 112
  - Median palmar cutaneous sensory nerve 120

- Posterior antebrachial cutaneous sensory nerve 124
- Radial sensory nerve to the base of the thumb 128

- **Ulnar Nerve**
  - Ulnar dorsal cutaneous sensory nerve 132
  - Ulnar sensory nerve to the 5th digit 136

- **Comparative Studies**
  - Median and radial sensory nerves to the thumb 144
  - Median and ulnar mixed nerve studies (transcarpal) 150
  - Median and ulnar sensory nerve studies to the 4th digit 156

3. **Lower Limb Motor Nerve Studies**

- Femoral motor nerve to the quadriceps 162

- **Peroneal Nerve**
  - Peroneal motor nerve to the extensor digitorum brevis 166
4. Lower Limb Sensory and Mixed Nerve Studies

Lateral femoral cutaneous sensory nerve 204
Medial calcaneal sensory nerve 210
Medial femoral cutaneous sensory nerve 214

Peroneal Nerve
  Deep peroneal sensory nerve 218
  Superficial peroneal sensory nerve 222

Posterior femoral cutaneous sensory nerve (medial and intermediate dorsal cutaneous branches) 228

Saphenous Nerve
  Saphenous sensory nerve (distal technique) 232
  Saphenous sensory nerve (proximal technique) 236

Sural Nerve
  Sural lateral dorsal cutaneous branch sensory nerve 240
  Sural sensory nerve 244
  Tibial mixed nerve (medial and lateral plantar branches) 248
5. **Head and Neck Studies**

- Blink reflex 254
- Cranial nerve VII 260
- Cranial nerve XI 264
- Greater auricular sensory nerve 268

6. **Root Stimulation**

- Cervical nerve root stimulation 272
- Lumbar nerve root stimulation 276

7. **Other Studies of Interest** 281

- Appendix: BMI Tables 287

- Index 291
Introduction

In training, residents and fellows often work at different EMG laboratories, which invariably have their own set of normal values. Discussions about how to derive these laboratory normal values typically raise many theories and suggestions, but generate little in the way of useful, practical guidance. The questions of how many normal subjects to study, which methods to use, and what machine and filter settings are most appropriate all must be considered. The unknown influence of factors such as temperature, age, height, and gender must be considered. Finally, the statistical analysis of the data must be completed, with the goal of producing appropriate normal values.

These tasks are daunting at best, and frustratingly difficult or impossible at worst, especially in a smaller lab. Yet every EMG laboratory has to use some set of normal values, whether developed internally or borrowed from elsewhere.

The first edition of this manual started the process of creating a state-of-the-art set of normal values based on easily performed, reproducible electrographic studies of the most commonly studied nerves. These normal values were based on large populations, and were analyzed with respect to a number of variables, such as height, body mass index, age, and gender. Where the newest and largest studies were unavailable, the most appropriate study was included, whether that be based upon sample size, technique, or general ‘acceptance’ in the field.

The second edition of this manual takes up where the first left off. Many more studies are updated, replacing older studies that might have been limited by factors such as sample size, or the difficulty or reliability of technique. When possible, studies with normal values based on larger groups of subjects with varied demographics were included. Side-to-side and same-limb comparisons of different nerves are often included, with the acceptable differences listed in the appropriate chapters.
Included for reference is a schematic of the brachial plexus inside the front cover, to be used as an aid in determining which nerves to study in complex cases.

One key difference in this edition is that the results are presented with the mean, standard deviation, the range, and the upper or lower limit of normal. While the upper and lower limits of normal have traditionally been defined as the mean ± 2 S.D., the 97th and 3rd percentiles of observed values are more appropriate when there is a large number of included subjects. Therefore, for this edition, we have included these values when possible. In studies with smaller numbers of subjects, or when researchers have not provided the 97th/3rd percentile data, we include the mean ± 2 S.D. values as the upper and lower limits of normal. For rare cases, authors may use a different method of deriving the normal ranges, and these are noted when they occur.

Care should be taken that the study technique is accurately reproduced when using these normal values. Differences in technique may not seem significant, but could yield results that lead to a patient being diagnosed inappropriately. For most studies in this book, common machine settings and techniques were used. However, in some special cases nonstandard techniques are presented. For these studies, the reader is cautioned to use the exact technique specified, in order to make the results valid.

This manual is not intended to be an introductory text or a teaching manual. There are many excellent textbooks available for these tasks. Instead, it is intended to be a bedside reference, used to quickly review how to perform a given study or to look up reference values that have not been committed to memory. This second edition offers a comprehensive, up-to-date set of normal values for clinical use. By following the described techniques, the user—trainee or clinician—will have normal values that can be used with confidence.

Ralph M. Buschbacher, MD
Nathan D. Prahlow, MD
Indiana University School of Medicine
Indianapolis
Manual of Nerve Conduction Studies

Second Edition
This page intentionally left blank
CHAPTER 1

Upper Limb/
Brachial Plexus
Motor Nerve
Studies
Typical waveform appearance

Electrode Placement
**Position:** This study is performed in the seated position.

**Active electrode (A):** Placement is over the most prominent portion of the middle deltoid.

**Reference electrode (R):** Placement is over the junction of the deltoid muscle and its tendon of insertion.

**Ground electrode (G):** Placement is on the acromion.

**Stimulation point (S):** Erb’s point—the cathode (C) is placed slightly above the upper margin of the clavicle lateral to the clavicular head of the sternocleidomastoid muscle. The anode (A) is superomedial.

**Machine settings:** Sensitivity—5 mV/division, Low frequency filter—2–3 Hz, High frequency filter—10 kHz, Sweep speed—2 msec/division.

**Nerve fibers tested:** C5 and C6 nerve roots, through the upper trunk, posterior division, and posterior cord of the brachial plexus.

**Normal values** (100 subjects) (temperature greater than or equal to 32 degrees Celsius):

**Onset latency (msec)**

<table>
<thead>
<tr>
<th>Height in cm (in)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤170 (5'7'')</td>
<td>4.1</td>
<td>0.4</td>
<td>3.1–4.9</td>
<td>4.8</td>
</tr>
<tr>
<td>&gt;170 (5'7'')</td>
<td>4.6</td>
<td>0.5</td>
<td>3.9–5.6</td>
<td>5.5</td>
</tr>
<tr>
<td>All subjects</td>
<td>4.3</td>
<td>0.5</td>
<td>3.1–5.6</td>
<td>5.4</td>
</tr>
</tbody>
</table>

**Amplitude (mV):** The data are divided into groups according to sex and body mass index (BMI), kg/m² (see Appendix).

<table>
<thead>
<tr>
<th>Sex</th>
<th>BMI</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>≤30</td>
<td>11.0</td>
<td>3.7</td>
<td>5.1–20.2</td>
<td>6.2</td>
</tr>
<tr>
<td>Male</td>
<td>&gt;30</td>
<td>9.1</td>
<td>3.7</td>
<td>3.3–14.9</td>
<td>3.3</td>
</tr>
<tr>
<td>Female</td>
<td></td>
<td>9.1</td>
<td>2.3</td>
<td>4.1–14.5</td>
<td>4.5</td>
</tr>
<tr>
<td>All subjects</td>
<td></td>
<td>9.9</td>
<td>3.3</td>
<td>3.3–20.2</td>
<td>4.6</td>
</tr>
</tbody>
</table>
Area of negative phase (µVsec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>62.8</td>
<td>20.6</td>
<td>20.8–130.8</td>
<td>27.3</td>
</tr>
</tbody>
</table>

Duration of negative phase (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.1</td>
<td>1.0</td>
<td>6.3–11.7</td>
<td>10.8</td>
</tr>
</tbody>
</table>

Acceptable Differences

The upper limit of normal increase in latency from one side to the other is 0.5 msec.

The upper limit of normal decrease in amplitude from one side to the other is 54%.

Helpful Hints

- The active electrode is placed over the region of greatest muscle mass, localized upon abduction of the shoulder.

Notes

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
REFERENCE


ADDITIONAL READINGS


LONG THORACIC MOTOR NERVE TO THE SERRATUS ANTERIOR

Electrode Placement
**Recording electrodes:** A concentric needle electrode (R) is placed at the digitation of the serratus anterior along the midaxillary line over the 5th rib (1). Alternately, a monopolar needle electrode can be placed in this same site, with the reference electrode 2 cm caudal and the ground electrode at the anterior axillary line over the 12th rib level (2).

**Stimulation point (S):** Erb’s point—the cathode (C) is placed slightly above the upper margin of the clavicle lateral to the clavicular head of the sternocleidomastoid muscle. The anode (A) is superomedial.

**Machine settings:** Standard motor settings are used.

**Nerve fibers tested:** Anterior primary branches of the C5, C6, and C7 nerve roots.

**Normal values:**

**Onset latency (1) (msec—44 subjects, concentric needle recording)**

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>20–35</td>
<td>3.6</td>
<td>0.3</td>
<td>4.2</td>
</tr>
<tr>
<td>36–50</td>
<td>3.8</td>
<td>0.4</td>
<td>4.6</td>
</tr>
<tr>
<td>51–65</td>
<td>4.0</td>
<td>0.4</td>
<td>4.8</td>
</tr>
</tbody>
</table>

**Onset latency (2) (msec—25 subjects, monopolar needle recording, room temperature 21–23 degrees Celsius)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.9</td>
<td>0.6</td>
<td>5.1</td>
</tr>
</tbody>
</table>

**Helpful Hints**

- In the study by Alfonzi and colleagues (1) the mean distance between stimulating and recording electrodes was 23.6 ± 1 cm, measured with obstetric calipers (range 22–25 cm). The latency was found to correlate with distance, with approximately a 0.2
msec increase in latency for each 1 cm increase in distance. In Kaplan’s study (2) the distances ranged from 17 to 23 cm.

- Surface recording techniques have also been described (1,3,4). Ma and Liveson (3) studied 15 subjects and placed the active electrode over the midaxillary line of the 5th or 6th ribs with the reference electrode at the anterior axillary line of the same rib and reported a latency of 3.0 \(\pm\) 0.2 msec. Alfonzi and coworkers (1) utilized surface recording with the active electrode at the digitation of the serratus anterior along the midaxillary line of the 5th rib with the reference electrode 3 cm in front of the active electrode. They reported latencies of 3.2 \(\pm\) 0.3 msec, 3.3 \(\pm\) 0.3 msec, and 3.3 \(\pm\) 0.3 msec, and amplitudes of 4.3 \(\pm\) 3.0 mV, 3.8 \(\pm\) 2.4 mV, and 2.7 \(\pm\) 1.2 mV for the age groups of 20–35, 36–50, and 51–65 years. They concluded that these recordings may be contaminated by volume conduction from other muscles and recommended using a needle recording technique. Cherrington (4) also studied this nerve using surface recording in 20 normal subjects. Stimulation was applied at Erb’s point and recording was just lateral to the nipple. Normal latencies ranged from 2.6 to 4.0 msec over a distance of 18.0–22.0 cm.

- Proper needle placement can be confirmed with active protraction.
- If the recording electrode is placed too far posteriorly, it may result in erroneous recording from the latissimus dorsi.

**Notes**

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
REFERENCES


ADDITIONAL READING/ALTERNATE TECHNIQUE

MEDIAN NERVE

MEDIAN MOTOR NERVE TO THE ABDUCTOR POLLICIS BREVIS

Typical waveform appearance

Electrode Placement
Position: This study is performed in the supine position.

Active electrode (A): Placement is halfway between the midpoint of the distal wrist crease and the first metacarpophalangeal joint.

Reference electrode (R): Placement is slightly distal to the first metacarpophalangeal joint.

Ground electrode (G): Placement is on the dorsum of the hand. If stimulus artifact interferes with the recording, the ground may be placed near the active electrode, between this electrode and the cathode.

Stimulation point 1 (S1): The cathode (C) is placed 8 cm proximal to the active electrode, in a line measured first to the midpoint of the distal wrist crease and then to a point slightly ulnar to the tendon of the flexor carpi radialis. The anode (A) is proximal.

Stimulation point 2 (S2): The cathode (C) is placed slightly medial to the brachial artery pulse in the antecubital region. The anode (A) is proximal.

F-wave stimulation: The cathode (C) is positioned as for stimulation point 1, but with the anode distal.

Machine settings: Sensitivity—5 mV/division, Low frequency filter—2–3 Hz, High frequency filter—10 kHz, Sweep speed—2 msec/division.

Nerve fibers tested: C8 and T1 nerve roots, through the lower trunk, anterior division, and medial cord of the brachial plexus.
Normal values (1) (249 subjects) (skin temperature over the dorsum of the hand greater than or equal to 32 degrees Celsius):

**Onset latency (msec)**

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19–49</td>
<td>3.8</td>
<td>0.4</td>
<td>3.0–4.6</td>
<td>4.6</td>
</tr>
<tr>
<td>50–79</td>
<td>4.0</td>
<td>0.4</td>
<td>3.0–4.8</td>
<td>4.7</td>
</tr>
<tr>
<td>Females</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19–49</td>
<td>3.5</td>
<td>0.4</td>
<td>2.8–4.8</td>
<td>4.4</td>
</tr>
<tr>
<td>50–79</td>
<td>3.8</td>
<td>0.4</td>
<td>2.9–4.6</td>
<td>4.4</td>
</tr>
<tr>
<td>All subjects</td>
<td>3.7</td>
<td>0.5</td>
<td>2.8–4.8</td>
<td>4.5</td>
</tr>
</tbody>
</table>

**Amplitude (mV)**

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>19–39</td>
<td>11.9</td>
<td>3.6</td>
<td>2.2–22.0</td>
<td>5.9</td>
</tr>
<tr>
<td>40–59</td>
<td>9.8</td>
<td>2.8</td>
<td>3.3–17.7</td>
<td>4.2</td>
</tr>
<tr>
<td>60–79</td>
<td>7.0</td>
<td>2.6</td>
<td>2.0–14.3</td>
<td>3.8</td>
</tr>
<tr>
<td>All subjects</td>
<td>10.2</td>
<td>3.6</td>
<td>2.0–22.0</td>
<td>4.1</td>
</tr>
</tbody>
</table>

**Area of negative phase (µVsec)**

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>19–49</td>
<td>37.4</td>
<td>12.9</td>
<td>8.1–93.7</td>
<td>14.6</td>
</tr>
<tr>
<td>50–59</td>
<td>30.9</td>
<td>8.6</td>
<td>14.1–45.6</td>
<td>15.3</td>
</tr>
<tr>
<td>60–79</td>
<td>23.7</td>
<td>9.3</td>
<td>6.6–50.9</td>
<td>11.9</td>
</tr>
<tr>
<td>All subjects</td>
<td>33.7</td>
<td>12.8</td>
<td>6.6–93.7</td>
<td>12.4</td>
</tr>
</tbody>
</table>

**Duration of negative phase (msec)**

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>19–79</td>
<td>5.9</td>
<td>0.9</td>
<td>4.1–9.6</td>
<td>8.0</td>
</tr>
</tbody>
</table>
### Nerve conduction velocity (m/sec)

**Males**

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>19–39</td>
<td>58</td>
<td>4</td>
<td>48–65</td>
<td>49</td>
</tr>
<tr>
<td>40–79</td>
<td>55</td>
<td>5</td>
<td>40–78</td>
<td>47</td>
</tr>
</tbody>
</table>

**Females**

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>19–39</td>
<td>60</td>
<td>3</td>
<td>50–66</td>
<td>53</td>
</tr>
<tr>
<td>40–79</td>
<td>57</td>
<td>5</td>
<td>43–77</td>
<td>51</td>
</tr>
<tr>
<td>All subjects</td>
<td>57</td>
<td>5</td>
<td>40–78</td>
<td>49</td>
</tr>
</tbody>
</table>

### F-wave latencies (msec) (2) (195 subjects)—shortest of 10 stimuli

**Age Range 19–49**

<table>
<thead>
<tr>
<th>Height in cm (in.)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;160 (5'3&quot;)</td>
<td>23.7</td>
<td>1.0</td>
<td>22.7–25.4</td>
<td>25.7</td>
</tr>
<tr>
<td>160–169 (5'3&quot;–5'6&quot;)</td>
<td>25.3</td>
<td>1.6</td>
<td>21.4–30.0</td>
<td>28.5</td>
</tr>
<tr>
<td>170–179 (5'7&quot;–5'10&quot;)</td>
<td>27.3</td>
<td>1.8</td>
<td>23.7–31.0</td>
<td>30.9</td>
</tr>
<tr>
<td>≥180 (5'11&quot;)</td>
<td>28.9</td>
<td>2.3</td>
<td>26.0–34.3</td>
<td>33.5</td>
</tr>
</tbody>
</table>

**Age Range 50–79**

<table>
<thead>
<tr>
<th>Height in cm (in.)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;160 (5'3&quot;)</td>
<td>25.2</td>
<td>1.7</td>
<td>21.0–27.6</td>
<td>28.6</td>
</tr>
<tr>
<td>160–169 (5'3&quot;–5'6&quot;)</td>
<td>27.5</td>
<td>1.4</td>
<td>25.5–30.5</td>
<td>30.3</td>
</tr>
<tr>
<td>170–179 (5'7&quot;–5'10&quot;)</td>
<td>28.7</td>
<td>1.4</td>
<td>25.9–31.3</td>
<td>31.5</td>
</tr>
<tr>
<td>≥180 (5'11&quot;)</td>
<td>30.4</td>
<td>1.9</td>
<td>26.5–33.0</td>
<td>34.2</td>
</tr>
<tr>
<td>All subjects</td>
<td>26.8</td>
<td>2.4</td>
<td>21.0–34.3</td>
<td>31.6</td>
</tr>
</tbody>
</table>

### Acceptable Differences

The upper limit of normal increase in latency from one side to the other is 0.7 msec.

The upper limit of normal decrease in amplitude from one side to the other is 54%.
The upper limit of normal decrease in nerve conduction velocity from one side to the other is 9 m/sec. The upper limit of normal decrease in amplitude from wrist to elbow stimulation is 24%. The upper limit of normal side to side difference in the shortest F-wave latency is 2.2 msec. The upper limit of normal difference between median (digit 3) and ulnar (digit 5) motor latency in the same limb is 1.4 msec (ages 19–49), 1.7 msec (ages 50–79), and 1.5 msec (all subjects) in cases where the median has the longer latency; it is 0.0 msec (ages 19–49), –0.3 msec (ages 50–79), and 0.0 msec (all subjects) in cases where the ulnar latency is longer (3).

Helpful Hints

■ Care should be taken to not concomitantly stimulate the ulnar nerve. The direction of thumb twitch will help in making sure that only the median nerve is stimulated. The waveforms, especially the deflections from baseline, should be similar on proximal and distal stimulation.

■ Stimulation can also be performed at the palm. If the amplitude with palm stimulation is significantly greater than with wrist stimulation, this can be a sign of neurapraxia at the wrist. Pease and coworkers (4) showed that the increase in amplitude with wrist stimulation is significantly larger in persons with carpal tunnel syndrome than in normal controls. Proximal to distal amplitude ratios of 0.5–0.8 have been recommended as the limits of normality (5,6). The 0.5 value is more conservative and seems reasonable for clinical use.

■ Palmar stimulation may cause a direct excitation of the thenar muscle mass or of the deep branch of the ulnar nerve. It is helpful to move the cathode slightly distally on the palm and stimulate the patient a few times while repositioning the cathode gradually more proximal to optimize the resultant waveform recording. Stimulus artifact can be a problem and may be minimized by rotating the anode about the cathode and stimulating at various locations. Because the skin of the palm is thick, a longer pulse duration may be needed. Needle stimulation may be necessary in some cases.
More proximal stimulation can also be performed at the axilla and at Erb’s point in the supraclavicular fossa. This can allow determination of waveform changes across more proximal segments of the nerve and calculation of more proximal nerve conduction velocity. When calculating the conduction velocity of the Erb’s point-to-axilla segment, obstetric calipers are used to measure the distance.

Anomalous innervation due to a Martin-Gruber (median to ulnar) anastomosis in the forearm is common, although it is much less commonly clinically significant during electrodiagnostic studies. When present in a patient with carpal tunnel syndrome, it may cause confusion. For instance, a complete block of the median nerve to wrist stimulation may seem to be reversed on elbow stimulation. Martin-Gruber anastomosis should be suspected if the median motor amplitude is larger on elbow stimulation than on wrist stimulation, and in persons with median nerve slowing across the wrist who have a higher than normal conduction velocity across the forearm. It should also be suspected if proximal (but not distal) median nerve stimulation results in an initially positive deflection.

Martin-Gruber anastomosis can usually be confirmed by repositioning the active electrode to the first dorsal interosseous muscle. Stimulation of the median nerve at the elbow, but not the wrist, results in a negative deflection. Stimulation at the elbow should also result in a significantly larger amplitude response than with wrist stimulation (7). An accurate forearm conduction velocity cannot be calculated in the person with carpal tunnel syndrome and a Martin-Gruber anastomosis.
REFERENCES

ADDITIONAL READINGS


MEDIAN MOTOR NERVE TO THE FLEXOR CARPI RADIALIS

Typical waveform appearance

Electrode Placement
**Position:** This study is performed in the supine position.

**Active electrode (A):** Placement is over the belly of the flexor carpi radialis, one third of the distance from the medial epicondyle to the radial styloid.

**Reference electrode (R):** Placement is over the radial styloid

**Ground electrode (G):** Placement is on the dorsum of the hand.

**Stimulation point (S):** 10 cm proximal to the active electrode, over the median nerve in the antecubital area. The anode is proximal.

**Machine settings:** Sensitivity—5 mV/division, Low frequency filter—2–3 Hz, High frequency filter—10 kHz, Sweep speed—2 msec/division.

**Nerve fibers tested:** C6, C7, and C8 nerve roots, through the upper, middle, and lower trunks, anterior divisions, and the medial and lateral cords of the brachial plexus.

**Normal values** (1) (208 subjects) (skin temperature over the dorsum of the hand greater than or equal to 32 degrees Celsius):

**Onset latency (msec)**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.8</td>
<td>0.4</td>
<td>2.1–3.8</td>
<td>3.6</td>
</tr>
</tbody>
</table>

**Amplitude (mV)**

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>19–49</td>
<td>11.5</td>
<td>3.4</td>
<td>1.9–18.2</td>
<td>3.0</td>
</tr>
<tr>
<td>50–79</td>
<td>8.3</td>
<td>4.0</td>
<td>1.5–22.4</td>
<td>1.7</td>
</tr>
<tr>
<td>All subjects</td>
<td>10.2</td>
<td>4.0</td>
<td>1.5–22.4</td>
<td>2.3</td>
</tr>
</tbody>
</table>

**Area of negative phase (µVsec)**

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>19–49</td>
<td>66.8</td>
<td>19.7</td>
<td>11.0–107.0</td>
<td>15.5</td>
</tr>
<tr>
<td>50–79</td>
<td>48.4</td>
<td>21.3</td>
<td>5.3–119.0</td>
<td>6.9</td>
</tr>
<tr>
<td>All subjects</td>
<td>59.0</td>
<td>22.3</td>
<td>5.3–119.0</td>
<td>12.9</td>
</tr>
</tbody>
</table>
**Duration of negative phase (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.7</td>
<td>1.2</td>
<td>6.1–13.1</td>
<td>11.8</td>
</tr>
</tbody>
</table>

**Acceptable Differences**

The upper limit of normal increase in latency from one side to the other is 0.8 msec.

The upper limit of normal decrease in amplitude from one side to the other is 53%.

The upper limit of normal difference between pronator teres and flexor carpi radialis latency in the same limb is 0.8 msec in cases where the pronator teres has the longer latency; it is 0.4 msec in cases where the flexor carpi radialis latency is longer.

**Notes**

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________
REFERENCE


ADDITIONAL READING

MEDIAN MOTOR NERVE (ANTERIOR INTEROSSEOUS BRANCH) TO THE FLEXOR POLLICIS LONGUS

Typical waveform appearance

Electrode Placement
**Position:** This study is performed in the supine position.

**Active electrode (A):** Placement is on the lateral forearm, 38% of the distance from the distal volar crease of the wrist to the antecubital crease of the elbow (distance varied from 9.1 to 10.2 cm from the distal wrist crease).

**Reference electrode (R):** Placement is over the distal tendon of the flexor pollicis longus.

**Ground electrode (G):** Placement is on the radius, between the stimulating and recording electrodes.

**Stimulation point (S):** Placement is just medial to the tendon of the biceps at the elbow, slightly proximal to the antecubital crease. The shoulder is held abducted 10 degrees, with the elbow extended and the forearm supinated.

**Machine settings:** Low frequency filter—10 Hz, High frequency filter—10 kHz.

**Nerve fibers tested:** C7, C8, and T1 nerve roots, through the middle and lower trunks, anterior divisions, and medial and lateral cords of the brachial plexus.

**Normal values** (1) (25 subjects):

**Onset latency (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.6</td>
<td>0.43</td>
<td>1.8–3.6</td>
<td>4.0</td>
</tr>
</tbody>
</table>

**Amplitude (mV)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.6</td>
<td>1.16</td>
<td>3.8–7.5</td>
<td>2.5</td>
</tr>
</tbody>
</table>
Helpful Hints

■ The data described must be viewed with caution because the cited research has significant limitations. The data were derived from the left hands of 25 women aged 20–25 years. The authors chose the recording electrode sites to maximize the recorded amplitude, not to localize the motor point of the muscle.

■ This technique may not provide for recording over the motor point. Initially positive deflections may be recorded. The waveform is characteristically bimodal, and up to four phases are common.

Notes

REFERENCE

ADDITIONAL READING/ALTERNATE TECHNIQUE

MEDIAN MOTOR NERVE (ANTERIOR INTEROSSEOUS BRANCH) TO THE PRONATOR QUADRATUS

Typical waveform appearance

Electrode Placement
Position: This study is performed in the supine position.

Active electrode (A): Placement is at the midpoint between the radius and ulna on the dorsal forearm, 3 cm proximal to the ulnar styloid. After an adequate waveform has been obtained, the distance between cathode and active electrode is measured with calipers. The caliper distance should be measured on a ruler, as caliper calibration is often erroneous. The caliper measurement may be transferred to the other limb for comparison study.

Reference electrode (R): Placement is over the radial styloid.

Ground electrode (G): Placement is on the dorsum of the hand.

Stimulation point (S): The cathode (C) is placed at the elbow, slightly medial to the brachial pulse. The anode (A) is proximal.

Machine settings: Sensitivity—5 mV/division, Low frequency filter—2–3 Hz, High frequency filter—10 kHz, Sweep speed—2 msec/division.

Nerve fibers tested: C7, C8, and T1 nerve roots, through the middle and lower trunks, anterior divisions, and medial and lateral cords of the brachial plexus.

Normal values (1) (207 subjects) (skin temperatures over the dorsum of the hand greater than or equal to 32 degrees Celsius):

### Onset latency (msec)

<table>
<thead>
<tr>
<th>Forearm Distance</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤23 cm</td>
<td>3.8</td>
<td>0.4</td>
<td>3.1–4.4</td>
<td>4.4</td>
</tr>
<tr>
<td>23.5–24.5 cm</td>
<td>4.0</td>
<td>0.4</td>
<td>3.5–5.1</td>
<td>4.8</td>
</tr>
<tr>
<td>≥25 cm</td>
<td>4.5</td>
<td>0.4</td>
<td>3.7–5.3</td>
<td>5.2</td>
</tr>
<tr>
<td>All subjects</td>
<td>4.2</td>
<td>0.5</td>
<td>3.1–5.3</td>
<td>5.1</td>
</tr>
</tbody>
</table>

### Amplitude (mV)

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>19–59</td>
<td>4.4</td>
<td>1.8</td>
<td>1.1–18.7</td>
<td>1.6</td>
</tr>
<tr>
<td>60–79</td>
<td>3.7</td>
<td>1.7</td>
<td>1.2–12.2</td>
<td>1.6</td>
</tr>
<tr>
<td>All subjects</td>
<td>4.3</td>
<td>1.8</td>
<td>1.1–18.7</td>
<td>1.6</td>
</tr>
</tbody>
</table>
Area of negative phase (µVsec)

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>19–59</td>
<td>17.1</td>
<td>6.0</td>
<td>2.9–34.9</td>
<td>6.0</td>
</tr>
<tr>
<td>60–79</td>
<td>13.7</td>
<td>5.4</td>
<td>2.9–30.2</td>
<td>6.0</td>
</tr>
<tr>
<td>All subjects</td>
<td>16.4</td>
<td>6.1</td>
<td>2.9–34.9</td>
<td>6.0</td>
</tr>
</tbody>
</table>

Duration of negative phase (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.2</td>
<td>1.1</td>
<td>4.2–12.0</td>
<td>9.3</td>
</tr>
</tbody>
</table>

Acceptable Differences

The upper limit of normal increase in latency from one side to the other is 0.6 msec.

The upper limit of normal decrease in amplitude from one side to the other is 37%.

Same-limb upper limit of normal difference for pronator quadratus minus flexor carpi radialis latencies are 2.0 msec (≤23 cm), 2.0 msec (23.5–24.5 cm), 2.4 msec (≥25 cm), and 2.2 msec (all subjects).

Same-limb upper limit of normal difference for pronator quadratus minus pronator teres latencies are 1.7 msec (≤23 cm), 1.7 msec (23.5–24.5 cm), 2.2 msec (≥25 cm), and 2.2 msec (all subjects).

Helpful Hints

- A needle recording technique has also been described (2), but Shafshak and El-Hinawy (3), who compared the two techniques, thought that the surface recording technique was more sensitive to pathology than was the needle recording technique.

- There are two heads of the pronator quadratus, which may result in a bimodal evoked response. This may limit the usefulness of the duration measurement.
REFERENCES


ADDITIONAL READING

MEDIAN MOTOR NERVE TO THE PRONATOR TERES

Typical waveform appearance

Electrode Placement
Position: This study is performed in the supine position.

Active electrode (A): An equilateral triangle is imagined, with the medial epicondyle and the biceps tendon (at the level of the epicondyle) as two of its points. The active electrode is placed at the third point, on the proximal forearm.

Reference electrode (R): Placement is over the radial styloid

Ground electrode (G): Placement is on the dorsum of the hand.

Stimulation point (S): 10 cm proximal to the active electrode, over the median nerve in the antecubital area. The anode is proximal.

Machine settings: Sensitivity—5mV/division, Low frequency filter—2–3 Hz, High frequency filter—10 kHz, Sweep speed—2 msec/division.

Nerve fibers tested: C6 and C7 nerve roots, through the upper and middle trunks, anterior divisions, and the lateral cord of the brachial plexus.

Normal values (1)(208 subjects)(skin temperature over the dorsum of the hand greater than or equal to 32 degrees Celsius):

<table>
<thead>
<tr>
<th>Onset latency (msec)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.9</td>
<td>0.3</td>
<td>2.2–4.4</td>
<td>3.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Amplitude (mV)</th>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>19–49</td>
<td>9.1</td>
<td>3.0</td>
<td>1.7–18.7</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>50–79</td>
<td>7.3</td>
<td>2.9</td>
<td>2.4–15.8</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td>All subjects</td>
<td>8.4</td>
<td>3.1</td>
<td>1.7–18.7</td>
<td>2.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Area of negative phase (µVsec)</th>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>19–49</td>
<td>48.2</td>
<td>16.1</td>
<td>6.9–92.7</td>
<td>14.3</td>
</tr>
<tr>
<td></td>
<td>50–79</td>
<td>40.5</td>
<td>18.2</td>
<td>4.4–88.6</td>
<td>7.2</td>
</tr>
<tr>
<td></td>
<td>All subjects</td>
<td>45.1</td>
<td>17.4</td>
<td>4.4–92.7</td>
<td>13.2</td>
</tr>
</tbody>
</table>
Duration of negative phase (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.0</td>
<td>1.4</td>
<td>5.4–14.0</td>
<td>12.5</td>
</tr>
</tbody>
</table>

Acceptable Differences

The upper limit of normal increase in latency from one side to the other is 0.6 msec.

The upper limit of normal decrease in amplitude from one side to the other is 54%.

The upper limit of normal difference between pronator teres and flexor carpi radialis latency in the same limb is 0.8 msec in cases where the pronator teres has the longer latency; it is 0.4 msec in cases where the flexor carpi radialis latency is longer.

Notes

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________
REFERENCE


ADDITIONAL READING

Typical waveform appearance

Electrode Placement
Position: This study is performed in the supine position.

Active electrode (A): Placement is on the palm, slightly radial to the long flexor tendon of the index finger (localized by flexion of the index finger) and 1 cm proximal to the midpalmar crease.

Reference electrode (R): Placement is at the base of the index finger.

Ground electrode (G): Placement is on the dorsum of the hand.

Stimulation point (S): The cathode (C) is placed 10 cm proximal to the active electrode, in a line measured first to the midpoint of the distal wrist crease and then to a point slightly ulnar to the tendon of the flexor carpi radialis. The anode (A) is proximal.

Machine settings: Sensitivity—5mV/division, Low frequency filter—2–3 Hz, High frequency filter—10 kHz, Sweep speed—2 msec/division.

Nerve fibers tested: C8 and T1 nerve roots, through the lower trunk, anterior division, and medial cord of the brachial plexus.

Normal values (1) (196 subjects) (skin temperature over the dorsum of the hand greater than or equal to 32 degrees Celsius):

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Onset latency (msec)</strong></td>
<td>3.6</td>
<td>0.4</td>
<td>2.7–4.8</td>
<td>4.4</td>
</tr>
<tr>
<td><strong>Amplitude (mV)</strong></td>
<td>2.5</td>
<td>2.0</td>
<td>0.7–11.2</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>Area of negative phase (µVsec)</strong></td>
<td>8.3</td>
<td>5.2</td>
<td>2.1–32.3</td>
<td>2.7</td>
</tr>
</tbody>
</table>
Duration of negative phase (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0</td>
<td>1.2</td>
<td>3.1–10.2</td>
<td>9.3</td>
</tr>
</tbody>
</table>

Acceptable Differences

The upper limit of normal increase in latency from one side to the other is 0.7 msec.

The upper limit of normal decrease in amplitude from one side to the other is 59%.

The upper limit of normal difference between 1st lumbrical and 2nd lumbrical latency in the same limb is 0.7 msec in cases where the 2nd lumbrical has the longer latency; it is 0.6 msec in cases where the 1st lumbrical latency is longer.

The upper limit of normal difference between 1st lumbrical and abductor pollicis brevis latency in the same limb is 1.0 msec in cases where the abductor pollicis brevis has the longer latency; it is 0.6 msec in cases where the 1st lumbrical latency is longer.

Helpful Hints

- Although probably less sensitive in detecting carpal tunnel syndrome (CTS), this test is nevertheless abnormal in some persons with CTS who have a normal latency to the abductor pollicis brevis.

- Stimulation can also be performed at the palm. If the amplitude with palm stimulation is significantly greater than with wrist stimulation, this may be a sign of neurapraxia at the wrist. The upper limit of normal increase in amplitude for palm versus wrist stimulation (mean + 2 S.D.) is 105% (mean increase 22%, range –4 to 70%). Palmar stimulation may be difficult in persons with thick skin and may also activate other nerve branches or muscles directly. The waveform shape should be the same as with wrist stimulation (2).
REFERENCES


MEDIAN MOTOR NERVE TO THE 2ND LUMBRICAL (SEE ALSO ULNAR MOTOR NERVE TO THE PALMAR INTEROSSEOUS)

Typical waveform appearance

Electrode Placement

See also page 92 for the Ulnar Motor Nerve to the Palmar Interosseous.
**Position:** This study is performed in the supine position.

**Active electrode (A):** Placement is on the palm, slightly radial to the midpoint of the third metacarpal.

**Reference electrode (R):** Placement is slightly distal to the third metacarpophalangeal joint.

**Ground electrode (G):** Placement is on the dorsum of the hand.

**Stimulation point (S):** The cathode (C) is placed 10 cm proximal to the active electrode, in a line measured first to the midpoint of the distal wrist crease and then to a point slightly ulnar to the tendon of the flexor carpi radialis. The anode (A) is proximal.

**Machine settings:** Sensitivity—5mV/division, Low frequency filter—2–3 Hz, High frequency filter—10 kHz, Sweep speed—2 msec/division.

**Nerve fibers tested:** C8 and T1 nerve roots, through the lower trunk, anterior division, and medial cord of the brachial plexus.

**Normal values** (1) (196 subjects) (skin temperature over the dorsum of the hand greater than or equal to 32 degrees Celsius):

<table>
<thead>
<tr>
<th>Onset latency (msec)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.7</td>
<td>0.4</td>
<td>2.7–5.1</td>
<td>4.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Amplitude (mV)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.0</td>
<td>2.0</td>
<td>0.7–11.7</td>
<td>1.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Area of negative phase (µVsec)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9.4</td>
<td>5.4</td>
<td>1.6–33.7</td>
<td>3.3</td>
</tr>
</tbody>
</table>
Duration of negative phase (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.7</td>
<td>1.1</td>
<td>3.3–10.4</td>
<td>8.4</td>
</tr>
</tbody>
</table>

Acceptable Differences

- The upper limit of normal increase in latency from one side to the other is 0.8 msec.
- The upper limit of normal decrease in amplitude from one side to the other is 67%.
- The upper limit of normal difference between 1st lumbrical and 2nd lumbrical latency in the same limb is 0.7 msec in cases where the 2nd lumbrical has the longer latency; it is 0.6 msec in cases where the 1st lumbrical latency is longer.
- The upper limit of normal difference between 2nd lumbrical and abductor pollicis brevis latency in the same limb is 1.0 msec in cases where the abductor pollicis brevis has the longer latency; it is 0.8 msec in cases where the 2nd lumbrical latency is longer.
- The upper limit of normal difference between 2nd lumbrical and interosseous latency in the same limb is 0.2 msec in cases where the interosseous has the longer latency; it is 1.2 msec in cases where the 2nd lumbrical latency is longer.

Helpful Hints

- Concomitant median and ulnar nerve stimulation must be avoided.
- The second lumbrical and interosseous muscles lie superimposed in this location. Stimulating the median nerve activates the lumbrical, whereas stimulating the ulnar nerve activates the interosseous muscle. Both nerve studies have approximately the same latencies and can thus be compared to detect slowing of one nerve or the other.
- Sometimes the median mixed nerve potential is seen before the desired motor response on median nerve stimulation. This potential is ignored and does not generally distort the recording from the second lumbrical.
- Anomalous innervation is common and may result in no response being seen to stimulation of one of the involved nerves.
Conduction to the lumbricals may be relatively spared in carpal tunnel syndrome.

Notes

REFERENCE


ADDITIONAL READINGS

H-REFLEX TO THE FLEXOR CARPI RADIALIS

Electrode Placement
**Position:** This study is performed in the supine position.

**Active electrode (A):** Placement is over the belly of the flexor carpi radialis, usually one third of the distance from the medial epicondyle to the radial styloid.

**Reference electrode (R):** Placement is over the brachioradialis.

**Ground electrode (G):** Placement is between the stimulating and recording electrodes.

**Stimulation point (S):** The median nerve is stimulated at the elbow with a 0.5–1.0 msec rectangular pulse with a frequency not more than 0.5 Hz. The cathode is proximal, and the anode is distal.

**Machine settings:** Standard motor settings are used, with a sweep speed of 5 msec/division and a sensitivity of 500 µV/division (1,2).

**Nerve fibers tested:** C6, C7, and C8 nerve roots, through the upper, middle, and lower trunks, anterior divisions, and the medial and lateral cords of the brachial plexus.

**Normal values** (1) (39 subjects) (room temperature of 70 degrees Fahrenheit [21 degrees Celsius]):

**Onset latency (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.9</td>
<td>1.5</td>
<td>18.9</td>
</tr>
</tbody>
</table>

**Amplitude (mV, baseline to highest negative peak)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6</td>
<td>0.4</td>
<td>0.8</td>
</tr>
</tbody>
</table>
Acceptable Difference

The upper limit of normal side to side difference in H-reflex latency is 1.0 msec (mean + 2 S.D.).

Helpful Hints

■ The paper’s author states that to be accepted as an H-reflex, the response must be obtained either without an M-response or with only a small M-response preceding it; its latency must be shortened when the nerve is stimulated proximally, and its amplitude must be decreased with increasing stimulation frequency. (In the opinion of this book’s authors, it may be difficult to obtain an H-reflex amplitude greater than the M-wave amplitude.)

■ When using these criteria, 90% of normal subjects were found to have an elicitable H-reflex. The author reports that in none of his subjects was the H-reflex absent on only one side, but this must be interpreted with caution because of the small sample size.

■ An alternate description places the reference electrode over the distal tendinous area of the forearm. The muscle can be palpated just medial to the pronator teres and can be palpated with resisted wrist flexion (2).

■ In the paper describing the above-referenced values, the cathode was placed proximally for determining both the H-reflex and the M-wave latencies. M-wave recordings usually are made with the anode proximal.

■ Kraft and Johnson (2) report that H-reflex latency is 17 ± 1.7 msec with highly variable amplitude and an upper limit of normal side to side difference of 0.85 msec.

■ Facilitation may be necessary to obtain an H-reflex response. The elbow should be slightly flexed.

■ With supramaximal stimulation, an F-wave response may be mistaken for an H-reflex.
REFERENCES


ADDITIONAL READINGS/ALTERNATE TECHNIQUES

MUSCULOCUTANEOUS MOTOR NERVE TO THE BICEPS BRACHII

Electrode Placement

Typical waveform appearance
Position: This study is performed in the seated position.

Active electrode (A): Placement is just distal to the midportion of the biceps brachii muscle.

Reference electrode (R): Placement is proximal to the antecubital fossa in the region of the junction of the muscle fibers and the biceps tendon.

Ground electrode (G): Placement is on the acromion.

Stimulation point (S): Erb’s point—the cathode is placed slightly above the upper margin of the clavicle lateral to the clavicular head of the sternocleidomastoid muscle. The anode is superomedial.

Machine settings: Sensitivity—5 mV/division, Low frequency filter—2–3 Hz, High frequency filter—10 kHz, Sweep speed—2 msec/division.

Nerve fibers tested: C5 and C6 nerve roots, through the upper trunk, anterior division, and lateral cord of the brachial plexus.

Normal values (1) (100 subjects) (temperature greater than or equal to 32 degrees Celsius):

### Onset latency (msec)

<table>
<thead>
<tr>
<th>Height in cm (in)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;160 (5'3&quot;)</td>
<td>4.5</td>
<td>0.4</td>
<td>3.8–5.3</td>
<td>5.3</td>
</tr>
<tr>
<td>160–170 (5'3&quot;–5'7&quot;)</td>
<td>4.7</td>
<td>0.4</td>
<td>3.9–5.6</td>
<td>5.6</td>
</tr>
<tr>
<td>&gt;170 (5'7&quot;)</td>
<td>5.1</td>
<td>0.4</td>
<td>4.2–6.2</td>
<td>5.8</td>
</tr>
<tr>
<td>All subjects</td>
<td>4.8</td>
<td>0.5</td>
<td>3.8–6.2</td>
<td>5.6</td>
</tr>
</tbody>
</table>

### Amplitude (mV)

<table>
<thead>
<tr>
<th>Sex</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>10.1</td>
<td>3.3</td>
<td>3.8–21.1</td>
<td>4.0</td>
</tr>
<tr>
<td>Female</td>
<td>7.4</td>
<td>2.5</td>
<td>3.8–15.0</td>
<td>3.8</td>
</tr>
<tr>
<td>All subjects</td>
<td>8.7</td>
<td>3.2</td>
<td>3.8–21.1</td>
<td>4.0</td>
</tr>
</tbody>
</table>
Area of negative phase (µVsec)

<table>
<thead>
<tr>
<th>Sex</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>85.5</td>
<td>21.8</td>
<td>38.4–124.8</td>
<td>47.8</td>
</tr>
<tr>
<td>Female</td>
<td>61.6</td>
<td>18.2</td>
<td>26.1–97.3</td>
<td>34.5</td>
</tr>
<tr>
<td>All subjects</td>
<td>73.8</td>
<td>23.3</td>
<td>26.1–124.8</td>
<td>36.0</td>
</tr>
</tbody>
</table>

Duration of negative phase (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.5</td>
<td>2.2</td>
<td>2.5–17.3</td>
<td>16.8</td>
</tr>
</tbody>
</table>

Acceptable Differences

The upper limit of normal increase in latency from one side to the other is 0.4 msec.

The upper limit of normal decrease in amplitude from one side to the other is 33%.

Notes

__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________

Upper Limb/Brachial Plexus Motor Nerve Studies
REFERENCE


ADDITIONAL READINGS

Electrode Placement

Typical waveform appearance
Position: This study is performed in the supine position, with the neck slightly neutral or extended (1).

Recording electrodes (R): In the cited study, self-adhesive 2.5 cm × 2.5 cm surface electrodes were used. One electrode is placed 5 cm superior to the tip of the xiphoid process. The other electrode is placed 16 cm distally along the costal margin (usually at the 7th intercostal space) (2).

Ground electrode (G): Placement is over the upper chest (3).

Stimulation point (S): Stimulation is applied at the posterior border of the sternocleidomastoid muscle in the supraclavicular fossa, with the cathode (C) approximately 3 cm superior to the clavicle. The anode (A) is superior to the cathode. In the cited study, two supramaximal responses were obtained and the results averaged (2).

Machine settings: Low frequency filter—5 Hz, High frequency filter—5 kHz.

Nerve fibers tested: C3, C4, and C5 nerve roots.

Normal values (2) (25 subjects):

Onset latency (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Suggested Normal Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.54</td>
<td>0.77</td>
<td>5.5–8.4</td>
<td>&lt; 8.1</td>
</tr>
</tbody>
</table>

Amplitude (µV)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Suggested Normal Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>660</td>
<td>201</td>
<td>301–1198</td>
<td>&gt; 300</td>
</tr>
</tbody>
</table>

Area (nVsec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Suggested Normal Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.28</td>
<td>2.09</td>
<td>4.0–12.8</td>
<td>&gt; 4.0</td>
</tr>
</tbody>
</table>
Duration from onset to return to baseline (msec)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Suggested Normal Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>19.4</td>
<td>2.7</td>
<td>13.4–24.1</td>
<td>&lt; 25</td>
</tr>
</tbody>
</table>

Acceptable Differences

Mean side-to-side difference for latency is 0.34 ± 0.27 msec with a range of 0–1.2 msec. The upper limit of normal difference, based on mean + 2 S.D., is 0.88 msec or 12.6%.

Mean side-to-side difference for amplitude is 109 ± 94 µV with a range of 0–360 µV. The upper limit of normal difference, based on mean + 2 S.D., is 297 µV or 39.5%.

Mean side-to-side difference for area is 1.41 ± 1.26 nVsec with a range of 0.02–5.04 nVsec. The upper limit of normal difference, based on mean + 2 S.D., is 3.92 nVsec or 46.3%.

Mean side-to-side difference for duration is 2.26 ± 1.69 msec with a range of 0.15–6.2 msec. The upper limit of normal difference, based on mean + 2 S.D., is 5.6 msec or 28.1%.

Helpful Hints

- Increasing age is associated with increasing latency. This may need to be taken into account when studying older subjects. A larger chest circumference is associated with increased amplitude (2).

- EKG artifact may occasionally be recorded as a prolonged (> 50 msec), large amplitude response. The stimulus should be repeated until a valid response is obtained (1,2).

- Improper stimulus location may inadvertently activate the brachial plexus. This results in a volume conducted potential being recorded. The latency is shorter and there is an initial positive phase of the waveform. Brachial plexus stimulation may cause arm movement, arm paresthesias, and a short-latency, low-amplitude, initially positive response being recorded (1,2).
Deep breathing should be avoided during the testing. Quiet breathing should not interfere with the results (1).

Because of amplitude variability, it may be helpful to repeat the study several times to obtain the two highest amplitudes; these should be relatively consistent.

Needle stimulation and more anterior surface stimulation just medial and superior to the clavicular insertion of the sternocleidomastoid muscle may also be performed (4,5).

Side to side difference in latency with needle stimulation has been described as $0.08 \pm 0.42$ msec (4).

Notes

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________
REFERENCES


ADDITIONAL READINGS/ALTERNATE TECHNIQUES


RADIAL NERVE

RADIAL MOTOR NERVE TO THE EXTENSOR CARPI ULNARIS AND BRACHIORADIALIS

Typical waveform appearance

Electrode Placement
**Position:** This study is performed in the supine position.

**Active electrode (A):** For the brachioradialis, placement is on the belly of the muscle, 3 cm distal to the elbow. For the extensor carpi ulnaris, placement is at the mid-forearm (equal distance between the lateral epicondyle and the ulnar styloid process), close to the “ulnar crease.”

**Reference electrode (R):** Placement is on the thumb.

**Stimulation point (S):** The cathode is a monopolar needle electrode inserted 5–6 cm proximal to the lateral epicondyle on the lateral upper arm. The anode is a subcutaneous needle electrode located 2 cm proximally.

**Machine settings:** Sensitivity—2–5 mV/division, Sweep speed—3 msec/division.

**Nerve fibers tested:** Extensor carpi ulnaris: C6, C7, and C8 nerve roots, through the upper, middle, and lower trunks, posterior divisions, and posterior cord of the brachial plexus, then through the radial nerve and the posterior interosseous branch of the radial nerve. Brachioradialis: C5 and C6 nerve roots, through the upper trunk, posterior division, and posterior cord of the brachial plexus.

**Normal values** (1) (40 subjects—data for both sides combined) (skin temperature over palm and forearm greater than 31 degrees Celsius):

**Onset latency (msec)**

<table>
<thead>
<tr>
<th></th>
<th>Brachioradialis</th>
<th></th>
<th>Extensor carpi ulnaris</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>2.66</td>
<td><strong>S.D.</strong></td>
<td>4.00</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td>1.8–3.5</td>
<td><strong>S.D.</strong></td>
<td>3.1–5.2</td>
</tr>
<tr>
<td><strong>Upper Limit of Normal</strong></td>
<td>3.3</td>
<td><strong>Upper Limit of Normal</strong></td>
<td>4.17</td>
</tr>
</tbody>
</table>
Acceptable Differences

The upper limit of normal difference in latency between the extensor carpi ulnaris versus the brachioradialis is 1.8 msec (mean 1.34 ± 0.23, range 0.8–2.0).

The upper limit of normal side to side difference in latency is 0.4 msec (mean 0.19 ± 0.06, range 0.0–0.4).

Helpful Hints

- The nerve branch to the brachioradialis does not pass through the “radial tunnel,” whereas the branch to the extensor carpi ulnaris does.

- The author states that needle stimulation is preferable to surface stimulation because surface stimulation at this point often requires painful high-intensity stimulation and often causes electrical artifacts. Needle stimulation also localizes the stimulation site more precisely.

Notes

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
REFERENCE

1. Seror P: Posterior interosseous nerve conduction: a new method of evalua-
RADIAL MOTOR NERVE TO THE EXTENSOR DIGITORUM COMMUNIS

Typical waveform appearance

Electrode Placement
Position: This study is performed in the supine position.

Active electrode (A): Placement is 8 cm distal to stimulation point 1 over the extensor digitorum communis. This site is localized in the reference (1) by grasping the radius and ulna of the subject’s pronated forearm with the thumb and middle finger at the junction of the upper third and middle third of the forearm. The index finger is placed halfway between these two points to identify the extensor digitorum communis.

Reference electrode (R): Placement is over the ulnar styloid process.

Ground electrode (G): Placement is between the stimulating and recording electrodes.

Stimulation point 1 (S1): The cathode (C) is placed in the antecubital fossa just lateral to the biceps tendon as the tendon crosses the flexor crease. The anode (A) is proximal. The the arm is supported and abducted 40–45 degrees.

Stimulation point 2 (S2): The cathode (C) is placed in the axilla between the coracobrachialis and the long head of the triceps. The anode (A) is proximal.

Machine settings: Sensitivity—5 mV/division, Low frequency filter—5 Hz, High frequency filter—10 kHz, Sweep speed—5 msec/division.

Nerve fibers tested: C7 and C8 nerve roots, through the middle and lower trunks, posterior divisions, and posterior cord of the brachial plexus, then through the radial nerve and posterior interosseous branch of the radial nerve.
Normal values For the right side (left side results were similar) (1) (30 subjects) (skin temperature over the forearm greater than or equal to 34 degrees Celsius):

**Onset latency (msec)**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.6</td>
<td>0.44</td>
<td>3.48</td>
</tr>
</tbody>
</table>

**Amplitude (mV)**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>11.31</td>
<td>3.5</td>
<td>4.31</td>
</tr>
</tbody>
</table>

**Nerve conduction velocity between S1 and S2 (m/sec)**—the distance is measured from the axilla, across the biceps anteriorly (see figure), to the elbow stimulation site [caliper measurement should give a similar distance measurement (2)].

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>68</td>
<td>7.0</td>
<td>54</td>
</tr>
</tbody>
</table>

**Helpful Hints**

- With proximal stimulation there can be a problem of recording volume conducted potentials from other muscles. Therefore, only the minimal stimulus intensity necessary to produce a waveform similar in appearance to that on distal stimulation is recommended.

- Rotation of the anode may be necessary to obtain an optimal recording.
REFERENCES


ADDITIONAL READING/ALTERNATE TECHNIQUE

RADIAL MOTOR NERVE TO THE EXTENSOR INDICIS PROPRIUS

Surface Recording

Electrode Placement
Position: This study is performed in the supine position. For surface recording, the elbow is extended and the forearm fully pronated.

Active electrode (A): Placement is 4 cm proximal to the ulnar styloid, over the motor point of the extensor indicis proprius.

Reference electrode (R): Placement is over the ulnar styloid.

Ground electrode (G): Placement over the dorsal forearm.

Stimulation point 1 (S1): The cathode is placed 8 cm proximal to the active electrode. The anode is proximal.

Stimulation point 2 (S2): The cathode is placed 8–10 cm proximal to the lateral epicondyle, over the radial groove. The anode is proximal.

F-wave stimulation: Electrode setup as above. The antecubital region is stimulated just lateral to the biceps tendon, with the cathode proximal.

Machine settings: Sensitivity—2 mV/division, Low frequency filter—10 Hz, High frequency filter—10 kHz, Sweep speed—2 msec/division.

Nerve fibers tested: C7 and C8 nerve roots, through the middle and lower trunks, posterior divisions, and posterior cord of the brachial plexus, then through the radial nerve and the posterior interosseous branch of the radial nerve.

Normal values (1) (skin temperature over the ventral forearm at least 33 degrees Celsius):

Onset latency (msec—25 subjects)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Amplitude (mV—25 subjects)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5</td>
<td>1.8</td>
<td>1.7–11.1</td>
</tr>
</tbody>
</table>
## Nerve conduction velocity (m/sec—25 subjects)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>71.7</td>
<td>4.7</td>
<td>60.2–79.2</td>
</tr>
</tbody>
</table>

## F-wave latencies (msec—23 subjects)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.8</td>
<td>3.7</td>
<td>16.2–24.1</td>
</tr>
</tbody>
</table>

### Notes

________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________

---

66 Upper Limb/Brachial Plexus Motor Nerve Studies
Needle Recording

Electrode Placement
Position: This study is performed in the supine position.

Recording electrodes (R): A concentric needle electrode is placed into the extensor indicis proprius on the dorsal forearm (2). The muscle is slightly radial to the ulna and extensor carpi ulnaris tendon, approximately 4 cm proximal to the ulnar styloid process, and approximately one half inch deep. Monopolar needle electrode recording has also been described with a surface reference electrode placed on the 5th digit (3,4).

Ground electrode (G): Placement is over the dorsum of the hand or between the stimulating and recording electrodes.

Stimulation point 1 (S1): The cathode (C) is placed 3–4 cm proximal to the needle insertion site between the extensor carpi ulnaris and the extensor digiti minimi. The anode (A) is proximal (4).

Stimulation point (S2): The cathode (C) is placed 5–6 cm proximal to the lateral epicondyle in the groove between the brachialis and brachioradialis muscles. The anode (A) is proximal.

Stimulation point 3 (S3): The stimulating electrodes are placed at Erb’s point.

Machine settings: Standard motor settings are used.

Normal values:

Onset latency over 2.8–6.6 cm distance (msec) (29 subjects, monopolar needle recording) (3)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.69</td>
<td>0.29</td>
<td>1.0–2.0</td>
</tr>
</tbody>
</table>
**Nerve conduction velocity** (the distal segment is measured with a tape measure, the proximal segment with obstetric calipers; arm abducted 10 degrees, elbow flexed 10–15 degrees, forearm pronated, head rotated away from side being tested)

**S1–S2 nerve conduction velocity (m/sec) (49 subjects) (2)**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>61.6</td>
<td>5.9</td>
<td>48–75</td>
</tr>
</tbody>
</table>

**S2–S3 nerve conduction velocity (m/sec) (49 subjects) (2)**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>72.0</td>
<td>6.3</td>
<td>56–93</td>
</tr>
</tbody>
</table>

**Acceptable Difference**

If the proximal velocity is less than 60 m/sec or if the distal velocity is more than 6 m/sec faster than the proximal velocity, a disturbance of conduction in the proximal segment may be suspected (2).

**Helpful Hints**

- Surface or needle recording has been described. It is important that the shape of the waveform be similar with proximal and distal stimulation (3,4).

- The site of needle insertion can usually be localized by first having the subject flex and extend the index finger while palpating the muscle. The needle is inserted and proper placement is confirmed by free-run electromyogram.

- The preceding nerve conduction velocity results were obtained with a concentric needle recording, but the same author also described monopolar needle recording from the same muscle (4). He found that this did not consistently provide a negative takeoff with Erb’s point stimulation. It seems reasonable to substitute a monopolar needle as long as proper care is given to recording an accurate onset of the waveform.
An armboard may help to stabilize the forearm and prevent needle movement (2).

A needle stimulation technique has also been described and recommended as more accurate than surface stimulation (5,6).

Axillary stimulation can also be performed. In a study that utilized needle stimulation and recording, the distal latency was 2.4 ± 0.5 msec, axilla to above elbow nerve conduction velocity was 69 ± 5.6 m/sec, and above elbow to forearm nerve conduction velocity was 62 ± 5.1 m/sec (5).
REFERENCES


ADDITIONAL READING/ALTERNATE TECHNIQUE

Electrode Placement
Position: This study is performed in the seated position.

Active electrode (A): For the supraspinatus, placement is 2 cm medial to the midpoint of the spine of the scapula. For the infraspinatus, placement is 2 cm inferior to the midpoint of the spine of the scapula.

Reference electrode (R): Placement is on the midline thoracic spine at the same level.

Ground electrode (G): Placement is on the acromion.

Stimulation point (S): Erb’s point—the cathode (C) is placed slightly above the upper margin of the clavicle lateral to the clavicular head of the sternocleidomastoid muscle. The anode (A) is superomedial.

Machine settings: Sensitivity—5 mV/division, Low frequency filter—2–3 Hz, High frequency filter—10 kHz, Sweep speed—2 msec/division.

Nerve fibers tested: C5 and C6 nerve roots, through the upper trunk of the brachial plexus.

Normal values (1) (100 subjects) (temperature greater than or equal to 32 degrees Celsius):

Onset latency (msec)

<table>
<thead>
<tr>
<th>Height in cm (in)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤170 (5'7'')</td>
<td>3.1</td>
<td>0.4</td>
<td>2.0–4.1</td>
<td>3.7</td>
</tr>
<tr>
<td>&gt;170 (5'7'')</td>
<td>3.4</td>
<td>0.6</td>
<td>2.3–5.2</td>
<td>4.6</td>
</tr>
<tr>
<td>All subjects</td>
<td>3.2</td>
<td>0.5</td>
<td>2.0–5.2</td>
<td>4.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Height in cm (in)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤170 (5'7'')</td>
<td>3.4</td>
<td>0.4</td>
<td>2.6–4.3</td>
<td>4.1</td>
</tr>
<tr>
<td>&gt;170 (5'7'')</td>
<td>3.9</td>
<td>0.7</td>
<td>2.7–6.1</td>
<td>5.4</td>
</tr>
<tr>
<td>All subjects</td>
<td>3.6</td>
<td>0.6</td>
<td>2.6–6.1</td>
<td>4.8</td>
</tr>
</tbody>
</table>
### Amplitude (mV)

<table>
<thead>
<tr>
<th></th>
<th>Supraspinatus</th>
<th>Infraspinatus</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S.D.</td>
</tr>
<tr>
<td>Supraspinatus</td>
<td>3.7</td>
<td>2.3</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td>Mean</td>
<td>S.D.</td>
</tr>
<tr>
<td>Male</td>
<td>3.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Female</td>
<td>4.1</td>
<td>1.7</td>
</tr>
<tr>
<td>All subjects</td>
<td>3.8</td>
<td>1.6</td>
</tr>
</tbody>
</table>

### Area of negative phase (µVsec)

<table>
<thead>
<tr>
<th></th>
<th>Supraspinatus</th>
<th>Infraspinatus</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S.D.</td>
</tr>
<tr>
<td>Supraspinatus</td>
<td>14.7</td>
<td>11.5</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>14.0</td>
<td>5.7</td>
</tr>
</tbody>
</table>

### Duration of negative phase (msec)

<table>
<thead>
<tr>
<th></th>
<th>Supraspinatus</th>
<th>Infraspinatus</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S.D.</td>
</tr>
<tr>
<td>Supraspinatus</td>
<td>6.7</td>
<td>2.8</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height in cm (in)</td>
<td>Mean</td>
<td>S.D.</td>
</tr>
<tr>
<td>≤160 (5'7&quot;)</td>
<td>5.1</td>
<td>1.6</td>
</tr>
<tr>
<td>&gt;160 (5'7&quot;)</td>
<td>6.3</td>
<td>2.3</td>
</tr>
<tr>
<td>All subjects</td>
<td>5.9</td>
<td>2.2</td>
</tr>
</tbody>
</table>
Acceptable Differences

The upper limit of normal increase in supraspinatus latency from one side to the other is 0.7 msec.

The upper limit of normal increase in infraspinatus latency from one side to the other is 0.4 msec.

The upper limit of normal decrease in supraspinatus amplitude from one side to the other is 48%.

The upper limit of normal decrease in infraspinatus amplitude from one side to the other is 48%.

The upper limit of normal increase in latency between supraspinatus and infraspinatus recording on the same side is 1.6 msec.

Notes

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________
REFERENCE

ADDITIONAL READINGS


THORACODORSAL MOTOR NERVE TO THE LATISSIMUS DORSI

Typical waveform appearance

Electrode Placement
**Position:** This study is performed in the supine position.

**Active electrode (A):** Placement is on the posterior axillary line at the level of the inferior pole of the scapula.

**Reference electrode (R):** Placement is on the ipsilateral flank.

**Ground electrode (G):** Placement is on the ipsilateral lateral chest wall.

**Stimulation point (S):** The cathode is placed in the axilla with the anode proximal. The subject is supine, with the arm abducted to 90 degrees.

**Machine settings:** Sensitivity—2 mV/division, Low frequency filter—2 Hz, High frequency filter—10 kHz, Sweep speed—1 msec/division, Pulse duration—0.2 msec.

**Nerve fibers tested:** C6, C7, and C8 nerve roots, through the upper, middle, and lower trunks, posterior divisions, and posterior cord of the brachial plexus.

**Normal values** (1) (30 subjects—right side data):

**Onset latency (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.9</td>
<td>0.4</td>
<td>1.2–2.7</td>
<td>2.7</td>
</tr>
</tbody>
</table>

**Amplitude (mV)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>1.8</td>
<td>1.4–10.2</td>
</tr>
</tbody>
</table>

**Acceptable Difference**

The upper limit of normal decrease in amplitude from one side to the other is 50%.
Helpful Hints

■ The latissimus dorsi can be localized by asking the subject to depress and internally rotate the shoulder.

■ The distance between the stimulation point and the active electrode ranged from 5 to 12 cm, measured with a tape measure with the arm abducted 90 degrees.

■ In obese subjects it may be helpful to press the stimulator deeper into the axilla toward the lateral margin of the scapula to obtain a response.

■ In the cited study, Erb’s point stimulation was performed to calculate a conduction velocity across the axillary segment. This measure was not deemed to be reliable.

Notes

__________________________________________________________________________________________

__________________________________________________________________________________________

__________________________________________________________________________________________

__________________________________________________________________________________________

__________________________________________________________________________________________

__________________________________________________________________________________________

__________________________________________________________________________________________

__________________________________________________________________________________________

__________________________________________________________________________________________
REFERENCE


ADDITIONAL READING/ALTERNATE TECHNIQUE

ULNAR NERVE

ULNAR MOTOR NERVE TO THE ABDUCTOR DIGITI MINIMI

Typical waveform appearance

Electrode Placement
**Position:** For this study the arm is positioned in a 45-degree abducted and externally rotated posture. The elbow is flexed to 90 degrees (right angle) and the forearm is in neutral position (thumb pointing toward the ear).

**Active electrode (A):** Placement is on the ulnar surface of the hypothenar eminence, halfway between the level of the pisiform bone and the 5th metacarpophalangeal joint.

**Reference electrode (R):** Placement is slightly distal to the 5th metacarpophalangeal joint.

**Ground electrode (G):** Placement is on the dorsum of the hand. If stimulus artifact interferes with the recording, the ground may be placed near the active electrode, between this electrode and the cathode.

**Stimulation point 1 (S1):** The cathode (C) is placed 8 cm proximal to the active electrode, in a line measured slightly radial to the tendon of the flexor carpi ulnaris. The anode (A) is proximal.

**Stimulation point 2 (S2):** The cathode (C) is placed approximately 4 cm distal to the medial epicondyle. The anode (A) is proximal.

**Stimulation point 3 (S3):** The cathode (C) is placed approximately 10 cm proximal to stimulation point 2, measured in a curve behind the medial epicondyle to a point slightly volar to the triceps. The anode (A) is proximal.

**Stimulation point 4 (S4):** The cathode (C) is placed in the axilla approximately 10 cm proximal to stimulation point 3. The anode (A) is proximal.

**F-wave stimulation:** The cathode (C) is positioned as for stimulation point 1, but with the anode distal.

**Machine settings:** Sensitivity—5 mV/division, Low frequency filter—2–3 Hz, High frequency filter—10 kHz, Sweep speed—2 msec/division.

**Nerve fibers tested:** C8 and T1 nerve roots, through the lower trunk, anterior division, and medial cord of the brachial plexus.
Normal values (1) (248 subjects) (skin temperature over the dorsum of the hand greater than or equal to 32 degrees Celsius):

### Onset latency (msec)

<table>
<thead>
<tr>
<th>Mean (msec)</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0</td>
<td>0.3</td>
<td>2.3–4.4</td>
<td>3.7</td>
</tr>
</tbody>
</table>

### Amplitude (mV)

<table>
<thead>
<tr>
<th>Mean (mV)</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.6</td>
<td>2.1</td>
<td>6.3–18.0</td>
<td>7.9</td>
</tr>
</tbody>
</table>

### Area of negative phase (µVsec)

<table>
<thead>
<tr>
<th>Mean (µVsec)</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>35.9</td>
<td>7.1</td>
<td>19.9–63.2</td>
<td>23.9</td>
</tr>
</tbody>
</table>

### Duration of negative phase (msec)

<table>
<thead>
<tr>
<th>Mean (msec)</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0</td>
<td>0.9</td>
<td>3.8–8.4</td>
<td>7.7</td>
</tr>
</tbody>
</table>

### Nerve conduction velocity (m/sec)

<table>
<thead>
<tr>
<th>Nerve Segment</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1–S2</td>
<td>61</td>
<td>5</td>
<td>49–74</td>
<td>52</td>
</tr>
<tr>
<td>S2–S3</td>
<td>61</td>
<td>9</td>
<td>35–83</td>
<td>43</td>
</tr>
<tr>
<td>S3–S4</td>
<td>61</td>
<td>7</td>
<td>44–87</td>
<td>50</td>
</tr>
</tbody>
</table>
F-wave latencies (msec) (2) (193 subjects)—shortest of 10 stimuli

Age Range 19–49

<table>
<thead>
<tr>
<th>Height in cm (in.)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;160 (5'3&quot;)</td>
<td>23.5</td>
<td>1.3</td>
<td>20.3–26.3</td>
<td>26.1</td>
</tr>
<tr>
<td>160–179 (5'3&quot;–5'10&quot;)</td>
<td>26.2</td>
<td>2.0</td>
<td>22.4–31.1</td>
<td>30.2</td>
</tr>
<tr>
<td>≥180 (5'11&quot;)</td>
<td>29.2</td>
<td>1.8</td>
<td>26.2–32.9</td>
<td>32.8</td>
</tr>
</tbody>
</table>

Age Range 50–79

<table>
<thead>
<tr>
<th>Height in cm (in.)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;160 (5'3&quot;)</td>
<td>25.0</td>
<td>1.9</td>
<td>22.9–28.4</td>
<td>28.8</td>
</tr>
<tr>
<td>160–179 (5'3&quot;–5'10&quot;)</td>
<td>28.1</td>
<td>1.4</td>
<td>26.3–30.8</td>
<td>30.9</td>
</tr>
<tr>
<td>≥180 (5'11&quot;)</td>
<td>30.4</td>
<td>1.7</td>
<td>28.3–32.4</td>
<td>33.8</td>
</tr>
<tr>
<td>All subjects</td>
<td>26.5</td>
<td>2.5</td>
<td>20.3–32.9</td>
<td>31.5</td>
</tr>
</tbody>
</table>

Acceptable Differences

The upper limit of normal increase in latency from one side to the other is 0.6 msec.

The upper limit of normal decrease in amplitude from one side to the other is 25%.

The upper limit of normal decrease in nerve conduction velocity from the S1–S2 to S2–S3 segment is 15 m/sec.

The upper limit of normal decrease in S1–S2 nerve conduction velocity from one side to the other is 9 m/sec.

The upper limit of normal decrease in S2–S3 nerve conduction velocity from one side to the other is 17 m/sec.

The upper limit of normal decrease in S3–S4 nerve conduction velocity from one side to the other is 16 m/sec.

The upper limit of normal decrease in amplitude from S1 to S2 stimulation is 35%.

The upper limit of normal decrease in amplitude from S2 to S3 stimulation is 16%.

The upper limit of normal decrease in amplitude from S3 to S4 stimulation is 21%.

The upper limit of normal side to side difference in the shortest F-wave latency is 2.5 msec.
The upper limit of normal difference between median (digit 3) and ulnar (digit 5) motor latency in the same limb is 1.4 msec (ages 19–49), 1.7 msec (ages 50–79), and 1.5 msec (all subjects) in cases where the median has the longer latency; it is 0.0 msec (ages 19–49), –0.3 msec (ages 50–79), and 0.0 msec (all subjects) in cases where the ulnar latency is longer (3).

**Helpful Hints**

- More proximal stimulation can also be performed at Erb’s point in the supraclavicular fossa. This can allow determination of waveform changes across a more proximal segment of the nerve and calculation of more proximal nerve conduction velocity. When calculating the conduction velocity of the Erb’s point-to-axilla segment, obstetric calipers are used to measure the distance.

- Anomalous innervation due to a Martin-Gruber (median to ulnar) anastomosis in the forearm is common, although it is much less commonly clinically significant during electrodiagnostic studies. It may result in a larger than expected ulnar compound motor action potential amplitude with wrist, as opposed to more proximal nerve, stimulation, but is usually not a confounding factor in ulnar nerve studies. If suspected, it can be investigated as described for the median motor nerve study to the abductor pollicis brevis.

- The ulnar nerve motor response to the abductor digiti minimi may be normal in Guyon’s canal entrapment neuropathy at the wrist, as this muscle is usually innervated by the superficial palmar branch of the ulnar nerve. If such a compression is suspected, the motor responses to the first dorsal interosseous or palmar interosseous muscles should be studied.

- Recording a response with S2 stimulation may at times be difficult, especially in obese or muscular individuals. It may be necessary to move the cathode around to find the optimal stimulation site. Increased stimulus intensity or duration or needle stimulation may occasionally be needed. When moving from the S2 to S3 site, the intensity should again be lowered because the nerve is much easier to stimulate at this site.
Occasionally an optimal amplitude cannot be obtained at S2 stimulation. This may give the false impression of a conduction block in the forearm. If S3 stimulation provides a normal amplitude, such a conduction block is not present. If the supramaximal S3 amplitude is not normal, a conduction block may be present. When a maximal S2 amplitude cannot be obtained, the conduction velocity calculation may be erroneous.

An “inching technique” called short segment incremental stimulation (SSIS) can be performed to localize the site of an ulnar neuropathy at the elbow. First the nerve’s course is mapped out with subthreshold stimuli by moving the stimulator perpendicular to the nerve’s course until the maximal M-wave amplitude for a given subthreshold intensity is obtained. This point is marked with a dot. This process is repeated along the length of the nerve, and the dots are joined to outline the course of the nerve. Then supramaximal stimulation is performed in 1 cm increments along the length of the nerve, taking care not to apply excessively supramaximal stimulation. The upper limit of normal segmental latency change is 0.4 msec. Abrupt changes in waveform shape or amplitude may be signs of local conduction block (4). The upper limit of normal segmental latency change recorded in 2 cm increments (elbow fixed at 90 degrees of flexion) has also been studied. The midpoint is determined by drawing a line between the medial epicondyle and the olecranon. The upper limit of normal latency change (msec) and amplitude change (%) are shown below (5).

<table>
<thead>
<tr>
<th>Latency Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latency</td>
</tr>
<tr>
<td>4 cm to 2 cm above elbow</td>
</tr>
<tr>
<td>2 cm above elbow to midpoint</td>
</tr>
<tr>
<td>Midpoint to 2 cm below elbow</td>
</tr>
<tr>
<td>2 cm to 4 cm below elbow</td>
</tr>
</tbody>
</table>

Ulnar neuropathy at the elbow may be due to compression at any of three sites: the retroepicondylar groove, the humeroulnar aponeurotic arcade, and the deep forearm aponeurosis at the point of exit from under the flexor carpi ulnaris (Pridgeon’s point). If possible, it is advisable to try to localize an ulnar neuropathy to one or more of these sites through incremental stimulation (4).
The terms *cubital tunnel syndrome* and *tardy ulnar palsy* are poorly defined, are often if not usually misapplied, and should be discarded. The term *ulnar neuropathy at the elbow* (UNE) should be used instead.

**REFERENCES**


**ADDITIONAL READINGS**


ULNAR MOTOR NERVE TO THE PALMAR INTEROSSEOUS (SEE ALSO MEDIAN MOTOR NERVE TO THE 2ND LUMBRICAL)

Typical waveform appearance

Electrode Placement

See also page 38 for the Median Motor Nerve to the 2nd Lumbrical.

92
Position: This study is performed in the supine position.

Active electrode (A): Placement is on the palm, slightly radial to the midpoint of the third metacarpal.

Reference electrode (R): Placement is slightly distal to the third metacarpophalangeal joint.

Ground electrode (G): Placement is on the dorsum of the hand.

Stimulation point (S): The cathode is placed 10 cm proximal to the active electrode, slightly to the radial side of the tendon of the flexor carpi ulnaris. The anode is proximal.

Machine settings: Sensitivity—5mV/division, Low frequency filter—2–3 Hz, High frequency filter—10 kHz, Sweep speed—2 msec/division.

Nerve fibers tested: C8 and T1 nerve roots, through the lower trunk, anterior division, and medial cord of the brachial plexus.

Normal values (1) (196 subjects) (skin temperature over the dorsum of the hand greater than or equal to 32 degrees Celsius):

Onset latency (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>0.3</td>
<td>2.6–4.4</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Amplitude (mV)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.9</td>
<td>2.3</td>
<td>1.7–15.4</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Area of negative phase (µVsec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>17.4</td>
<td>6.6</td>
<td>4.4–42.3</td>
<td>6.9</td>
</tr>
</tbody>
</table>

Duration of negative phase (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.6</td>
<td>0.7</td>
<td>2.7–6.8</td>
<td>6.3</td>
</tr>
</tbody>
</table>
Acceptable Differences

The upper limit of normal increase in latency from one side to the other is 0.5 msec.

The upper limit of normal decrease in amplitude from one side to the other is 58%.

The upper limit of normal difference between 2nd lumbrical and interosseous latency in the same limb is 0.2 msec in cases where the interosseous has the longer latency; it is 1.2 msec in cases where the 2nd lumbrical latency is longer.

Helpful Hints

■ Concomitant median and ulnar nerve stimulation must be avoided.

■ The second lumbrical and interosseous muscles lie superimposed in this location. Stimulating the median nerve activates the lumbrical, whereas stimulating the ulnar nerve activates the interosseous muscle. Both nerve studies have approximately the same latencies and can thus be compared to detect slowing of one nerve or the other.

■ Anomalous innervation is common and may result in no response being seen to stimulation of one of the involved nerves.

Notes

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________
REFERENCE


ADDITIONAL READINGS

ULNAR MOTOR NERVE TO THE 1ST DORSAL INTEROSSEOUS

Typical waveform appearance

Electrode Placement
**Position:** This study is performed in the supine position.

**Active electrode (A):** Placement is on the dorsum of the first web space, in the center of the triangle formed by the first carpometacarpal joint, the first metacarpophalangeal joint, and the second metacarpophalangeal joint.

**Reference electrode (R):** Placement is slightly distal to the fifth metacarpophalangeal joint.

**Ground electrode (G):** Placement is on the dorsum of the hand.

**Stimulation point (S):** The cathode is placed at the S1 stimulation point for the ulnar motor nerve study to the abductor digiti minimi.

**Machine settings:** Sensitivity—5mV/division, Low frequency filter—2–3 Hz, High frequency filter—10 kHz, Sweep speed—2 msec/division.

**Nerve fibers tested:** C8 and T1 nerve roots, through the lower trunk, anterior division, and medial cord of the brachial plexus and the deep palmar branch of the ulnar nerve.

**Normal values (1) (199 subjects) (skin temperature over the dorsum of the hand greater than or equal to 32 degrees Celsius):**

**Onset latency (msec)**

<table>
<thead>
<tr>
<th>Sex</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>3.8</td>
<td>0.5</td>
<td>3.1–4.9</td>
<td>4.7</td>
</tr>
<tr>
<td>Female</td>
<td>3.4</td>
<td>0.5</td>
<td>2.5–4.6</td>
<td>4.4</td>
</tr>
<tr>
<td>All subjects</td>
<td>3.6</td>
<td>0.5</td>
<td>2.5–4.9</td>
<td>4.6</td>
</tr>
</tbody>
</table>

**Amplitude (mV)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.8</td>
<td>4.9</td>
<td>2.7–30.1</td>
<td>5.1</td>
</tr>
</tbody>
</table>

**Area of negative phase (µVsec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>37.6</td>
<td>12.3</td>
<td>4.3–65.9</td>
<td>12.3</td>
</tr>
</tbody>
</table>
**Duration of negative phase (msec)**

<table>
<thead>
<tr>
<th>Height in cm (in)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;180 cm (5'11&quot;)</td>
<td>5.1</td>
<td>0.8</td>
<td>3.3–7.3</td>
<td>6.7</td>
</tr>
<tr>
<td>≥180 cm (5'11&quot;)</td>
<td>5.5</td>
<td>1.0</td>
<td>4.3–9.3</td>
<td>8.2</td>
</tr>
<tr>
<td>All subjects</td>
<td>5.2</td>
<td>0.8</td>
<td>3.3–9.3</td>
<td>6.7</td>
</tr>
</tbody>
</table>

**Acceptable Differences**

The upper limit of normal increase in latency from one side to the other is 0.8 msec.

The upper limit of normal decrease in amplitude from one side to the other is 52%.

The upper limit of normal difference between first dorsal interosseous and abductor digiti minimi latency in the same limb is 1.3 msec.

**Helpful Hints**

- If information about more proximal ulnar nerve conduction velocity is desired, it should be obtained by studying the nerve to the abductor digiti minimi. Stimulation at the more proximal sites often activates both the median and the ulnar nerves, which causes volume conduction artifact to be recorded when studying the 1st dorsal interosseous muscle.

- Anomalous innervation of the 1st dorsal interosseous muscle is sometimes present.

- In 82% of subjects the amplitude to the 1st dorsal interosseous is greater than that recorded from the abductor digiti minimi.

**Notes**

_____________________________________________________

_____________________________________________________

_____________________________________________________

_____________________________________________________

98

Upper Limb/Brachial Plexus Motor Nerve Studies
REFERENCE


ADDITIONAL READINGS

CHAPTER 2

Upper Limb Sensory and Mixed Nerve Studies
Typical waveform appearance

Electrode Placement
Position: This study is performed in the supine position.

Recording electrodes: A 3 cm bar electrode is placed on the lateral aspect of the forearm, in line with the long axis of the forearm, with the active electrode (A) 10 cm distal to the stimulation point. The reference electrode (R) is distal.

Ground electrode (G): Placement is on the mid-volar aspect of the proximal forearm.

Stimulation point (S): The cathode (C) is placed just lateral to the distal biceps tendon, with the anode (A) proximal.

Machine settings: Sensitivity—5–10 µV/division, Low frequency filter—20 Hz, High frequency filter—2 kHz, Sweep speed—1 msec/division.

Nerve fibers tested: C5 and C6 nerve roots, through the upper trunk, anterior division, and lateral cord of the brachial plexus. This is the continuation of the musculocutaneous nerve.

Normal values (1) (213 subjects) (skin temperature over the dorsum of the hand greater than or equal to 32 degrees Celsius):

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Onset latency (msec)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.7</td>
<td>0.2</td>
<td>1.3–2.3</td>
<td>2.1</td>
</tr>
<tr>
<td><strong>Peak latency (msec)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.2</td>
<td>0.2</td>
<td>1.6–2.8</td>
<td>2.5</td>
</tr>
<tr>
<td><strong>Onset to peak amplitude (µV)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>10</td>
<td>4–56</td>
<td>5</td>
</tr>
<tr>
<td><strong>Peak to peak amplitude (µV)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>15</td>
<td></td>
<td>6</td>
</tr>
</tbody>
</table>
Area under the curve from onset to positive peak (nVsec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>7</td>
<td>3–44</td>
<td>4</td>
</tr>
</tbody>
</table>

Rise time (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.1</td>
<td>0.2–0.7</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Duration from onset to positive peak (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>0.2</td>
<td>0.7–1.7</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Acceptable Differences

The upper limit of normal increase in onset latency from one side to the other is 0.2 msec.

The upper limit of normal increase in peak latency from one side to the other is 0.3 msec.

The upper limit of normal decrease in onset to peak amplitude from one side to the other is 69%.

The upper limit of normal decrease in peak-to-peak amplitude from one side to the other is 68%.

The upper limit of normal difference between medial antebrachial cutaneous and lateral antebrachial cutaneous onset and peak latency in the same limb is 0.3 msec in cases where the medial antebrachial cutaneous has the longer latency; it is also 0.3 msec in cases where the lateral antebrachial cutaneous latency is longer (2).

Helpful Hints

- When compared with the medial antebrachial cutaneous nerve study, the lateral antebrachial nerve generally has a larger amplitude.

- The cathode should be placed immediately next to the biceps tendon to obtain an optimal recording. Slight pressure may be necessary.
REFERENCES


ADDITIONAL READINGS


MEDIAL ANTEBRACHIAL CUTANEOUS SENSORY NERVE

Typical waveform appearance

Electrode Placement
Position: This study is performed in the supine position.

Recording electrodes: A 3 cm bar electrode is placed on the medial aspect of the forearm, in line with the long axis of the forearm, so that the distance between the active electrode (A) and the cathode (C) is 10 cm. The reference electrode (R) is distal.

Ground electrode (G): Placement is on the mid-volar aspect of the forearm.

Stimulation point (S): The cathode (C) is placed at the midpoint between the medial epicondyle and the distal biceps tendon, with the anode (A) proximal.

Machine settings: Sensitivity—5–10 μV/division, Low frequency filter—20 Hz, High frequency filter—2 kHz, Sweep speed—1 msec/division.

Nerve fibers tested: C8 and T1 nerve roots, through the lower trunk, anterior division, and medial cord of the brachial plexus.

Normal values (1) (207 subjects) (skin temperature over the dorsum of the hand greater than or equal to 32 degrees Celsius):

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onset latency (msec)</td>
<td>1.7</td>
<td>0.2</td>
<td>1.3–2.4</td>
<td>2.0</td>
</tr>
<tr>
<td>Peak latency (msec)</td>
<td>2.2</td>
<td>0.2</td>
<td>1.8–2.8</td>
<td>2.6</td>
</tr>
</tbody>
</table>
### Onset to peak amplitude (µV)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>7</td>
<td>3–46</td>
<td>4</td>
</tr>
</tbody>
</table>

### Peak-to-peak amplitude (µV)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>7</td>
<td>2–43</td>
<td>3</td>
</tr>
</tbody>
</table>

### Area under the curve from onset to positive peak (nVsec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>3</td>
<td>1–25</td>
<td>2</td>
</tr>
</tbody>
</table>

### Rise time (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.1</td>
<td>0.3–0.7</td>
<td>0.6</td>
</tr>
</tbody>
</table>

### Duration from onset to positive peak (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0.2</td>
<td>0.6–1.6</td>
<td>1.3</td>
</tr>
</tbody>
</table>

### Acceptable Differences

The upper limit of normal increase in onset and peak latency from one side to the other is 0.3 msec.

The upper limit of normal decrease in onset to peak amplitude from one side to the other is 67%.

The upper limit of normal decrease in peak-to-peak amplitude from one side to the other is 78%.

The upper limit of normal difference between medial antebrachial cutaneous and lateral antebrachial cutaneous onset and peak latency in the same limb is 0.3 msec in cases where the medial antebrachial cutaneous has the longer latency; it is also 0.3 msec in cases where the lateral antebrachial cutaneous latency is longer.
Helpful Hints

- When compared with the medial antebrachial cutaneous nerve study, the lateral antebrachial nerve generally has a larger amplitude.

- Occasionally, motor artifact can obscure the recording. Lowering the stimulus intensity may be helpful.

- Occasionally, stimulus artifact can interfere with the recording. Rotating the anode or moving the ground electrode to the back of the forearm may be helpful.

Notes __________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________
REFERENCE

ADDITIONAL READINGS


MEDIAN NERVE

MEDIAN SENSORY NERVE TO THE 2ND AND 3RD DIGITS

Typical waveform appearance

Electrode Placement
**Position:** This study is performed in the supine position.

**Active electrode (A):** A ring or clip electrode is placed in contact with the radial and ulnar sides of the digit being tested, slightly distal to the base of the digit.

**Reference electrode (R):** A ring or clip electrode is placed in contact with the radial and ulnar sides of the digit being tested, 4 cm distal to the active electrode.

**Ground electrode (G):** Placement is on the dorsum of the hand.

**Stimulation point 1 (S1):** The subject is asked to straighten the fingers. The cathode (C) is placed 14 cm proximal to the active electrode over the median nerve at the wrist, between the tendons of the flexor carpi radialis and the palmaris longus (if the palmaris longus is absent, stimulation is applied slightly medial to the flexor carpi radialis tendon). The anode (A) is proximal.

**Stimulation point 2 (S2):** The cathode (C) is placed at the midpoint of the line from the active electrode to stimulation point 1. The anode (A) is proximal.

**Machine settings:** Sensitivity—20 µV/division, Low frequency filter—20 Hz, High frequency filter—2 kHz, Sweep speed—1 msec/division.

**Nerve fibers tested:** C6 (2nd digit) and C7 (3rd digit) nerve roots through the upper and middle trunks, anterior divisions, and lateral cord of the brachial plexus.
Normal values: (1) (258 subjects) (skin temperature over the dorsum of the hand 32 degrees Celsius or greater). The data presented are for the 3rd digit; the results for the 2nd digit are virtually identical.

### Onset latencies (msec)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>2.7</td>
<td>0.3</td>
<td>1.8–3.6</td>
<td>3.2</td>
</tr>
<tr>
<td>S2</td>
<td>1.4</td>
<td>0.2</td>
<td>1.0–2.1</td>
<td>1.8</td>
</tr>
</tbody>
</table>

### Peak latencies (msec)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>3.4</td>
<td>0.3</td>
<td>2.8–4.7</td>
<td>4.0</td>
</tr>
<tr>
<td>S2</td>
<td>2.0</td>
<td>0.4</td>
<td>1.6–2.6</td>
<td>2.4</td>
</tr>
</tbody>
</table>

### Onset to peak amplitude (µV) The data are divided into groups according to age and body mass index (BMI), kg/m² (see Appendix).

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age Range 19–49</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI &lt;24</td>
<td>51</td>
<td>19</td>
<td></td>
<td>19</td>
</tr>
<tr>
<td>BMI ≥24</td>
<td>45</td>
<td>19</td>
<td></td>
<td>15</td>
</tr>
<tr>
<td>Age Range 50–79</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI &lt;24</td>
<td>30</td>
<td>10</td>
<td></td>
<td>13</td>
</tr>
<tr>
<td>BMI ≥24</td>
<td>24</td>
<td>10</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>All subjects</td>
<td>41</td>
<td>20</td>
<td>6–107</td>
<td>10</td>
</tr>
</tbody>
</table>
**Peak-to-peak amplitude (µV)** The data are divided into groups according to age and body mass index (BMI), kg/m² (see Appendix).

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age Range 19–49</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI &lt;24</td>
<td>82</td>
<td>33</td>
<td></td>
<td>27</td>
</tr>
<tr>
<td>BMI ≥24</td>
<td>69</td>
<td>31</td>
<td></td>
<td>19</td>
</tr>
<tr>
<td>Age Range 50–79</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI &lt;24</td>
<td>47</td>
<td>16</td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>BMI ≥24</td>
<td>34</td>
<td>16</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>All subjects</td>
<td>63</td>
<td>33</td>
<td>4–174</td>
<td>12</td>
</tr>
</tbody>
</table>

**Area under the curve from onset to positive peak (nVsec)** The data are divided into groups according to age and body mass index (BMI), kg/m² (see Appendix).

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age Range 19–49</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI &lt;24</td>
<td>65</td>
<td>31</td>
<td></td>
<td>22</td>
</tr>
<tr>
<td>BMI ≥24</td>
<td>53</td>
<td>27</td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>Age Range 50–79</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI &lt;24</td>
<td>37</td>
<td>15</td>
<td></td>
<td>15</td>
</tr>
<tr>
<td>BMI ≥24</td>
<td>27</td>
<td>13</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>All subjects</td>
<td>49</td>
<td>29</td>
<td>8–138</td>
<td>13</td>
</tr>
</tbody>
</table>

**Rise time (msec)**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>0.7</td>
<td>0.1</td>
<td>0.5–1.4</td>
<td>1.0</td>
</tr>
<tr>
<td>S2</td>
<td>0.6</td>
<td>0.3</td>
<td>0.2–0.9</td>
<td>0.8</td>
</tr>
</tbody>
</table>
**Duration from onset to positive peak (msec)**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>2.1</td>
<td>0.4</td>
<td>1.0–3.4</td>
<td>2.9</td>
</tr>
<tr>
<td>S2</td>
<td>1.8</td>
<td>0.5</td>
<td>0.6–6.2</td>
<td>2.7</td>
</tr>
</tbody>
</table>

**Acceptable Differences**

The upper limit of normal increase in onset and peak latency from one side to the other is 0.4 msec.

The upper limit of normal decrease in onset to peak amplitude from one side to the other is 51%.

The upper limit of normal decrease in peak-to-peak amplitude from one side to the other is 55%.

The upper limit of normal decrease in area from one side to the other is 63%.

The upper limit of normal percentage of the S1 onset latency attributable to the wrist-to-palm segment (S1 minus S2/S1) is 58%.

The upper limit of normal percentage of the S1 peak latency attributable to the wrist-to-palm segment (S1 minus S2/S1) is 50%.

The upper limit of normal increase in onset to peak and peak-to-peak amplitude from S1 to S2 is approximately 50%.

The upper limit of normal increase in latency from digit 2 to digit 3 is 0.4 msec for onset latency and 0.3 msec for peak latency.

The upper limit of normal increase in latency from digit 3 to digit 2 is 0.2 msec for onset and peak latency.

The upper limit of normal decrease in onset to peak amplitude from one digit to the other is approximately 44–48%.

The upper limit of normal decrease in peak-to-peak amplitude from one digit to the other is approximately 50%.

The upper limit of normal decrease in area from one digit to the other is approximately 40–50%.

The upper limit of normal difference between median (digit 3) and ulnar (digit 5) sensory onset latency in the same limb is 0.5 msec in cases where the median has the longer latency; it is 0.3 msec in cases where the ulnar latency is longer (2).

The upper limit of normal difference between median (digit 3) and ulnar (digit 5) sensory peak latency in the same limb is 0.4 msec in
cases where the median has the longer latency; it is 0.5 msec in cases where the ulnar latency is longer (2).

**Helpful Hints**

- After applying the clip electrodes to the digits, they should be rotated from side to side to help spread the electrode paste.

- Volume conduction from the muscles of the hand may be seen as a motor wave, usually slightly after the sensory response. If this is obscuring the sensory recording, the active and recording electrodes may need to be repositioned slightly more distal on the digit. In the case of an absent sensory response, the examiner may misidentify the motor response as a delayed sensory recording.

- If there is doubt about whether the observed recording is truly a sensory response, the recording and stimulating electrodes may need to be reversed to perform an orthodromic recording. If this is done, the evoked response amplitudes can be expected to be smaller than with digital recording. Such responses may need to be averaged or even recorded with near nerve needle recording.

- If the skin of the palm is thick, it can make the S2 response difficult to elicit. Mild abrasion of the skin or needle stimulation may be needed.

- To avoid contamination of the response by contact of the clips with the adjacent fingers, a small roll of gauze may be placed between the digits to hold them apart.

- In persons with short hands, the normal 7 cm S2 site may be situated over the wrist rather than in the palm. In such cases, S2 may be moved more distally. This will still allow amplitude comparison from S1 to S2, but not latency comparison. Alternatively, S1 may be placed 12 cm proximal to the active electrode and S2 would be at 6 cm. This will still allow a latency ratio comparison.

- Stimulation can be applied across the wrist in 1 cm increments in the so-called “inching” technique. Normally, as the stimulus is applied 1 cm more distally the latency increases by 0.16–0.21 msec per 1 cm increment. Greater incremental latency changes can help to localize focal slowing (3). Upper limits of normal
increase in incremental latencies of 0.4 msec and 0.5 msec, or a
doubling of the adjacent segments’ latencies, have been recom-
mended (4,5). Ross and Kimura recommend that inching be done
not to diagnose carpal tunnel syndrome, but to confirm the site of
slowing (6).

REFERENCES

1. Buschbacher RM: Median 14 cm and 7 cm antidromic sensory studies to
2. Grossart EA, Prahlow ND, Buschbacher RM. Acceptable differences in
sensory and motor latencies between the median and ulnar nerves. In press: 
Journal of Long-term Effects of Medical Implants.
3. Kimura J: The carpal tunnel syndrome: localization of conduction abnor-
malities within the distal segment of the median nerve. Brain 1979;
102:619–635.
4. Nathan PA, Keniston RC, Meadows KD, Lockwood RS: Predictive value of
nerve conduction measurements at the carpal tunnel. Muscle Nerve 1993;
16:1377–1382.


**ADDITIONAL READINGS**


Typical waveform appearance

Electrode Placement
**Position:** This study is performed in the supine position. Set-up is as for median motor nerve conduction to the abductor pollicis brevis.

**Active electrode (A):** Placement is halfway between the midpoint of the distal wrist crease and the 1st metacarpophalangeal joint.

**Reference electrode (R):** Placement is slightly distal to the 1st metacarpophalangeal joint.

**Ground electrode (G):** Placement is on the dorsum of the hand. If stimulus artifact interferes with the recording, the ground may be placed near the active electrode, between this electrode and the cathode.

**Stimulation point (S):** The cathode (C) is placed 8 cm proximal to the active electrode, in a line measured first to the midpoint of the distal wrist crease and then to a point slightly ulnar to the tendon of the flexor carpi radialis. The anode (A) is proximal.

**Machine settings:** Sensitivity—10 µV/division. Low frequency filter—20 Hz, High frequency filter 2 kHz, Sweep speed—1 msec/division

**Nerve fibers tested:** C6 nerve root through the upper trunk, anterior division, and lateral cord of the brachial plexus. This branch leaves the median nerve above the carpal tunnel.

**Normal values (1) (10 subjects):**

**Peak latency (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.54</td>
<td>0.08</td>
<td>1.38–1.70</td>
<td>1.70</td>
</tr>
</tbody>
</table>

**Peak-to-peak amplitude (µV)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.03</td>
<td>10.58</td>
</tr>
</tbody>
</table>
Helpful Hints

- There are two small amplitude negative waves preceding the compound motor action potential of the abductor pollicis brevis. Both waves should be visualized using the technique described above. This will enable the examiner to correctly identify the sensory nerve action potential of the median palmar cutaneous nerve, which is the first of the two small amplitude negative waves. The second negative wave is a far field recording of either the junctional potential of the median digital nerve entering the thumb or that of a fixed neural generator in the palm.

- The cathode may be repositioned laterally to attempt to selectively depolarize the median palmar cutaneous nerve. Using a short duration stimulus may decrease the recording interference from the stimulus artifact. Using a submaximal stimulus intensity from that used to record the motor response may also be helpful. Repositioning of the active electrode proximally may also be helpful. The amplitude will be larger with more proximal placement and therefore may be more easily detected in some individuals. Care should be taken not to place the active electrode too far medially, as the sensory recording might be obscured by depolarization of the main median trunk.

Notes

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________
REFERENCE


ADDITIONAL READING/ALTERNATE TECHNIQUE

POSTERIOR ANTEBRACHIAL CUTANEOUS NERVE

Electrode Placement

Typical waveform appearance
Position: This study is performed in the supine position, with the forearm pronated.

Recording electrodes: Placement is along a line from the stimulation point to the mid-dorsum of the wrist (midway between the radial and ulnar styloid processes). The active electrode (A) is placed approximately 12 cm distal to the stimulating electrode. The reference electrode (R) is 3 cm distal.

Ground electrode (G): Placement is between the stimulating and recording electrodes.

Stimulation point (S): Placement of the cathode is just above the lateral epicondyle, between the biceps and triceps. The anode is proximal.

Machine settings: Low frequency filter—5 Hz, High frequency filter—5 kHz.

Nerve fibers tested: C5–C8 nerve roots, through the upper, middle, and lower trunks, posterior divisions, and posterior cord of the brachial plexus, and then through the radial nerve.

Normal values (1) (63 subjects) (distance 12.0 cm, skin temperature 32-34 degrees):

**Onset latency (msec)**

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>20–39</td>
<td>2.00</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>40–59</td>
<td>2.05</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>≥60</td>
<td>2.19</td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td>All subjects</td>
<td>2.07</td>
<td>0.16</td>
<td>1.80–2.60</td>
</tr>
</tbody>
</table>

**Peak latency (msec)**

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>20–39</td>
<td>2.25</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>40–59</td>
<td>2.34</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>≥60</td>
<td>2.48</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>All subjects</td>
<td>2.35</td>
<td>0.15</td>
<td>2.05–2.90</td>
</tr>
</tbody>
</table>
Peak to peak amplitude (µV)

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>20–39</td>
<td>6.93</td>
<td>2.01</td>
<td></td>
</tr>
<tr>
<td>40–59</td>
<td>6.41</td>
<td>2.10</td>
<td></td>
</tr>
<tr>
<td>≥60</td>
<td>4.74</td>
<td>1.54</td>
<td></td>
</tr>
<tr>
<td>All subjects</td>
<td>6.10</td>
<td>2.11</td>
<td>2.90–13.00</td>
</tr>
</tbody>
</table>

Acceptable Difference

The study authors’ suggested upper limit of normal decrease in amplitude from side to side is 40%.

Helpful Hints

- This nerve supplies sensation to the skin of the lateral arm and elbow and dorsal forearm to the wrist.
- The waveform may be difficult to record because of motor artifact. Lower intensity stimulation may be necessary. Adjustment of the stimulating and recording electrodes may be needed as well.
- Initially stimulation should be performed 1/2–2 cm directly above the lateral epicondyle. If no response is obtained, the stimulator should be moved anteriorly or posteriorly.
- Stimulation may be better if done slightly closer to the triceps muscle.

Notes

_________________________________________________________________________________
_________________________________________________________________________________
_________________________________________________________________________________
_________________________________________________________________________________
REFERENCE


ADDITIONAL READING/ALTERNATE TECHNIQUE

RADIAL SENSORY NERVE TO THE BASE OF THE THUMB

Typical waveform appearance

Electrode Placement
Position: This study is performed in the supine position.

Recording electrodes: A 3 cm bar is placed with the active electrode (A) over the radial sensory nerve as the nerve passes over the extensor pollicis longus tendon. The reference electrode (R) is distal.

Ground electrode (G): Placement is on the dorsum of the hand.

Stimulation point (S): The cathode (C) is placed on the radial side of the forearm 10 cm proximal to the active electrode. The anode (A) is proximal.

Machine settings: Sensitivity—5–10 µV/division, Low frequency filter—20 Hz, High frequency filter—2 kHz, Sweep speed—1 msec/division.

Nerve fibers tested: C6 nerve root, through the upper trunk, posterior division, and posterior cord of the brachial plexus.

Normal values (1) (212 subjects) (skin temperature over the dorsum of the hand greater than or equal to 32 degrees Celsius):

<table>
<thead>
<tr>
<th>Onset latency (msec)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.9</td>
<td>0.2</td>
<td>1.4–2.4</td>
<td>2.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Peak latency (msec)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.4</td>
<td>0.2</td>
<td>1.9–3.1</td>
<td>2.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Onset to peak amplitude (µV)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>29</td>
<td>13</td>
<td>4–75</td>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Peak-to-peak amplitude (µV)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>33</td>
<td>14</td>
<td>4–92</td>
<td>11</td>
</tr>
</tbody>
</table>
**Area under the curve from onset to positive peak (nVsec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>7</td>
<td>3–47</td>
<td>6</td>
</tr>
</tbody>
</table>

**Rise time (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.1</td>
<td>0.2–0.8</td>
<td>0.7</td>
</tr>
</tbody>
</table>

**Duration from onset to positive peak (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2</td>
<td>0.2</td>
<td>0.9–2.6</td>
<td>1.6</td>
</tr>
</tbody>
</table>

**Acceptable Differences**

The upper limit of normal increase in onset and peak latency from one side to the other is 0.3 msec.

The upper limit of normal decrease in onset to peak amplitude from one side to the other is 64%.

The upper limit of normal decrease in peak-to-peak amplitude from one side to the other is 54%.

The upper limit of normal difference between radial and dorsal ulnar cutaneous onset latency in the same limb is 0.5 msec in cases where the radial has the longer latency; it is 0.3 msec in cases where the dorsal ulnar cutaneous latency is longer.

The upper limit of normal difference between radial and dorsal ulnar cutaneous peak latency in the same limb is 0.4 msec in cases where the radial has the longer latency; it is also 0.4 msec in cases where the dorsal ulnar cutaneous latency is longer.

**Helpful Hint**

- Asking the subject to actively extend the thumb may help in palpating and localizing the nerve.
REFERENCE


ADDITIONAL READINGS

ULNAR NERVE

ULNAR DORSAL CUTANEOUS SENSORY NERVE

Typical waveform appearance

Electrode Placement
**Position:** This study is performed in the supine position, with elbow flexed to 90 degrees.

**Recording electrodes:** A 3 cm bar is placed with the active electrode (A) in the “V” formed by the proximal dorsal 4th and 5th metacarpals. The reference electrode (R) is distal.

**Ground electrode (G):** Placement is on the dorsum of the hand.

**Stimulation point (S):** The cathode (C) is placed 10 cm proximal to the active electrode over the ulna or between the ulna and the flexor carpi ulnaris. The anode (A) is proximal.

**Machine settings:** Sensitivity—5–10 µV/division, Low frequency filter—20 Hz, High frequency filter—2 kHz, Sweep speed—1 msec/division.

**Nerve fibers tested:** C8 nerve root, through the lower trunk, anterior division, and medial cord of the brachial plexus.

**Normal values** (1) (194 subjects) (skin temperature over the dorsum of the hand greater than or equal to 32 degrees Celsius):

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Onset latency (msec)</strong></td>
<td>1.8</td>
<td>0.3</td>
<td>1.2–4.5</td>
<td>2.3</td>
</tr>
<tr>
<td><strong>Peak latency (msec)</strong></td>
<td>2.3</td>
<td>0.4</td>
<td>1.8–6.1</td>
<td>2.9</td>
</tr>
<tr>
<td><strong>Onset to peak amplitude (µV)</strong></td>
<td>17</td>
<td>10</td>
<td>4–50</td>
<td>5</td>
</tr>
<tr>
<td><strong>Peak-to-peak amplitude (µV)</strong></td>
<td>20</td>
<td>13</td>
<td>5–76</td>
<td>5</td>
</tr>
</tbody>
</table>
Area under the curve from onset to positive peak (nVsec)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>11</td>
<td>7</td>
<td>3–43</td>
<td>3</td>
</tr>
</tbody>
</table>

Rise time (msec)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
<td>0.1</td>
<td>0.2–1.6</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Duration from onset to positive peak (msec)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.2</td>
<td>0.2</td>
<td>0.8–2.6</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Acceptable Differences

The upper limit of normal increase in onset latency from one side to the other is 0.5 msec.

The upper limit of normal increase in peak latency from one side to the other is 0.4 msec.

The upper limit of normal decrease in onset to peak amplitude from one side to the other is 59%.

The upper limit of normal decrease in peak-to-peak amplitude from one side to the other is 67%.

The upper limit of normal difference between radial and dorsal ulnar cutaneous onset latency in the same limb is 0.5 msec in cases where the radial has the longer latency; it is 0.3 msec in cases where the dorsal ulnar cutaneous latency is longer.

The upper limit of normal difference between radial and dorsal ulnar cutaneous peak latency in the same limb is 0.4 msec in cases where the radial has the longer latency; it is also 0.4 msec in cases where the dorsal ulnar cutaneous latency is longer.

Helpful Hints

- Anomalous innervation to this area may be present.
- This sensory recording is often obscured by motor artifact, especially if the waveform is delayed. Submaximal stimulation can be useful if this is the case.
Kim and coworkers reported that if difficulty was encountered in obtaining a response, the following maneuvers can be used: (1) stimulator can be moved 2–3 cm more proximal or distal, (2) an orthodromic technique can be used, and (3) the radial and musculocutaneous nerves can be stimulated to test for an anomalous innervation pattern (2).

Hoffman and coworkers reported that supinating the forearm produced better recordings (3).

Notes

______________________________________________________

______________________________________________________

______________________________________________________

REFERENCES


ADDITIONAL READINGS

Electrode Placement

ULNAR SENSORY NERVE TO THE 5TH DIGIT

Typical waveform appearance
Position: This study is performed in the supine position.

**Active electrode (A):** A ring or clip electrode is placed in contact with the radial and ulnar sides of the 5th digit, slightly distal to the base of the digit.

**Reference electrode (R):** A ring or clip electrode is placed in contact with the radial and ulnar sides of the 5th digit, 4 cm distal to the active electrode (or in small fingers as far distally as possible).

**Ground electrode (G):** Placement is on the dorsum of the hand.

**Stimulation point 1 (S1):** The subject is asked to straighten the fingers. The cathode (C) is placed 14 cm proximal to the active electrode over the ulnar nerve at the wrist, slightly radial to the tendon of the flexor carpi ulnaris. The anode (A) is proximal.

**Stimulation point 2 (S2):** The cathode (C) is placed at the midpoint of the line from the active electrode to stimulation point 1. The anode (A) is proximal.

**Machine settings:** Sensitivity—20 µV/division, Low frequency filter—20 Hz, High frequency filter—2 kHz, Sweep speed—1 msec/division.

**Nerve fibers tested:** C8 nerve root, through the lower trunk, anterior division, and medial cord of the brachial plexus.

**Normal values** (1) (258 subjects) (skin temperature over the dorsum of the hand 32 degrees Celsius or greater):

**Onset latencies (msec)**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>2.6</td>
<td>0.2</td>
<td>2.0–3.3</td>
<td>3.1</td>
</tr>
<tr>
<td>S2</td>
<td>1.4</td>
<td>0.2</td>
<td>0.9–1.9</td>
<td>1.8</td>
</tr>
</tbody>
</table>
**Peak latencies (msec)**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>3.4</td>
<td>0.3</td>
<td>2.7–4.8</td>
<td>4.0</td>
</tr>
<tr>
<td>S2</td>
<td>2.0</td>
<td>0.2</td>
<td>1.6–2.8</td>
<td>2.5</td>
</tr>
</tbody>
</table>

**Onset to peak amplitude (µV)** The data are divided into groups according to age and body mass index (BMI), kg/m² (see Appendix).

<table>
<thead>
<tr>
<th>S1</th>
<th>Age Range 19–49</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BMI &lt;24</td>
<td>43</td>
<td>17</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BMI ≥24</td>
<td>36</td>
<td>16</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Age Range 50–79</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BMI &lt;24</td>
<td>27</td>
<td>11</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BMI ≥24</td>
<td>20</td>
<td>9</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>All subjects</td>
<td>33</td>
<td>17</td>
<td>1–85</td>
<td>6</td>
</tr>
</tbody>
</table>

**Peak-to-peak amplitude (µV)** The data are divided into groups according to age and body mass index (BMI), kg/m² (see Appendix).

<table>
<thead>
<tr>
<th>S1</th>
<th>Age Range 19–49</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BMI &lt;24</td>
<td>70</td>
<td>36</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BMI ≥24</td>
<td>54</td>
<td>31</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Age Range 50–79</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BMI &lt;24</td>
<td>37</td>
<td>13</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BMI ≥24</td>
<td>27</td>
<td>15</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>All subjects</td>
<td>50</td>
<td>32</td>
<td>1–179</td>
<td>4</td>
</tr>
</tbody>
</table>
Area under the curve from onset to positive peak \((nV\text{sec})\) The data are divided into groups according to age and body mass index (BMI), \(\text{kg/m}^2\) (see Appendix).

<table>
<thead>
<tr>
<th>S1</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age Range 19–49</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI &lt;24</td>
<td>53</td>
<td>29</td>
<td></td>
<td>14</td>
</tr>
<tr>
<td>BMI ≥24</td>
<td>38</td>
<td>22</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Age Range 50–79</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI &lt;24</td>
<td>28</td>
<td>11</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>BMI ≥24</td>
<td>22</td>
<td>14</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>All subjects</td>
<td>37</td>
<td>24</td>
<td>3–138</td>
<td>8</td>
</tr>
</tbody>
</table>

**Rise time (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1 0.8</td>
<td>0.2</td>
<td>0.5–2.1</td>
<td>1.1</td>
</tr>
<tr>
<td>S2 0.6</td>
<td>0.1</td>
<td>0.3–1.3</td>
<td>0.9</td>
</tr>
</tbody>
</table>

**Duration from onset to positive peak (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1 1.9</td>
<td>0.4</td>
<td>1.0–3.5</td>
<td>2.7</td>
</tr>
<tr>
<td>S2 1.7</td>
<td>0.3</td>
<td>1.0–3.0</td>
<td>2.5</td>
</tr>
</tbody>
</table>

**Acceptable Differences**

The upper limit of normal increase in onset latency from one side to the other is 0.3 msec.

The upper limit of normal increase in peak latency from one side to the other is 0.4 msec.
The upper limit of normal decrease in onset to peak amplitude from one side to the other is 53%.
The upper limit of normal decrease in peak-to-peak amplitude from one side to the other is 64%.
The upper limit of normal decrease in area from one side to the other is 65%.
The upper limit of normal percentage of the S1 onset latency attributable to the wrist-to-palm segment (S1 minus S2/S1) is 54%.
The upper limit of normal percentage of the S1 peak latency attributable to the wrist-to-palm segment (S1 minus S2/S1) is 47%.
The upper limit of normal increase in onset to peak amplitude from S1 to S2 is 71%.
The upper limit of normal increase in peak-to-peak amplitude from S1 to S2 is 60%.
The upper limit of normal difference between median (digit 3) and ulnar (digit 5) sensory onset latency in the same limb is 0.5 msec in cases where the median has the longer latency; it is 0.3 msec in cases where the ulnar latency is longer (2).
The upper limit of normal difference between median (digit 3) and ulnar (digit 5) sensory peak latency in the same limb is 0.4 msec in cases where the median has the longer latency; it is 0.5 msec in cases where the ulnar latency is longer (2).

Helpful Hints

■ After applying the clip electrodes to the digits, they should be rotated from side to side to help spread the electrode paste.

■ Volume conduction from the muscles of the hand may be seen as a motor wave, usually slightly after the sensory response. If this is obscuring the sensory recording, the active and recording electrodes may need to be repositioned slightly more distal on the digit. In the case of an absent sensory response, the examiner may misidentify the motor response as a delayed sensory recording.

■ If there is doubt about whether the observed recording is truly a sensory response, the recording and stimulating electrodes may need to be reversed to perform an orthodromic recording. If this
is done, the evoked response amplitudes can be expected to be smaller than with digital recording. Such responses may need to be averaged or even recorded with near nerve needle recording.

- If the skin of the palm is thick, it may make the S2 response difficult to elicit. Mild abrasion of the skin or needle stimulation may be needed.

- To avoid contamination of the response by contact of the clips with the adjacent finger, a small roll of gauze may be placed between the digits to hold them apart.

- In persons with short hands, the normal 7 cm S2 site may be situated over the wrist rather than in the palm. In such cases, S2 may be moved more distally. This will still allow amplitude comparison from S1 to S2, but not latency comparison. Alternatively, S1 may be placed 12 cm proximal to the active electrode and S2 would be at 6 cm. This will still allow a latency ratio comparison.

- The sensory studies are usually performed only for relatively short distances. This is due to the fact that sensory compound action potentials are particularly sensitive to phase cancellation, causing a rapid decrease in amplitude with increasing distance from the recording site. One study has presented the data for sensory recording with more proximal stimulation for 20 subjects (averaging used). The mean ± 2 S.D. value for latency change for a 10 cm segment across the elbow (see ulnar nerve motor study to the abductor digiti minimi) was 1.8 msec for onset latency and 1.9 msec for peak latency. Side-to-side difference (mean ± 2 S.D.) in latency change across this segment was 0.6 msec for onset latency and 0.3 msec for peak latency. The upper limit of normal decrement of peak-to-peak amplitude was 74% (range 12–72%) across the wrist to below elbow segment and 41% (range 0–50%) for the below to above elbow segment. The lower limits of normal nerve conduction velocity (calculated for onset latency) were 59 m/sec below the elbow and 50 m/sec across the elbow) (3).
REFERENCES


ADDITIONAL READINGS


COMPARATIVE STUDIES

MEDIAN AND RADIAL SENSORY NERVES TO THE THUMB

Typical waveform appearance

Electrode Placement
Position: This study is performed in the supine position, with the forearm in supination.

Active electrode (A): A ring or clip electrode is placed just distal to the first metacarpophalangeal joint.

Reference electrode (R): A ring or clip electrode is placed 4 cm distally on the thumb. For subjects with short thumbs, it is placed as far distal as possible.

Ground electrode (G): Placement is on the dorsum of the hand.

Stimulation point (S-Radial): The cathode (C) is placed 10 cm proximal to the active electrode, along the lateral border of the radius. The measurement is taken with the thumb held in line with the radius to allow measuring along the straightest line possible.

Stimulation point (S-Median): The cathode (C) is placed 10 cm proximal to the active electrode, in a line measured first to the midpoint of the distal wrist crease and then to a point slightly ulnar to the tendon of the flexor carpi radialis. The anode (A) is proximal.

Machine settings: Sensitivity—5–20 µV/division, Low frequency filter—20 Hz, High frequency filter—2 kHz, Sweep speed—1 msec/division.

Nerve fibers tested: Median: C6 nerve root through the upper trunk, anterior division, and lateral cord of the brachial plexus. Radial: C6 nerve root through the upper trunk, posterior division, and posterior cord of the brachial plexus.

Normal values (1) (203 subjects) (skin temperature over the dorsum of the hand greater than or equal to 32 degrees Celsius):

Onset latency (msec)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>2.1</td>
<td>0.2</td>
<td>1.7–3.3</td>
<td>2.5</td>
</tr>
<tr>
<td>Radial</td>
<td>2.0</td>
<td>0.2</td>
<td>1.6–2.5</td>
<td>2.4</td>
</tr>
</tbody>
</table>
### Peak latency (msec)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>2.7</td>
<td>0.2</td>
<td>2.2–3.2</td>
<td>3.1</td>
</tr>
<tr>
<td>Radial</td>
<td>2.6</td>
<td>0.2</td>
<td>2.1–3.4</td>
<td>3.0</td>
</tr>
</tbody>
</table>

### Onset to peak amplitude (µV)

<table>
<thead>
<tr>
<th>Sex</th>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median Female</td>
<td>19–49</td>
<td>46</td>
<td>14</td>
<td>14–79</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>50–79</td>
<td>23</td>
<td>9</td>
<td>9–46</td>
<td>10</td>
</tr>
<tr>
<td>Male</td>
<td>19–49</td>
<td>31</td>
<td>13</td>
<td>5–68</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>50–79</td>
<td>19</td>
<td>8</td>
<td>8–39</td>
<td>8</td>
</tr>
<tr>
<td>All subjects</td>
<td></td>
<td>33</td>
<td>16</td>
<td>5–79</td>
<td>10</td>
</tr>
<tr>
<td>Radial All subjects</td>
<td></td>
<td>9</td>
<td>6</td>
<td>3–46</td>
<td>3</td>
</tr>
</tbody>
</table>

### Peak-to-peak amplitude (µV)

<table>
<thead>
<tr>
<th>Sex</th>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median Female</td>
<td>19–49</td>
<td>62</td>
<td>19</td>
<td>24–119</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>50–79</td>
<td>33</td>
<td>17</td>
<td>9–94</td>
<td>12</td>
</tr>
<tr>
<td>Male</td>
<td>19–49</td>
<td>45</td>
<td>25</td>
<td>5–117</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>50–79</td>
<td>23</td>
<td>11</td>
<td>9–50</td>
<td>9</td>
</tr>
<tr>
<td>All subjects</td>
<td></td>
<td>45</td>
<td>24</td>
<td>5–119</td>
<td>11</td>
</tr>
<tr>
<td>Radial All subjects</td>
<td></td>
<td>12</td>
<td>9</td>
<td>3–64</td>
<td>4</td>
</tr>
</tbody>
</table>

### Area (nVsec-onset to positive peak)

<table>
<thead>
<tr>
<th>Sex</th>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median Female</td>
<td>19–49</td>
<td>36</td>
<td>14</td>
<td>11–78</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>50–79</td>
<td>21</td>
<td>12</td>
<td>6–63</td>
<td>7</td>
</tr>
<tr>
<td>Male</td>
<td>19–49</td>
<td>28</td>
<td>15</td>
<td>4–75</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>50–79</td>
<td>15</td>
<td>7</td>
<td>6–29</td>
<td>6</td>
</tr>
<tr>
<td>All subjects</td>
<td></td>
<td>27</td>
<td>15</td>
<td>4–78</td>
<td>6</td>
</tr>
<tr>
<td>Radial All subjects</td>
<td></td>
<td>8</td>
<td>6</td>
<td>2–37</td>
<td>3</td>
</tr>
</tbody>
</table>
### Rise time (msec)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>0.6</td>
<td>0.1</td>
<td>0.3–1.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Radial</td>
<td>0.6</td>
<td>0.1</td>
<td>0.2–1.0</td>
<td>0.9</td>
</tr>
</tbody>
</table>

### Duration from onset to positive peak (msec)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>1.6</td>
<td>0.3</td>
<td>0.5–2.7</td>
<td>2.3</td>
</tr>
<tr>
<td>Radial</td>
<td>1.5</td>
<td>0.4</td>
<td>0.8–2.6</td>
<td>2.2</td>
</tr>
</tbody>
</table>

### Acceptable Differences

The upper limit of normal increase in median onset latency from one side to the other is 0.3 msec.

The upper limit of normal increase in median peak latency from one side to the other is 0.4 msec.

The upper limit of normal decrease in median onset to peak amplitude from one side to the other is 47%.

The upper limit of normal decrease in median peak-to-peak amplitude from one side to the other is 63%.

The upper limit of normal increase in radial onset latency from one side to the other is 0.3 msec.

The upper limit of normal increase in radial peak latency from one side to the other is 0.4 msec.

The upper limit of normal decrease in radial onset to peak amplitude from one side to the other is 69%.

The upper limit of normal decrease in radial peak-to-peak amplitude from one side to the other is 66%.

The upper limit of normal difference between medial and radial onset latency in the same limb is 0.5 msec in cases where the median has the longer latency; it is 0.3 msec in cases where the radial latency is longer.

The upper limit of normal difference between medial and radial peak latency in the same limb is 0.6 msec in cases where the median has the longer latency; it is 0.4 msec in cases where the radial latency is longer.
REFERENCE


ADDITIONAL READINGS


Typical waveform appearance

Electrode Placement
**Position:** This study is performed in the supine position.

**Recording electrodes (median):** A 3 cm bar electrode is placed with the active electrode (A) at the proximal wrist crease slightly ulnar to the tendon of the flexor carpi radialis. The reference electrode (R) is proximal.

**Recording electrodes (ulnar):** A 3 cm bar electrode is placed with the active electrode (A) at the proximal wrist crease slightly radial to the tendon of the flexor carpi ulnaris. The reference electrode (R) is proximal.

**Ground electrode (G):** Placement is on the dorsum of the hand.

**Stimulation point (S-Median):** The cathode (C) is placed 8 cm distal to the active electrode in the mid-palm. The anode (A) is placed distally.

**Stimulation point (S-Ulnar):** The cathode (C) is placed 8 cm distal to the active electrode in the lateral palm between the tendons of the flexors of the 4th and 5th digits.

**Machine settings:** Sensitivity—20 µV/division, Low frequency filter—20 Hz, High frequency filter—2 kHz, Sweep speed—1 msec/division.

**Normal values** (1) (248 subjects): (skin temperature over the dorsum of the hand at least 32 degrees Celsius):

**Onset latencies (msec)**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>1.6</td>
<td>0.2</td>
<td>1.2–2.4</td>
<td>2.0</td>
</tr>
<tr>
<td>Ulnar</td>
<td>1.6</td>
<td>0.2</td>
<td>1.2–2.0</td>
<td>1.9</td>
</tr>
</tbody>
</table>

**Peak latencies (msec)**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>2.1</td>
<td>0.2</td>
<td>1.6–3.1</td>
<td>2.4</td>
</tr>
<tr>
<td>Ulnar</td>
<td>2.1</td>
<td>0.2</td>
<td>1.7–2.6</td>
<td>2.4</td>
</tr>
</tbody>
</table>
**Onset to peak amplitude (µV), peak-to-peak amplitude (µV), and area (nV sec-onset to positive peak).** The means and standard deviations were derived independently for subgroups divided by age, sex, and body mass index (BMI—kg/m²). The reader is directed to the reference article should this information be required. The lower limits of normal differed only for women under age 50 for the median nerve and for women under age 30 with a BMI less than 24 kg/m² for the ulnar nerve.

### Lower limits of normal

<table>
<thead>
<tr>
<th></th>
<th>Onset-to-Peak Amplitude</th>
<th>Peak-to-Peak Amplitude</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Median</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women under 50</td>
<td>27</td>
<td>32</td>
<td>17</td>
</tr>
<tr>
<td>All others</td>
<td>15</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td><strong>Ulnar</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women under 30 with BMI under 24</td>
<td>22</td>
<td>33</td>
<td>14</td>
</tr>
<tr>
<td>All others</td>
<td>6</td>
<td>6</td>
<td>4</td>
</tr>
</tbody>
</table>

**Rise time (msec)**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Median</strong></td>
<td>0.5</td>
<td>0.1</td>
<td>0.4–0.8</td>
<td>0.6</td>
</tr>
<tr>
<td><strong>Ulnar</strong></td>
<td>0.5</td>
<td>0.1</td>
<td>0.3–0.7</td>
<td>0.7</td>
</tr>
</tbody>
</table>

**Duration from onset to positive peak (msec)**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Median</strong></td>
<td>1.2</td>
<td>0.3</td>
<td>0.9–4.1</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>Ulnar</strong></td>
<td>1.2</td>
<td>0.2</td>
<td>0.7–2.0</td>
<td>1.5</td>
</tr>
</tbody>
</table>
Acceptable Differences

The upper limit of normal increase in onset latency from one side to the other for the median and ulnar nerves is 0.3 msec.

The upper limit of normal increase in peak latency from one side to the other is 0.3 msec for the median nerve and 0.4 msec for the ulnar nerve.

The upper limit of normal decrease in onset to peak amplitude from one side to the other is 64% for the median nerve and 73% for the ulnar nerve.

The upper limit of normal decrease in peak-to-peak amplitude from one side to the other is 64% for the median nerve and 72% for the ulnar nerve.

The upper limit of normal decrease in area from one side to the other is approximately 59% for the median nerve and 73% for the ulnar nerve.

The upper limit of normal increase in onset or peak latency of one nerve versus the other is 0.3 msec.

Helpful Hints

- If stimulus is applied fairly distally in the palm, a more purely sensory response is recorded.

- If the subject’s hand is small and the cathode is placed too distally to perform the technique, the bar electrode may need to be repositioned more proximally.
REFERENCE


ADDITIONAL READINGS

MEDIAN AND ULNAR SENSORY STUDIES TO THE 4TH DIGIT

Electrode Placement

Typical waveform appearance
Position: This study is performed in the supine position.

Active electrode (A): A finger clip or ring electrode is placed slightly distal to the fourth metacarpophalangeal joint.

Reference electrode (R): A finger clip or ring electrode is placed 4 cm distally on the same digit.

Ground electrode (G): Placement is on the dorsum of the hand.

Median stimulation point (S-Median): The cathode (C) is placed 14 cm proximal to the active electrode, slightly ulnar to the tendon of the flexor carpi radialis. The anode (A) is proximal.

Ulnar stimulation point (S-Ulnar): The cathode (C) is placed 14 cm proximal to the active electrode, slightly radial to the tendon of the flexor carpi ulnaris. The anode (A) is proximal.

Machine settings: Sensitivity—10–20 µV/division, Low frequency filter—20 Hz, High frequency filter—2 kHz, Sweep speed—1 msec/division.

Nerve fibers tested: Median: C8 nerve root through the lower trunk, anterior division, and medial cord of the brachial plexus. Ulnar: C8 nerve root through the lower trunk, anterior division, and medial cord of the brachial plexus.

Normal values (1) (192 subjects) (skin temperature over the dorsum of the hand greater than or equal to 32 degrees Celsius):

### Onset latency (msec)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>2.7</td>
<td>0.3</td>
<td>2.2–3.7</td>
<td>3.4</td>
</tr>
<tr>
<td>Ulnar</td>
<td>2.6</td>
<td>0.2</td>
<td>2.0–3.3</td>
<td>3.0</td>
</tr>
</tbody>
</table>

### Peak latency (msec)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>3.4</td>
<td>0.3</td>
<td>2.7–4.8</td>
<td>4.1</td>
</tr>
<tr>
<td>Ulnar</td>
<td>3.3</td>
<td>0.3</td>
<td>2.4–4.7</td>
<td>3.9</td>
</tr>
</tbody>
</table>
### Onset to peak amplitude (µV)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>21</td>
<td>12</td>
<td>4–84</td>
<td>5</td>
</tr>
<tr>
<td>Ulnar</td>
<td>23</td>
<td>12</td>
<td>4–63</td>
<td>5</td>
</tr>
</tbody>
</table>

### Peak-to-peak amplitude (µV)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>34</td>
<td>20</td>
<td>4–130</td>
<td>10</td>
</tr>
<tr>
<td>Ulnar</td>
<td>36</td>
<td>23</td>
<td>4–138</td>
<td>10</td>
</tr>
</tbody>
</table>

### Area under the curve from onset to positive peak (nVsec)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>25</td>
<td>17</td>
<td>4–107</td>
<td>6</td>
</tr>
<tr>
<td>Ulnar</td>
<td>28</td>
<td>19</td>
<td>3–145</td>
<td>7</td>
</tr>
</tbody>
</table>

### Rise time (msec)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>0.7</td>
<td>0.1</td>
<td>0.3–1.1</td>
<td>1.0</td>
</tr>
<tr>
<td>Radial</td>
<td>0.7</td>
<td>0.2</td>
<td>0.1–1.4</td>
<td>1.1</td>
</tr>
</tbody>
</table>

### Duration from onset to positive peak (msec)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>1.9</td>
<td>0.4</td>
<td>1.0–2.9</td>
<td>2.7</td>
</tr>
<tr>
<td>Radial</td>
<td>1.9</td>
<td>0.5</td>
<td>0.8–3.9</td>
<td>2.8</td>
</tr>
</tbody>
</table>

### Acceptable Differences

The upper limit of normal increase in median onset and peak latency from one side to the other is 0.4 msec.

The upper limit of normal decrease in median onset to peak amplitude from one side to the other is 62%.

The upper limit of normal decrease in median peak-to-peak amplitude from one side to the other is 56%.

The upper limit of normal increase in ulnar onset and peak latency from one side to the other is 0.3 msec.

The upper limit of normal decrease in ulnar onset to peak amplitude from one side to the other is 63%.
The upper limit of normal decrease in ulnar peak-to-peak amplitude from one side to the other is 73%.

The upper limit of normal difference between median and ulnar onset and peak latency in the same limb is 0.5 msec in cases where the median has the longer latency.

The upper limit of normal difference between median and ulnar onset latency in the same limb is 0.2 msec in cases where the ulnar latency is longer.

The upper limit of normal difference between median and ulnar peak latency in the same limb is 0.3 msec in cases where the ulnar latency is longer.

Helpful Hints

- Anomalous innervation patterns may be encountered.
- To avoid contamination of the response by contact of the ring electrodes with the adjacent fingers, a small roll of gauze may need to be placed between the digits to hold them apart.

Notes

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________
REFERENCE


ADDITIONAL READINGS


CHAPTER 3

Lower Limb Motor Nerve Studies
FEMORAL MOTOR NERVE TO THE QUADRICEPS

Electrode Placement

Typical waveform appearance
**Position:** This study is performed in the supine position.

**Active electrode (A):** Placement is over the center of the vastus medialis.

**Reference electrode (R):** Placement is over the quadriceps tendon just proximal to the patella (1). Placement over the patella has also been described (2).

**Ground electrode (G):** Placement is between the stimulating and recording electrodes.

**Stimulation point 1 (S1):** A monopolar needle electrode is used as the cathode for all but the most thin subjects (2). The stimulus is applied superior to the inguinal ligament just lateral to the femoral artery. The anode is under the buttock.

**Stimulation point 2 (S2):** A needle electrode is used as well, but inferior to the inguinal ligament and lateral to the femoral artery.

**Machine settings:** Sensitivity—1 mV/division, Sweep speed—2 msec/division.

**Nerve fibers tested:** L2, L3, and L4 nerve roots, through the posterior division of the lumbosacral plexus.

**Normal values (1) (100 subjects):**

**Latency for stimulation above ligament (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1</td>
<td>0.7</td>
<td>6.1–8.4</td>
<td>8.5</td>
</tr>
</tbody>
</table>

**Latency for stimulation below ligament (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0</td>
<td>0.7</td>
<td>5.5–7.5</td>
<td>7.4</td>
</tr>
</tbody>
</table>
### Delay across inguinal ligament (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>0.4</td>
<td>0.8–1.8</td>
<td>1.9</td>
</tr>
</tbody>
</table>

### Amplitude (mV) (2)

- **Range**
  - 0.2–11.0

### Helpful Hints

- Too low a stimulus intensity may result in an H-reflex being elicited.
- In the cited reference, only 75 of 100 studies were included in the final results because satisfactory recordings were not obtained in all subjects. Certain portions of the study for the remaining 25 studies were also used. The subjects were not true “normals.” The data were derived using surface stimulation (1).
- Proper stimulator placement can be confirmed by observing contraction of quadriceps.
- The length of the femoral nerve segment in the cited reference was 35.4 ± 1.9 cm (range 29–38).
- The distance between stimulation point above and below the inguinal ligament in the cited reference was 5.5 ± 1.6 cm (range 4.2–6.6).

### Notes

________________________________________________
________________________________________________
________________________________________________
________________________________________________
________________________________________________
REFERENCES


ADDITIONAL READING/ALTERNATE TECHNIQUE

PERONEAL NERVE

PERONEAL MOTOR NERVE TO THE EXTENSOR DIGITORUM BREVIS

Typical waveform appearance

Electrode Placement
**Position:** This study is performed in the supine position.

**Active electrode (A):** Placement is over the midpoint of the extensor digitorum brevis muscle on the dorsum of the foot.

**Reference electrode (R):** Placement is slightly distal to the 5th metatarsophalangeal joint.

**Ground electrode (G):** Placement is over the dorsum of the foot.

**Stimulation point 1 (S1):** The cathode (C) is placed 8 cm proximal to the active electrode, slightly lateral to the tibialis anterior tendon. The anode (A) is proximal.

**Stimulation point 2 (S2):** The cathode (C) is slightly posterior and inferior to the fibular head. The anode (A) is proximal.

**Stimulation point 3 (S3):** The cathode (C) is placed approximately 10 cm proximal to the S2 cathode placement and medial to the tendon of the biceps femoris. The anode (A) is proximal.

**F-wave stimulation:** The cathode is positioned as for S1, but with the anode distally.

**Machine settings:** Sensitivity—5 mV/division, Low frequency filter—2–3 Hz, High frequency filter—10 kHz, Sweep speed—5 msec/division.

**Nerve fibers tested:** L5 and S1 nerve roots, through the posterior division of the lumbosacral plexus, and the sciatic and common peroneal nerves.
Normal values (1) (242 subjects) (skin temperature over the dorsum of the foot greater than or equal to 31 degrees Celsius):  

**Onset latency (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.8</td>
<td>0.8</td>
<td>3.1–6.9</td>
<td>6.5</td>
</tr>
</tbody>
</table>

**Amplitude (mV)**

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>19–39</td>
<td>6.8</td>
<td>2.5</td>
<td>1.6–13</td>
<td>2.6</td>
</tr>
<tr>
<td>40–79</td>
<td>5.1</td>
<td>2.5</td>
<td>0.4–11.7</td>
<td>1.1</td>
</tr>
<tr>
<td>All subjects</td>
<td>5.9</td>
<td>2.6</td>
<td>0.4–13.8</td>
<td>1.3</td>
</tr>
</tbody>
</table>

**Area (µVsec)**

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>19–49</td>
<td>20.2</td>
<td>8.0</td>
<td>0.7–39.3</td>
<td>6.8</td>
</tr>
<tr>
<td>50–79</td>
<td>14.9</td>
<td>7.6</td>
<td>2.9–37.1</td>
<td>3.6</td>
</tr>
<tr>
<td>All subjects</td>
<td>18.3</td>
<td>8.2</td>
<td>0.7–39.3</td>
<td>4.3</td>
</tr>
</tbody>
</table>

**Duration (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.7</td>
<td>1.0</td>
<td>2.9–9.0</td>
<td>7.7</td>
</tr>
</tbody>
</table>

**Nerve conduction velocity (m/sec)**

**S1–S2**

<table>
<thead>
<tr>
<th>Height in cm (in.)</th>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;170 cm (&lt;5'7&quot;)</td>
<td>19–39</td>
<td>49</td>
<td>4</td>
<td>42–64</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>40–79</td>
<td>47</td>
<td>5</td>
<td>38–65</td>
<td>39</td>
</tr>
<tr>
<td>≥170 cm (≥ 5'7&quot;)</td>
<td>19–39</td>
<td>46</td>
<td>4</td>
<td>37–56</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>40–79</td>
<td>44</td>
<td>4</td>
<td>33–56</td>
<td>36</td>
</tr>
<tr>
<td>All subjects</td>
<td>47</td>
<td>4</td>
<td>33–65</td>
<td>38</td>
<td></td>
</tr>
</tbody>
</table>

**S2–S3**

| All subjects       | 57        | 9    | 38–78 | 42     |
**F-wave latencies (2) (180 subjects)—shortest of 10 stimuli**

**Age Range 19–39**

<table>
<thead>
<tr>
<th>Height in cm (in.)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;160 (&lt;5'3&quot;)</td>
<td>43.6</td>
<td>2.5</td>
<td>38.5–47.2</td>
<td>48.6</td>
</tr>
<tr>
<td>160–169 (5'3&quot;–5'6&quot;)</td>
<td>47.1</td>
<td>3.7</td>
<td>40.8–54.6</td>
<td>54.5</td>
</tr>
<tr>
<td>≥170 (≥5'7&quot;)</td>
<td>51.5</td>
<td>4.1</td>
<td>45.6–60.5</td>
<td>59.7</td>
</tr>
</tbody>
</table>

**Age Range 40–79**

<table>
<thead>
<tr>
<th>Height in cm (in.)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;160 (&lt;5'3&quot;)</td>
<td>45.4</td>
<td>4.8</td>
<td>39.8–58.1</td>
<td>55.0</td>
</tr>
<tr>
<td>160–169 (5'3&quot;–5'6&quot;)</td>
<td>49.6</td>
<td>4.6</td>
<td>44.1–60.0</td>
<td>58.8</td>
</tr>
<tr>
<td>≥170 (≥5'7&quot;)</td>
<td>54.6</td>
<td>4.5</td>
<td>45.0–64.2</td>
<td>63.6</td>
</tr>
</tbody>
</table>

**All subjects**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>50.2</td>
<td>5.5</td>
<td>38.5–64.2</td>
<td>61.2</td>
</tr>
</tbody>
</table>

**Acceptable Differences**

The upper limit of normal increase in latency from one side to the other is 1.6 msec.

The upper limit of normal decrease in amplitude from one side to the other is 61%.

The upper limit of normal decrease in S1–S2 nerve conduction velocity from one side to the other is 8 m/sec.

The upper limit of normal decrease in S2–S3 nerve conduction velocity from one side to the other is 19 m/sec.

The upper limit of normal decrease in nerve conduction velocity from S1–S2 to S2–S3 is 6 m/sec.

The upper limit of normal decrease in amplitude from S1 to S2 is 32%.

The upper limit of normal decrease in amplitude from S2 to S3 is 25%.

The upper limit of normal side to side difference in the shortest F-wave latency is 5.1 msec.

The upper limit of normal difference between latencies of the peroneal motor to the extensor digitorum brevis and the tibial motor to the abductor hallucis in the same limb is 1.8 msec in cases where the peroneal nerve has the longer latency; it is 1.5 msec in cases where the tibial nerve latency is longer (3).
Helpful Hints

- Care must be taken at popliteal stimulation to not concomitantly activate the tibial nerve.

- An accessory peroneal nerve is commonly present (20–25% incidence), although it is less commonly of clinical significance (4,5). The accessory peroneal nerve passes behind the lateral malleolus to innervate the extensor digitorum brevis. Its presence should be suspected if the amplitude to proximal stimulation is greater than on ankle stimulation. Its presence can be confirmed by stimulating behind the lateral malleolus. If a response is recorded from the extensor digitorum brevis, an accessory peroneal nerve is present.

- A short segment incremental stimulation (“inching”) technique has been described for testing the conduction of the peroneal nerve across the knee. The nerve is stimulated in 2 cm increments, starting 4 cm distal and proceeding to 6 cm proximal to the head of the fibula. In normal subjects the difference in latency between successive stimulation points varies from 0.2 to 0.65 msec. Abrupt waveform changes or decreases in amplitude may be a sign of conduction block (6).

- The compound nerve action potential may be recorded across the fibular head using a technique described by Lee (7). A bar electrode is placed at the very distal portion of the fibular neck. Stimulation is at the medial aspect of the lateral hamstring tendon at the level of the popliteal crease. Sensory settings are used. Normal values were obtained on 70 nerves in 35 normal subjects. The mean amplitude ranged between 23.3 and 24.8 µV, with a standard deviation from 6.9 to 7.4 µV. Mean conduction velocities ranged from 61.6 to 61.7 m/s, with a standard deviation from 4.3 to 4.5 m/s.
REFERENCES


ADDITIONAL READINGS


Typical waveform appearance

Electrode Placement
Position: This study is performed in the supine position.

Active electrode (A): A 32 mm disc electrode is placed two-fifths of the distance from the head of the fibula to the tip of the lateral malleolus.

Reference electrode (R): Placement is 4 cm distal to the active electrode over the muscle tendon.

Ground electrode (G): Placement is over the tibia, 3–4 cm distal to the reference electrode.

Stimulation point 1 (S1): The cathode is placed slightly below the head of the fibula. The anode is proximal.

Stimulation point 2 (S2): The cathode is placed just medial to the lateral border of the popliteal space at the level of the mid-patella, approximately 10 cm proximal to stimulation point 1.

Machine settings: Standard motor settings are used.

Nerve fibers tested: L5, S1, and S2 nerve roots, through the posterior division of the sacral plexus and the sciatic nerve.

Normal values (1) (34 subjects) (room temperature 22.2–23.3 degrees Celsius):

Onset latency (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0</td>
<td>0.8</td>
<td>1.7–5.4</td>
<td>4.6</td>
</tr>
</tbody>
</table>

Amplitude (mV)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.3</td>
<td>1.7</td>
</tr>
</tbody>
</table>
**Nerve conduction velocity (m/sec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>55.3</td>
<td>10.2</td>
<td>34.9</td>
</tr>
</tbody>
</table>

Notes

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

____________________________________
REFERENCE

Electrode Placement

Typical waveform appearance
Position: This study is performed in the supine position.

Active electrode (A): Placement is 8 cm from the cathode over the peroneus longus on the lateral surface of the fibula.

Reference electrode (R): Placement is at the ankle over the tendon of the peroneus longus muscle.

Ground electrode (G): Placement is over the upper anterior lower leg.

Stimulation point (S): The cathode (C) is placed at the posterolateral aspect of the fibular neck. The anode (A) is proximal.

Machine settings: Sensitivity—2 mV/division (1 mV to determine onset latency), Low frequency filter—2 Hz, High frequency filter—10 kHz, Sweep speed—2 msec/division.

Nerve fibers tested: L5, S1, and S2 nerve roots, through the posterior division of the lumbosacral plexus and the sciatic nerve.

Normal values (1) (81 subjects) (skin temperature over the lateral surface just below the knee joint greater than or equal to 32 degrees Celsius):

Onset latency (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.6</td>
<td>0.2</td>
<td>1.9–3.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Amplitude (mV)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.2</td>
<td>1.7</td>
<td>3.4–10.6</td>
</tr>
</tbody>
</table>

Helpful Hints

- This technique utilizes a fixed distance measurement from a given stimulation site rather than from a given recording site. There-
fore, the active electrode is not always over the motor point. This may cause submaximal amplitude measurements to be recorded. It is also not known how accurate the latency measurements are with such a technique. Caution is advised when using such a technique for persons at the extremes of height.

- The recorded action potential may exhibit multiple peaks, possibly from the volume conducted potentials of adjacent muscles.
REFERENCES

Typical waveform appearance

Electrode Placement
Position: This study is performed in the supine position.

Active electrode (A): Placement is one-third of the distance from the tibial tubercle to the lateral malleolus.

Reference electrode (R): Placement is 4 cm inferomedial to the active electrode, on the bony surface of the tibia.

Ground electrode (G): Placement is between the stimulus and recording electrodes.

Stimulation point 1 (S1): Cathode is placed slightly posterior and inferior to the fibular head, with the anode proximal.

Stimulation point 2 (S2): Approximately 10 cm proximal to the S1 site, slightly medial to the tendon of the biceps femoris. The anode is proximal.

Machine settings: Sensitivity—5 mV/division, Low frequency filter—2-3 Hz, High frequency filter—10 kHz, Sweep speed—2 msec/division.

Nerve fibers tested: L4 and L5 nerve roots, through the posterior division of the lumbosacral plexus and the sciatic nerve.

Normal values: (1) (244 subjects) (skin temperature over the dorsum of the foot greater than or equal to 31 degrees Celsius):

### Onset latency (msec)

<table>
<thead>
<tr>
<th>Height in cm (in)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;160 cm (5'3&quot;)</td>
<td>3.1</td>
<td>0.5</td>
<td>2.2–4.1</td>
<td>4.1</td>
</tr>
<tr>
<td>160–180 cm (5'3&quot;–5'11&quot;)</td>
<td>3.5</td>
<td>0.6</td>
<td>2.2–5.2</td>
<td>4.7</td>
</tr>
<tr>
<td>&gt;180 cm (5'11&quot;)</td>
<td>4.2</td>
<td>0.6</td>
<td>2.7–5.4</td>
<td>5.4</td>
</tr>
<tr>
<td>All subjects</td>
<td>3.6</td>
<td>0.6</td>
<td>2.2–5.4</td>
<td>4.9</td>
</tr>
</tbody>
</table>

### Amplitude (mV)

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>19–29</td>
<td>4.3</td>
<td>1.9</td>
<td>1.3–10.7</td>
<td>2.1</td>
</tr>
<tr>
<td>30–79</td>
<td>3.6</td>
<td>1.9</td>
<td>1.1–20.0</td>
<td>1.5</td>
</tr>
<tr>
<td>All subjects</td>
<td>3.8</td>
<td>2.0</td>
<td>1.1–20.0</td>
<td>1.7</td>
</tr>
</tbody>
</table>
Area of negative phase ($\mu$Vsec)

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>19–29</td>
<td>27.4</td>
<td>15.8</td>
<td>4.5–69.6</td>
<td>7.3</td>
</tr>
<tr>
<td>30–79</td>
<td>20.2</td>
<td>11.1</td>
<td>4.1–62.1</td>
<td>6.3</td>
</tr>
<tr>
<td>All subjects</td>
<td>21.9</td>
<td>12.8</td>
<td>4.1–69.6</td>
<td>6.8</td>
</tr>
</tbody>
</table>

Duration of negative phase (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.1</td>
<td>2.5</td>
<td>3.9–15.9</td>
<td>15.0</td>
</tr>
</tbody>
</table>

Nerve conduction velocity (m/sec)

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Height in cm (in)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>19–59</td>
<td>&lt;170 (5'7&quot;)</td>
<td>66</td>
<td>9</td>
<td>45–87</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>\text{\geq}170 (5'7&quot;)</td>
<td>59</td>
<td>11</td>
<td>30–89</td>
<td>39</td>
</tr>
<tr>
<td>60–79</td>
<td>&lt;170 (5'7&quot;)</td>
<td>57</td>
<td>6</td>
<td>47–71</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>\text{\geq}170 (5'7&quot;)</td>
<td>57</td>
<td>10</td>
<td>37–73</td>
<td>37</td>
</tr>
<tr>
<td>All subjects</td>
<td></td>
<td>62</td>
<td>10</td>
<td>30–89</td>
<td>43</td>
</tr>
</tbody>
</table>

Acceptable Differences

The upper limit of normal increase in latency from one side to the other is 1.2 msec.

The upper limit of normal decrease in amplitude from one side to the other is 50%.

The upper limit of normal decrease in nerve conduction velocity from one side to the other is 23 m/sec or 20%.

The upper limit of normal decrease in amplitude between below fibular head stimulation (S1) and above fibular head stimulation (S2) is 36%.

The upper limit of normal difference between tibialis anterior and extensor digitorum brevis latency in the same limb is 1.5 msec in cases where the tibialis anterior has the longer latency; it is 1.8 msec in cases where the extensor digitorum brevis latency is longer.
Helpful Hints

- Mean NCV across the fibular head was 5 m/sec faster with this study than when recording from the extensor digitorum brevis (1,2).

Notes

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

REFERENCES


ADDITIONAL READINGS

SCIATIC NERVE

SCIATIC MOTOR NERVE RECORDING FROM THE FOOT

Electrode Placement

184
**Position:** This study is performed in the prone position.

**Recording electrodes:** Placement is on the distal muscles of the foot, such as the extensor digitorum brevis (peroneal portion) abductor hallucis (tibial portion), or abductor digiti minimi (tibial portion) (see other sections of this book describing recording from these sites) (1,2).

**Ground electrode (G):** Placement is between the stimulating and recording electrodes.

**Stimulation point 1 (S1):** Surface stimulation is applied in the popliteal fossa with the cathode (C) distal and the anode (A) proximal.

**Stimulation point 2 (S2):** A long needle electrode (cathode) is used to stimulate the sciatic nerve just below the gluteal fold in a line directly above the apex of the popliteal fossa. The anode is placed nearby.

**Machine settings:** Standard motor settings are used.

**Normal values** (1) (18 subjects) (room temperature 23–26 degrees Celsius):

<table>
<thead>
<tr>
<th>Nerve conduction velocity (m/sec)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tibial portion</td>
<td>52.75</td>
<td>4.66</td>
<td>46.7–59.6</td>
</tr>
<tr>
<td>Peroneal portion</td>
<td>54.33</td>
<td>4.36</td>
<td>48.5–61.5</td>
</tr>
</tbody>
</table>

**Helpful Hints**

- Finding the correct gluteal fold stimulation site may be difficult. The peroneal portion of the nerve lies a bit lateral, with the tibial portion being more medial. Observing the foot motion will help identify which portion is being stimulated the most (1).

- With proximal stimulation the recordings made at the extensor digitorum brevis may include volume conducted potentials from other foot muscles that are innervated by the tibial portion of the nerve. (2)
Stimulation can also be applied at the ankle to calculate conduction velocity along the lower leg.
REFERENCES


ADDITIONAL READINGS/ALTERNATE TECHNIQUES


H-REFLEX TO THE CALF

Typical waveform appearance

Electrode Placement
Position: This study is performed in the prone position.

Active electrode (A): The subject is placed prone. The knee is passively flexed by the examiner to mark the popliteal crease. The lower leg is then lowered onto a pillow with the foot hanging over the edge of the table and the ankle slightly plantarflexed. A second mark is placed on the posterior calcaneus. The distance between the two marked points is measured and the active electrode is placed at the midpoint.

Reference electrode (R): Placement is over the posterior calcaneus.

Ground electrode (G): Placement is between the stimulating and recording electrodes.

Stimulation point (S): The cathode (C) is placed at the mid-popliteal crease with the anode (A) distal.

Machine settings: Sensitivity—500 µV/division, Low frequency filter—2–3 Hz, High frequency filter—10 kHz, Sweep speed—10 msec/division, Stimulus duration—1.0 msec

Nerve fibers tested: S1 nerve roots, afferent and efferent sciatic nerve, and their spinal cord connection.

Normal values (1) (251 subjects): (skin temperature over the ankle 31 degrees Celsius or greater):
### Onset latency (msec)

#### Age 19–39

<table>
<thead>
<tr>
<th>Height in cm (in.)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;160 (&lt;5'3&quot;)</td>
<td>27.1</td>
<td>1.8</td>
<td>23.9–29.8</td>
<td>29.8</td>
</tr>
<tr>
<td>160–169 (5'3&quot;–5'6&quot;)</td>
<td>28.6</td>
<td>1.9</td>
<td>21.3–34.1</td>
<td>32.3</td>
</tr>
<tr>
<td>170–179 (5'7&quot;–5'10&quot;)</td>
<td>30.3</td>
<td>1.8</td>
<td>26.0–33.7</td>
<td>33.7</td>
</tr>
<tr>
<td>≥180 (≥5'11&quot;)</td>
<td>32.0</td>
<td>2.1</td>
<td>28.2–35.9</td>
<td>35.9</td>
</tr>
</tbody>
</table>

#### Age 40–49

<table>
<thead>
<tr>
<th>Height in cm (in.)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;160 (&lt;5'3&quot;)</td>
<td>27.8</td>
<td>1.1</td>
<td>26.4–29.7</td>
<td>29.7</td>
</tr>
<tr>
<td>160–169 (5'3&quot;–5'6&quot;)</td>
<td>30.2</td>
<td>1.4</td>
<td>27.2–33.0</td>
<td>32.8</td>
</tr>
<tr>
<td>170–179 (5'7&quot;–5'10&quot;)</td>
<td>31.0</td>
<td>1.6</td>
<td>28.4–33.5</td>
<td>33.5</td>
</tr>
<tr>
<td>≥180 (≥5'11&quot;)</td>
<td>32.7</td>
<td>2.1</td>
<td>28.2–35.3</td>
<td>35.3</td>
</tr>
</tbody>
</table>

#### Age 50–79

<table>
<thead>
<tr>
<th>Height in cm (in.)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;160 (&lt;5'3&quot;)</td>
<td>29.3</td>
<td>1.9</td>
<td>25.9–35.3</td>
<td>33.6</td>
</tr>
<tr>
<td>160–169 (5'3&quot;–5'6&quot;)</td>
<td>31.7</td>
<td>1.6</td>
<td>28.1–35.9</td>
<td>35.6</td>
</tr>
<tr>
<td>170–179 (5'7&quot;–5'10&quot;)</td>
<td>31.9</td>
<td>1.7</td>
<td>27.9–35.1</td>
<td>35.6</td>
</tr>
<tr>
<td>≥180 (≥5'11&quot;)</td>
<td>33.2</td>
<td>2.5</td>
<td>29.7–36.4</td>
<td>36.4</td>
</tr>
</tbody>
</table>

**All subjects**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>30.3</td>
<td>2.4</td>
<td>21.3–36.4</td>
<td>35.0</td>
</tr>
</tbody>
</table>

### Acceptable Difference

The upper limit of normal increase in latency from one side to the other is 2.0 msec.

### Helpful Hints

- Older persons have a higher incidence of unelicitable H-reflexes than do young persons.
- If the H-reflex is unelicitable on one side, there is a higher likelihood that it will also be unelicitable contralaterally.
Jankus and colleagues studied side to side amplitude variability for the tibial H-reflex. They included only subjects with side to side latency differences of less than 1.5 msec. They concluded that a side to side peak to peak amplitude ratio smaller than 0.4 in the face of normal latency is probably abnormal (2).

The H-reflex can be facilitated with slight active plantarflexion.

REFERENCES


ADDITIONAL READINGS

TIBIAL NERVE

TIBIAL MOTOR NERVE (MEDIAL PLANTAR BRANCH) TO THE ABDUCTOR HALLUCIS

Typical waveform appearance

Electrode Placement
Position: This study is performed in the supine position.

Active electrode (A): Placement is over the medial foot, slightly anterior and inferior to the navicular tubercle (at the most superior point of the arch formed by the junction of plantar skin and dorsal foot skin).

Reference electrode (R): Placement is slightly distal to the 1st metatarsophalangeal joint, on the medial surface of the joint.

Ground electrode (G): Placement is over the dorsum of the foot.

Stimulation point 1 (S1): The cathode (C) is placed 8 cm proximal to the active electrode (measured in a straight line with the ankle in neutral position) and slightly posterior to the medial malleolus. The anode (A) is proximal.

Stimulation point 2 (S2): The cathode (C) is placed at the mid-popliteal fossa or slightly medial or lateral to the midline. The anode (A) is proximal.

F-wave stimulation: The cathode is positioned as for stimulation point 1, but with the anode distally.

Machine settings: Sensitivity—5 mV/division, Low frequency filter—2–3 Hz, High frequency filter—10 kHz, Sweep speed—5 msec/division

Nerve fibers tested: S1 and S2 nerve roots, through the anterior division of the lumbosacral plexus and the sciatic nerve.

Normal values (1) (250 subjects) (skin temperature over the dorsum of the foot greater than or equal to 31 degrees Celsius):

Onset latency (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5</td>
<td>0.8</td>
<td>3.2–7.4</td>
<td>6.1</td>
</tr>
</tbody>
</table>
### Amplitude (mV)

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>19–29</td>
<td>15.3</td>
<td>4.5</td>
<td>5.3–26.6</td>
<td>5.8</td>
</tr>
<tr>
<td>30–59</td>
<td>12.9</td>
<td>4.5</td>
<td>1.8–25.6</td>
<td>5.3</td>
</tr>
<tr>
<td>60–79</td>
<td>9.8</td>
<td>4.2</td>
<td>1.0–19.4</td>
<td>1.1</td>
</tr>
<tr>
<td>All subjects</td>
<td>12.9</td>
<td>4.8</td>
<td>1.0–26.6</td>
<td>4.4</td>
</tr>
</tbody>
</table>

### Area (µVsec)

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>19–49</td>
<td>38.9</td>
<td>14.3</td>
<td>7.1–74.8</td>
<td>14.2</td>
</tr>
<tr>
<td>50–79</td>
<td>29.2</td>
<td>13.3</td>
<td>1.8–67.0</td>
<td>5.0</td>
</tr>
<tr>
<td>All subjects</td>
<td>35.3</td>
<td>14.7</td>
<td>1.8–74.8</td>
<td>9.1</td>
</tr>
</tbody>
</table>

### Duration (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.3</td>
<td>1.2</td>
<td>3.7–11.2</td>
<td>8.7</td>
</tr>
</tbody>
</table>

### Nerve conduction velocity (m/sec)

#### Age Range 19–49

<table>
<thead>
<tr>
<th>Height in cm (in.)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;160 (&lt;5'3&quot;)</td>
<td>51</td>
<td>4</td>
<td>44–59</td>
<td>44</td>
</tr>
<tr>
<td>160–169 (5'3&quot;–5'6&quot;)</td>
<td>49</td>
<td>6</td>
<td>39–77</td>
<td>42</td>
</tr>
<tr>
<td>≥170 (≥ 5'7&quot;)</td>
<td>47</td>
<td>5</td>
<td>36–67</td>
<td>37</td>
</tr>
</tbody>
</table>

#### Age Range 50–79

<table>
<thead>
<tr>
<th>Height in cm (in.)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;160 (&lt;5'3&quot;)</td>
<td>49</td>
<td>5</td>
<td>40–62</td>
<td>40</td>
</tr>
<tr>
<td>160–169 (5'3&quot;–5'6&quot;)</td>
<td>45</td>
<td>5</td>
<td>37–56</td>
<td>37</td>
</tr>
<tr>
<td>≥170 (≥ 5'7&quot;)</td>
<td>44</td>
<td>5</td>
<td>34–52</td>
<td>34</td>
</tr>
</tbody>
</table>

**All subjects** | 47   | 6    | 34–77 | 39                    |
F-wave latencies (msec) (2) (180 subjects)—shortest of 10 stimuli

Age Range 19–39

<table>
<thead>
<tr>
<th>Height in cm (in.)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;160 (&lt;5'3&quot;)</td>
<td>43.2</td>
<td>2.2</td>
<td>39.1–45.4</td>
<td>47.6</td>
</tr>
<tr>
<td>160–169 (5'3&quot;–5'6&quot;)</td>
<td>47.2</td>
<td>3.0</td>
<td>41.9–52.7</td>
<td>53.2</td>
</tr>
<tr>
<td>170–179 (5'7&quot;–5'10&quot;)</td>
<td>52.0</td>
<td>4.0</td>
<td>45.6–59.2</td>
<td>60.0</td>
</tr>
<tr>
<td>≥180 (≥5'11&quot;)</td>
<td>53.1</td>
<td>4.4</td>
<td>47.0–59.8</td>
<td>61.9</td>
</tr>
</tbody>
</table>

Age Range 40–79

<table>
<thead>
<tr>
<th>Height in cm (in.)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;160 (&lt;5'3&quot;)</td>
<td>46.8</td>
<td>4.6</td>
<td>38.5–57.2</td>
<td>56.0</td>
</tr>
<tr>
<td>160–169 (5'3&quot;–5'6&quot;)</td>
<td>50.5</td>
<td>3.5</td>
<td>44.8–59.7</td>
<td>57.5</td>
</tr>
<tr>
<td>170–179 (5'7&quot;–5'10&quot;)</td>
<td>53.9</td>
<td>3.6</td>
<td>45.1–59.0</td>
<td>61.1</td>
</tr>
<tr>
<td>≥180 (≥5'11&quot;)</td>
<td>57.9</td>
<td>5.3</td>
<td>52.0–767.0</td>
<td>68.5</td>
</tr>
</tbody>
</table>

All subjects

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>50.8</td>
<td>5.3</td>
<td>38.5–67.0</td>
<td>61.4</td>
</tr>
</tbody>
</table>

Acceptable Differences

The upper limit of normal increase in latency from one side to the other is 1.4 msec.
The upper limit of normal decrease in amplitude from one side to the other is 50%.
The upper limit of normal decrease in nerve conduction velocity from one side to the other is 10 m/sec.
The upper limit of normal decrease in amplitude from ankle to knee stimulation is 71%.
The upper limit of normal side to side difference in the shortest F-wave latency is 5.7 msec.

Helpful Hints

■ Ankle stimulation should be approximately halfway between the medial malleolus and the Achilles tendon.
■ Care should be taken to not concomitantly stimulate the peroneal nerve at the knee. Stimulation should be close to the midline of
the popliteal fossa, but the stimulator may need to be moved slightly medially or laterally to obtain an optimal response. Watching for the direction of foot motion on stimulation will help ensure that the proper nerve is stimulated.

■ Obtaining a true supramaximal response at knee stimulation may be difficult at times. The amplitude drop with knee versus ankle stimulation for this nerve study is greater than that seen with most other nerve studies.

■ In subjects with large feet, the 8 cm fixed distance between stimulating and recording electrodes may fail to include the entire “tarsal tunnel” area. A 10 cm distance can be used (3,4). With the active electrode 1 cm posterior and inferior to the navicular tubercle and a 10 cm distance between the stimulating and recording electrodes, the mean latency has been described as 3.8 ± 0.5 msec (at 29–34 degrees Celsius) (3). In a series of elderly subjects using slightly different methodology from the data presented above, the mean latency at 10 cm (again recording posterior and inferior to the navicular tubercle) was 4.5 ± 0.7 msec (4).
REFERENCES


ADDITIONAL READINGS


TIBIAL MOTOR NERVE (LATERAL PLANTAR BRANCH) TO THE FLEXOR DIGITI MINIMI BREVIS

Typical waveform appearance

Electrode Placement
Position: This study is performed in the supine position.

Active electrode (A): Placement is on the midpoint of the inferolateral edge of the 5th metatarsal.

Reference electrode (R): Placement is slightly distal to the 5th metatarsophalangeal joint on the lateral surface of the joint.

Ground electrode (G): Placement is on the dorsum of the foot.

Stimulation point (S): Stimulation is applied at the same point as for the study recording from the abductor hallucis (see section on the tibial motor nerve study to the abductor hallucis). The cathode (C) is placed behind the medial malleolus 8 cm proximal to a point slightly anterior and inferior to the navicular tubercle on the medial foot. The anode (A) is proximal.

Machine settings: Sensitivity—5 mV/division, Low frequency filter—2–3 Hz, High frequency filter—10 kHz, Sweep speed—5 msec/division.

Nerve fibers tested: S1 and S2 nerve roots, through the anterior division of the lumbosacral plexus and the sciatic nerve.

Normal values (1) (205 subjects) (skin temperature over the dorsum of the foot at least 31 degrees Celsius):

**Onset latency (msec)**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6.4</td>
<td>1.0</td>
<td>2.8-11.0</td>
<td>8.3</td>
</tr>
</tbody>
</table>

**Amplitude (mV)**

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>19–29</td>
<td>7.8</td>
<td>3.2</td>
<td>2.5–16.9</td>
<td>2.8</td>
</tr>
<tr>
<td>30–59</td>
<td>6.0</td>
<td>3.2</td>
<td>1.2–15.9</td>
<td>1.7</td>
</tr>
<tr>
<td>60–79</td>
<td>4.7</td>
<td>3.1</td>
<td>1.0–15.1</td>
<td>1.0</td>
</tr>
</tbody>
</table>

| All subjects | 6.1  | 3.3  | 1.0–16.9 | 1.4                   |
Area (µVsec)

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>19–59</td>
<td>17.5</td>
<td>9.5</td>
<td>1.8–48.7</td>
<td>4.2</td>
</tr>
<tr>
<td>60–79</td>
<td>11.8</td>
<td>6.6</td>
<td>1.0–26.8</td>
<td>3.1</td>
</tr>
<tr>
<td>All subjects</td>
<td>16.2</td>
<td>9.2</td>
<td>1.0–48.7</td>
<td>3.1</td>
</tr>
</tbody>
</table>

Duration (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.8</td>
<td>1.7</td>
<td>2.1–11.9</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Acceptable Differences

The upper limit of normal increase in latency from one side to the other is 1.5 msec.

The upper limit of normal decrease in amplitude from one side to the other is 58%.

Normally, the lateral branch latency is greater than the medial branch latency. The upper limit of normal increase in latency to the flexor digiti minimi brevis versus the abductor hallucis is 3.5 msec. If the medial latency comes within 0.3 msec of the lateral latency or exceeds the lateral latency, this is a sign of medial branch slowing.

Helpful Hints

- This study is very easy to perform and allows comparison of the lateral tibial branch versus the medial branch.

- Previous authors have used this same recording site but have remarked that the recording is from the abductor digiti minimi. Recent research has identified the source of this potential to be coming from the flexor digiti minimi brevis (2).
REFERENCES


ADDITIONAL READINGS


CHAPTER 4

Lower Limb Sensory and Mixed Nerve Studies
LATERAL FEMORAL CUTANEOUS SENSORY NERVE

Electrode Placement—Ma and Liveson Technique
Ma and Liveson Technique

**Position:** This study is performed in the supine position.

**Recording electrodes:** Surface electrodes are placed along a line connecting the anterior superior iliac spine (ASIS) to the lateral border of the patella with the active electrode (A) 17–20 cm distal to the ASIS and the reference electrode (R) 3 cm more distal.

**Ground electrode (G):** Placement is between the stimulating and recording electrodes.

**Stimulation point 1 (S1):** Stimulation can be applied below the inguinal ligament over the origin of the sartorius.

**Stimulation point 2 (S2):** Stimulation can be applied above the inguinal ligament 1 cm medial to the ASIS.

**Machine settings:** Standard sensory settings are used.

**Nerve fibers tested:** L2 and L3 nerve roots through the posterior division of the lumbosacral plexus.

**Normal values** (1) (20 subjects) (room temperature 23–26 degrees Celsius):

<table>
<thead>
<tr>
<th></th>
<th>Mean (msec)</th>
<th>S.D.</th>
<th>Range (msec)</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1 (14–18 cm)</td>
<td>2.5</td>
<td>0.2</td>
<td>2.2–2.8</td>
<td>2.9</td>
</tr>
<tr>
<td>S2 (17–20 cm)</td>
<td>2.8</td>
<td>0.4</td>
<td>2.3–3.2</td>
<td>3.6</td>
</tr>
</tbody>
</table>

**Peak-to-peak amplitude (µV)**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>7.0</td>
<td>1.8</td>
<td>4–11</td>
</tr>
<tr>
<td>S2</td>
<td>6.0</td>
<td>1.5</td>
<td>3–10</td>
</tr>
</tbody>
</table>

**Helpful Hints**

- This study is technically difficult, especially in overweight persons. Absent responses are of questionable clinical significance.
- For S2 stimulation it may help to exert pressure toward the ASIS. Rotating the anode may be necessary to reduce stimulus artifact.
Typical waveform appearance

Electrode Placement—Spevak and Prevec Technique
Spevak and Prevec Technique

Position: This study is performed in the supine position.

Recording electrodes: Two 8-cm long strip electrodes are placed 2.5 cm apart (A and R) on the anterolateral thigh, approximately 25 cm distal to the stimulating electrode.

Ground electrode (G): Placement is between the stimulating and recording electrodes.

Stimulation point (S): Stimulation is applied 6–10 cm below the ASIS. The point where a sensation radiates to the lateral thigh is sought. Stimulus duration is 0.1 msec with the intensity set to double the sensory threshold and not above 150 V. Eight to 32 responses are averaged.

Machine settings: Sensitivity—1–2 µV/division, Low frequency filter—100 Hz, High frequency filter—5 kHz, Sweep speed—1 msec/division.

Normal values (2) (29 subjects—distance 25.3 ± 3.5 cm) (skin temperature over the thigh 29–32.5 degrees Celsius):

Onset latency (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>0.7</td>
<td>5.5</td>
</tr>
</tbody>
</table>

Peak latency (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.6</td>
<td>0.7</td>
<td>6.0</td>
</tr>
</tbody>
</table>

Nerve conduction velocity (m/sec) calculated for onset latency

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>62.3</td>
<td>5.5</td>
<td>51.3</td>
</tr>
</tbody>
</table>
**Peak-to-peak amplitude (µV)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

**Duration (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.9</td>
<td>0.5</td>
<td>2.9</td>
</tr>
</tbody>
</table>

**Acceptable Differences**

The side-to-side difference in conduction velocity is $2.6 \pm 2.2$ m/sec and never exceeded 6 m/sec in the cited study. The side-to-side difference in amplitude is $0.86 \pm 0.89$ µV.

**Helpful Hints**

- If the response is unobtainable, it is of doubtful clinical significance. If present, slowing of conduction velocity or a greater than normal side to side conduction velocity difference are most sensitive to pathology.

- This study will be normal in cases of purely local slowing across the inguinal ligament segment.

**Notes**

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________
REFERENCES


ADDITIONAL READINGS/ALTERNATE TECHNIQUES

Typical waveform appearance

Electrode Placement
**Position:** This study is performed in the supine position.

**Active electrode (A):** Placement is one-third of the distance from the apex of the heel to a point midway between the navicular tubercle and the prominence of the medial malleolus.

**Reference electrode (R):** Placement is over the apex of the heel.

**Ground electrode (G):** Placement is between the stimulating and recording electrodes.

**Stimulation point (S):** The cathode (C) is placed 10 cm proximal to the active electrode, measuring first to the posterior tip of the medial malleolus and then along the medial border of the tibia. The cathode is placed 1–2 cm posterior to the medial edge of the tibia. The anode (A) is proximal or rotated to minimize stimulus artifact.

**Machine settings:** Sensitivity—10–20 µV/division, Low frequency filter—2 Hz, High frequency filter—2 kHz, Sweep speed—1 msec/division.

**Nerve fibers tested:** S1 nerve root through the anterior division of the lumbosacral plexus and the tibial nerve.

**Normal values** (1) (36 subjects) (skin temperature greater than or equal to 31 degrees Celsius):

**Onset latency (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.7</td>
<td>0.3</td>
<td>1.4–2.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

**Peak latency (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>0.3</td>
<td>2.2–2.8</td>
<td>2.8</td>
</tr>
</tbody>
</table>
Baseline to peak amplitude ($\mu$V)

<table>
<thead>
<tr>
<th>Mean</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>8–34</td>
<td>8</td>
</tr>
</tbody>
</table>

Acceptable Differences

The upper limit of normal side-to-side difference in onset latency is 0.3 msec.

The upper limit of normal side-to-side difference in peak latency is 0.3 msec.

The upper limit of normal side-to-side difference in amplitude is 12 $\mu$V.

Helpful Hints

■ This sensory response may need to be averaged.

■ The sensory response is often followed by volume conducted motor artifact.

■ To derive the above normal values, the authors prepared the active and reference electrode sites with abrasive tape and cleansed the skin with alcohol.

Notes

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
REFERENCE

MEDIAL FEMORAL CUTANEOUS SENSORY NERVE

Typical waveform appearance

Electrode Placement
Position: This study is performed in the supine position.

Active electrode (A): The active electrode is placed 14 cm distal to the femoral pulse in the inguinal area, along an imaginary line from the pulse to the medial border of the patella.

Reference electrode (R): The reference electrode is placed 4 cm distal to the active electrode on this same imaginary line.

Ground electrode (G): Placement is proximal to the active electrode on the lateral thigh.

Stimulation point (S): The cathode (C) is placed immediately lateral to the femoral artery in the inguinal area. The anode (A) is proximal.

Machine settings: Sensitivity—5 µV/division, Low frequency filter—20 Hz, High frequency filter—2 kHz, Sweep speed—1 msec/division, Stimulator pulse duration—0.2 msec.

Nerve fibers tested: L2 and L3 nerve roots through the posterior division of the lumbosacral plexus and the femoral nerve.

Normal values (1) (32 subjects) (temperature over the mid-medial thigh of 33 degrees Celsius or more):

Onset latency (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.3–2.4</td>
<td>0.2</td>
<td>1.9–2.9</td>
<td>2.7–2.8</td>
</tr>
</tbody>
</table>

Peak latency (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.9</td>
<td>0.2–0.3</td>
<td>2.3–3.5</td>
<td>3.3–3.5</td>
</tr>
</tbody>
</table>

Onset to peak amplitude (µV)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.8–4.9</td>
<td>1.0</td>
<td>3.4–7.9</td>
</tr>
</tbody>
</table>
Helpful Hints

- Averaging of approximately five to 10 recordings is often necessary.
- Anode rotation is often required to reduce stimulus artifact.
- The stimulating electrodes may need to be moved medially or laterally to obtain a recording.
- The leg should be relaxed with the knee slightly flexed. It may be useful to support the knee with a pillow.

Notes

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
REFERENCE

Position: This study is performed in the supine position.

Active electrode (A): Placement is over the terminal sensory branch of the nerve at the interspace between the 1st and 2nd metatarsal heads.

Reference electrode (R): Placement is 3 cm distal to the active electrode on the 2nd digit.

Ground electrode (G): Placement is between the stimulating and recording electrodes on the dorsum of the foot.

Stimulation point (S): The cathode (C) is placed at the ankle, 12 cm proximal to the active electrode and just lateral to the extensor hallucis longus tendon. The anode (A) is proximal.

Machine settings: Averager is used (5–20 stimuli). Sensitivity—5 µV/division, Low frequency filter—20 Hz, High frequency filter—2 kHz, Sweep speed—1 msec/division.

Nerve fibers tested: L5 nerve root, through the posterior division of the lumbosacral plexus and the common and deep peroneal nerves.

Normal values (1) (40 subjects) (skin temperature over the dorsum of the foot greater than or equal to 29 degrees Celsius):

**Onset latency (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.9</td>
<td>0.4</td>
<td>2.1–3.6</td>
<td>3.7</td>
</tr>
</tbody>
</table>

**Peak latency (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.6</td>
<td>0.4</td>
<td>2.7–4.2</td>
<td>4.4</td>
</tr>
</tbody>
</table>

**Onset to peak amplitude (µV)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.4</td>
<td>1.2</td>
<td>1.6–6.6</td>
</tr>
</tbody>
</table>
REFERENCE

ADDITIONAL READINGS/ALTERNATE TECHNIQUES


SUPERFICIAL PERONEAL SENSORY NERVE (MEDIAL AND INTERMEDIATE DORSAL CUTANEOUS BRANCHES)

Typical waveform appearance

Electrode Placement
Izzo et al. Technique

Position: This study is performed in the supine position.

Active electrodes (A): Placement is at the level of the ankle after local-ization by inspection and palpation during plantar flexion and inversion. The medial branch passes over the anterior ankle to the dorsum of the foot. It lies just lateral to the tendon of the extensor hallucis longus. The intermediate branch lies 1–2 cm medial to the lateral malleolus.

Reference electrode (R): Placement is 3–4 cm distal to the active electrode for both branches (1,2).

Ground electrode (G): Placement is over the distal dorsal lower leg, between the active electrodes and the cathode.

Stimulation point (S): The cathode (C) is placed 14 cm proximal to the active electrode on the anterolateral aspect of the lower leg. The anode (A) is proximal.

Machine settings: Sensitivity—20 µV/division, Low frequency filter—20 Hz, High frequency filter—2 kHz, Sweep speed—2 msec/division.

Nerve fibers tested: L4, L5, and S1 nerve roots, through the posterior division of the lumbosacral plexus and the common peroneal nerve.
Normal values (1) (80 subjects) (ankle skin temperature of at least 28 degrees Celsius):

**Onset latency (msec)**

<table>
<thead>
<tr>
<th></th>
<th>Medial Branch</th>
<th>Intermediate Branch</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>2.8</td>
<td>2.8</td>
</tr>
<tr>
<td><strong>S.D.</strong></td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td>2.2–3.6</td>
<td>2.2–3.6</td>
</tr>
<tr>
<td><strong>Upper Limit of Normal</strong></td>
<td>3.4</td>
<td>3.4</td>
</tr>
</tbody>
</table>

**Peak latency (msec)**

<table>
<thead>
<tr>
<th></th>
<th>Medial Branch</th>
<th>Intermediate Branch</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>3.4</td>
<td>3.4</td>
</tr>
<tr>
<td><strong>S.D.</strong></td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td>2.7–4.7</td>
<td>2.8–4.6</td>
</tr>
<tr>
<td><strong>Upper Limit of Normal</strong></td>
<td>4.2</td>
<td>4.2</td>
</tr>
</tbody>
</table>

**Peak-to-peak amplitude (µV)**

<table>
<thead>
<tr>
<th></th>
<th>Medial Branch</th>
<th>Intermediate Branch</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>18.3</td>
<td>15.1</td>
</tr>
<tr>
<td><strong>S.D.</strong></td>
<td>8.0</td>
<td>8.2</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td>5–44</td>
<td>4–40</td>
</tr>
</tbody>
</table>
Data for 122 elderly subjects (unobtainable in 12), aged 60–89 years, mean 74.1, with skin temperature over the extensor digitorum brevis at least 29 degrees Celsius (2).

**Onset latency (msec)**

**Medial Branch**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>0.3</td>
<td>3.7</td>
</tr>
</tbody>
</table>

**Onset to peak amplitude (µV)**

**Medial Branch**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.7</td>
<td>3.9</td>
</tr>
</tbody>
</table>

**Helpful Hints**

- These nerve branches are superficial and can often be palpated or seen passing under the surface of the skin, especially when the foot is plantarflexed and inverted (1).
- A stimulus duration of 0.05–0.1 msec was used to derive the data presented by Izzo and colleagues (1).
- In approximately 2 percent of subjects a response is unobtainable from the intermediate branch (1).
Jabre Technique (Intermediate Branch)

Recording electrodes: A bar electrode is placed at the level of the lateral malleolus, one to two fingerbreadths medial to the malleolus. The active electrode (A) is proximal and the reference electrode (R) is distal (3,4).

Ground electrode (G): The ground electrode is placed over the anterior lower leg, between the stimulating and recording electrodes.

Stimulation point (S): The cathode (C) is placed 12 cm proximal to the active electrode with the stimulator probe held firmly against the anterior aspect of the fibula. The anode (A) is proximal.

Machine settings: Sensitivity—10 µV/division, Low frequency filter—32 Hz, High frequency filter—1.6 kHz, Sweep speed—2 msec/division.

Normal values (3) (36 subjects) (data derived at an ambient temperature of 70 degrees Fahrenheit):

Peak latency (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.9</td>
<td>0.3</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Onset to negative peak amplitude (µV)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.5</td>
<td>6.1</td>
</tr>
</tbody>
</table>

Helpful Hints

- In some cases the nerve can be palpated for easier localization.
- A relatively low stimulus intensity may be necessary to avoid contamination by motor artifact.
- The data reported here were derived using a 0.05 msec pulse duration. A 0.1 msec pulse duration may be required in some cases.
- A second, more proximal stimulation allows for calculation of a conduction velocity. Stimulation is applied 8–9 cm proximal to the above-described stimulation point. The conduction velocity of 17 subjects was 65.7 ± 3.7 m/sec between these points (3).
REFERENCES


ADDITIONAL READINGS/ALTERNATE TECHNIQUES

Typical waveform appearance

Electrode Placement
Position: This study is performed in the prone position.

Recording electrodes: A bar electrode is placed at the midline of the posterior thigh, with the active electrode (A) 6 cm proximal to the mid-popliteal region. The reference (R) electrode is distal.

Ground electrode (G): Placement is just proximal to the bar electrode.

Stimulation point (S): The cathode (C) is placed 12 cm proximal to the active electrode on a line connecting the active electrode with the ischial tuberosity, in the groove between the medial and lateral hamstring musculature (the intermuscular groove can be palpated by having the subject flex the knee. The anode (A) is proximal.

Machine settings: Sensitivity—5 µV/division, Low frequency filter—20 Hz, High frequency filter—2 kHz, Sweep speed—1–2 msec/division.

Nerve fibers tested: Posterior divisions of the S1 and S2 nerve roots and anterior divisions of the S2 and S3 nerve roots.

Normal values (1) (40 subjects) (skin temperature of the posterior thigh maintained between 32 and 33 degrees Celsius):

Peak latency (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.8</td>
<td>0.2</td>
<td>2.3–3.3</td>
<td>3.2</td>
</tr>
</tbody>
</table>

Peak-to-peak amplitude (µV)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.5</td>
<td>1.5</td>
<td>4.1–12.0</td>
</tr>
</tbody>
</table>

Helpful Hint

- Local depolarization of the surrounding musculature may occur on stimulation. This does not generally obscure the sensory waveform but is a theoretical confounding factor.
REFERENCE

SAPHENOUS NERVE

SAPHENOUS SENSORY NERVE (DISTAL TECHNIQUE)

Electrode Placement

Typical waveform appearance
Position: This study is performed in the supine position.

Recording electrodes: A 3-cm bar electrode is used. The reference electrode (R) is positioned slightly anterior to the highest prominence of the medial malleolus, between the malleolus and the tendon of the tibialis anterior. The active electrode (A) is proximal and slightly medial to the tibialis anterior tendon.

Ground electrode (G): Placement is between the recording electrodes and the cathode.

Stimulation point (S): The cathode (C) is placed 14 cm proximal to the active electrode deep to the medial border of the tibia. The anode (A) is proximal.

Machine settings: Sensitivity—2–5 µV/division, Low frequency filter—20 Hz, High frequency filter—2 kHz, Sweep speed—1 msec/division.

Nerve fibers tested: L3 and L4 nerve roots, through the posterior division of the lumbosacral plexus. This nerve is a continuation of the femoral nerve.

Normal values (1) (230 subjects) (skin temperature over the dorsum of the foot greater than or equal to 32 degrees Celsius):

Onset latency (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2</td>
<td>0.3</td>
<td>2.1–3.9</td>
<td>3.8</td>
</tr>
</tbody>
</table>

Peak latency (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.8</td>
<td>0.3</td>
<td>2.3–4.6</td>
<td>4.4</td>
</tr>
</tbody>
</table>

Onset to peak amplitude (µV)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>3</td>
<td>1–15</td>
<td>2</td>
</tr>
</tbody>
</table>
**Peak-to-peak amplitude (nVsec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>4</td>
<td>1–24</td>
<td>1</td>
</tr>
</tbody>
</table>

**Area under the curve from onset to positive peak (nVsec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>3</td>
<td>1–16</td>
<td>1</td>
</tr>
</tbody>
</table>

**Duration (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.3</td>
<td>0.3</td>
<td>0.4–2.3</td>
<td>1.9</td>
</tr>
</tbody>
</table>

**Acceptable Differences**

The upper limit of normal increase in onset and peak latency from one side to the other is 0.5 msec.

The upper limit of normal decrease in onset to peak amplitude from one side to the other is 65%.

The upper limit of normal decrease in peak-to-peak amplitude from one side to the other is 78%.

The upper limit of normal difference between sural and saphenous onset latency in the same limb is 0.3 msec in cases where the sural has the longer latency; it is 0.7 msec in cases where the saphenous latency is longer.

The upper limit of normal difference between sural and saphenous peak latency in the same limb is 0.5 msec in cases where the sural has the longer latency; it is 0.6 msec in cases where the saphenous latency is longer.

**Helpful Hints**

- Small amplitudes are common.
- Firm pressure should be applied to the stimulator. The plantar flexors should be relaxed and the ankle can be placed in slight plantarflexion (2).
- Averaging may be necessary.
This response is often unrecordable.

A sweep speed of 5 msec/division has been described to improve visualization of the waveform with low amplitude potentials (2).

REFERENCES


ADDITIONAL READING

Typical waveform appearance

Electrode Placement
**Position:** This study is performed in the supine position.

**Recording electrodes:** The active electrode (A) is placed 15 cm distal to the cathode on the medial border of the tibia. The reference electrode (R) is placed 3 cm distally. A 3 cm bar electrode can be used.

**Ground electrode (G):** Placement is between the stimulating and recording electrodes.

**Stimulation point (S):** The knee is slightly flexed. The cathode (C) is placed on the medial knee between the tendons of the sartorius and gracilis muscles, approximately 1 cm above the level of the inferior border of the patella. The anode (A) is proximal.

**Machine settings:** Sensory settings are used.

**Nerve fibers tested:** L3 and L4 nerve roots, through the posterior division of the lumbosacral plexus. This nerve is a continuation of the femoral nerve.

**Normal values** (1) (28 subjects—over a 13–16 cm distance) (room temperature 23–26 degrees Celsius):

**Onset latency (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>0.19</td>
<td>2.2–2.8</td>
<td>2.88</td>
</tr>
</tbody>
</table>

**Peak to peak amplitude (µV)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.23</td>
<td>2.05</td>
<td>7.0–15.0</td>
</tr>
</tbody>
</table>

**Helpful Hints**

- This nerve may be difficult to localize, especially in obese persons. The hamstring tendon can be palpated at the posterior aspect of the medial knee. Anterior to this is the gracilis, then the sartorius.
If stimulation is performed too far anteriorly, subjects may report a sensation in the patellar region. They should feel paresthesias in the medial foreleg to the ankle.

Firm pressure should be applied to the stimulating and recording electrodes.

A study of the infrapatellar branch of the saphenous nerve has also been described (2). Twenty-five subjects were tested using an active electrode at the inferior medial edge of the patella with the reference electrode on the lower edge of the patella. Stimulation was applied just superior to the medial epicondyle of the femur between the sartorius and gracilis muscles. Onset latency was $1.56 \pm 0.3$ msec. Peak latency was $1.9 \pm 0.2$ msec. Baseline to peak amplitude was $4 \pm 2.1$ µV. Maximum side-to-side difference was 0.4 msec for latency and 3.7 µV for amplitude. A response was obtained in 90% of subjects after averaging 20 recordings.
REFERENCES


SURAL NERVE

SURAL LATERAL DORSAL CUTANEOUS BRANCH SENSORY NERVE

Electrode Placement
**Position:** This study is performed in the supine position.

**Recording electrodes:** Felt-tip electrodes with a fixed interelectrode distance of 37 mm were used in the cited study. Placement is such that the active electrode (A) is over the dorsolateral surface of the foot at the midpoint of the 5th metatarsal and just lateral to the extensor digitorum brevis tendon of the 5th toe. The reference electrode (R) is distal.

**Ground electrode (G):** Placement is on the dorsum of the foot.

**Stimulation point (S):** The cathode (C) is placed 12 cm proximal to the active electrode behind the lateral malleolus. The anode (A) is proximal.

**Machine settings:** Averager is used (5–10 stimuli). Sensitivity—5 µV/division, Low frequency filter—20 Hz, High frequency filter—2 kHz, Sweep speed—1 msec/division.

**Nerve fibers tested:** S1 and S2 nerve roots, through the anterior and posterior divisions of the lumbosacral plexus and the tibial and peroneal nerves.

**Normal values** (1) (40 subjects) (skin temperature over the dorsum of the foot greater than or equal to 31 degrees Celsius):

**Onset latency (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2</td>
<td>0.4</td>
<td>2.5–4.0</td>
<td>4.0</td>
</tr>
</tbody>
</table>

**Peak latency (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.9</td>
<td>0.5</td>
<td>3.0–4.9</td>
<td>4.9</td>
</tr>
</tbody>
</table>

**Baseline to peak amplitude (µV)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.8</td>
<td>2.1</td>
<td>3.0–11.0</td>
</tr>
</tbody>
</table>
REFERENCE


ADDITIONAL READING/ALTERNATE TECHNIQUE

SURAL SENSORY NERVE

Typical waveform appearance

Electrode Placement
**Position**: This study is performed in the side-lying position.

**Recording electrodes**: A 3-cm bar electrode is used. Placement of the active electrode (A) is behind the lateral malleolus with the reference electrode (R) distal.

**Ground electrode (G)**: Placement is between the stimulating and recording electrodes.

**Stimulation point (S)**: The cathode (C) is placed 14 cm proximal to the active electrode in the midline or slightly lateral to the midline of the posterior lower leg. The anode (A) is proximal.

**Machine settings**: Sensitivity—2–5 µV/division, Low frequency filter—20 Hz, High frequency filter—2 kHz, Sweep speed—1 msec/division.

**Nerve fibers tested**: S1 and S2 nerve roots, through the anterior and posterior divisions of the lumbosacral plexus and the tibial and peroneal nerves.

**Normal values** (1) (230 subjects) (skin temperature over the dorsum of the foot greater than or equal to 32 degrees Celsius):

**Onset latency (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>0.3</td>
<td>2.2–3.9</td>
<td>3.6</td>
</tr>
</tbody>
</table>

**Peak latency (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.8</td>
<td>0.3</td>
<td>2.8–4.6</td>
<td>4.5</td>
</tr>
</tbody>
</table>

**Onset to peak amplitude (µV)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>10</td>
<td>2–56</td>
<td>4</td>
</tr>
</tbody>
</table>
Peak-to-peak amplitude (µV)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>12</td>
<td>3–69</td>
<td>4</td>
</tr>
</tbody>
</table>

Area under the curve from onset to positive peak (nVsec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Lower Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>8</td>
<td>2–54</td>
<td>4</td>
</tr>
</tbody>
</table>

Duration (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6</td>
<td>0.3</td>
<td>1.0–2.1</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Acceptable Differences

The upper limit of normal increase in onset latency from one side to the other is 0.4 msec.

The upper limit of normal increase in peak latency from one side to the other is 0.5 msec.

The upper limit of normal decrease in onset to peak amplitude from one side to the other is 72%.

The upper limit of normal decrease in peak-to-peak amplitude from one side to the other is 67%.

The upper limit of normal difference between sural and saphenous onset latency in the same limb is 0.3 msec in cases where the sural has the longer latency; it is 0.7 msec in cases where the saphenous latency is longer.

The upper limit of normal difference between sural and saphenous peak latency in the same limb is 0.5 msec in cases where the sural has the longer latency; it is 0.6 msec in cases where the saphenous latency is longer.

Helpful Hints

- The stimulator may need to be moved slightly to one side or the other to obtain a response.
- The technique is best performed with the subject lying on his side.
- Occasionally the responses may need to be averaged.
REFERENCE


ADDITIONAL READINGS

TIBIAL MIXED NERVE (MEDIAL AND LATERAL PLANTAR BRANCHES)

Typical waveform appearance

Electrode Placement
**Position:** This study is performed in the supine position.

**Recording electrodes:** A bar electrode is placed over the tibial nerve just proximal to the flexor retinaculum (proximal to a line from the posterior calcaneus to the medial malleolus. The active electrode (A) is distal and the reference electrode (R) is proximal (1).

**Ground electrode (G):** Placement is over the dorsum of the foot.

**Stimulation points (S):** The cathode (C) is placed 14 cm distal to the active recording electrode as shown in the accompanying figure for both the medial and lateral plantar branches. The anode (A) is distal. For the medial branch the distance is measured 10 cm to the interspace between the 1st and 2nd metatarsals and then 4 cm distally. For the lateral branch the stimulation site is between the 4th and 5th metatarsals (1).

**Machine settings:** Routine sensory settings are used.

**Normal values** (2) (41 subjects) (skin temperature over the tarsal tunnel and the medial and lateral sole of the foot 26–32 degrees Celsius):

**Peak latency (msec)**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial</td>
<td>3.16</td>
<td>0.26</td>
<td>2.6–3.7</td>
<td>3.68</td>
</tr>
<tr>
<td>Lateral</td>
<td>3.15</td>
<td>0.25</td>
<td>2.7–3.7</td>
<td>3.65</td>
</tr>
</tbody>
</table>

**Amplitude (µV)**

<table>
<thead>
<tr>
<th></th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial</td>
<td>10–30</td>
</tr>
<tr>
<td>Lateral</td>
<td>8–20</td>
</tr>
</tbody>
</table>
Helpful Hints

■ Although technically a mixed nerve study, this technique approximates a sensory study.

■ Firm pressure should be exerted on the stimulating and recording electrodes.

■ Stimulus artifact may interfere with the recording, especially in persons with thick plantar skin.

■ This response is often difficult to elicit even in normal subjects. Unelicitable waveforms must be interpreted with caution.

Notes ______________________________________________________
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
REFERENCES


ADDITIONAL READINGS/ALTERNATE TECHNIQUES


CHAPTER 5

Head and Neck Studies
BLINK REFLEX

Electrode Placement
Figure 17-1, from *Electrodiagnosis in Diseases of Nerve and Muscle*, 3rd ed., by Jun Kimura, copyright © 2001 by Oxford University Press, Inc. Used by permission of Oxford University Press, Inc.
Active electrode (A): Placement is over the lower lateral orbicularis oculi muscle bilaterally (1).

Reference electrode (R): Placement is over the temple or the lateral surface of the nose above the nasalis muscle (1,2).

Ground electrode (G): Placement is under the chin or on the forehead or cheek (1,2).

Stimulation point (S): Stimulation is applied with the cathode (C) over the supraorbital nerve at the supraorbital notch. The anode (A) is superiolateral. (Direct stimulation can also be applied to the facial nerve—see section on CN VII) (1,2).

Machine settings: Sensitivity—50–200 µV, Low frequency filter—20 Hz, High frequency filter—10 kHz, Sweep speed—10 msc/division (1,2).

Nerve fibers tested: Afferent CN V and efferent CN VII fibers, as well as their central connections.

Normal values (1)(83 subjects) (Upper limit of normal = mean + 3 S.D.):

Direct latency (D) to facial nerve stimulation (msec)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>2.9</td>
<td>0.4</td>
<td>4.1</td>
</tr>
</tbody>
</table>

R1 latency (msec)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>10.5</td>
<td>0.8</td>
<td>13.0</td>
</tr>
</tbody>
</table>

Ipsilateral R2 latency (msec)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>R2</td>
<td>30.5</td>
<td>3.4</td>
<td>40</td>
</tr>
</tbody>
</table>
**Contralateral R2 latency (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>30.5</td>
<td>4.4</td>
<td>41</td>
</tr>
</tbody>
</table>

**Acceptable Differences**

The upper limit of normal side-to-side difference in direct response latency (D) is 0.6 msec.

The upper limit of normal side to side difference in R1 latency is 1.2 msec (3 S.D.).

The upper limit of normal side-to-side difference in R2 latency evoked by stimulation on one side (dual channel recording) is 5 msec. If the R2 is recorded by first stimulating one side and then the other (single channel recording), the upper limit of normal difference is 7 msec.

**Helpful Hints**

- The subject should be relaxed.
- The R2 latency may be variable.
- Several blink responses should be tested and the shortest latencies chosen. Kimura recommends that at least eight trials be performed (1).
- Latency should be measured to the first deflection from the baseline.
- Excessive numbers of stimuli may lead to habituation and should be avoided.
- A ratio of R1 latency (R) to the direct response latency (D) to facial nerve stimulation (see section on CN VII) can be calculated. This R/D ratio should not fall outside the range of 2.6 to 4.6 (1). A larger ratio, with a normal D, is indicative of slowing of the trigeminal portion of the arc. If the R/D ratio is low, it is indicative of slowing of the facial nerve component.
■ Care should be taken to aim the anode away from the contralateral side so that bilateral stimulation is not performed inadvertently.

■ In 5–10% of normal subjects paired stimuli are necessary to record a stable R1 (1).

■ A glabellar tap with a special hammer can be used instead of electrical stimulation.

Notes ___________________________________________________________
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
REFERENCES


ADDITIONAL READINGS/ALTERNATE TECHNIQUES

Electrode Placement
Position: This study is performed in the seated position.

Active electrode (A): Placement can be over the nasalis, orbicularis oris, orbicularis oculi, and levator labii superioris (or essentially any muscle innervated by the nerve). For recording from the nasalis, the active electrode is placed on the lateral mid-nose. The subject may “wrinkle the nose” and the electrode is placed on the most prominent bulge of the muscle. For the orbicularis oculi the active electrode is placed under the eye in line with the pupil. An alternate position is at the lateral border of the eye. For the orbicularis oris the active electrode is placed lateral to the angle of the mouth (1-4).

Reference electrode (R): Placement is on the tip or bridge of the nose (1,2).

Ground electrode (G): Placement is over the base of the neck or on the cheek (1,2).

Stimulation point (S): Preauricular stimulation is performed with the cathode (C) just anterior to the lower ear over the substance of the parotid gland and several centimeters superior to the angle of the mandible. Postauricular stimulation is performed by placing the cathode just behind the lower ear, below the mastoid process and behind the neck of the mandible. The anode (A) is posterior (1,2).

Machine settings: Sensitivity—200–1000 µV, Low frequency filter—8 Hz, High frequency filter—8 kHz, Sweep speed—1–2 msec/division (2).

Nerve fibers tested: CN VII efferent motor fibers.
Normal values (1) (44 subjects) (room temperature 23–26 degrees Celsius):

**Preauricular stimulation latency to the nasalis (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.57</td>
<td>0.35</td>
<td>2.8–4.1</td>
</tr>
</tbody>
</table>

**Postauricular stimulation latency to the nasalis (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.88</td>
<td>0.36</td>
<td>3.2–4.4</td>
</tr>
</tbody>
</table>

**Acceptable Difference**

A side-to-side difference in amplitude of greater than 50% is suggestive of pathology, but the waveform must be similar on both sides (2).

**Helpful Hints**

- Serial study of the amplitude may be clinically useful.
- Recordings may be made from any CN VII muscle. Surface recording is preferred as this allows assessment of amplitude. The amplitude should be measured from onset to the peak of the negative wave. Needle recording technique has also been described (3,4). With concentric needle recording from the orbicularis oris and stimulation with the cathode over the stylomastoid foramen, the latency in 40 adult subjects was reported as 4.0 ± 0.5 msec (3).
- The motor points in the facial muscles may be poorly defined and an initially negative deflection may not be obtained. If this is the case, latency should be recorded at the initial deflection from baseline (2).
- In cases of CN VII pathology, direct activation of the masseter, especially when recording from orbicularis oris, can give a false volume conducted response. This muscle can be palpated to ensure that this is not occurring. If this is a confounding factor, the facial nerve can be stimulated under the zygoma. This results in a shorter latency recording, but side to side comparisons can still be made (2).
REFERENCES


ADDITIONAL READINGS/ALTERNATE TECHNIQUES

Typical waveform appearance

Electrode Placement
Position: This study is performed in the seated position.

Active electrode (A): Placement is over the upper trapezius, about 9 cm lateral to the 7th spinous process.

Reference electrode (R): Placement is 3 cm lateral to the active electrode.

Ground electrode (G): Placement is between the stimulating and recording electrodes.

Stimulation point (S): The cathode (C) is placed in the posterior triangle of the neck, 1–2 cm posterior to the posterior border sternocleidomastoid muscle and slightly above the midpoint of this muscle. This is a point halfway between the mastoid process and the suprasternal notch. The anode (A) is superior (1,2).

Nerve fibers tested: CN XI.

Machine settings: Standard motor settings are used, with a sweep speed of 1–2 msec/division (2).

Normal values (1) (28 subjects) (room temperature 23–26 degrees Celsius):

<table>
<thead>
<tr>
<th>Onset latency (msec)</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.3</td>
<td>0.4</td>
<td>1.7–3.0</td>
</tr>
</tbody>
</table>

Peak-to-peak amplitude (mV)

>3–4

Helpful Hints

- Care should be taken not to stimulate the brachial plexus.
- The shoulder should shrug with activation of CN XI.
REFERENCES


ADDITIONAL READINGS/ALTERNATE TECHNIQUES

GREATER AURICULAR SENSORY NERVE

Typical waveform appearance

Electrode Placement
**Position**: This study is performed in the seated position.

**Recording electrodes**: Placement is on the back of the ear lobe, 2 cm apart. The active electrode (A) is inferior.

**Ground electrode (G)**: Placement is on the back of the neck.

**Stimulation point (S)**: Stimulation is applied along the lateral border of the sternocleidomastoid muscle, with the cathode (C) superior and located 8 cm from the active electrode. The anode (A) is inferior.

**Machine settings**: Low frequency filter 32 Hz, high frequency filter 3.2 kHz, sweep speed 1 msec/division, gain 20 µV/division.

**Nerve fibers tested**: C2 and C3 nerve roots.

**Normal values** (1) (64 nerves in 32 subjects, ranging in age from 14–88 years) (skin temperature maintained at or above 33 degrees Celsius):

**Onset latency (msec)**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.34</td>
<td>0.15</td>
<td>1.64</td>
</tr>
</tbody>
</table>

**Peak latency (msec)**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.89</td>
<td>0.21</td>
<td>2.31</td>
</tr>
</tbody>
</table>

**Peak-to-peak amplitude (mV)**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>22.4</td>
<td>8.93</td>
</tr>
</tbody>
</table>

**Duration (msec) (2)**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.8</td>
<td>0.2</td>
<td>12</td>
</tr>
</tbody>
</table>
Helpful Hints

- This study may be difficult to perform in those subjects who are heavy-set with short necks.
- Recording may be done from the mastoid process (2).
- Palliyath found similar peak latencies of 1.7 ± 0.2 msec; onset to peak amplitudes were 12.7 ± 4.1 µV (2).

REFERENCES

CHAPTER 6

Root Stimulation
CERVICAL NERVE ROOT STIMULATION

Recording electrodes: Depending on which nerve roots are being tested, placement is over the motor points of the abductor digiti minimi (C8–T1 roots), biceps (C5–C6 roots), or triceps (C6–C8 roots) muscles. The reference electrode is placed over a distal tendon (1).

Stimulation point (S): Stimulation is performed with a 50 mm monopolar needle electrode. This cathode is inserted perpendicular to the skin immediately lateral to the spinous processes so that the tip rests on the vertebral laminae. For the C5/C6 root, the needle is placed at the level of the C5 vertebra. For the C6/C7/C8 roots, the needle is placed at the level of the C6 vertebra. The C8/T1 roots are stimulated at the level of the C7 vertebra. The anode is a surface electrode and is placed 1 cm caudal and slightly medial to the cathode.

Machine settings: Low frequency filter—8 Hz, High frequency filter—8 kHz.

Acceptable Differences (1) (30 root pairs in 12 subjects)

The upper limit of normal latency asymmetry from side to side is 1.0 msec.

The upper limit of normal amplitude asymmetry (percentage reduction from the larger to the smaller value) from side-to-side is 20%.

Helpful Hints

■ Needle recording has also been recommended when recording from the triceps (2). Reliable amplitude measurements can, however, only be made using surface electrode recording.

■ A slightly different stimulation procedure has also been studied. Stimulation is similar to that described above, but the monopolar needle electrode is inserted 1–2 cm lateral and inferior to the corresponding spinous processes. The needle is inserted until bone is encountered and is then withdrawn several millimeters. A stimulus duration of 0.05 msec is usually adequate. The anode can be
either a surface electrode or another monopolar needle electrode inserted at the same site contralaterally (2-4).

- This is a nonspecific test and does not alone make the diagnosis of radiculopathy. Any other pathology along the route of the nerve can cause slowing, so other pathology needs to be ruled out.
- Side-to-side comparison is limited if pathology is bilateral.
- A reduction in amplitude of 50% or more between limb stimulation and root stimulation has been used to define a proximal conduction block. The limb stimulation is applied above the common sites of nerve compression (for example, for the ulnar nerve it is applied above the elbow) (5).
REFERENCES


ADDITIONAL READINGS/ALTERNATE TECHNIQUES


LUMBAR NERVE ROOT STIMULATION

Electrode Placement

S1

S2
**Recording electrodes:** The active and reference electrodes can be placed on any appropriate muscle of the lower extremity (1–3). The active electrode is placed over the motor point or central portion of the muscle. The reference electrode is placed over the distal tendinous insertion of that muscle. Needle recording may be used.

**Ground electrode:** Placement is between the stimulating and recording electrodes.

**Stimulation point 1 (S1):** A 50–75 mm monopolar needle electrode is used as the cathode. To access the L2/L3/L4 nerve roots, the needle is inserted 2–2.5 cm lateral to the spinous process of the L4 vertebral body. The needle is positioned on the periosteum of the vertebral arch overlying the L4 root. The anode is also a needle electrode and is located on the contralateral side in a similar position (1,2).

To access the L5/S1 nerve roots, a similar setup is used but the needle electrodes are inserted just medial and a bit caudal to the posterior superior iliac spine (1,2).

An alternate technique for the L5/S1 root has been described, which involves placing a superficial electrode on the abdomen as the anode. It is placed opposite the cathode (3).

**Stimulation point 2 (S2) (optional):** For the L2/L3/L4 nerve roots, a second stimulus can be applied to the femoral nerve at the inguinal region (see section on femoral nerve). For the L5/S1 roots, a second stimulus can be applied to the sciatic nerve at the gluteal fold (see section on sciatic nerve). The latency from S2 stimulation is subtracted from the S1 latency to calculate a trans-plexus conduction time (1,2).

**Machine settings:** Sensitivity—2–5 mV/division, Low frequency filter—10 Hz, High frequency filter—10 kHz, Sweep speed—2–5 msec/division (1).
Normal values:

**L5/S1 latency to the soleus (msec) (3)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.4</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Side-to-side difference: 0.2 msec (range 0.0–0.8)

**Latency to tibialis anterior (msec) (4) (12 subjects)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.5</td>
<td>1.2</td>
<td>11.4–15.9</td>
</tr>
</tbody>
</table>

**Latency to tibialis anterior (msec) (5) (30 subjects)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.4</td>
<td>1.3</td>
<td>10.8–13.7</td>
</tr>
</tbody>
</table>

Side-to-side difference: mean 0.3 ± 0.2 msec (range 0.0–0.9)
Upper limit of normal difference: <0.7 msec

**Latency to flexor hallucis brevis (msec) (4) (14 subjects)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.1</td>
<td>2.0</td>
</tr>
</tbody>
</table>

**L2/L3/L4 Trans-plexus conduction time recording from the vastus medialis (msec) (1,2)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.4</td>
<td>0.6</td>
<td>2.0–4.4</td>
<td>4.6</td>
</tr>
</tbody>
</table>

Side-to-side difference: 0.0–0.9 msec
**L5/S1 Trans-plexus conduction time recording from the abductor hallucis (msec) (1,2)**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Upper Limit of Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.9</td>
<td>0.7</td>
<td>2.5–4.9</td>
<td>5.3</td>
</tr>
</tbody>
</table>

Side-to-side difference: 0.0–1.0 msec

**Amplitude to tibialis anterior (mV) (5) (30 subjects)**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5.7</td>
<td>2.4</td>
<td>3.2–10.5</td>
</tr>
</tbody>
</table>

Side-to-side difference: mean 3.8% ± 2.9 (range 1.4–12.7)

Upper limit of normal difference: 9.6%

**Area to tibialis anterior (µVsec) (5) (30 subjects)**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25.2</td>
<td>9.6</td>
<td>15.7–41.3</td>
</tr>
</tbody>
</table>

Side-to-side difference: 6.1% ± 3.1 (range 3.6–17.1)

Upper limit of normal difference: 12.3%

**Helpful Hints**

- A reduction in amplitude of 50% or more between limb stimulation and root stimulation has been used to define a proximal conduction block. The limb stimulation is applied above the common sites of nerve compression (for example, for the peroneal nerve it is applied above the knee) (6).
REFERENCES


ADDITIONAL READING/ALTERNATE TECHNIQUE

The following is a list of some other nerve conduction tests that have been published. This list obviously is not all-inclusive, but it does give the reader references for other studies that may be necessary from time to time. It is anticipated that most of these studies will not be performed routinely by most electrodiagnostics. As a rule, these studies also require more in-depth reading, study, and practice than is possible to summarize in the format of the preceding sections.

**Autonomic Nervous System**


**Axillary F-Loop/Central Latency**


**Axillary Sensory Nerve Conduction**


**Bulbocavernosus Reflex/Perineal/Pudendal Nerve Conduction**


**Dorsal Nerve of the Penis**


**Dorsal Rami, Sensory Conduction**


**Dorsal Scapular Nerve Motor Conduction**


**Femoral/Obturator Nerves**


**Hypoglossal Motor Nerve Conduction**

**Ilioinguinal Nerve Conduction**


**Intercostal Nerve Conduction**


**Lateral Cutaneous Sensory Nerve of the Calf**


**Near-Nerve Needle Conduction Studies**


**Posterior Interosseous Sensory Response**

**Quadriceps Late Responses**


**Radial Nerve Motor Conduction Study to the Triceps**


**Repetitive Stimulation**


**Trigeminal Motor Nerve Conduction**


**Trigeminal Sensory Nerve Conduction**

This page intentionally left blank
APPENDIX

BMI Tables
**BMI (body mass index—kg/m²)**

<table>
<thead>
<tr>
<th>Height (cm)</th>
<th>45</th>
<th>50</th>
<th>55</th>
<th>60</th>
<th>65</th>
<th>70</th>
<th>75</th>
<th>80</th>
<th>85</th>
<th>90</th>
<th>95</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>20</td>
<td>22</td>
<td>24</td>
<td>27</td>
<td>29</td>
<td>31</td>
<td>33</td>
<td>36</td>
<td>38</td>
<td>40</td>
<td>42</td>
<td>44</td>
</tr>
<tr>
<td>160</td>
<td>18</td>
<td>20</td>
<td>21</td>
<td>23</td>
<td>25</td>
<td>27</td>
<td>29</td>
<td>31</td>
<td>33</td>
<td>35</td>
<td>37</td>
<td>39</td>
</tr>
<tr>
<td>170</td>
<td>16</td>
<td>17</td>
<td>19</td>
<td>21</td>
<td>22</td>
<td>24</td>
<td>26</td>
<td>28</td>
<td>29</td>
<td>31</td>
<td>33</td>
<td>35</td>
</tr>
<tr>
<td>180</td>
<td>14</td>
<td>15</td>
<td>17</td>
<td>19</td>
<td>20</td>
<td>22</td>
<td>23</td>
<td>25</td>
<td>26</td>
<td>28</td>
<td>29</td>
<td>31</td>
</tr>
<tr>
<td>190</td>
<td>12</td>
<td>14</td>
<td>15</td>
<td>17</td>
<td>18</td>
<td>19</td>
<td>21</td>
<td>22</td>
<td>24</td>
<td>25</td>
<td>26</td>
<td>28</td>
</tr>
<tr>
<td>200</td>
<td>11</td>
<td>13</td>
<td>14</td>
<td>15</td>
<td>16</td>
<td>18</td>
<td>19</td>
<td>20</td>
<td>21</td>
<td>23</td>
<td>24</td>
<td>25</td>
</tr>
<tr>
<td>Height (in)</td>
<td>110</td>
<td>115</td>
<td>120</td>
<td>125</td>
<td>130</td>
<td>135</td>
<td>140</td>
<td>145</td>
<td>150</td>
<td>155</td>
<td>160</td>
<td>165</td>
</tr>
<tr>
<td>------------</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>5'0&quot;</td>
<td>21</td>
<td>22</td>
<td>23</td>
<td>24</td>
<td>25</td>
<td>26</td>
<td>27</td>
<td>28</td>
<td>29</td>
<td>30</td>
<td>31</td>
<td>32</td>
</tr>
<tr>
<td>5'1&quot;</td>
<td>21</td>
<td>22</td>
<td>23</td>
<td>24</td>
<td>25</td>
<td>26</td>
<td>27</td>
<td>28</td>
<td>29</td>
<td>30</td>
<td>31</td>
<td>32</td>
</tr>
<tr>
<td>5'2&quot;</td>
<td>20</td>
<td>21</td>
<td>22</td>
<td>23</td>
<td>24</td>
<td>25</td>
<td>26</td>
<td>27</td>
<td>28</td>
<td>29</td>
<td>30</td>
<td>31</td>
</tr>
<tr>
<td>5'3&quot;</td>
<td>19</td>
<td>20</td>
<td>21</td>
<td>22</td>
<td>23</td>
<td>24</td>
<td>25</td>
<td>26</td>
<td>27</td>
<td>28</td>
<td>29</td>
<td>30</td>
</tr>
<tr>
<td>5'4&quot;</td>
<td>19</td>
<td>20</td>
<td>21</td>
<td>21</td>
<td>22</td>
<td>23</td>
<td>24</td>
<td>25</td>
<td>26</td>
<td>27</td>
<td>28</td>
<td>29</td>
</tr>
<tr>
<td>5'5&quot;</td>
<td>18</td>
<td>19</td>
<td>20</td>
<td>21</td>
<td>21</td>
<td>22</td>
<td>23</td>
<td>24</td>
<td>25</td>
<td>26</td>
<td>27</td>
<td>28</td>
</tr>
<tr>
<td>5'6&quot;</td>
<td>18</td>
<td>19</td>
<td>19</td>
<td>20</td>
<td>21</td>
<td>22</td>
<td>23</td>
<td>24</td>
<td>25</td>
<td>26</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>5'7&quot;</td>
<td>17</td>
<td>18</td>
<td>19</td>
<td>20</td>
<td>20</td>
<td>21</td>
<td>22</td>
<td>23</td>
<td>23</td>
<td>24</td>
<td>25</td>
<td>26</td>
</tr>
<tr>
<td>5'8&quot;</td>
<td>17</td>
<td>17</td>
<td>18</td>
<td>19</td>
<td>20</td>
<td>21</td>
<td>21</td>
<td>22</td>
<td>22</td>
<td>23</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>5'9&quot;</td>
<td>16</td>
<td>17</td>
<td>17</td>
<td>18</td>
<td>19</td>
<td>20</td>
<td>21</td>
<td>21</td>
<td>22</td>
<td>23</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>5'10&quot;</td>
<td>16</td>
<td>17</td>
<td>17</td>
<td>18</td>
<td>19</td>
<td>20</td>
<td>21</td>
<td>22</td>
<td>22</td>
<td>23</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>5'11&quot;</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>18</td>
<td>19</td>
<td>20</td>
<td>20</td>
<td>21</td>
<td>22</td>
<td>22</td>
<td>23</td>
<td>24</td>
</tr>
<tr>
<td>6'0&quot;</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>18</td>
<td>19</td>
<td>20</td>
<td>20</td>
<td>21</td>
<td>21</td>
<td>22</td>
<td>23</td>
<td>24</td>
</tr>
<tr>
<td>6'1&quot;</td>
<td>15</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>18</td>
<td>19</td>
<td>20</td>
<td>20</td>
<td>21</td>
<td>22</td>
<td>23</td>
<td>24</td>
</tr>
<tr>
<td>6'2&quot;</td>
<td>14</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>18</td>
<td>19</td>
<td>20</td>
<td>21</td>
<td>21</td>
<td>22</td>
<td>23</td>
<td>24</td>
</tr>
<tr>
<td>6'3&quot;</td>
<td>14</td>
<td>14</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>18</td>
<td>19</td>
<td>20</td>
<td>21</td>
<td>21</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>6'4&quot;</td>
<td>13</td>
<td>14</td>
<td>15</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>18</td>
<td>19</td>
<td>19</td>
<td>20</td>
<td>21</td>
<td>21</td>
</tr>
</tbody>
</table>

English Calculation

Weight (lbs)
Index
Note: Boldface numbers indicate illustrations.

abductor digiti minimi, ulnar motor nerve to, 84–91, 84
abductor hallucis, tibial motor nerve (medial plantar branch) to, 192–197, 192
abductor pollicis brevis, median motor nerve to, 10–17, 10
auricular sensory nerve (greater), 268–270, 268
autonomic nervous system, 282
axillary F-loop/central latency, 282
axillary motor nerve to the deltoid, 2–5, 2
axillary nerve, front cover
axillary sensory nerve conduction

biceps radii, musculocutaneous motor nerve to, 46–49, 46
blink reflex, 254–259, 254, 255
Body Mass Index (BMI) tables, 287–289
brachial plexus, phrenic motor nerve to diaphragm and, 52
brachioradialis, radial motor nerve to, 56–59, 56
bulbocavernosus reflex/perineal/pudendal nerve conduction, 282–283
calf, H-reflex to, 188–191
carpal tunnel syndrome (CTS), median motor nerve to first lumbrical and, 36
cervical nerve root stimulation, 272–275
comparative studies
median and radial sensory nerve to thumb, 144–149, 144
median and ulnar mixed nerve studies (transcarpal), 150–155, 150
comparative studies (continued)
median and ulnar sensory studies to fourth digit, 156–160, 156
cranial nerve VII, 260–263, 260
cranial nerve XI, 264–267, 264
cubital tunnel syndrome, 90. See ulnar neuropathy at the elbow (UNE), 90
deltoid, axillary motor nerve to the, 2–5, 2
diaphragm, phrenic motor nerve to, 50–55, 50
dorsal interosseous, ulnar motor nerve to first, 96–99, 96
dorsal nerve of penis, 283
dorsal rami, sensory conduction, 283
dorsal scapular nerve motor conduction, 283
dorsal scapular nerve, front cover
EKG artifacts, phrenic motor nerve to diaphragm, 52
Erb’s point
median motor nerve to abductor pollicis brevis and, 15
ulnar motor nerve to abductor digiti minimi and, 88
extensor carpi ulnaris, radial motor nerve to, 56–59, 56
extensor digitorum brevis, peroneal motor nerve to, 166–171, 166
extensor digitorum communis, radial motor nerve to, 60–63, 60
extensor indicus proprius, radial motor nerve to, 64–67, 64
femoral motor nerve to quadriceps, 162–165, 162
femoral/obturator nerves, 283
flexor carpi radialis
  H-reflex to, 42–45, 42
  median motor nerve to, 18–21, 18
flexor carpi ulnaris, ulnar motor nerve to abductor digiti minimi and, 89
flexor digiti minimi brevis, tibial motor nerve (lateral palmar branch) to, 198–201, 198
flexor pollicis longus, median motor nerve (anterior interosseous branch) to, 22–25, 22
foot
  medial calcaneal sensory nerve, 210–213, 210
  peroneal (deep) sensory nerve, 218–221, 218
  peroneal (superficial) sensory nerve (medial and intermediate dorsal cutaneous branches), 222–227, 222
  saphenous sensory nerve (distal technique), 232–235, 232
  saphenous sensory nerve (proximal technique), 236–239, 236
  sural lateral dorsal cutaneous branch sensory nerve, 240–243, 240
  sural sensory nerve, 244–247, 244
  tibial mixed nerve (medial and lateral plantar branches), 248–252, 248
  tibial motor nerve (lateral palmar branch) to flexor digiti minimi brevis, 198–201, 198
  tibial motor nerve (medial plantar branch) to abductor hallucis, 192–197, 192
  greater auricular sensory nerve, 268–270, 268
  Guyon’s canal entrapment neuropathy, ulnar motor nerve to abductor digiti minimi and, 88
H-reflex to flexor carpi radialis, 42–45, 42
H-reflex to the calf, 188–191
hand
  comparative studies
  median and radial sensory nerve to thumb, 144–149, 144
  median and ulnar mixed nerve studies (transcarpal), 150–155, 150
  median and ulnar sensory studies to fourth digit, 156–160, 156
  lateral antebrachial cutaneous sensory nerve, 102–105, 102
  medial antebrachial cutaneous sensory nerve, 106–111, 106
  median palmar cutaneous sensory nerve, 120–123, 120
  median sensory nerve to second and third digits, 112–119
  posterior antebrachial cutaneous nerve, 124–127, 124
  radial sensory nerve to base of thumb, 128–131
  ulnar dorsal cutaneous sensory nerve, 132–135, 132
  ulnar sensory nerve to fifth digit, 136–143, 136
head and neck studies, 253–270
  blink reflex, 254–259, 254, 255
  cranial nerve VII, 260–263, 260
  cranial nerve XI, 264–267, 264
  greater auricular sensory nerve, 268–270, 268
  hypoglossal motor nerve conduction, 283
  ilioinguinal nerve conduction, 284
“inching technique.” See short segment incremental stimulation, 89
inferior subscapular nerve, front cover
infraspinatus, suprascapular motor nerve to, 74–79, 74
intercostal nerve conduction, 284
lateral antebrachial cutaneous sensory nerve, 102–105, 102
lateral cutaneous sensory nerve of calf, 284
lateral femoral cutaneous sensory nerve, 204–209, 204
Spevak and Prevec technique, 206, 207–208
lateral femoral cutaneous sensory nerve, 204–209, 204
lateral pectoral nerve, front cover
latissimus dorsi, thoracodorsal motor nerve to, 80–83, 80
long thoracic motor nerve to serratus anterior, 6–9, 6
long thoracic nerve, front cover
lower limb motor nerve studies, 161–201
femoral motor nerve to quadriceps, 162–165, 162
H-reflex to the calf, 188–191
peroneal motor nerve to extensor digitorum brevis, 166–171, 166
peroneal motor nerve to peroneus brevis, 172–175, 172
peroneal motor nerve to peroneus longus, 176–179, 176
peroneal motor nerve to tibialis anterior, 180–183, 180
sciatic nerve recording from the root, 184–187, 184
tibial motor nerve (lateral palmar branch) to flexor digiti minimi brevis, 198–201, 198
lower limb motor nerve studies (continued)
tibial motor nerve (medial plantar branch) to abductor hallucis, 192–197, 192
lower limb sensory and mixed nerve studies, 203–252
lateral femoral cutaneous sensory nerve, 204–209, 204
medial calcaneal sensory nerve, 210–213, 210
medial femoral cutaneous sensory nerve, 214–217, 214
peroneal (deep) sensory nerve, 218–221, 218
peroneal (superficial) sensory nerve (medial and intermediate dorsal cutaneous branches), 222
posterior femoral cutaneous sensory nerve, 228–231, 228
saphenous sensory nerve (distal technique), 232–235, 232
saphenous sensory nerve (proximal technique), 236–239, 236
sural lateral dorsal cutaneous branch sensory nerve, 240–243, 240
sural sensory nerve, 244–247, 244
tibial mixed nerve (medial and lateral plantar branches), 248–252, 248
lumbar nerve root stimulation, 276–280, 276
lumbrical
median motor nerve to first, 34–37, 34
median motor nerve to second, 38–41, 38
Index

Martin-Gruber anastomosis
median motor nerve to abductor pollicis brevis and, 15
ulnar motor nerve to abductor digiti minimi and, 88
mean values, xii
medial antebrachial cutaneous nerve, front cover
medial antebrachial cutaneous sensory nerve, 106–111, 106
medial brachial cutaneous nerve, front cover
medial calcaneal sensory nerve, 210–213, 210
medial femoral cutaneous sensory nerve, 214–217, 214
medial pectoral nerve, front cover
median and radial sensory nerve to thumb, comparative studies, 144–149, 144
median and ulnar mixed nerve studies (transcarpal), comparative studies, 150–155, 150
median and ulnar sensory studies to fourth digit, comparative studies, 156–160, 156
median motor nerve
anterior interosseous branch to flexor pollicis longus, 22–25, 22
anterior interosseous branch to pronator quadratus, 26–29, 26
to abductor pollicis brevis, 10–17, 10
to first lumbrical, 34–37, 34
to flexor carpi radialis, 18–21, 18
to pronator teres, 30–33, 30
to second lumbrical, 38–41, 38
median nerve, front cover
median palmar cutaneous sensory nerve, 120–123, 120
median sensory nerve to second and third digits, 112–119
musculocutaneous motor nerve to biceps brachii, 46–49, 46
musculocutaneous nerve, front cover
near-nerve needle conduction studies, 284
normal values, xi–xii
obturator nerves, 283
palmar interosseous, ulnar motor nerve to, 92–95, 92
palmar stimulation
median motor nerve to abductor pollicis brevis and, 14
median motor nerve to first lumbrical and, 36
penis, dorsal nerve of, 283
perineal/pudendal nerve conduction, 282–283
peroneal (deep) sensory nerve, 218–221, 218
peroneal (superficial) sensory nerve (medial and intermediate dorsal cutaneous branches), 222–227, 222
peroneal motor nerve
to extensor digitorum brevis, 166–171, 166
to peroneus brevis, 172–175, 172
to peroneus longus, 176–179, 176
to tibialis anterior, 180–183, 180
peroneus brevis, peroneal motor nerve to, 172–175, 172
peroneus longus, peroneal motor nerve to, 176–179, 176
phrenic motor nerve to diaphragm, 50–55, 50
posterior antebbranchial cutaneous nerve, 124–127, 124
posterior femoral cutaneous sensory nerve, 228–231, 228
posterior interosseous sensory response, 284
Pridgeon’s point, ulnar motor nerve to abductor digiti minimi and, 89
pronator quadratus, median motor nerve (anterior interosseous branch) to, 26–29, 26
pronator teres, median motor nerve to, 30–33, 30
pudendal nerve conduction, 282–283
quadriceps
  femoral motor nerve to, 162–165, 162
  late response, 285
radial motor nerve
  to extensor carpi ulnaris and brachioradialis, 56–59, 56
  to extensor digitorum communis, 60–63, 60
  to extensor indicis proprius, 64–67, 64
radial nerve motor conduction study to triceps, 285
radial nerve, front cover
radial sensory nerve to base of thumb, 128–131
range of values, xii
repetitive stimulation, 285
root stimulation, 271–280
  cervical nerve, 272–275
  lumbar nerve, 276–280, 276
saphenous sensory nerve (distal technique), 232–235, 232
saphenous sensory nerve (proximal technique), 236–239, 236
sciatic nerve recording from the root, 184–187, 184
serratus anterior, long thoracic motor nerve to, 6–9, 6
short segment incremental stimulation (SSIS)
  median sensory nerve to second and third digits, 117–118
  peroneal motor nerve to extensor digitorum brevis and, 170
  ulnar motor nerve to abductor digiti minimi and, 89
standard deviation of values, xii
superior subscapular nerve, front cover
suprascapular motor nerve to supraspinatus and infraspinatus, 74–79, 74
suprascapular nerve, front cover
  supraspinatus, suprascapular motor nerve to, 74–79, 74
sural lateral dorsal cutaneous branch sensory nerve, 240–243, 240
sural sensory nerve, 244–247, 244
tardy ulnar palsy, 90. See ulnar neuropathy at the elbow (UNE), 90
thoracodorsal motor nerve to latissimus dorsi, 80–83, 80
thoracodorsal nerve, front cover
tibial mixed nerve (medial and lateral plantar branches), 248–252, 248
tibial motor nerve (lateral palmar branch) to flexor digiti minimi brevis, 198–201, 198
tibial motor nerve (medial plantar branch) to abductor hallucis, 192–197, 192
tibialis anterior, peroneal motor nerve to, 180–183, 180
triceps, radial nerve motor conduction study to, 285
trigeminal motor nerve conduction, 285
trigeminal sensory nerve conduction, 285
ulnar dorsal cutaneous sensory nerve, 132–135, 132
ulnar motor nerve
to abductor digiti minimi, 84–91, 84
to first dorsal interosseous, 96–99, 96
to palmar interosseous, 92–95, 92
ulnar nerve, front cover
ulnar neuropathy at the elbow (UNE), ulnar motor nerve to abductor digiti minimi and, 89–90
ulnar sensory nerve to fifth digit, 136–143, 136
upper limb sensory and mixed nerve studies, 101–160
comparative studies
median and radial sensory nerve to thumb, 144–149, 144
median and ulnar mixed nerve studies (transcarpal), 150–155, 150
median and ulnar sensory studies to fourth digit, 156–160, 156
lateral antebrachial cutaneous sensory nerve, 102–105, 102
medial antebrachial cutaneous sensory nerve, 106–111, 106
median palmar cutaneous sensory nerve, 120–123, 120
median sensory nerve to second and third digits, 112–119
posterior antebrachial cutaneous nerve, 124–127, 124
radial sensory nerve to base of thumb, 128–131
ulnar dorsal cutaneous sensory nerve, 132–135, 132
ulnar sensory nerve to fifth digit, 136–143, 136
upper limb/brachial plexus motor nerve studies, 1–99
axillary motor nerve to the deltoid, 2–5, 2
H-reflex to flexor carpi radialis, 42–45, 42
long thoracic motor nerve to serratus anterior, 6–9, 6
median motor nerve (anterior interosseous branch) to flexor pollicis longus, 22–25, 22
median motor nerve (anterior interosseous branch) to pronator quadratus, 26–29, 26
median motor nerve to abductor pollicis brevis, 10–17, 10
median motor nerve to first lumbrical, 34–37, 34
median motor nerve to flexor carpi radialis, 18–21, 18
median motor nerve to pronator teres, 30–33, 30
median motor nerve to second lumbrical, 38–41, 38
musculocutaneous motor nerve to biceps brachii, 46–49, 46
phrenic motor nerve to diaphragm, 50–55, 50
radial motor nerve to extensor carpi ulnaris and brachioradialis, 56–59, 56
radial motor nerve to extensor digitorum communis, 60–63, 60
radial motor nerve to extensor indicis proprius, 64–67, 64
suprascapular motor nerve to supraspinatus and infraspinatus, 74–79, 74
thoracodorsal motor nerve to latissimus dorsi, 80–83, 80
ulnar motor nerve to abductor digiti minimi, 84–91, 84
upper limb/brachial plexus motor nerve studies (continued)
ulnar motor nerve to first dorsal interosseous, 96–99, 96

upper limb/brachial plexus motor nerve studies (continued)
ulnar motor nerve to palmar interosseous, 92–95, 92