BUSCHBACHER’S MANUAL OF NERVE CONDUCTION STUDIES

THIRD EDITION

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To our families, our teachers, and our patients
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We are delighted to present this updated manual on nerve conduction studies. It has been a reference standard adopted by many electrophysiological laboratories in North America and the world. Included are “state-of-the-art” reference values derived by systematically assessing healthy control subjects. Where possible, the reference values have been based upon large sample sizes and have included analyses of a number of variables including height, weight, age, and gender. The presented values have used the best statistical techniques available as well as a one-tailed design. We believe that this most appropriately represents the healthy population.

The current edition adds to the previous editions of the book by including up-to-date systematic literature reviews of each nerve presented so that the reader will be able to refer to the most relevant information available on each topic.

The format of presentation in the various chapters allows side-to-side comparisons as well as same limb comparisons of different nerves with acceptable differences listed. We have also added appendices that cover common anomalous innervations such as the Martin–Gruber anastomosis.

This book is not intended to be an introductory text or a teaching manual. There are excellent textbooks available that cover these important areas. Our intention was to create a book that could be used at the bedside as a reference, used to quickly review how to perform a nerve conduction study, or to look up reference values that have not been committed to memory. We have emphasized clinical utility when developing the format of this book. This edition offers a comprehensive, up-to-date set of reference values for clinical use. By following the described techniques, the user—trainee or clinician—will have reference values that can be used with confidence.

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Lawrence Robinson, MD
Ralph Buschbacher, MD
In training, residents and fellows often work at different EMG laboratories, which invariably have their own set of normal (reference) 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 thoughtfully completed, with the goal of producing appropriate normal values which take into account the distribution of the data.

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.

Subsequent editions of this manual take 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 have been 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.

As in the second edition, 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 SD, the 97th and 3rd percentiles of observed values are more appropriate when the distribution...
is not a bell-shaped curve (which is more commonly the case). Therefore, 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 SD 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 material at first, 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.
BUSCHBACHER’S
MANUAL OF NERVE
CONDUCTION STUDIES

THIRD EDITION
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 to 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.

Reference values (1) (100 subjects) (temperature greater than or equal to 32°C) (Upper and Lower Reference values given as 97 and 3 percentile values, respectively):

Onset latency (msec)

<table>
<thead>
<tr>
<th>Height in cm (in)</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Upper Reference Value</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 2).

<table>
<thead>
<tr>
<th>Sex</th>
<th>BMI</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Lower Reference Value</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 (mVms)

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Lower Reference Value</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>
4  UPPER LIMB/BRACHIAL PLEXUS MOTOR NERVE STUDIES

Duration of negative phase (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Upper Reference Value</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.
- Be aware that stimulation often also activates the biceps and brachialis, which can conduct volume to the recording electrodes.

Notes

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____________________________________________________________________________________________________

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____________________________________________________________________________________________________

____________________________________________________________________________________________________
REFERENCE


ADDITIONAL READINGS


LONG THORACIC MOTOR NERVE TO THE SERRATUS ANTERIOR

Electrode Placement
**Recording electrodes:** A concentric needle (CN) electrode 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, and the long thoracic nerve.

**Reference values:**

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

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>SD</th>
<th>Upper Reference Value</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°C to 23°C)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
<th>Upper Reference Value</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 Alfonsi 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 ± 0.2 msec. Alfonsi and coworkers (1) utilized surface recording but 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 to 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 (MCP) joint.

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

Reference values (1) (249 subjects) (skin temperature over the dorsum of the hand greater than or equal to 32°C):

Onset latency (msec)

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Upper Reference Value</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>SD</th>
<th>Range</th>
<th>Lower Reference Value</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 (mVms)

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Lower Reference Value</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>SD</th>
<th>Range</th>
<th>Upper Reference Value</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>SD</th>
<th>Range</th>
<th>Lower Reference Value</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>SD</th>
<th>Range</th>
<th>Lower Reference Value</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>SD</th>
<th>Range</th>
<th>Upper Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;160 (5’3”)</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”–5’6”)</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”–5’10”)</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”)</td>
<td>28.9</td>
<td>2.3</td>
<td>26.0–34.3</td>
<td>33.5</td>
</tr>
</tbody>
</table>
**MEDIAN MOTOR NERVE TO THE ABDUCTOR POLlicis BREVIS**

**Age Range 50–79**

<table>
<thead>
<tr>
<th>Height in cm (in)</th>
<th>Median Motor Nerve to Abductor Pollicis</th>
<th>Median Motor Nerve to Wrist</th>
<th>Ulnar Motor Nerve to Wrist</th>
<th>Ulnar Motor Nerve to Elbow</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;160 (5’3”)</td>
<td>25.2 1.7 21.0–27.6 28.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>160–169 (5’3”–5’6”)</td>
<td>27.5 1.4 25.5–30.5 30.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>170–179 (5’7”–5’10”)</td>
<td>28.7 1.4 25.9–31.3 31.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥180 (5’11”)</td>
<td>30.4 1.9 26.5–33.0 34.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All subjects</td>
<td>26.8 2.4 21.0–34.3 31.6</td>
<td></td>
<td></td>
<td></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. In addition to observing the twitch while stimulating the waveforms, the deflections from baseline and their shape should especially be monitored for change in shape. The waveforms should be similar on proximal and distal stimulation.

- Stimulation can also be performed at the palm. This technique stimulates the second lumbral and interossei muscles. If the amplitude with palm stimulation is significantly greater than with wrist stimulation, this can be a sign of neurapraxia at the wrist (4,5). Pease and coworkers (6) 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 to 0.8 have been recommended as the limits of normality (5,7). The 0.5 value is more conservative, reduces the possibility of false positives, and seems reasonable for clinical use. Anatomically, it is known that the fibers from the median nerve to the second lumbrical are relatively spared as compared to those supplying the thenar eminence; a lumbrical response may be obtained in severe median mononeuropathy when the compound muscle action potential (CMAP) recorded from the abductor pollicis brevis (APB) is absent (1,8,9).

- Midpalmar stimulation may cause a direct excitation of the thenar muscle mass or of the deep branch of the ulnar nerve. Please keep in mind that the ulnar nerve can supply a component of the thenar muscle mass (4,8,10). 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 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 (10). An accurate forearm conduction velocity cannot be calculated in the person with carpal tunnel syndrome and a Martin–Gruber anastomosis.

Martin–Gruber anastomosis is described in detail in Appendix 1.
Notes

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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 to 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.

Reference values (1) (208 subjects) (skin temperature over the dorsum of the hand greater than or equal to 32°C):

Onset latency (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Upper Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<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>SD</th>
<th>Range</th>
<th>Lower Reference Value</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 (mVms)

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Lower Reference Value</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>
20  UPPER LIMB/BRACHIAL PLEXUS MOTOR NERVE STUDIES

Duration of negative phase (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Upper Reference Value</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 READINGS


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 to 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.

Reference values (1) (207 subjects) (skin temperatures over the dorsum of the hand greater than or equal to 32°C):

Onset latency (msec)

<table>
<thead>
<tr>
<th>Forearm Distance</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Upper Reference Value</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>SD</th>
<th>Range</th>
<th>Lower Reference Value</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 (mVms)**

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Lower Reference Value</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>SD</th>
<th>Range</th>
<th>Upper Reference Value</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.
MEDIAN MOTOR NERVE TO THE PRONATOR QUADRATUS

Notes

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—5 mV/division, Low frequency filter—2 to 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.

Reference values (1) (208 subjects) (skin temperature over the dorsum of the hand greater than or equal to 32°C):

**Onset latency (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Upper Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.9</td>
<td>0.3</td>
<td>2.2–4.4</td>
<td>3.6</td>
</tr>
</tbody>
</table>

**Amplitude (mV)**

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Lower Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<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>50–79</td>
<td>7.3</td>
<td>2.9</td>
<td>2.4–15.8</td>
<td>2.9</td>
</tr>
<tr>
<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>

**Area of negative phase (mVms)**

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Lower Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<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>50–79</td>
<td>40.5</td>
<td>18.2</td>
<td>4.4–88.6</td>
<td>7.2</td>
</tr>
<tr>
<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>
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**Duration of negative phase (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Upper Reference Value</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 READINGS

MEDIAN MOTOR NERVE TO THE 1ST LUMBRICAL

Typical waveform appearance

Electrode Placement

30

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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—5 mV/division, Low frequency filter—2 to 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.

Reference values (1) (196 subjects) (skin temperature over the dorsum of the hand greater than or equal to 32°C):

**Onset latency (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Upper Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.6</td>
<td>0.4</td>
<td>2.7–4.8</td>
<td>4.4</td>
</tr>
</tbody>
</table>

**Amplitude (mV)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Lower Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>2.0</td>
<td>0.7–11.2</td>
<td>0.8</td>
</tr>
</tbody>
</table>

**Area of negative phase (mVms)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Lower Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<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>SD</th>
<th>Range</th>
<th>Upper Reference Value</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 APB latency in the same limb is 1.0 msec in cases where the APB has the longer latency; it is 0.6 msec in cases where the 1st lumbrical latency is longer.

Helpful Hint

- 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 SD) 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).

Notes
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 82 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 and proximal (1 cm) to the midpoint of the third metacarpal and the distal wrist crease.

**Reference electrode (R):** Placement is slightly distal to the third MCP 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—2 mV/division, Low frequency filter—2 to 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.

**Reference values** (1) (196 subjects) (skin temperature over the dorsum of the hand greater than or equal to 32°C):

**Onset latency (msec)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Upper Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.7</td>
<td>0.4</td>
<td>2.7–5.1</td>
<td>4.5</td>
</tr>
</tbody>
</table>

**Amplitude (mV)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Lower Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0</td>
<td>2.0</td>
<td>0.7–11.7</td>
<td>1.0</td>
</tr>
</tbody>
</table>

**Area of negative phase (mVms)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Lower Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<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>SD</th>
<th>Range</th>
<th>Upper Reference Value</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 APB latency in the same limb is 1.0 msec in cases where the APB 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.
- Prolonged wrist flexion (2–5 minutes) can result in elevations in latency; therefore, we suggest that the median nerve study be standardized to avoid this. This can result in false positive diagnoses of median nerve mononeuropathy (2,3).
- 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 (pre-motor potential) is seen before the desired motor response on median nerve stimulation. This potential should be ignored and does not generally distort the measurement 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 persist in carpal tunnel syndrome even when the APB response is absent. Therefore, this technique is especially helpful in patients with severe median mononeuropathy at the wrist because a lumbrical response may be obtained when responses from the APB are absent (4–7).
Notes

REFERENCES


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: 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 (C) is proximal, and the anode (A) 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.

Reference values (1) (39 subjects) temperature not reported. Upper and lower reference values are calculated as mean ± 2 SD:

Onset latency (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
<th>Upper Reference Value</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>SD</th>
<th>Lower Reference Value</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 SD).
Helpful Hints

• Jabre (1) 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 intensity. (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.

• Calculation of reference values using mean ± 2 SD may produce misleading results when distributions are skewed.

• 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).

• From the reference values located on page 39 (Jabre (1)), 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. For this reason, we recommend that the starting stimulus intensity should be low; in addition, monitor the M wave amplitude rise and watch the H reflex amplitude begin to increase. When the stimulus intensity is too high the H will abruptly disappear and become the F wave.

• The H reflex has been described as an adjunct determinant for diagnosing a C7 radiculopathy (3).
H-REFLEX TO THE FLEXOR CARPI RADIALIS  41

Notes

REFERENCES


ADDITIONAL READINGS/ALTERNATE TECHNIQUES


MUSCULOCUTANEOUS MOTOR NERVE TO THE BICEPS BRACHII

Typical waveform appearance

Electrode Placement
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 to 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.

Reference values (1) (100 subjects) (temperature greater than or equal to 32°C):

Onset latency (msec)

<table>
<thead>
<tr>
<th>Height in cm (in)</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Upper Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;160 (5’3”)</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”–5’7”)</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”)</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>SD</th>
<th>Range</th>
<th>Lower Reference Value</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>
44  UPPER LIMB/BRACHIAL PLEXUS MOTOR NERVE STUDIES

**Area of negative phase (mVms)**

<table>
<thead>
<tr>
<th>Sex</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Lower Reference Value</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>SD</th>
<th>Range</th>
<th>Upper Reference Value</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**

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REFERENCE


ADDITIONAL READINGS


PHRENIC MOTOR NERVE TO THE DIAPHRAGM

Typical waveform appearance

Electrode Placement
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 (R1) is placed 5 cm superior to the tip of the xiphoid process. The other electrode (R2) is placed 16 cm distally along the lower 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, and phrenic nerve.

Reference values (2) (25 subjects) (temperature not reported):

Onset latency (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Suggested Reference Value</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>SD</th>
<th>Range</th>
<th>Suggested Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>660</td>
<td>201</td>
<td>301–1198</td>
<td>&gt;300</td>
</tr>
</tbody>
</table>

Area (mVms)

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Suggested Reference Value</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>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Suggested Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<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 to 1.2 msec. The upper limit of normal difference, based on mean + 2 SD, is 0.88 msec.

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

Mean side-to-side difference for area is 1.41 ± 1.26 mVms with a range of 0.02 to 5.04 mVms. The upper limit of normal difference, based on mean + 2 SD, is 46.3%.

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

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 duration), 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). Simultaneous recording over the deltoid (in a 2nd channel) can detect this.

- 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). Needle recording electrodes can also be used to improve amplitude and waveform consistency. We recommend the utilization of ultrasound guidance for placement of the needle.

- Visualization of the diaphragmatic twitch with diaphragm ultrasound or fluoroscopy when performing the nerve conduction study will help to confirm diaphragm contraction (6).
- Side-to-side difference in latency with needle stimulation has been described as $0.08 \pm 0.42$ msec (4).

**REFERENCES**


**ADDITIONAL READINGS/ALTERNATE TECHNIQUES**


RADIAL NERVE

RADIAL MOTOR NERVE TO THE EXTENSOR CARPI ULNARIS AND BRACHIORADIALIS

Typical waveform appearance

Electrode Placement

Extensor carpi ulnaris

Brachioradialis

A C R
RADIAL MOTOR NERVE

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 midFOREARM (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: The cathode (C) is a monopolar needle electrode inserted 5 to 6 cm proximal to the lateral epicondyle on the lateral upper arm. This is ideally performed under ultrasound guidance. The anode (A) is a subcutaneous needle electrode located 2 cm proximally.

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

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, posterior cord of the brachial plexus, and then radial nerve.

Reference values (1) (40 subjects—data for both sides combined) (skin temperature over palm and forearm greater than 31°C):

Onset latency (msec)

<table>
<thead>
<tr>
<th>Nerve fibers</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Upper Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brachioradialis</td>
<td>2.66</td>
<td>0.32</td>
<td>1.8–3.5</td>
<td>3.3</td>
</tr>
<tr>
<td>Extensor carpi ulnaris</td>
<td>4.00</td>
<td>0.35</td>
<td>3.1–5.2</td>
<td>4.2</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


ADDITIONAL READING

RADIAL MOTOR NERVE TO THE EXTENSOR DIGITORUM

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. This site is localized in the reference (1) by grasping the radius and ulna of the subject’s pronated forearm with a line between the thumb and middle finger and 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. Confirmation is obtained by asking the patient to extend the MCP joints.

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 arm is supported and abducted 40 to 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.

Reference values For the right side (left side results were similar) (1) (30 subjects) (skin temperature over the forearm greater than or equal to 34°C) (reference values derived by using mean ± 2 SD):

Onset latency (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
<th>Upper Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.6</td>
<td>0.44</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Amplitude (mV)

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
<th>Lower Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.31</td>
<td>3.5</td>
<td>4.3</td>
</tr>
</tbody>
</table>
Nerve conduction velocity between S1 and S2 (m/sec)—the distance is measured from the axilla, measure posteriorly, to the elbow stimulation site [caliper measurement should give a similar distance measurement (2)].

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
<th>Lower Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<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.

• Calculation of reference values using mean ± 2 SD may produce misleading results when distributions are skewed; thus use the previous values with caution.

Notes

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REFERENCES


ADDITIONAL READINGS/ALTERNATE TECHNIQUES


RADIAL MOTOR NERVE TO THE EXTENSOR INDICIS: 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.

**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 to 10 cm proximal to the lateral epicondyle, over the radial groove. The anode is proximal.

**F-wave stimulation:** Electrode setup as noted previously (A, R, G). 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.

**Reference values (1)(skin temperature over the ventral forearm at least 33°C):**

**Onset latency (msec—25 subjects)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</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>SD</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>
## 60 UPPER LIMB/BRACHIAL PLEXUS MOTOR NERVE STUDIES

**Nerve conduction velocity (m/sec—25 subjects)**

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</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>SD</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**

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RADIAL MOTOR NERVE TO THE EXTENSOR INDICIS: NEEDLE RECORDING

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

Recording electrodes (R): A concentric needle electrode is placed (preferably using ultrasound guidance) into the extensor indicis 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 to 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 to 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.

Reference values:

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

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</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>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<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>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<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, an abnormality 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 electromyography or ultrasound.

- 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 (with ultrasound guidance) 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). We recommend ultrasound guidance for proper needle placement.

- 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


SUPRASCAPULAR MOTOR NERVE TO THE SUPRASPINATUS AND INFRASPINATUS

Typical waveform appearance

Electrode Placement
SUPRASCAPULAR MOTOR NERVE

**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 to 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 and suprascapular nerve.

**Reference values** (1) (100 subjects) (temperature greater than or equal to 32°C):

**Onset latency (msec)**

<table>
<thead>
<tr>
<th>Height in cm (in)</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Upper Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supraspinatus</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<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>
<tr>
<td>Infraspinatus</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<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>Supraspinatus</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Lower Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.7</td>
<td>2.3</td>
<td>1.2–12.6</td>
<td>1.6</td>
</tr>
</tbody>
</table>
Infraspinatus

<table>
<thead>
<tr>
<th>Sex</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Lower Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>3.5</td>
<td>1.5</td>
<td>1.4–7.8</td>
<td>1.5</td>
</tr>
<tr>
<td>Female</td>
<td>4.1</td>
<td>1.7</td>
<td>1.4–8.6</td>
<td>1.4</td>
</tr>
<tr>
<td>All subjects</td>
<td>3.8</td>
<td>1.6</td>
<td>1.4–8.6</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Area of negative phase (mVms)

<table>
<thead>
<tr>
<th>Supraspinatus</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Lower Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14.7</td>
<td>11.5</td>
<td>3.5–53.0</td>
<td>4.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Infraspinatus</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Lower Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14.0</td>
<td>5.7</td>
<td>3.5–30.3</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Duration of negative phase (msec)

<table>
<thead>
<tr>
<th>Supraspinatus</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Upper Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6.7</td>
<td>2.8</td>
<td>2.9–14.2</td>
<td>13.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Infraspinatus</th>
<th>Height in cm (in)</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Upper Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>≤160 (5'7&quot;)</td>
<td>5.1</td>
<td>1.6</td>
<td>2.8–9.1</td>
<td>9.1</td>
</tr>
<tr>
<td></td>
<td>&gt;160 (5'7&quot;)</td>
<td>6.3</td>
<td>2.3</td>
<td>2.3–13.9</td>
<td>10.7</td>
</tr>
<tr>
<td></td>
<td>All subjects</td>
<td>5.9</td>
<td>2.2</td>
<td>2.3–13.9</td>
<td>10.1</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


Edgar TS, Lotz BP. A nerve conduction technique for the evaluation of suprascapular neuropathies. Presented at: The AAEM Annual Meeting; October 16, 1998; Orlando, FL.

THORACODORSAL MOTOR NERVE TO THE LATISSIMUS DORSI

Typical waveform appearance

Latissimus dorsi muscle

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 shoulder 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, posterior cord of the brachial plexus, and thoracodorsal nerve.

Reference values (1) (30 subjects—right side data) (temperature not reported):

Onset latency (msec)

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Upper Reference Value</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>SD</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 shoulder 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 MCP joint.

Reference electrode (R): Placement is slightly distal to the 5th MCP 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 to 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, medial cord of the brachial plexus, and ulnar nerve.

Reference values (1) (248 subjects) (skin temperature over the dorsum of the hand greater than or equal to 32°C):

<table>
<thead>
<tr>
<th>Onset latency (msec)</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Upper Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.0</td>
<td>0.3</td>
<td>2.3–4.4</td>
<td>3.7</td>
</tr>
</tbody>
</table>
UPPER LIMB/BRACHIAL PLEXUS MOTOR NERVE STUDIES

Amplitude (mV)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Lower Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<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 (mVms)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Lower Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<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></th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Upper Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<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></th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Lower Reference Value</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

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Upper Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age Range 19–49</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height in cm (in)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;160 (5’3”)</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”–5’10”)</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”)</td>
<td>29.2</td>
<td>1.8</td>
<td>26.2–32.9</td>
<td>32.8</td>
</tr>
<tr>
<td>Age Range 50–79</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height in cm (in)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;160 (5’3”)</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”–5’10”)</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”)</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 to S2 nerve conduction velocity from one side to the other is 9 m/sec.
The upper limit of normal decrease in S2 to S3 nerve conduction velocity from one side to the other is 17 m/sec.
The upper limit of normal decrease in S3 to 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 (APB) and ulnar (ADM) 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.

- Assessment of C8 nerve root can be performed by needle stimulation and recording over the hypothenar eminence. Livingstone et al. (4) describe the best position for upper extremity measurement of mid-humerus-cervical spine distance as at 60 degrees of shoulder abduction, 45 degrees of internal rotation, and at the distance of 35 cm, measured by caliper. Using this position and distance the following normal values were obtained (n = 20):

1. Mid-humerus F-wave minimal latencies were 21.8 ± 1.2 msec, and conduction velocity was 59.7 ± 2.4 m/sec.
2. C8 root stimulation and latency difference to the mid-humerus was 4.9 ± 0.2 msec with a velocity of 71.4 ± 2.2 m/sec, (4).
• Anomalous innervation due to a Martin–Gruber (median to ulnar) anastomosis in the forearm is common. It may result in a smaller ulnar compound motor action potential amplitude at the elbow than the wrist, and can simulate conduction block in the forearm. If suspected, it can be investigated by stimulating the median nerve in the elbow, while recording from ADM. For more information please refer to the median nerve section.

• 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, including moving it proximally. Increased stimulus intensity or duration or needle stimulation may occasionally be needed. When moving from the S2 to S3 site, the intensity should be lowered before stimulation 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 and one should go back to S2 stimulation to see if a larger response can be obtained.

• An “inching technique” called short segment incremental stimulation (SSIS) can be performed to localize the site of an ulnar neuropathy at the elbow (UNE). 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 (5). The upper limit of normal segmental latency change recorded in 2-cm increments (elbow fixed at 90 degrees of flexion) is 0.7 msec. The midpoint is determined by drawing a line between the medial epicondyle and the olecranon. Focal demyelination is more likely when focal slowing and conduction block are seen at the same site. The upper limit of normal latency change (msec) and amplitude change (%) follow (6).
ULNAR MOTOR NERVE TO THE ABDUCTOR DIGITI MINIMI

<table>
<thead>
<tr>
<th>Latency</th>
<th>Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 cm to 2 cm above elbow</td>
<td>0.63</td>
</tr>
<tr>
<td>2 cm above elbow to midpoint</td>
<td>0.84</td>
</tr>
<tr>
<td>Midpoint to 2 cm below elbow</td>
<td>0.74</td>
</tr>
<tr>
<td>2 cm to 4 cm below elbow</td>
<td>0.43</td>
</tr>
</tbody>
</table>

• UNE 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 (Prideon’s point). If possible, it is advisable to try to localize an ulnar neuropathy to one or more of these sites through incremental stimulation (5).

• 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.

• The Riche-Cannieu anastomosis (sometimes referred to as the “All Ulnar Hand”) most likely results from palmar communication between ulnar and median branches (Riche-Cannieu anastomoses). There was no evidence of anomalous communication in the forearm. Digital sensory fibers were normally distributed in median and ulnar nerves (7–9).

**Notes**
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 34 for the Median Motor Nerve to the 2nd Lumbral.

82
ULNAR MOTOR NERVE TO THE PALMAR INTEROSSEOUS 83

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 MCP 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, slightly to the radial side of the tendon of the flexor carpi ulnaris. The anode (A) is proximal.

Machine settings: Sensitivity—5 mV/division, Low frequency filter—2 to 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, medial cord of the brachial plexus, and ulnar nerve.

Reference values (1) (196 subjects) (skin temperature over the dorsum of the hand greater than or equal to 32°C):

Onset latency (msec)

Mean  SD  Range  Upper Reference Value
3.1   0.3  2.6–4.4  4.0

Amplitude (mV)

Mean  SD  Range  Lower Reference Value
6.9   2.3  1.7–15.4  3.0

Area of negative phase (mVms)

Mean  SD  Range  Lower Reference Value
17.4  6.6  4.4–42.3  6.9

Duration of negative phase (msec)

Mean  SD  Range  Upper Reference Value
4.6   0.7  2.7–6.8  6.3
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 MCP joint, and the second MCP joint.

Reference electrode (R): Placement is slightly distal to the thumb IP joint.

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

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

Machine settings: Sensitivity—5 mV/division, Low frequency filter—2 to 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.

Reference values (1) (100 subjects) (skin temperature over the dorsum of the hand greater than or equal to 32°C):

Onset latency (msec)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Upper Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>All subjects</td>
<td>3.4</td>
<td>0.3</td>
<td>2.8–4.5</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Amplitude (mV)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Lower Reference Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.8</td>
<td>4.2</td>
<td>8.8–26.1</td>
<td>9.2</td>
<td></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. This is the muscle most commonly innervated by crossing fibers of the Martin–Gruber anastomosis.

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

Notes

REFERENCE


ADDITIONAL READINGS

