Median Nerve F-Wave Conduction in Healthy Subjects

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This study of the normal median nerve was designed 1) to compare techniques of using the shortest and average F-wave latencies, F-wave values between extremities, and F-wave values with the conventional motor response values and 2) to determine the relationships between F-wave latency and arm length. We examined 40 median nerves in 20 subjects with no known pathology. The motor response latency was measured from wrist and elbow stimulation sites by conventional techniques. We then applied multiple stimuli at the same sites to record a series of 10 F-wave latencies and determined shortest and average F-wave latencies. Values of F-wave and M-response conduction are reported. No significant difference was found in F-wave latency or velocity between extremities within subjects, using either the shortest or average latency technique. We propose a formula for calculating the estimated F-wave distal latency based on the conventional motor response distal latency. The F-wave conduction velocities of the forearm were faster and more variable than the motor nerve conduction velocities. A high correlation was found between F-wave distal latency and arm length. Using the method described, the F wave can be a useful measure in evaluating the conduction of proximal segments of peripheral motor nerves.

Key Words: Arm, Extremities, Neural conduction, Physical therapy.

When a peripheral motor nerve is electrically stimulated, impulses travel orthodromically toward the muscle and antidromically toward the spinal cord. The antidromic impulses are capable of discharging alpha motoneurons that then elicit recurrent orthodromic impulses, resulting in a low amplitude motor response that is variable in latency and shape. These variable responses were labeled F waves by Magladery and McDougal and first thought to be reflex in origin. Since 1950, investigations have shown that the F wave persists after acute and chronic deafferentation in man and baboons. Although the exact mechanism responsible for the F wave is unknown, some authors propose that the antidromic impulse causes depolarization of the alpha motoneuron's soma-dendritic membrane and subsequent recurrent (orthodromic) impulse propagation after a brief central delay at the cell body. Another hypothesis suggests that the antidromic impulse traverses synaptic interconnections between motoneurons by recurrent axon collaterals. Investigations by Kimura and Kimura and Butzer on the variation of F-wave latencies showed that the difference between the shortest distal latency and the proximal F-wave latency is the same as the corresponding latency difference of the conventional motor or M response. Kimura's observations led him to speculate that the impulse giving the shortest F-wave latency was conducted along the same axon as the impulse for the shortest M latency. A constant central delay for reactivation of the antidromic impulse at the anterior horn cell is assumed to be 1 msec. Other investigators have shown that F-wave latency will vary from one stimulus to the next and that a direct comparison of M and F responses is questionable. When comparing the M and F responses, some authors propose calculating an average of a series of F-wave latencies; others propose using the shortest of a series of latencies. Investigators have attempted to use F-wave conduction values as a diagnostic tool in conditions that affect the proximal portion of peripheral nerves. The F wave has been reported to be useful in the assessment of conditions such as Charcot-Marie-Tooth disease, Guillain-Barré syndrome, chronic renal failure, entrapment neuropathies, radicular injury, motor neuron disease, diabetes, and hemiplegia. Controversy has surrounded acceptance of using the F wave for clinical assessment, primarily because of its variability in latency, wave shape, occurrence, and the potential technical errors bearing on the calculation of the conduction velocity of the F wave.

Our study was undertaken to provide information that would help resolve some of the F-wave controversy. The purposes were as follows:

1. To determine whether using the shortest F-wave distal latency (FmWDL) would be as reliable as using the average F-wave distal latency (FmWCV) measurement technique.

2. To determine the relationships between the conventional motor nerve distal latency (MDL) and the F-wave distal latency (FWDL) and between the motor nerve conduction velocity (MNCV) and the F-wave conduction velocity (FWCV) of the median nerve forearm segment.

3. To determine the relationship between the FWDL of the median nerve and arm length.

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The purposes were tested by the following hypotheses:
1. No significant difference exists in the FWDL and FWCV between median nerves of the right and left extremities, using either the shortest or average measurement technique.
2. A positive correlation exists between the MDL and the FWDL of the median nerve.
3. A positive correlation exists between the MNCV and the FWCV of the median nerve forearm segment.
4. A positive correlation exists between FWDL of the median nerve and arm length.

METHOD

We evaluated the conduction of 40 median motor nerves from 20 healthy subjects (9 men and 11 women). The median age of the subjects was 25 years, ranging between 18 and 34 years. Each subject was screened for history of diabetes, alcoholism, renal or metabolic dysfunction, peripheral vascular disease, myopathy, or neuropathy. The procedure was described to each subject, who then consented to participate in the study.

We performed all nerve-conduction tests in the same room with a constant temperature of 19°C. Subjects were tested in the supine position with the arm at the side and supported on the table. Immediately before nerve-conduction testing, the skin temperature over the volar wrist surface was measured with a thermistor thermometer.*

A Disa 1500 EMG† was used for testing. The active recording electrode was placed over the area of the motor point of the abductor pollicis brevis muscle. The reference electrode was attached 2.4 cm distally, near the tendon insertion. A ground strap encircled the forearm of the subjects. To obtain the M-distal and M-proximal responses, we applied a supramaximal 0.1 msec duration stimulus at a rate of 1 per second over the median nerve at the wrist, with the cathode 8 cm proximal to the active recording electrode, and at the elbow, just medial to the tendon of the biceps brachii muscle. Amplifier gain setting was 2 mV/division or 5 mV/division, depending on response amplitude; sweep speed setting was 5 msec/division. The F waves were elicited at the same stimulation sites; however, the polarity of the stimulator was reversed so that the cathode was placed in the proximal position. Amplifier gain setting for the F-wave response was 200 µV/division and sweep speed was 10 msec/division. We recorded a single M response and 10 F waves from each stimulation site. The F responses were displayed in step-function mode and latencies were measured on the Disa storage oscilloscope using the latency indicator. We performed the M- and F-nerve conduction tests bilaterally on all subjects. Latencies were measured from the onset of the stimulus to the initial negative deflection of the evoked M and F responses. We determined the shortest and average latency of the 10 F-wave responses for each extremity.

We measured forearm distance between the proximal and distal stimulation sites. Arm length was measured between the C7 spinous process and the distal stimulation site with the arm abducted 90 degrees and the forearm supinated.‡ The MNCV, shortest F-wave conduction velocity (FsWCV), and average F-wave conduction velocity (FaWCV) of the forearm segment of the median nerve were calculated using the following formulas:

\[
\text{MNCV} = \frac{\text{Distance between forearm stimulation sites (mm)}}{\text{Proximal M latency (msec)}} - \text{distal M latency (msec)}
\]

\[
\text{FsWCV (or FaWCV)} = \frac{\text{Distance between forearm stimulation sites (mm)}}{\text{Distal F latency (msec)}} - \text{proximal F latency (msec)}
\]

Data Analysis

The F-wave and M-response latencies and velocities were compared using a two-tailed t test for independent means with a probability of p < .05. Relationships between values were determined using the Pearson product-moment correlation coefficient.

RESULTS

Values for the median nerve F-wave conduction are shown in Table 1. Distal F-wave latencies were obtained on all 40 nerves. The mean of the FsWDL for all nerves was 24.5 ± 2.2 msec and the mean of the FaWDL for all nerves was 26.1 ± 2.6 msec. The series of 10 F-wave distal latencies recorded for each subject had a mean range of 4.1 ± 2.5 msec. No significant difference was found between F-wave distal latencies of the left and right extremities within subjects, using either the shortest or average latency technique. (FsWDL t = 1.09 and FaWDL t = 0.53 with df = 1, 19). The correlation between F-wave distal latencies of the left and right extremities was r = .93, using either the shortest or average latency technique. The FsWDL had been recorded in 67 percent of the subjects by the sixth response. The rank of the FsWDL in the series of 10 F waves was determined for each subject. For all 40 nerves, the rank

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* Rochester Model B-2, Rochester Electro-Medical, Inc, 7308 Aspen Lane, Minneapolis, MN 55428.
† Disa Electronics, 779 Susquehanna Ave, Franklin Lakes, NJ 07417.
of the FsWDL had a median of 4.5 and a mode of 2.

A proximal F-wave latency could not be obtained from one subject; therefore, F-wave velocities were determined on 19 subjects (38 nerves). The mean FsWCV for all nerves was 75.29 ± 23.4 m/sec with no significant difference between left and right extremities (t = 0.38; df = 1, 18). The mean FaWCV for all nerves was 71.1 ± 22.9 m/sec and again, no significant difference existed between left and right extremities (t = 0.88; df = 1, 18) (Tab. 1). The mean MDL for all nerves was 2.8 ± 0.46 msec and the mean MNCV was 56 ± 4.3 m/sec (Tab. 2). The mean ratio of MDL to FsWDL for all nerves was 0.1143 ± 0.01. The correlation between the MDL and FsWDL was r = .59.

No correlation was found between the MNCV and FsWCV and a low positive correlation was found between the MNCV and FaWCV (r = .35) of the median nerve forearm segment (Tab. 2). No significant difference in either the MDL (t = -.46; df = 1, 19) or MNCV (t = 0.14; df = 1, 18) was found between extremities of each subject. When we compared the subjects' arm length with FsWDL and FaWDL, we found correlations of r = .88 and r = .86, respectively.

Skin temperature ranged from 29°C to 34°C for all subjects. Because no difference greater than 1°C was found between extremities on any subject, temperature was not considered to be a critical factor in this study.

**DISCUSSION**

The distal and proximal F-wave latencies obtained in our study are similar to those reported by Baba et al. and Eisen et al but shorter than those reported by Kimura (Tab. 3). The shorter latencies found in our study compared with latencies of other investigators could be related to the distance used between stimulating and recording electrodes in the different studies. The age of our subjects was restricted to a younger sample than the age of subjects in other studies and therefore may have been a factor contributing to the shorter latencies (Tab. 3). A slowing of conventional motor nerve conduction has been demonstrated with increasing age; however, little documentation of the effects of age on F-wave conduction has been reported.

Because we found no significant difference in FWDL or FWCV between right and left extremities, we pooled the values. This consistency of FWDL between extremities was similar to the findings of Kimura and Fisher et al. A small standard deviation from the mean for all nerves was found using either the shortest or average latency technique; therefore, we believe an examiner could use either method for evaluation of F-wave conduction. Although Fisher et al have advocated using the average distal latency, we prefer to do as others do and use a measurement of the shortest F-wave latency. We think our measurement is the more efficient method because no additional mathematical calculations are required, as would be necessary to determine the average latency. Because of the variability of F waves, a researcher cannot be certain that the shortest latency has actually been obtained, even from a large number of stimuli. Occasionally, 30 to 40 stimulations were required in our study to obtain 10 measurable F waves. Panayiotopoulos has proposed using 100 F waves to determine the chronodispersion or histogram showing the latency difference between each F wave and the shortest F wave. In analyzing the tibial nerve F-wave latencies, Panayiotopoulos found a mean chronodispersion or range of 6.4 ± 0.8 msec. In our study, the latencies in the series of 10 FWDL for all subjects had a mean range of 4.1 ± 2.5 msec. The shortest FWDL latency was most frequently the second F wave elicited, and in 67 percent of the subjects, the shortest F wave appeared by the sixth response. The number of F waves necessary to measure the shortest latency would depend on the consistency of values obtained in any given patient. The discretion of the examiner would be necessary, but based on our findings, the evaluation of six F waves would be a useful guide in making the determination.

The MDL obtained is slightly shorter than those reported by other authors (Tab. 3). A shorter distance between stimulating and recording electrodes and the younger age of our subjects may explain the shorter conduction latencies. The MDL latency difference of 0.24 ± 0.21 msec we found between right and left extremities was even less than the difference of 1.1 ± 0.6 msec found by Trojaborg. The ratio of the MDL to the FWDL was 0.1143. By inverting this ratio, a value of 8.74 is obtained as the ratio of FWDL to MDL. This value of 8.74 can then be used as a factor to multiply the MDL to give an estimation of the FWDL in a given patient. Although this simple mathematical formula (estimated FWDL = 8.74 × MDL) gives only an estimate of the FWDL and does not indicate the precise location of an area of conduction delay, in the presence of a normal MDL, a prolonged FWDL would suggest a compromise proximal to the stimulation site. This procedure is similar but less complex than the F ratio proposed by Kimura that also compares the conduction time in the peripheral nerve segment from the spinal cord to the stimulation site with the segment from the stimulation site to the muscle.

The MNCV of the median nerve forearm segment is similar to values re-

**TABLE 2**

<table>
<thead>
<tr>
<th>Nerves (n)</th>
<th>MDL* (msec)</th>
<th>FsWDL* (msec)</th>
<th>MNCV* (m/sec)</th>
<th>Ratio</th>
<th>MDL:FswDL</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 right</td>
<td>2.8 ± 0.46</td>
<td>24.3 ± 2.1</td>
<td>56.0 ± 4.2</td>
<td>.59</td>
<td>.59</td>
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</tr>
<tr>
<td>20 left</td>
<td>2.8 ± 0.44</td>
<td>24.7 ± 2.3</td>
<td>56.1 ± 4.5</td>
<td>.35</td>
<td>.35</td>
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</tr>
<tr>
<td>40</td>
<td>2.8 ± 0.46</td>
<td>24.5 ± 2.2</td>
<td>56.0 ± 4.3</td>
<td>.09</td>
<td>.09</td>
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</tr>
<tr>
<td>MDL to FsWDL</td>
<td>0.1143 ± 0.01</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>MNCV to FsWCV forearm</td>
<td>0.35</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>MNCV to FaWCV forearm</td>
<td>.88</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mb to arm length</td>
<td>.86</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Mb to arm length</td>
<td>.86</td>
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</table>

* MDL = motor distal latency.
  FsWDL = shortest F-wave distal latency.
  MNCV = motor nerve conduction velocity.
TABLE 3

<table>
<thead>
<tr>
<th>Nerves (n)</th>
<th>Age (yr)</th>
<th>M response latency (<em>X</em>)</th>
<th>Distal latency (msec)</th>
<th>Proximal F-wave latency (msec)</th>
<th>Forearm MNCV (m/sec)</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>18-34</td>
<td>2.8</td>
<td>24.5</td>
<td>22</td>
<td>21.2</td>
<td>56.0</td>
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<tr>
<td>40</td>
<td>... (38)</td>
<td>3.2</td>
<td>25.2</td>
<td>1.5</td>
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<td>60.0</td>
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<tr>
<td>60</td>
<td>11-74</td>
<td>3.4</td>
<td>26.6</td>
<td>2.2</td>
<td>22.4</td>
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</tr>
<tr>
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<td>22-58</td>
<td>3.5</td>
<td>29.1</td>
<td>2.3</td>
<td>24.8</td>
<td>56.0</td>
</tr>
<tr>
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<td>29-67</td>
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<td>...</td>
<td>...</td>
<td>...</td>
<td>57.0</td>
</tr>
<tr>
<td>25</td>
<td>19-65</td>
<td>3.8</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>57.5</td>
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<tr>
<td>72</td>
<td>20-50</td>
<td>4.3</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>56.1</td>
</tr>
</tbody>
</table>

"MNCV = motor nerve conduction velocity."

ported by other investigators. Our findings of no significant difference in MNCV between extremities is in agreement with other findings.

Previous work with the F wave had shown that as the stimulation site was moved proximally, the M latency increased in proportion to the decrease of the F latency. This relationship prompted Kimura and others to calculate FWCV in the proximal segments of peripheral nerves with the use of a standard "turnaround" time of 1 millisecond. We deleted the 1 millisecond central delay time from our formula because it would be cancelled out in the calculation. We did not find studies in the literature comparing the MNCV with the FWCV of the median nerve forearm segment. The large difference between MNCV and FWCV for the median nerve forearm segment found in our study is in sharp contrast with Kimura and Butzer's findings for the proximal segment. They found that the MNCV for the axilla to elbow segment was comparable to the FWCV for the axilla to spinal cord segment of the median nerve. Eisen et al., however, reported a slight but significantly greater mean conduction velocity for the median nerve F-wave elbow to cord segment compared with the MNCV of the elbow to wrist segment. To determine how our FWCV values compared with those of other investigators, we used Kimura's formula to calculate the FWCV for the spinal cord to elbow segment and obtained 66.9 ± 6.8 m/sec, which was similar to the 62.2 ± 5.2 m/sec reported by Kimura and Butzer and 62.3 ± 5.0 m/sec found by Eisen et al. The basic assumption for using these formulas is that the M and F waves travel along the same axon. The large standard deviation in the FWCV we found is related to a large variation in F-wave latency in the forearm segment and to the additional variable of arm length measurement that is used in calculating velocity. Because of this variation in velocity of the forearm segment, the theory proposed by some investigators that the M and F waves are propagated along the same axon cannot be assumed. Although the reason for the disproportionate forearm latencies is unclear, it could be caused by the recording of impulses that are conducted along different axons or by a variation in the central delay time. The accuracy of calculating FWCV is compromised by the need for using surface distance measurements and the use of the assumed 1 millisecond central delay time. The use of latency measurements rather than the more complicated FWCV calculations would provide a more accurate assessment of the integrity of the proximal segment of motor peripheral nerves and is in agreement with Young and Shahani.

The high positive correlation found in this study between FWDL of the median nerve and arm length is comparable with that of Conrad et al. A nomogram or index for plotting F-wave latency as a function of arm length could be constructed and would be a useful clinical tool.

CONCLUSION

1. The technique of using the shortest FWDL of at least six recorded F waves is effective and less complex than the technique of calculating an average FWDL. No significant difference was found in the shortest FWDL, FWCV, MDL, or MNCV between right and left extremities.

2. A positive correlation exists between the MDL and the FsWDL of the median nerve (r = .59). The product of 8.74 times the MDL can be used as an estimate of FWDL of the median nerve.

3. The FWCV of the forearm segment was faster and more variable than the MNCV of that segment.

4. A high correlation exists between the FWDL and the arm length as measured from C7 spinous process to stimulation site.

The inaccuracy of calculating F-wave velocity is compounded by the variability of the F-wave latency, the use of surface measurements over long distances and uneven contours, and the use of an assumed 1 millisecond central delay time. When determining the functional integrity of the proximal segments of motor peripheral nerves, simple values of the shortest F-wave latency are more valuable than trying to calculate a velocity. Acceptable alternate methods of assessing the proximal segments are the use of normal values of F latencies, nomograms, and comparison of latencies between extremities of the same subject. Despite its known variability in occurrence, latency, and shape, the F-wave latency can be a useful measure when evaluating the proximal segments of peripheral motor nerves.

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REFERENCES


