

# Chapter 31:

## Electrophysiologic Testing

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### I. Introduction

Electrophysiologic (or electrodiagnostic) testing procedures are common clinical studies used for investigating the neuromuscular system at different levels of the neuromuscular system. This includes: muscle tissue, neuromuscular junctions, distal, middle or proximal segments of peripheral nerves, nerve roots, spinal cord (both local reflex circuits and long pathways), brain stem reflex circuits and even cortical functions. There are studies that evaluate motor or sensory fascicles of peripheral nerves, or sensory-motor reflex connections. Electrophysiologists may design the study protocol to evaluate the degree of cellular and system dysfunction related to the pathologic entity of the neuromuscular disorder in question. The usual purpose of the selected testing procedures is to confirm or rule out a provisional clinical diagnosis. The electrophysiologic examination may be performed either by a physician (usually a neurologist or physiatrist) or a qualified physical therapist.

The purpose of this chapter is to provide insight for the hand therapist into the interpretation of the electromyography/nerve conduction (EMG/NCV) report related to upper extremity neurologic disorders; and to improve the utility of its information for rehabilitation purposes. It is important to note that the information in the EMG/NCV report is essentially adjunct to the findings of clinical testing and should complement physical examination, imaging and clinical laboratory results. This concept applies to both upper and lower extremity EMG/NCV studies.

#### A. Pathologies that are commonly tested by EMG/NCV

1. Muscledisorders: myopathiessuch as Duchene’s muscular dystrophy, myositis, myotonias
2. Myoneural junction disorders: myasthenia gravis, myasthenic syndromes (Lambert-Eaton myasthenic syndrome)
3. Peripheral neuropathies: Carpal Tunnel syndrome, tarsal tunnel syndrome, other impingement syndrome and mononeuropathies, e.g. ulnar nerve impingement at the Guyon’s canal, Bell’s and bulbar palsy, polyneuropathies (e.g. diabetic, arsenic, lead, or other heavy metal), traumatic nerve injuries or peripheral nerve anomalies such as Martin-Gruber anastomosis
4. Plexopathies: Brachial plexus and lumbosacral plexus injuries, thoracic outlet syndrome, meralgia paresthetica
5. Nerve Root impingements and diseases: Disc protrusions, proximal neuropathies such as Guillain Barré syndrome, nerve root avulsion injuries or nerve root compression by adhesions after spinal surgeries
6. Spinal cord injuries and diseases: Partial or complete spinal cord injuries, motor neuron diseases, transverse myelitis, multiple sclerosis, tabes dorsalis, poliomyelitis and post polio syndrome
7. Brain stem dysfunctions: Brain stem tumors, multiple sclerosis

- B. While normally performed together during a comprehensive electrophysiological assessment, EMGs and nerve conduction studies are separate tests, with each providing a different insight into the functioning of the neuromuscular system. Together, they are

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used to support or refute a clinical diagnosis and to differentiate they type of neurologic injury as primary or segmental demyelination, or axonal degeneration.

1. In the extremities, nerve conduction studies require an electrical stimulus to elicit (evoke) a nerve or muscle action potential
2. The time from stimulus to the evoked response (latency), and the amplitude and duration of the evoked response are recorded
3. These tests are normally performed with surface electrodes
4. Electromyography (EMG) records the electrical activity of muscles during different degrees of contraction; this normally requires the use of hypodermic (needle) electrodes inserted into the muscle.

### II. Recording of Biopotentials

- A. Electrical signals from nerve/muscle action potentials are measured in millivolts (mv) or microvolts ( $\mu\text{v}$ ). They spread through the body fluids by a process called “*volume conduction*.”
  1. The further the recording electrode is from the source of the potential, the smaller is the voltage it receives
  2. Clinical needle electrodes can record the potentials generated by single motor units. Some needle electrodes are small enough to record single muscle or nerve fiber potentials; but this has limited clinical significance.
  3. Surface electrodes record the combined potential of all nerve fibers or motor units in the region under the electrodes; these are usually referred to as either the **Sensory Nerve Action Potential (SNAP)** or the **Compound Muscle Action Potential (CMAP)**, respectively.
- B. In recording these signals, three electrodes are used: a recording electrode, a reference electrode and a ground.
  1. In modern EMG/NCV recording, after being detected (at the recording electrode), the very small electrical signals are amplified, digitized and then displayed on a screen. The recordings may also be stored in a digital format and may be printed out.
  2. According to electrophysiological convention:
    - a. A negative potential produces an upward deflection on the recorder (screen).
    - b. The horizontal sweep on the screen is used to measure time intervals, in milliseconds (ms).

### III. Nerve Conduction Studies

Nerve conduction studies are performed to assess the ability of nerves to transmit signals. They normally consist of providing an (electrical) stimulus, recording an evoked response and measuring the time from the stimulus to the response. In many conduction studies, by measuring the distance between two stimulation sites or from the sensory stimulus to response allows calculation of conduction velocity along that nerve segment. This is normally measured in meters/second (M/s). Abnormalities identified by nerve conduction studies normally are caused by some demyelination of nerve fibers. This demyelination may due to local compression or to systemic disease (such as diabetes).

- A. Latency: This is the time, measured in milliseconds (ms.) from the start of the stimulus to the recorded response, the evoked action potential. When looking at the screen of an EMG unit:
1. The electrical stimulation will create a stimulus artifact or spike at the beginning of the timed sweep of the tracing. This will be followed by a period of no electrical activity, then by the evoked action potential.
  2. The action potential will start with the deflection that may be either negative (up) or positive (down)
  3. For motor nerves (Fig. 1), the latency is normally measured to the start of the muscle potential response wave
  4. For sensory nerves, it is often measured to the first peak of the response wave (Fig. 2)
  5. Abnormalities are usually recognized by an increase in latency time, which reflects slower conduction
- B. Distal or terminal latency: This is the latency at the most distal stimulation site. For the upper extremity, this is usually at the wrist. For Motor nerves, this latency time is made up of three components:
1. The conduction time along the distal segment of the tested nerve;
  2. Time for the neurotransmitter to cross the myoneural junction
  3. The conduction time along the muscle fiber
    - a. Because of the three components, one cannot calculate nerve conduction velocity in the distal segments of a motor nerve; because the latency time could be affected by conduction changes in the neurons, myoneural junction or muscle fibers.
    - b. The latency for sensory nerves is normally less than for motor nerves, in part because sensory nerves have a faster conduction velocity (thicker myelin), but also because there is no myoneural junction delay
    - c. The latencies for sensory nerves may also be measured either orthodromic (normal direction of conduction, stimulating on the digit and recording the signal over the nerve trunk) or antidromic (opposite to normal, by stimulating over the nerve proximally and recording the signal in the digital nerves). Figures 3 and 4 show electrode placements for distal latency antidromic sensory recordings of the median and ulnar nerves.
    - d. Sensory and possibly motor distal latencies are usually prolonged for the median in carpal tunnel syndrome or for the ulnar nerve with impingement at Guyon's Canal. It is also prolonged in polyneuropathy conditions (e.g. diabetes), which affect both nerves.
  4. The distal latency is useful in testing the distal segments of peripheral nerves, by comparing the recorded latency over a fixed distance to normal values and/or to the uninvolved contralateral side
    - a. An increased distal latency found when comparing the affected nerve to the unaffected side, as well as to normative standards, is important for evaluating the degree of pathology. Therefore, it is necessary to record distal latency along a same, standardized length of that nerve.
    - b. In the upper limbs, a distance of 8 or 10 cm. from the stimulating electrode (negative) to the recording electrode is normally used

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- c. The duration of the distal latency depends on the thickness of neural myelination. Demyelination increases latency proportionate to the amount of loss.
  - i. For a sensory nerve test, a difference of 0.5 ms. in the distal latency between the affected and non-affected hands would be clinically significant for a mild degree sensory neural impingement. However, 1-2 ms. difference in such distal latency would indicate moderate to severe neural involvement. Such an electrodiagnostic finding is usually associated with sensory hypoesthesia or anesthesia in the areas supplied by the tested nerve.
  - ii. Distal motor latency that is prolonged more than 1.0 ms. compared to the non-affected side would indicate impingement of motor fascicles. This is usually associated with muscle weakness and atrophy of the muscles supplied by the tested nerve. See Figures 1 and 2 for normal distal motor and sensory latency recordings.
- C. Proximal latency: This is latency for electrical stimulation of peripheral nerves at more proximal sites along the nerve, e.g. elbow, axilla or neck (Erb's point), in the upper extremity
  1. The proximal latency time is relative to the distance between the stimulation site and recording electrodes. Proximal latencies are longer in milliseconds than the distal or terminal latency because of the additional nerve length.
  2. Similar to distal latency, proximal latency is useful in testing axonal nerve function of nerve segment
    - a. A prolonged latency relative to the same segment on the non-involved side would indicate compromise of nerve fibers between the stimulation and recording sites
      - i. A peripheral nerve injury at the forearm level would cause prolonged proximal latency during stimulation at the elbow and any more proximal levels
      - ii. Comparing proximal latency of the symptomatic to the non-symptomatic limb, for the same length of nerve segment, is necessary to assess the degree of neural compromise
      - iii. Measuring the proximal latency would assess the degree of neural demyelination and axonal loss for the tested nerve segment
      - iv. Measuring both proximal and distal latencies allows one to calculate the nerve conduction velocity of the nerve segment between the two stimulation sites
- D. Nerve Conduction Velocity (NCV): This is normally measured in meters/second, (M/s). Knowing both the proximal and distal latencies, and the distance between them, one can calculate the conduction velocity for the nerve segment between the stimulation sites.
  1. Because the terminal delay is the same for both of these stimulation sites, by subtracting the distal latency from the proximal one, you get the conduction time between the stimulation sites. Dividing this into the distance (millimeters, mm) between them gives you the velocity along this segment.

## Chapter 31 Figures

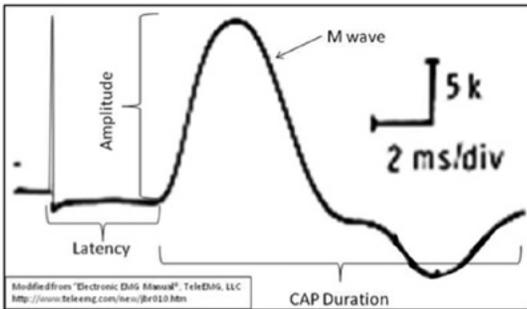


Fig. 1. Normal distal motor latency.<sup>5</sup>

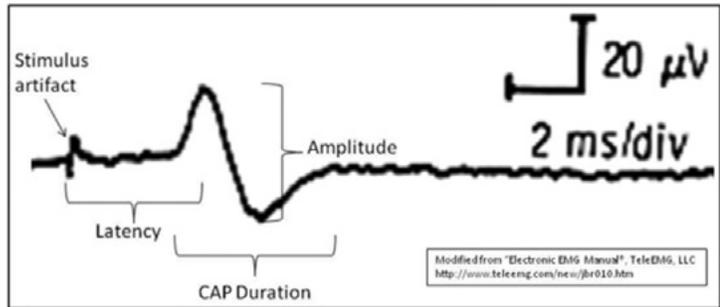


Fig. 2. Normal distal motor latency.<sup>5</sup>

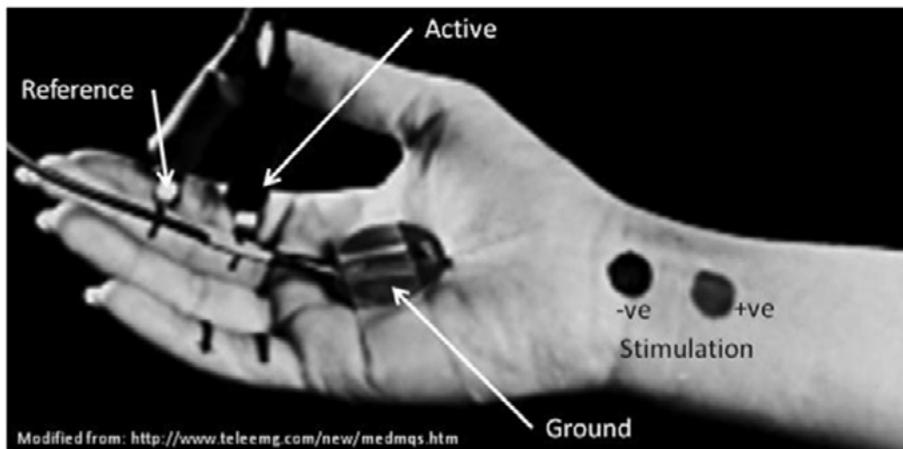


Fig. 3. Stimulation and recording electrode placements for median nerve distal antidromic sensory recording.<sup>5</sup>

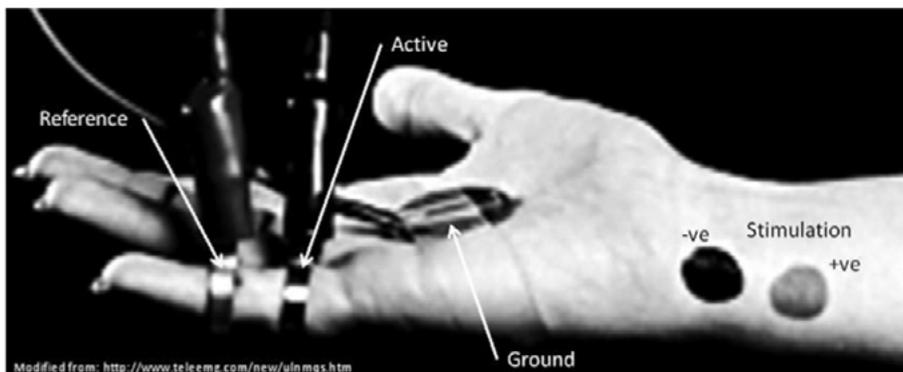


Fig. 4. Stimulation and recording electrode placements for ulnar nerve distal antidromic sensory recording.<sup>5</sup>

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- a. Thus the equation to calculate NCV along a nerve segment is:

$$\text{Velocity (M/s)} = \frac{\text{Distance between stimulation sites (mm)}}{\text{Proximal latency (ms)} - \text{Distal latency (ms)}}$$

2. The conduction velocity measures the neural conduction for the largest nerve axons in the tested nerve segment. This value is relevant to that nerve segment and should be compared to proximal or distal segments of the same nerve, to the same segment of that nerve on the contralateral side and to a similar segment of another nerve on the ipsilateral side (e.g. ulnar nerve, if testing median).
  3. Figures 5, 6 and 7 show stimulation sites for the median, ulnar and radial nerves. (Fig. 5 also shows the progression of motor latencies for evaluation of median nerve segments with stimulation at the wrist, above elbow, axilla and Erb's point.)
    - a. Increased latency and slower conduction velocity value for the median nerve segment between the wrist (S1) and the cubital fossa (S2) would indicate neuropathic changes in that segment, such as pronator teres syndrome; slower conduction for segment between the cubital fossa (S2) and axilla (S3) may indicate neuropathic changes at the arm segment.
    - b. Increased latency and lower conduction velocity value between median nerve segment at the axilla (S3) and shoulder girdle, Erb's point (not seen at the para-clavicular region) may indicate neuropathic changes affecting the lateral cord of the brachial plexus such as those seen in brachial plexus traction injury.
  4. Fig. 7 shows a similar progression of motor latencies during evaluation of ulnar nerve segments with stimulation at the wrist, below elbow, above elbow, axilla and Erb's point.
    - a. An increased distal latency for the ulnar nerve between the wrist crease and the abductor digiti minimi may indicate neuropathic changes at Guyon's canal
    - b. Slower conduction for the ulnar nerve segment between the below elbow (S2) and above elbow (S3) may indicate neuropathic changes at the medial epicondyle (such as cubital tunnel syndrome)
    - c. Delayed conduction for the ulnar nerve segment between the axilla (S4) and shoulder girdle (Erb's point, S5) may indicate neuropathic changes affecting the medial cord of the brachial plexus, as may be seen in thoracic outlet syndrome or brachial plexus traction injury affecting the medial cord
  5. For the radial nerve:
    - a. Increased distal latency at S1 may indicate posterior interosseous nerve compression
    - b. Increased latency and reduced conduction velocity for the segment between stimulation sites S1 and S2 may indicate neuropathic changes for the deep branch of nerve in the Arcade of Frohse (radial tunnel syndrome), or where it crosses the lateral epicondyle
    - c. The segment between stimulation sites S2 and S3 evaluate the radial nerve as it passes through the spiral groove, and could show as increased latency and reduced NCV following a mid shaft humeral fracture in this region
- E. Amplitude: This is measured in microvolts, ( $\mu\text{v}$ .) or millivolts (mv.)

# Chapter 31 Figures

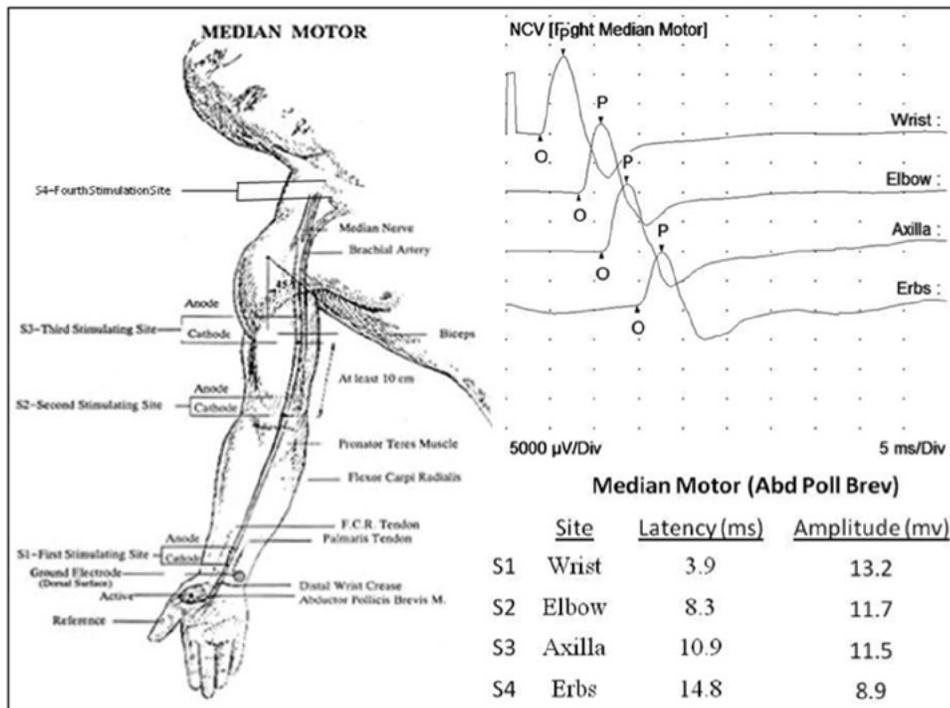


Fig. 5. Motor conduction stimulation sites and latency recordings for the median nerve.

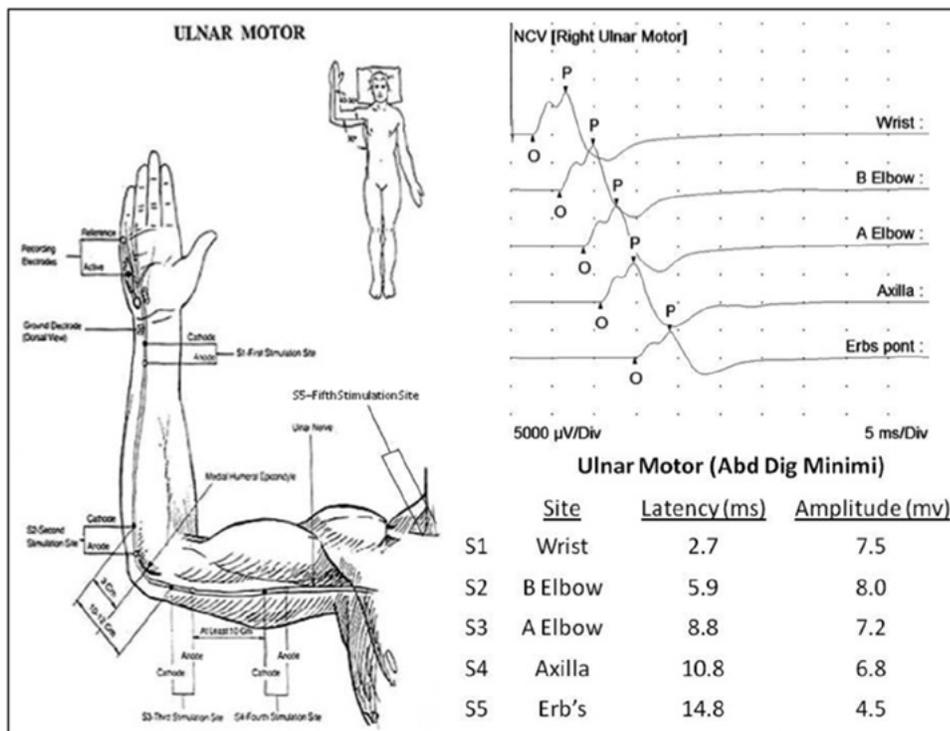


Fig. 6. Motor conduction stimulation sites and latency recordings for the ulnar nerve.

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1. Electrical stimulation of peripheral nerves generates an evoked compound action potential (SNAP or CMAP)
  - a. Median nerve motor stimulation generating an evoked muscle action potential in the abductor Pollicis Brevis would be called evoked CMAP
  - b. Sensory orthodromic stimulation of the digital nerves of the thumb or index would generate an evoked SNAP in the median nerve at the wrist
2. These evoked potentials may be measured either from the peak-to-peak (usual for SNAP) or baseline-to-peak (usual for CMAP) to record the amplitude of the evoked potential
  - a. The value of the amplitude (in microvolts, ( $\mu\text{v}$ ), for sensory, or millivolts, (mv.), for motor relates to the number of viable axons conducting the action potential from the stimulation site to the recording site
  - b. Reduced amplitude of the CMAP would indicate axonal loss or slowing in the nerve segment, between the stimulation and recording electrodes
3. By comparing the amplitude of the affected side with that of the non-affected side the electrophysiologist can assess the degree of the axonal loss
  - a. A decrease of 1 to 2 mv. In the amplitude of the CMAP of the symptomatic side, compared to non-symptomatic side would indicate mild degree axonal loss in the tested nerve segment
  - b. A reduced CMAP of  $>2$  mv. Would indicate moderate to severe axonal loss in that nerve segment
    - i. This is usually associated with muscle weakness and wasting/atrophy. Polyphasic CMAPs that have reduced amplitude and prolonged duration may indicate a situation where some motor units that were denervated, have been re-innervated by adjacent axons.
4. Comparison of the latency and amplitude data for distal site stimulation with those of the proximal site is useful in identifying the location of the pathology
  - a. For instance: a prolonged proximal latency, with stimulation at the elbow, of more than 2-3 ms. with reduced CMAP; and a normal distal (wrist) latency and amplitude, would indicate neural compromise in the forearm.

### (TABLE 1)

- F. The H-reflex latency and amplitude: H-reflex latency is the time from an electric stimulus of sensory neurons to the reflex muscle response
1. The signal travels from the stimulation site toward the spinal cord along Ia sensory afferents; there, it synapses and activates alpha motor neurons and then travels distally to the muscle supplied by that nerve. The H-reflex latency is consistent over repeated measurements.
  2. The reflex arc tested with the H-reflex is available for only certain muscles in the upper and lower limbs; it is useful in testing for nerve root pathologies, proximal neuropathy or Guillain Barrés syndrome.
    - a. Patients with radiculopathy usually show an increased latency and reduced amplitude of the H-reflex for the compromised root level in the limb affected by radiculopathy. Therefore it is important to test contralateral limbs and compare H-reflex latencies and amplitudes.

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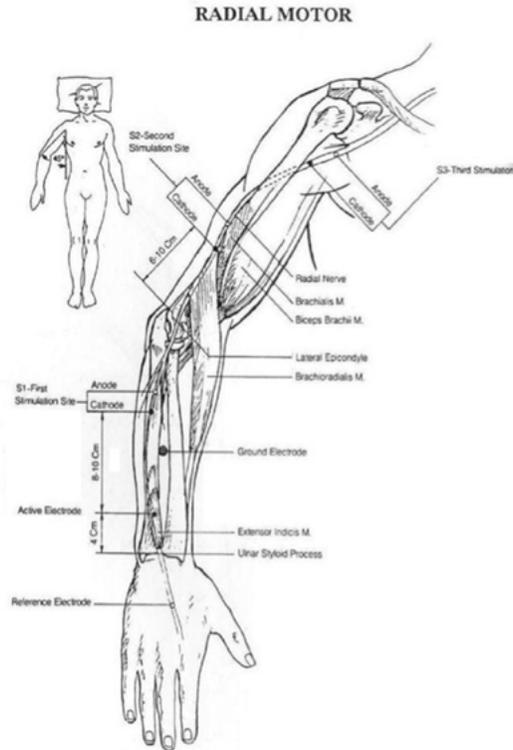


Fig. 7. Motor conduction stimulation sites for the radial nerve.

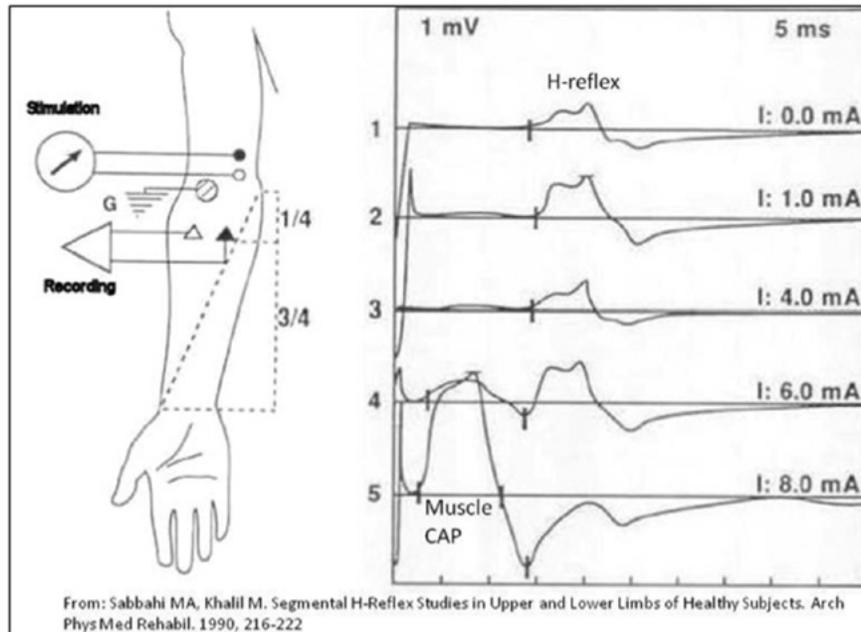


Fig. 8. H-reflex for flexor carpi radialis, showing electrode set up and H-reflex response at different stimulus amplitudes in normal subjects.<sup>1</sup>

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# Chapter 31 Figures

Nerve	Motor Latency (distal)	Sensory Latency (distal)	Conduction Velocity			
	Nerve segment	Range (ms.)	Nerve segment	Range (ms.)	Nerve segment	Range (M/s)
Median	Wrist – APB, 10 – 13 cm	2 – 4.2 (<5)	Wrist – digit III, 10 – 13 cm	2.3 – 3.2 (<4)	All	47 – 70
Median F-wave	Wrist	22 – 31				
Ulnar	Wrist – ADM, 10 – 13 cm	2 – 3.4 (<4)	Wrist – digit V, 10-13 cm	2.1 – 3 (<4)	Axilla – above Elbow	50 – 75
					Across elbow	45 – 65
					Elbow – wrist	45 – 75
Ulnar F-wave	Wrist	23 – 31				
Radial	Below elbow – extensor indicis, 6 cm	1.5 – 3.4				
Musculo-cutaneous	Biceps				Erb's point – axilla	60 – 75

**Table 1. Representative Normal Value Ranges for Upper Extremity Conduction Studies.\***

\* Depending on their protocol, each provider should establish and report normal values for their procedures.

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- b. AnH-reflex latency that is prolonged by more than 2 ms. compared to the contralateral side is usually indicative of radiculopathy
  3. H-reflex latency is usually measured from the electrical stimulation artifact to the deflection, from the baseline, of the reflex action potential
    - a. In the upper limb, Flexor Carpi Radialis (FCR) H-reflex can be recorded by electrical stimulation of the median nerve at the cubital fossa, where it is used to investigate the C7 nerve root level (see Fig. 8)
    - b. Normal values for the FCR H-reflex are: Latency 13 – 19 ms; amplitude 0.3 – 2.5 mv<sup>1</sup>
  4. H-reflex latency is also influenced by the patient's height and age
    - a. Tall individuals usually have a greater value for H-reflex latency compared to shorter persons, because of the longer distance the nerve signal must travel
    - b. Normal older persons usually have a longer H-reflex latency and reduced amplitude.<sup>2</sup> This is explained by degenerative processes that occur in the axons with aging.
    - c. Such degeneration usually affects the larger diameter axons, which conduct faster, leaving smaller diameter axons with slower conduction; this results in slowed H-reflex
    - d. The H-reflex latency or amplitude is not significantly affected in patients with pathologies distal to the stimulation site (e.g. CTS), distal (diabetic) neuropathies or muscle diseases (however, the amplitude will be lowered for patients with myopathies)
- G. The F-wave latency: F-wave recording relies on the phenomenon that when a nerve is stimulated at some point along its course, the action potentials travel in both directions from the point of stimulation
  1. For a motor nerve, they would travel in the normal, distal direction (orthodromic) and in the opposite, proximal direction (antidromic)
  2. The F-wave latency is the time from an electric stimulus to a motor nerve to a secondary muscle response
  3. This stimulus travels in the motor axons, (antidromically) toward the spinal cord, where it activates the  $\alpha$  motor neuron cell body and then returns along the same axons, to the muscle supplied by that nerve
  4. The F-wave is not a reflex response, since it does not travel through the sensory fibers and synapses, like the H-reflex
    - a. It is useful because of the fact that it travels up and down the alpha motor axon and would show any possible compromise along that route. In brachial plexopathy for example, the signal would be delayed when traveling proximally and then again traveling distally (amplifying the delay).
  5. The F-wave latency would be prolonged in muscles innervated through a compromised region of the brachial plexus, as in thoracic outlet syndrome or a traction injury
    - a. In such a case, the H-reflex would be minimally delayed compared to the F-wave

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6. F wave Testing
    - a. The F-wave for the Abductor Pollicis Brevis following electrical stimulation of the median nerve would test the integrity of the lateral cord of the brachial plexus
    - b. F-wave for the Abductor Digiti Minimi following stimulation of the ulnar nerve would test the integrity of the medial cord of the Brachial plexus
      - i. Since these represent similar distances, comparing both F-waves would be useful in order to identify whether medial or lateral cords are affected, or both, when compared to the contra-lateral limb
    - c. In patients with advanced CTS, the F-wave for median nerve stimulation would be prolonged compare to ulnar nerve F-wave for the same limb due to the median nerve compression at the wrist
    - d. On the contrary, F-wave for ulnar nerve stimulation would be prolonged compared to median F-wave in patients with impingement of the ulnar nerve at Guyon's canal. Both of these situations should also show increased latency for the distal segment of the respective nerve.
  7. The F-wave amplitude is rarely used because of the fact that its action potential represents 5-10% of the whole motor neuron pool for the tested muscle
    - a. Both the latency and the shape of the composite action potentials for the F-wave differ with each stimulus, because of different activation of different motor neuron pools
      - i. Several recordings are taken and the shortest latency is used, (see Fig. 9)
    - b. **F-wave tests are useful in patients with Thoracic outlet syndrome, traction injuries of the brachial plexus, Erb's Palsy or space occupying lesions at shoulder girdle region. It can be useful in testing patients with other motor neuropathy at the proximal level of the neural tree. (TABLE 2)**
- H. Repeated Stimulation: This test is sometimes performed with motor nerve conduction studies to detect motor end plate disorders, such as myasthenia gravis
1. Because of more rapid motor end plate fatigue, the amplitude of the CMAP will decrease with repeated stimulation for patients with a motor end plate disease
  2. This amplitude decrement is not seen in normal, healthy persons

### IV. Electromyography

This is the use of hypodermic needle electrodes to record electrical activity within the muscle, by detecting the voltages generated by motor units close to the needle. The skilled electromyographer uses their ears to listen to the sounds generated by this electrical activity, as well as their eyes, watching the screen. This helps them identify normal and abnormal signals. This needle examination normally consists of 4 components: insertion activity, resting muscle, mild contraction and strong contraction. These steps are normally repeated in different regions of a muscle, by testing at different depths and locations within the muscle. Representative muscles

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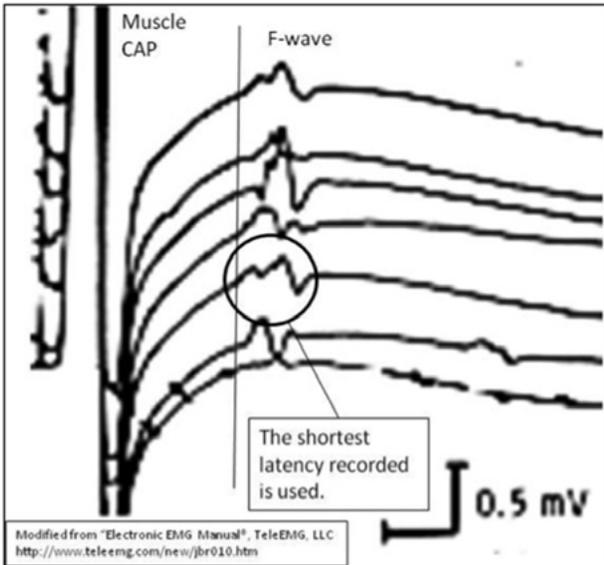


Fig. 9. F-wave recordings.<sup>5</sup> Note the variability in the response wave, and that the wave with the shortest latency is used.

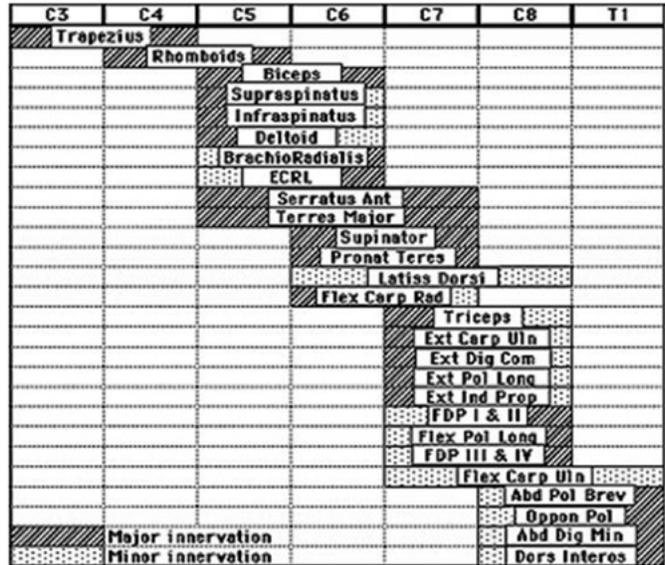


Fig. 10. Upper extremity innervation according to brachial plexus nerve roots.<sup>5</sup>

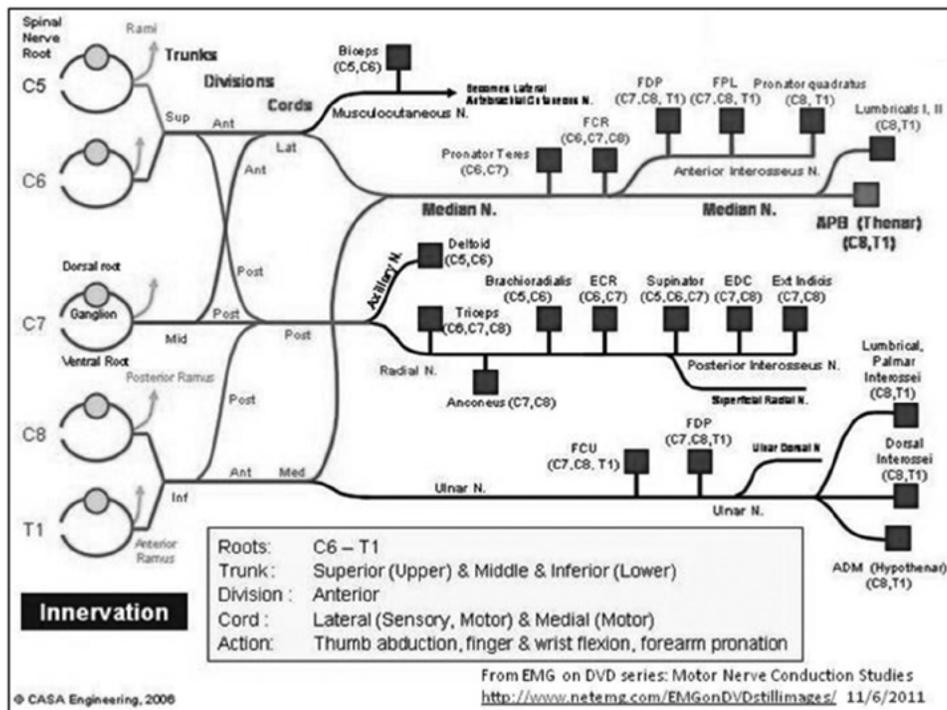


Fig. 11. Diagram of brachial plexus and major upper extremity nerves, showing nerve and root innervation pattern.<sup>6</sup>

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are chosen, which based on nerve and myotomal distributions, allows the electromyographer to differentiate between isolated nerve injuries and nerve root injuries. Figures 10 and 11 provide schema that may be used to differentiate nerve root from peripheral nerve injuries.

In observing this activity, the electromyographer pays attention to the appearance of the waves on the screen. What they look for is the amplitude (height) of the wave, in microvolts ( $\mu\text{v}$ .), the duration of the wave, in milliseconds (ms) and the number of phases. Each time the tracing crosses the baseline represents a phase. A monophasic wave would go up (negative) or down (positive) and then return to baseline. A biphasic wave would have both a negative and a positive phase; a triphasic wave would show three phases (etc.) a wave having more than three phases is usually referred to as being *polyphasic*.

- A. Insertion activity: Inserting a needle into the muscle causes mechanical activation of the pierced muscle fibers
  1. This activation normally lasts for 50 – 100 ms. in healthy subjects (Fig. 12).
  2. In denervated muscles this duration would be prolonged indicating increased irritability of the denervated muscle fibers
  3. The electromyographer would record the duration of the insertion activity based on visual observation and/or duration of the sound produced by the needle insertion
- B. Resting muscle: Immediately after needle insertion, the electromyographer keeps the needle still and looks and listens for any spontaneous electrical activity
  1. In healthy muscle, you will seldom find any spontaneous activity in muscles at rest. Healthy muscles are usually “silent” (electrically) during rest.
  2. However, denervated muscles usually show spontaneous activities in the form of *fibrillation potentials* and *positive sharp waves*
    - a. Fibrillation potentials: These are short duration, usually biphasic potentials of 100-200  $\mu\text{v}$ . amplitude
      - i. They may occur randomly when the muscle is at rest, creating momentary high pitched sounds. Fibrillation potentials represent activation of single denervated motor units that depolarize (fire) spontaneously, without neural control (as opposed to fasciculation potentials which will be presented following).
    - b. Positive (+ve) Sharp waves: Similarly, +ve sharp waves are spontaneous activity of single motor units with a characteristic positive deflection (downward) from the baseline
      - i. They are normally monophasic and of short duration. Like fibrillation potentials, +ve sharp waves indicate denervation of muscles fibers and represent random spontaneous activity of motor units.
    - c. Fibrillation potentials and +ve sharp waves when present, are usually reported as an index of the amount of this activity in a range from +1, +2, +3 or +4
    - d. The higher the number of the fibrillation potentials and +ve sharp waves the greater the denervation of the muscle, and represents axonal injury of the nerve

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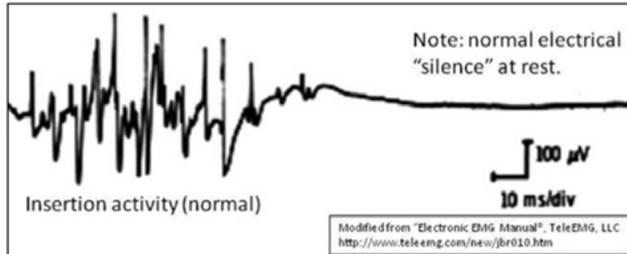


Fig. 12. Normal EMG insertional activity.<sup>5</sup>

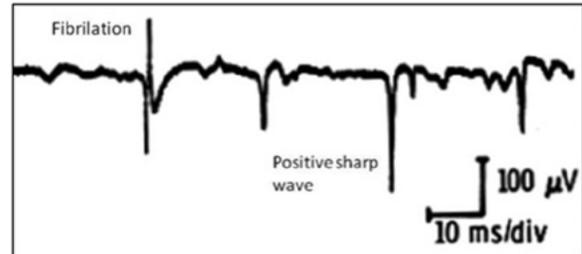


Fig. 13. Fibrillation and positive sharp wave potentials.<sup>5</sup>

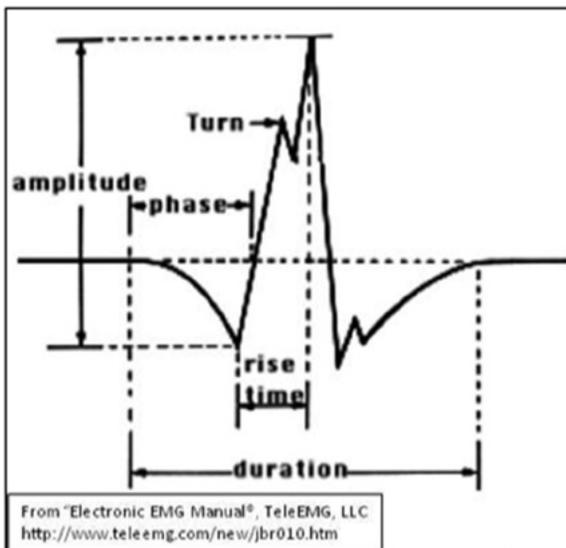


Fig. 14. Terminology used in describing characteristics of motor unit potentials.<sup>5</sup>

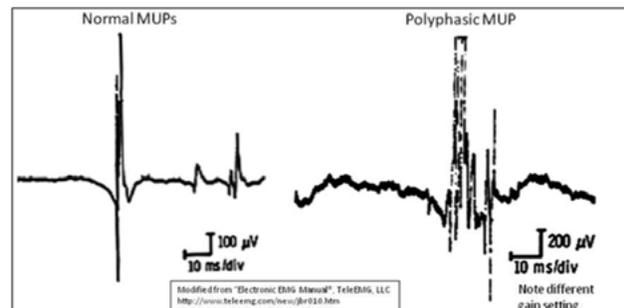


Fig. 15. Comparison of normal and polyphasic motor unit potentials (MUP).<sup>5</sup>

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- i. These denervation patterns may occur in patients with CTS in the muscles supplied by the median nerve such as the Abductor Pollicis Brevis
    - ii. They might also occur in patients with radiculopathy especially in the muscles supplied by the compromised nerve root
    - iii. The pattern of muscles showing these abnormalities allows the electromyographer to distinguish between the two types of pathology
  - e. Fasciculation potentials: Fasciculation potentials are large amplitude longer duration potentials of motor units occurring spontaneously, at rest
    - i. They are due to instability of the motor neuron or its cell body
    - ii. This neuronal instability might occur due to calcium deficiency or other ionic imbalance at the cell membrane
    - iii. This may be caused by mechanical irritation, such as nerve root compression
    - iv. Fasciculation potentials are also more common in patients with spinal cord diseases and other central nervous system pathologies
    - v. Frequent consumption of coffee could also cause an increased number of fasciculation potentials, which would be seen in different locations about the body such, as in the orbicularis oculi and vastus medialis muscles
    - vi. The electromyographer reports the incidence of fasciculation potentials in a pattern of muscles, which may indicate localized pathology at a certain spinal segment of the spinal cord
- C. Mild muscle contraction: This is the third stage of the needle EMG examination. During a mild muscle contraction, the electromyographer can observe the motor unit potentials (MUPs) caused by firing of motor units in the region of the needle electrode.
  1. The patient is asked to perform sufficient contraction level that the electromyographer is able to study the shapes, amplitude and duration of the MUPs, phases and turns
  2. Different regions of the muscle are assessed during this phase, to look for abnormalities
  3. The voluntary MUPs seen during muscle contraction with needle EMG are representative of single motor units and not the composite of all motor units seen with surface electrodes in an evoked response studies (e.g. NCV)
    - a. Motor unit potentials (MUP):
      - i. A motor unit potential **phase** is any upward or downward deflection away from the baseline
      - ii. A **turn** is a change in the action potential shape that does not cross the baseline
      - iii. The normal motor unit potential shape is biphasic, but could also be triphasic, usually starting with upward (negative) deflection, followed by downward deflection (Figs. 14 and 15)
      - iv. Similar to evoked potentials, the voluntary MUP amplitude may be measured either peak-to-peak or from the baseline to the negative (upward) peak

## Chapter 31 Figures

(PRIVATE) Characteristic	H-reflex	F wave
Pathway	Sensory neurons synapse with motor neurons (1a- $\alpha$ motoneurons $\blacktriangleright$ motor axons $\blacktriangleright$ muscle fibers)	Reactivation phenomenon within motor neurons ( $\alpha$ axon antidromic $\blacktriangleright$ motoneuron, orthodromic)
Stimulus intensity	Lower, sensory only	Supramaximal (at or above threshold for motor neurons)
M wave (CMAP)	Small or none	Maximal
Latency	Constant, predictable	Variable; the shortest latency is used
Amplitude & Duration of response wave	Constant, predictable	Variable
Availability	Only certain muscles	Most muscles

**Table 2. Characteristics of H-reflex & F-wave.**

Potential	Amplitude ( $\mu\text{V}$ )	Duration (ms.)	Phases
Normal motor units	500 – 3000	2 – 10	2 – 3
Fibrillation	20 – 200	1 – 5	2 (or 3)
Positive sharp wave	50 – 1000	1 – 10	1 (or 2)
Polyphasic	50 – 3000	10 – 25	>3
Large Amplitude	3000 – 10,000	1000 – 6000	Usually 3
Myopathic	50 – 500	1000 – 6000	(2) – 3

**Table 3. Parameters of EMG potentials.**

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- v. Motor unit potential duration is measured from the first deflection of the action potential from the baseline to the point of final return of the action potential to the same baseline. A greater number of phases (more than 3) could be pathologic (Fig. 14).
4. In patients with a denervation pattern, e.g. CTS or other neuropathy, a motor unit potential may contain more than 4 or 5 phases due to axonal loss in which some motor units were denervated, then re-innervated by adjacent axons
  - a. Such “collateral” sprouting or nerve growth is usually slower in conduction velocity and often adds to the normal motor potentials, but results in a longer duration, causing the appearance of multiple phases and a prolonged motor unit potential
  - b. Recording “polyphasic” motor unit potentials during needle electrode recording is indicative of a denervation-reinnervation process in the tested muscle (Fig. 15 for comparison of normal and polyphasic MUPs)
5. It is important to note that a small percentage of polyphasic MUPs are seen in the muscles of healthy subjects due to minimal injury processes from daily activities or exercises. Therefore, it is clinically consistent to report an “increased percentage of polyphasia” in pathologic conditions.
  - a. Furthermore, the degree of polyphasia might increase in healthy subjects in aged population. This is mostly due to on-going degenerative processes in the neuromuscular system.
  - b. Older patients must have a greater increased proportion of polyphasic MUPs to correctly diagnose a pathologic condition compared to younger persons
  - c. Denervation and re-innervation processes are usually associated with increased MUP duration, increased polyphasia and increased MUP amplitude values
6. Persons with long-term partial denervation will show “**Large Amplitude**” motor units because remaining viable axons have expanded their motor units to innervate previously denervated muscle fibers
7. End-plate activity: This may be recorded if the needle electrode is close to the myoneural junction (motor end-plate).
  - a. It is usually recognized as noise of low amplitude (10-20  $\mu$ v.) short duration (2-4 ms.) monophasic potentials
    - i. It may also be of moderate amplitude (100  $\mu$ v.) biphasic potentials occurring at spontaneous (uncontrolled) activities with higher frequencies
  - b. It is seldom reported in the EMG report
- D. Full muscle contraction: During muscular contraction at higher force levels, all motor units are recruited causing a full complement of motor unit potentials on the screen of the EMG unit; and no baseline is normally seen. This is referred to as a **recruitment pattern**.
  1. As the patient increases muscle tension, the electromyographer observes the normal increased recruitment of different motor units and their increased frequency of activation
    - a. The complete obliteration of the baseline due to full motor unit activation is called **full recruitment pattern**, and the activity fills the screen

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- b. If the activity of some motor units is lost, this will result in gaps in the pattern; and this is called a ***partial or incomplete recruitment pattern***. In a partial recruitment pattern, the electromyographer will be able to parts of the baseline, with no MUPs (Fig. 16).
  - i. Such reduction in recruitment will increase with the increased axonal loss associated with denervation of motor units
  - ii. In compression neuropathies, this process will continue to increase until the compression is relieved and the axons re-grow to the denervated muscle
  - iii. The electromyographer will report the reduced recruitment in the EMG-muscle table by number or by the presence of low recruitment
- E. Differentiating between Neuropathy and Radiculopathy: By reviewing the pattern of muscles with abnormal findings, the electromyographer can identify which nerves are compromised, and can differentiate between peripheral nerve compression and nerve root involvement
  1. For example, a denervated abductor pollicis Brevis as well as the 1<sup>st</sup> lumbrical muscles with no denervation at the cervical paraspinal muscles would be associated with carpal tunnel syndrome especially if these data are associated with prolonged distal latency (motor or sensory) of the median nerve
  2. Denervation potentials of the same muscles with similar findings in the cervical paraspinal muscles at C8 spinal segment may indicate C8 cervical radiculopathy, at C7-T1 spinal vertebral level. In this latter case, no prolongation of distal latency of the median nerve should be expected.
- F. Differentiating between Neuropathy and Myopathy:
  1. With a myopathy, because of the damaged muscle fibers, the motor unit potentials will have much lower amplitude, less than 500  $\mu\text{v}$  (Fig. 16) and a higher frequency (firing rate)
    - a. This will be apparent in both the mild contraction phase and the full contraction phases of the study. The recruitment pattern will be complete, with all motor units recruited, at a low level force of contraction with low amplitude potentials. Nerve conduction latencies should be within normal limits.
- G. Other abnormal EMG Potentials: These are associated with muscle pathologies, such as myotonias and myositis
  1. Myotonic Discharge: Appears with myotonic conditions, due to altered membrane conductance parameters or some electrolyte imbalances.
    - a. Bursts of muscle fiber action potentials with high frequency activity may be recorded (from the speaker, it sounds like a revving engine or “dive-bomber” sound).
  2. Myositis: This appears on the EMG as reduced motor unit potentials (Fig. 17)
    - a. Since there are fewer muscle fibers firing in each motor unit, the voltage generated by their activity is less
    - b. The recruitment pattern (with stronger contraction) is usually described as being full (because there is no neurologic involvement, and so a normal frequency of motor unit recruitment), but low amplitude

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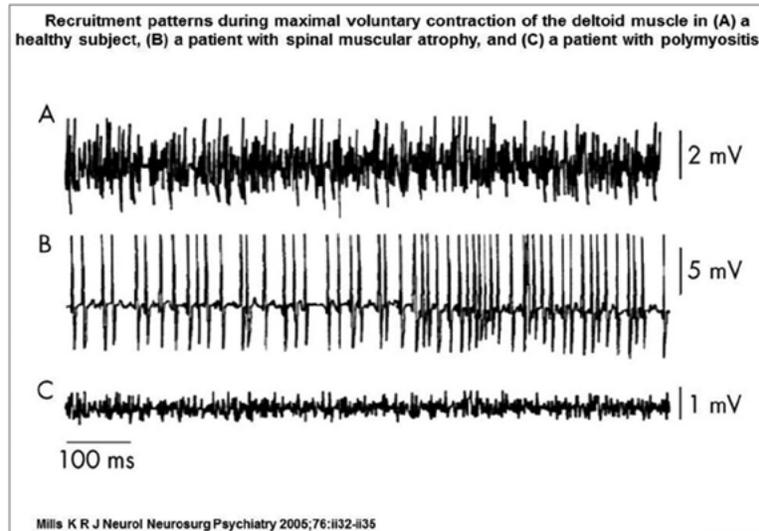
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### (TABLE 3)

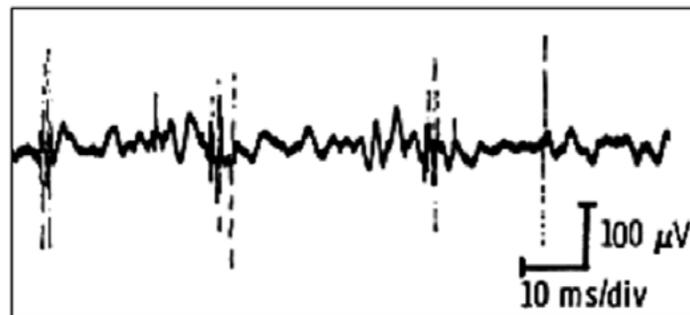
#### V. Common Neuronal Disorders Assessed by NCV/EMG

- A. Demyelination: Local degeneration of the myelin sheath for the nerve fiber or nerve root (demyelination) is a common pathologic change occurring with neural impingement syndromes
1. This is usually associated with conduction delay or block at that site
    - a. A demyelination, caused by compression, of the median nerve in the carpal tunnel may result in increased motor nerve latency for the nerve segment from proximal to the wrist crease to the abductor pollicis brevis
    - b. Demyelination of sensory fascicles of the same nerve at the same location may be shown as increased sensory latency between digital nerves of the index or thumb to a point over the median nerve segment proximal to the wrist crease
    - c. Similarly, demyelination of C7 nerve root caused by a C6-7 disc lesion, might be identified by a delayed flexor Carpi radialis H-reflex of that side
    - d. Demyelination of the medial cord of the brachial plexus is usually associated with delayed or blocked conduction of ulnar nerve F-wave to the abductor digiti minimi
  2. Demyelination of nerve axons or nerve root occurs usually at the acute/subacute stages of neural compression. Unless resolved, this would be followed by axonal damage and loss. This latter could be identified by EMG techniques.
  3. Demyelination also occurs with systemic and metabolic diseases, such as diabetes
    - a. In these conditions, the demyelination normally involves multiple nerves and occurs bilaterally, so nerve conduction studies would show conduction delays in multiple nerves, bilaterally
    - b. In this way, the electromyographer can differentiate between local conduction defects and systemic ones
- B. Neurapraxia: This might be called the “first degree injury” of the neural structures
1. In neurapraxia, demyelination occurs, which causes slowing or block of neural conduction
  2. At this pathologic level, damage occurs to the myelin sheath due to a compressive force or localized ischemia, but the axons are spared
  3. The degree of demyelination ranges from mild to complete, dependent on the degree and duration of insult
  4. Nerve conduction studies will show normal conduction when stimulating the nerve either distal to the site of injury. Stimulation proximal to the site of injury would show delayed or absent conduction.
  5. EMG examination would show silence at rest
    - a. If conduction is only partially blocked, an incomplete recruitment pattern is reported with strong contraction, since not all motor units will be activated
    - b. If conduction is completely blocked, there will be no volitional activity
- C. Axonotmesis (axonal loss): This might be called the “second degree injury” resulting in damage and loss of continuity of the axons sparing the neural tube and possibly myelin sheath

## Chapter 31 Figures



**Fig. 16. Recruitment pattern, seen with full muscle contraction. Comparison of normal with pathologies.<sup>7</sup>**



**Fig. 17. Myopathic motor unit potentials.<sup>5</sup>**

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1. This is a common condition in an ischemic lesion of the nerve or nerve root or blunt force trauma to a nerve
2. It is common that smaller diameter axons will be damaged before large diameter axons with ischemic injuries
3. Axonotmesis results in Wallerian degeneration of the axon distal to the site of injury
4. With axonotmesis, nerve conduction studies will show no evoked response (once Wallerian degeneration is complete), to distally innervated muscles when stimulating the nerve either proximal or distal to the site of injury. Prior to completion of Wallerian degeneration, there may be a response to distal stimulation.
5. EMG examination will show denervation potentials
6. Because the neurilemma tube is intact, with more distal injuries, the prognosis for appropriate reinnervation is good

D. Neurotmesis: This is the most severe form of neural injuries, where the axons and the supporting structures of the myelin sheath are damaged and lose continuity

1. As with axonotmesis, nerve conduction is blocked and signals do not pass the site of damage. This is seen in traumatic nerve injuries, where the nerves are severed or severely crushed.
2. The electromyographer will report no evoked response distal to the site of the lesion when electrically stimulating the nerve proximal to the lesion site
3. EMG examination will show denervation potentials, until the muscle tissue itself degenerates (12 – 18 months)
4. Because the neurilemma tube is not intact, the prognosis for appropriate and complete reinnervation is poor

### VI. Components of the EMG/NCV Report

#### A. The Narrative:

1. The EMG/NCV report usually starts with text describing the patient's information as well the history and results of other physical examinations and tests. This standard clinical information is needed in part to justify the application of the electrophysiologic test.
2. A second section of the text might include the type and number of testing procedures employed in the EMG/NCV exam
  - a. For example in a routine EMG/NCV test for suspected cervical radiculopathy, motor and sensory conduction tests for the median and ulnar nerves as well as radial sensory test would be carried out. Flexor Carpi Radialis H-reflex for both upper limbs would be tested. Needle EMG test for the paraspinal cervical muscle and selected muscles (representing myotomal distributions) in both upper limbs would also be a common routine test. Some investigators would also test the median and ulnar F-waves latencies. These testing procedures with electrode application sites and type of applied electrodes would be identified in this section of the text.
3. A third section of the text would report the findings of the different testing procedures

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- a. This should be discussed in relation to its physiologic and clinical meaning. For example a prolonged distal latency of median motor conduction test at the wrist level would be interpreted as demyelination of the median nerve at the anterior aspect of the wrist.
  - b. A delayed latency of FCR H-reflex with reduced peak-to-peak amplitude, for the right upper extremity compared to the left, would be interpreted as compromised C7 nerve root for the right side
  - c. In this section the data from the nerve conduction, reflex studies and needle EMG would be pooled together to explain a pathologic entity from the physiologic aspect
  - d. The degree of axon loss and demyelination for different nerves, or nerve root(s) associated with the denervation pattern of the muscles supplied by those nerves/nerve roots would be included in this part of the document
4. The final section of the text would include the “Clinical Impression”
- a. A sentence or two of the clinical impression stating a possible diagnosis or pathologic entity that is supported by electrophysiologic data, other physical examination or other findings would be included in this section
  - b. Any recommendations for possible repeated or serial studies and appropriate time intervals might be included for certain pathologies such as diabetic polyneuropathy or recovering nerve injury, in order to assess the progression or regression related to the clinical condition
  - c. Further laboratory testing, e.g. blood analysis or imaging studies, might be suggested to confirm the results of the electrophysiologic studies
- B. The numerical values of the report: Numeric data obtained for different procedures ideally are presented in easy-to-read tables, usually starting with the conduction studies and followed by a table of EMG findings for different muscles tested
1. In the table for nerve conduction studies, the values for measured data would be presented with a column for the normative values
  2. Some modern EMG machines generate reports automatically and would highlight the abnormal (pathologic) data if it is significantly different from normative values; others would perform an automatic comparison of data between the right and left sides to highlight any difference in those values.
  3. The values that are significantly different (lower conduction velocity, smaller amplitudes, delayed latency) in a specific limb would be highlighted for visual comparison
  4. The EMG table reporting data for all tested muscles is an integral part of the EMG/NCV report
    - a. These describe findings during insertion activity, spontaneous activity followed by motor unit activity during low and strong contraction (recruitment pattern) of each muscle tested and identify any abnormalities in each component
    - b. In most newer EMG machine reports, each muscle is matched with its corresponding primary nerve root supply (e.g. First Dorsal Interosseous =C8). This facilitates reading and interpreting the EMG report.
- C. The traces: The traces for nerve conduction studies as well as those of the H-reflexes and F-waves would be presented in the report

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1. Studying these traces allows for verifying the data presented in previous section (numeric values)
  2. Amplitudes, latency (distal and proximal), shapes of the evoked potentials should be visually screened for analysis and interpretation
  3. Traces should include the gain ( $\mu\text{v}$ . per division) of recording and the time base (ms. per division). These allow the reviewer to verify the values of the amplitudes and latencies of different evoked potentials (motor and sensory conduction, F and H waves).
- D. Normal and abnormal values quoted in the report: Most EMG equipment reports give the normal value (range) for most of the tested parameters e.g. distal latency, conduction velocity
1. This is important for comparison to the recorded (tested) values
  2. The electromyographer should use the guidelines supplied by the EMG equipment manufacturer in order to validly state that a recorded value is abnormal
    - a. For example if the normal distal values provided by the EMG device are based on an 8 cm. distance, between the stimulation and recording electrode, the investigator must apply a similar protocol/method when measuring distal latency
    - b. If the investigator used a 10 cm distance for testing distal latency, an adjustment for the extra 2 cm should be made
    - c. The normal values provided with the machine are measured from normal adult subjects. These “normal” parameters would be different in a population of healthy older subjects. For example the normal nerve conduction velocity of a healthy 80 year old person is expected to be less than that of a healthy 25 year old.
- E. Matching abnormal values to clinical impression of the report:
1. In order to decide on the clinical impression, the electromyographer usually studies all the EMG/NCV findings in light of the patient’s history and physical (including neurologic) exam in order to reach an electrophysiologic impression
    - a. For example a delayed flexor carpi radialis H-reflex associated with smaller amplitude and denervation pattern in the cervical paraspinal muscles as well as the triceps and flexor carpi radialis muscles could indicate C7 radiculopathy. If the electromyographer found no abnormal values in the EMG signal and the nerve conduction studies, H-reflex and F-wave test a diagnosis of “essentially normal EMG/NCV studies” will be given. However, while abnormal NCV/EMG findings help confirm a clinical diagnosis, it is increasingly recognized that normal NCV/EMG findings do not necessarily rule one out. This is particularly true for peripheral compression neuropathies, such as carpal tunnel syndrome.<sup>3</sup> In one study, 25% of cases had normal nerve conduction studies.<sup>4</sup>
- F. Matching abnormal traces to clinical impression of the report:
1. Recorded traces are an integral part of the EMG/NCV study
  2. Ideally, anyone reviewing an EMG/NCV report should examine these traces or print-out, to verifying correct distal latency, amplitude and shape of the evoked responses and to look for possible abnormalities that may have not been identified by the computer in the EMG/NCV device

**Patient Case Examples**

1. Multilevel cervical radiculopathy with extensive denervation
2. Carpal tunnel syndrome with diabetic neuropathy
3. Carpal Tunnel syndrome with cervical radiculopathy

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## 00251662336251661312251659264251660288 Case Study Patient 1: Multilevel cervical radiculopathy

### History/Comments:

This patient has been complaining of pain and limitation of movements in the neck and shoulder with radiating pain to shoulder girdles. Current complaints are pain in the neck and both shoulders and shoulder girdles and sometimes radiates to the arms; no major complaints of numbness at the arm, forearm or hands; mild complaints of weakness and heaviness at the shoulders. Symptoms are constant but aggravated at night sometimes. Patient reported no previous history of HTN, diabetes or surgeries related to the site of the injury. DTR: WNL Skin Sensation: WNL

*Note: Patient history and physical findings are necessary to design the testing procedures.*

### Motor Nerve Study

Median Nerve		Lat (ms)		Dur (ms)		Amp (mV)		Area (mVms)		Dist (mm)		C.V. (m/s)	
Rec Site: APB	STIM SITE	L	R	L	R	L	R	L	R	L	R	L	R
Wrist		4.7	4.2	6.3	6.8	7.3	6.8	26.4	26.0				
Elbow		9.0	9.2	6.3	6.7	7.0	6.0	26.2	24.0	230	250	53.0	50.0

Ulnar Nerve		Lat (ms)		Dur (ms)		Amp (mV)		Area (mVms)		Dist (mm)		C.V. (m/s)	
Rec Site: ADM	STIM SITE	L	R	L	R	L	R	L	R	L	R	L	R
Wrist		3.3	3.7	8.5	7.0	4.2	6.5	19.8	22.5				
B.Elbow		7.8	8.0	8.0	7.7	4.2	4.7	19.1	21.7	235	255	52.2	58.8

### Sensory Nerve Study

Median Nerve		Lat (ms)		Pk Lat (ms)		Amp (uV)		Dist (mm)		C.V. (m/s)	
Stim Site: Wrist	REC SITE	L	R	L	R	L	R	L	R	L	R
Thumb		2.5	2.5	3.5	3.4	14.7	12.7				
Index		2.9	2.4	3.4	3.4	24.3	11.7				
3rd dig.		2.5	2.5	3.4	3.4	6.7	5.0				
Ring		3.1	2.3	2.6	2.8	7.6	6.6				

### F-Wave Study

Median Nerve		Latency ms		Amplitude mV	
Rec Site: APB	Stim Site: Wrist	L	R	L	R
M wave		5.00	3.67		
F wave		30.50	30.33		
F-M		25.50	26.67		

*Note: values for conduction velocities were within normal range. Similarly, for F-waves of the median and ulnar nerves.*

Ulnar Nerve		Latency ms		Amplitude mV	
Rec Site: ADM	Stim Site: Wrist	L	R	L	R
M wave		3.67	3.83		
F wave		32.67	32.50		
F-M		29.00	28.67		

### H Reflex Study

Left Median Nerve		Latency ms	
Rec Site: F Car.Rad	Stim Site: Elbow	L	R
M wave		15.00	
H wave		25.00	

Median Nerve		Latency ms		Amplitude mV	
Rec Site: F Car.Rad	Stim Site: Elbow	L	R	L	R
M wave		15.00	15.00		
H wave		25.00	19.00		

*Note prolonged latency (25 ms) FCR H-reflex on the L. This indicates C7 nerve root*

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### EMG Study

Name	Ins Act	Fibs	PSW	Fascics	Polyph	MU	AmpMU	Dur	Config	Pattern	Int Pat	Recruit
R. Paraspinals	inc	2+	2+	none	inc	inc	inc	norm	norm	norm	full	norm
R. Deltoid	inc	2+	2+	none	inc	inc	inc	poly	irreg	full	full	norm
R. Biceps Brachi.	inc	2+	2+	none	none	inc	inc	poly	norm	full	full	norm
R. Triceps	inc	2+	2+	none	inc	inc	inc	norm	norm	full	full	norm
R. Flx.Car.Rad.	inc	2+	2+	none	inc	inc	inc	poly	norm	full	full	norm
R. Flx.Car.Uln.	inc	2+	2+	none	inc	inc	inc	poly	norm	full	full	norm
R. Dors.Int.1	inc	2+	2+	none	inc	inc	inc	poly	irreg	reduc	full	norm
R. Abd.Dig.Mn.	inc	2+	2+	none	inc	inc	norm	norm	norm	full	full	norm
L. Paraspinals	inc	2+	2+	none	inc	inc	inc	poly	irreg	full	full	norm
L. Deltoid	inc	2+	2+	none	inc	inc	inc	poly	irreg	reduc	full	norm
L. Biceps Brachi.	inc	2+	2+	none	inc	inc	inc	poly	irreg	full	full	norm
L. Triceps	inc	2+	2+	none	inc	inc	inc	norm	norm	full	full	norm
L. Flx.Car.Rad.	inc	1+	1+	none	inc	inc	inc	norm	norm	full	full	norm
L. Flx.Car.Uln.	inc	2+	2+	none	inc	inc	inc	norm	norm	full	full	norm
L. Dors.Int.1	inc	1+	1+	none	inc	inc	inc	norm	norm	full	full	norm
L. Abd.Dig.Mn.	inc	2+	2+	none	inc	inc	inc	norm	norm	full	full	norm

Note extensive denervation pattern (unusual) in both paraspinal and limb muscles for corresponding spinal (myotomal) level.

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### Summary/Interpretation:

The following testing procedures were carried out in both Upper Extremities:

Needle EMG for the paraspinal cervical muscles and selected UE muscles (2 limbs needle EMG); motor conduction studies for the median and ulnar nerves at the forearm and arm segments (4 motor segments); sensory studies for the median, ulnar and radial nerves (6 sensory units); median and ulnar F-waves (4 F-waves) and FCR H-reflex (2 H-reflexes). H-reflex was tested during dynamic postural modification to identify the neck posture of maximum neural decompression and compression (Kinesiologic H-reflex)

Results showed significant reduction in the amplitude of the FCR H-reflex of the right and left upper extremities indicating compromised C6-7 nerve root. This was substantiated with denervation pattern in the paraspinal cervical muscles, triceps, FCR and EDC. It was also associated with denervation pattern in the deltoid, biceps, FDI and ADM indicating compromised C5 and C8 nerve roots. The compromised nerve roots were decompressed by postural modification. Nerve conduction studies, F-waves and EMG for other muscles were WNL.

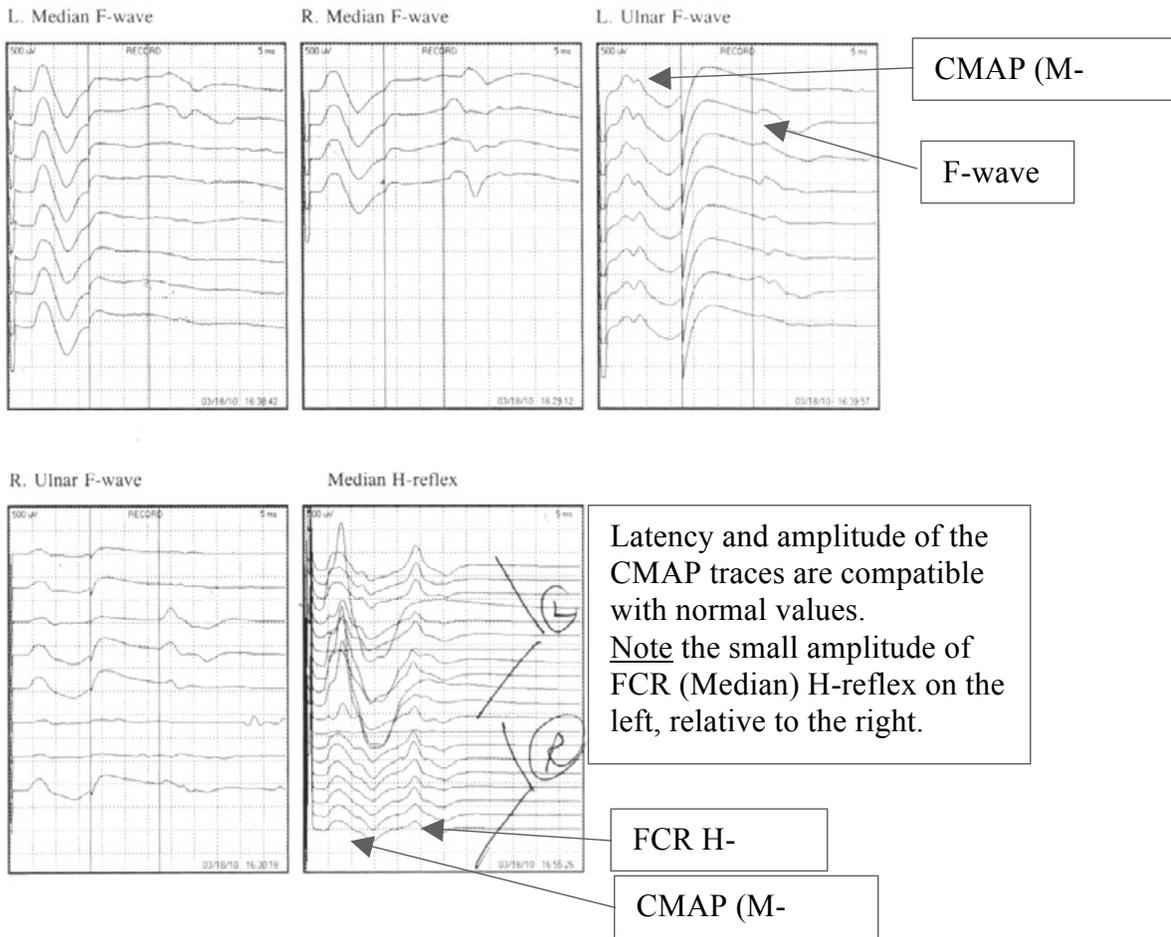
### CLINICAL IMPRESSION:

COMPATIBLE WITH COMPROMISED C5, C7 AND C8 NERVE ROOTS AFFECTING THE RIGHT AND LEFT UPPER EXTREMITIES SIMILAR TO THOSE SEEN IN CERVICAL RADICULOPATHY OF DEGENERATIVE ORIGIN. CLINICAL CORRELATION IS NECESSARY.

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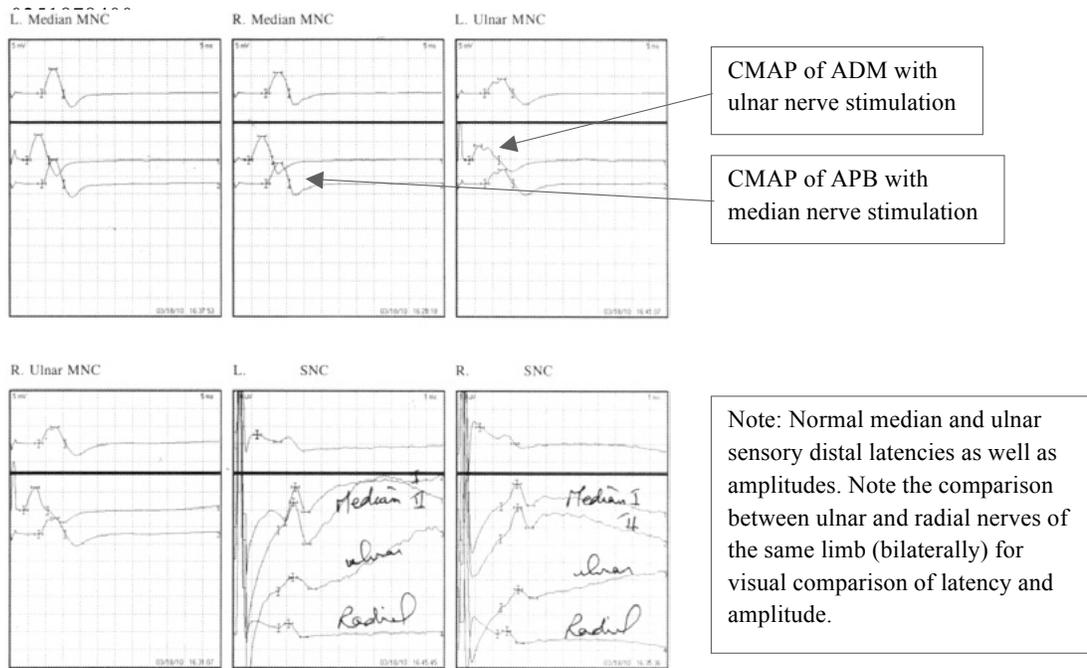
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## Case Study Patient 2: Diabetic polyneuropathy with CTS

### History/Comments:

This patient has been complaining of pain and numbness in the hand and arm of the right and left sides for the last 24 months. Current complaints are pain- aching in the hands and forearms and radiating to the right shoulder, with burning sensation in the hands in the right more than left with numbness and tingling in the hands and all fingers as well as the forearm; weakness and heaviness in the arms and hands with weak handgrip function in the right more than left hand. Symptoms are intermittent but aggravated at night when the symptoms wake the patient from sleep. Patient reported having a history of HTN and diabetes for the last 25 yrs. and no prior history of decompression surgery at the affected hand. Evaluation showed atrophy in the thenar muscles in both hands; Tinel test: negative (bil) Phalen test: positive (bil.) DTR: reduced Bi and TRI (bil.) Skin sensation: hyperesthesia in the lateral aspect of the hand in the right more than left.

### Motor Nerve Study

Median Nerve		Lat (ms)		Dur (ms)		Amp (mV)		Area (mVms)		Dist (mm)		C.V. (m/s)	
Rec Site: APB	STIM SITE	L	R	L	R	L	R	L	R	L	R	L	R
Wrist		7.3	7.0	3.3	4.3	.533	1.1	1.1	2.7	235	260	32.7	53.7
Elbow		14.5	11.8	8.2	46.2	.133	.400	0.6	3.1				

Ulnar Nerve		Lat (ms)		Dur (ms)		Amp (mV)		Area (mVms)		Dist (mm)		C.V. (m/s)	
Rec Site: ADM	STIM SITE	L	R	L	R	L	R	L	R	L	R	L	R
Wrist		3.8	5.5	7.5	6.3	2.9	1.3	11.8	5.2				
B.Elbow		10.2	11.5	7.8	8.5	1.3	1.1	6.3	5.5	245	230	38.6	38.3

### Sensory Nerve Study

Median Nerve		Lat (ms)		Pk Lat (ms)		Amp (uV)		Dist (mm)		C.V. (m/s)	
Stim Site: Wrist	REC SITE	L	R	L	R	L	R	L	R	L	R
Thumb		1.4	4.3	2.4	4.9	2.7	0				
Index		1.3	1.4	1.3	1.4	5.7	6.7				
3rd dig.		4.0	4.0	4.9	4.9	0	2.7				
Ring		1.1	2.4	1.9	2.4	5.3	5.3				

*Note that this patient suffers symptoms both distal and proximal to the wrist level with reduced tendon triceps reflex.*

*Note prolonged distal latency and small amplitude of the CMAP for the median compared to the ulnar motor nerve (both right and left).*

*Note lower value of motor conduction velocities for the right and left ulnar nerve and left median nerve.*

*Note prolonged distal latency and small amplitude of SNAP for the median, ulnar and radial nerves (right and left)*

# Chapter 31: Electrophysiologic Testing

Mohamed Sabbahi, PT, PhD, ECS and Charles Costello, PT, PhD, CHT

## F-Wave Study

Median Nerve  
Rec Site: APB  
Stim Site: Wrist

M wave  
F wave  
F-M

Latency ms	R	Amplitude mV	R
L	7.17	L	6.83
	44.33	L	37.17
	37.17	R	30.39

Ulnar Nerve  
Rec Site: ADM  
Stim Site: Wrist

M wave  
F wave  
F-M

Latency ms	R	Amplitude mV	R
L	4.33	L	5.33
	46.50	L	35.83
	42.17	R	30.50

Note delayed latency on the left side for the F-waves of the median (44.3, L; 37.1, R) and ulnar (46.5, L; 35.8, R) nerves. This indicates neuropathic changes affecting motor axons of the proximal segments.

## H Reflex Study

Right Median Nerve  
Rec Site: F Car.Rad  
Stim Site: Elbow

M wave  
H wave

Latency ms	
M wave	15.00
H wave	20.83

Note delayed FCR H-reflexes.

## EMG Study

Name	Ins Act	Fibs	PSW	Fascics	Polyph	MU Amp	MU Dur	Config	Pattern	Int Pat	Recruit
R. Deltoid	inc	1+	1+	none	inc	norm	norm	norm	norm	full	norm
R. Paraspinals	Normal	norm	none	none	none	norm	norm	norm	norm	full	norm
R. Biceps Brachi.	inc	1+	1+	none	inc	norm	norm	norm	norm	full	norm
R. Triceps	inc	1+	1+	none	inc	inc	norm	norm	norm	full	norm
R. Flx.Car.Rad.	inc	2+	2+	none	inc	inc	norm	norm	norm	full	norm
R. Flx.Car.Uln.	inc	2+	2+	none	inc	inc	norm	norm	norm	full	norm
R. Dors.Int.1	inc+	3+	3+	none	inc	inc	poly	irreg	irreg	reduc	dec
R. Abd.Dig.Mn.	inc+	2+	2+	none	inc	inc	poly	irreg	irreg	reduc	dec
R. Abd.Pol.Br.	inc	2+	2+	none	inc	inc+	poly	irreg	irreg	reduc	dec
L. Abd.Pol.Br.	inc+	2+	2+	none	inc	inc	poly	irreg	irreg	reduc	dec
L. Paraspinals	Normal	norm	none	none	none	norm	norm	norm	norm	full	norm
L. Deltoid	inc	1+	1+	none	inc	norm	norm	norm	norm	full	norm
L. Biceps Brachi.	inc	1+	1+	none	inc	norm	norm	norm	norm	full	norm
L. Triceps	inc	1+	1+	none	inc	inc	norm	norm	norm	full	norm
L. Flx.Car.Rad.	inc	1+	1+	none	inc	inc	norm	norm	norm	full	norm
L. Flx.Car.Uln.	inc	2+	2+	none	inc	inc	poly	irreg	irreg	full	norm
L. Dors.Int.1	inc+	2+	2+	none	inc	inc	poly	irreg	irreg	reduc	dec
L. Abd.Dig.Mn.	inc+	2+	2+	none	inc	inc+	poly	irreg	irreg	reduc	dec

Note extensive (unusual) denervation pattern in the distal muscles supplied by the median nerve, as well as muscles supplied by other nerves (ulnar and axillary) both proximal and distal, although to a lesser degree.

But no denervation pattern in the cervical paraspinal muscles.

The following testing procedures were carried out in both Upper Extremities:

Needle EMG for the paraspinal cervical muscles and selected UE muscles (2 limbs needle EMG); motor conduction studies for the median and ulnar nerves at the forearm and arm segments (4 motor segments); sensory studies for the median, ulnar and radial nerves (6 sensory units); median and ulnar F-waves (4 F-waves) and FCR H-reflex (2 H-reflexes).

Results showed significant prologation in the distal latency and reduced amplitude of the CAP for the median,radial and ulnar nerve (motor and sensory) in both upper extremities in the right more than left. This indicates neuropathic changes similar to those seen in diabetic neuropathy. These changes were more pronounced in the median nerve more than other nerves of the right more than left indicating carpal tunnel syndrome. This neuropathic changes were substantiated with prologation in the median more than ulnar F-waves with denervation pattern in the APB more than ADM, FDI, FCR and FCU. Diabetic neuropathy was also substantiated with slower value of nerve conduction studies associated with prolonged FCR H-reflexes and small amplitude.

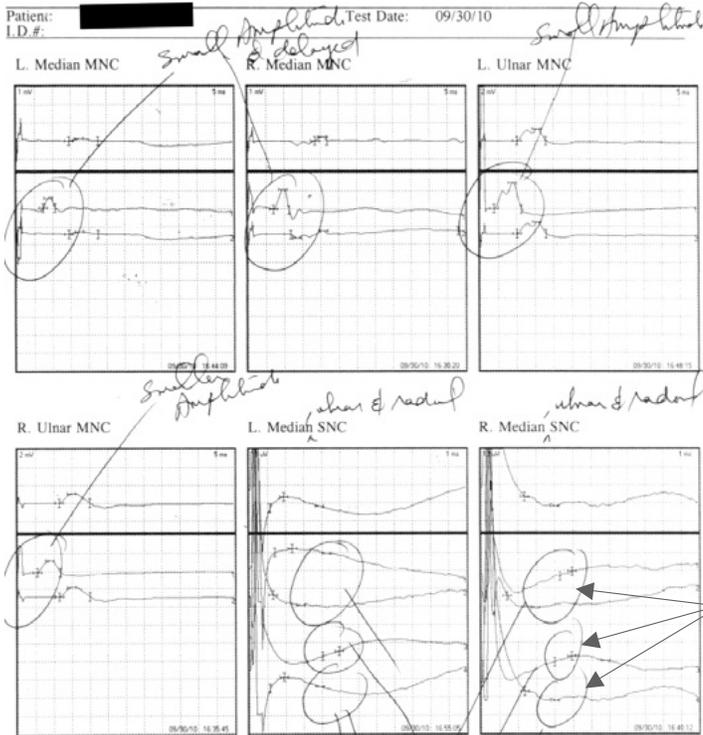
### CLINICAL IMPRESSION:

COMPATIBLE WITH **COMPROMISED MEDIAN NERVE** AT THE WRITS LEVEL SIMILAR TO CARPAL TUNNEL SYNDROME WITH AXONAL LOSS AND DEMYELINATION AND AFFECTING RIGHT MORE THAN LEFT SIDE. THIS WAS ALSO ASSOCIATED WITH FINDINGS **COMPATIBLE WITH DIABETIC POLYNEUROPATHY AFFECTING BOTH UPPER EXTREMITIES**. CLINICAL CORRELATION IS NECESSARY.  
THANK YOU FOR YOUR REFERRAL.

# Chapter 31: Electrophysiologic Testing

Mohamed Sabbahi, PT, PhD, ECS and Charles Costello, PT, PhD, CHT

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Note small amplitude and increased distal latency for median compared to ulnar nerve; also, left compared to right side. This indicates axonal loss as well as demyelination in the median nerve.

Note small amplitude and delayed SNAPs for the median, ulnar and radial nerves (right and left side), indicating polyneuropathies affecting sensory axons of the median, ulnar and radial nerves bilaterally.

# Chapter 31: Electrophysiologic Testing

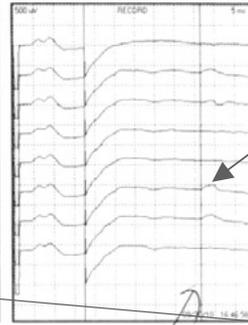
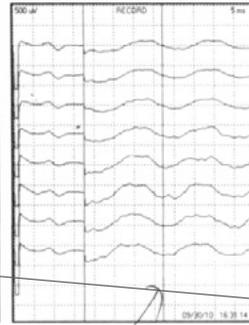
Mohamed Sabbahi, PT, PhD, ECS and Charles Costello, PT, PhD, CHT

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L. Median F-wave

R. Median F-wave

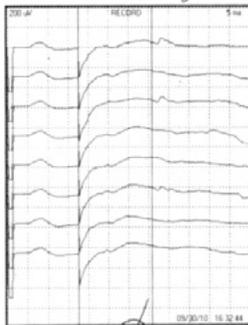
L. Ulnar F-wave



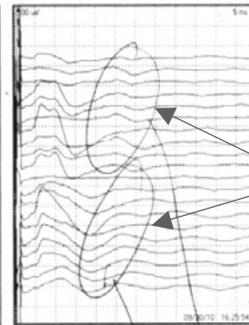
Note delayed F-wave latency for the median and ulnar nerves (both sides), indicating that the neuropathic changes affected proximal segments of motor neurons of the median and ulnar nerves.

Note: delayed CMAP due to

R. Ulnar F-wave



R. Median H-reflex



Note: Small amplitude and delayed FCR H-reflexes (both sides) indicating neuropathic changes affected also the proximal segment of the median nerve.

# Chapter 31: Electrophysiologic Testing

Mohamed Sabbahi, PT, PhD, ECS and Charles Costello, PT, PhD, CHT

## 251878400 Case Study Patient 3: Bilateral CTS with C7, C8 radiculopathy

### History/Comments:

This patient has been complaining of pain and numbness in the hand and arm of the right and left side for the last 10 yrs that get worse during the last 3 yrs. Current complaints are pain- aching in the left wrist, radiating to the forearm and sometimes to the arm and shoulder of the left side with numbness and tingling in both hands; weakness and heaviness in the left hand and arm with weak handgrip function in the left and right hands. Symptoms are constant but aggravated at night when the symptoms wake the patient from sleep. Patient reported having no prior history of HTN but she is diabetics for the last 5 yrs with no prior history of decompression surgery at the affected hand. Evaluation showed no atrophy or wasting or postural changes in the hand; Tincl test: positive at the wrist (R side) Phalen test: positive (R) DTR: reduced Tri., Bi. DTR (L) Skin sensation: hyposthesia in C6-7 and C7-8 (L)

### Motor Nerve Study

Median Nerve												
Rec Site: APB												
STIM SITE												
Lat (ms)		Dur (ms)		Amp (mV)		Area (mVms)		Dist (mm)		C.V. (m/s)		
L	R	L	R	L	R	L	R	L	R	L	R	
Wrist	6.0	6.5	5.5	5.2	4.0	2.8	12.6	8.3				
Elbow	9.0	9.7	5.3	5.5	10.3	7.1	31.1	22.9	172	200	57.3 63.1	

Note prolonged distal latency for the median nerve (motor) with smaller amplitude of the CMAP in the right (2.8 mv.) compared to left (4 mv.)

Ulnar Nerve												
Rec Site: ADM												
STIM SITE												
Lat (ms)		Dur (ms)		Amp (mV)		Area (mVms)		Dist (mm)		C.V. (m/s)		
L	R	L	R	L	R	L	R	L	R	L	R	
Wrist	3.0	3.0	5.2	5.5	8.2	8.5	24.1	28.3				
B.Elbow	5.7	5.7	5.2	5.5	7.2	8.2	20.3	28.6	162	170	60.7 63.7	

Note prolonged distal latency for the median (sensory 3.4 ms) in both hands, compared to the ulnar and radial nerves (1.6 ms and 1.4 ms respectively).

### Sensory Nerve Study

Median Nerve												
Stim Site: Wrist												
REC SITE												
Lat (ms)		Pk Lat (ms)		Amp (uV)		Dist (mm)		C.V. (m/s)				
L	R	L	R	L	R	L	R	L	R			
Thumb	3.4	3.5	4.0	4.0	17.3	11.7						
Index	3.4	3.7	4.1	4.4	14.7	0.7						
3rd dig.	1.6	1.2	2.1	2.2	11.3	18.3						
Ring	1.4	1.3	1.7	1.9	27.3	12.3						

Note smaller amplitude for SNAP for the median nerve in the right, compared to the left side.

### F-Wave Study

Median Nerve												
Rec Site: APB												
Stim Site: Wrist												
M wave		Latency (ms)		Amplitude (mV)								
L	R	L	R	L	R							
M wave		4.50	4.50									
F wave		27.8	28.1									
F-M		23.3	23.67									

*Delayed compared to ulnar F-wave*

Ulnar Nerve												
Rec Site: ADM												
Stim Site: Wrist												
M wave		Latency (ms)		Amplitude (mV)								
L	R	L	R	L	R							
M wave		2.67	2.67									
F wave		24.6	23.6									
F-M		22.00	21.00									

### H Reflex Study

Right Median Nerve		Latency (ms)
Rec Site: F Car. Rad		
Stim Site: Elbow		
M wave		15.00
H wave		14.33

### EMG Study

Name	Ins	Ac	Fibs	PSW	Fascics	Polyph	MU	Am	MU	Du	Config	Pattern	Int	Pat	Recruit
R. Deltoid	Normal	norm	none	none	none	none	norm	norm	norm	norm	norm	norm	full	norm	norm
R. Paraspinals	inc	2+	2+	none	inc	inc	inc	inc	norm	norm	norm	norm	full	norm	norm
R. Triceps	Normal	norm	none	none	none	none	norm	norm	norm	norm	norm	norm	full	norm	norm
R. Ext. Pol. Br.	Normal	norm	none	none	none	none	norm	norm	norm	norm	norm	norm	full	norm	norm
R. Dors. Int. 1	inc	2+	2+	none	inc	inc	norm	norm	norm	norm	norm	norm	full	norm	norm
R. Abd. Dig. Mn.	inc	1+	1+	none	inc	inc	norm	norm	norm	norm	norm	norm	full	norm	norm
L. Paraspinals	inc	2+	2+	none	inc	inc	inc	inc	poly	norm	norm	norm	full	norm	norm
L. Deltoid	Normal	norm	none	none	none	none	norm	norm	norm	norm	norm	norm	full	norm	norm
L. Triceps	Normal	norm	none	none	none	none	norm	norm	norm	norm	norm	norm	full	norm	norm
L. Ext. Pol. Br.	Normal	norm	none	none	none	none	norm	norm	norm	norm	norm	norm	full	norm	norm
L. Dors. Int. 1	inc	1+	1+	none	inc	inc	inc	inc	norm	norm	norm	norm	full	norm	norm
L. Abd. Dig. Mn.	inc	2+	2+	none	inc	inc	norm	norm	norm	norm	norm	norm	full	norm	norm

Note abnormal (denervation) potentials in the paraspinal muscles, and others associated with C7 and C8 nerve roots.

## Chapter 31: Electrophysiologic Testing

Mohamed Sabbahi, PT, PhD, ECS and Charles Costello, PT, PhD, CHT

### Summary/Interpretation:

The following testing procedures were carried out in both upper extremities:

Needle EMG for the paraspinal cervical muscles and selected UE muscles (2 limbs EMG); motor conduction studies for the median and ulnar nerves at the forearm and arm segments (4 motor segments), sensory studies for the median, ulnar and radial nerves (6 sensory units); median and ulnar F-waves (4 F-waves) and FCR H-reflex (2 H-reflexes).

Results showed significant reduction in the amplitude and prolongation of the distal latency for the median nerve at the right and left hand-limb for the motor and sensory fascicles. This indicates compromised median nerve at the wrist level in both hands. This was substantiated with significant denervation for the APB, FDI and first lumbricals muscles. It was also substantiated with prolongation in the median F-wave when compared to ulnar F-wave in the same limb. This was also associated with reduced amplitude of the FCR H-reflex in the left more than right side indicating compromised C7-8 nerve root. This was also associated with denervation pattern in the FDI and ADM in both Hands. Other parameters of nerve conduction studies and EMG for other muscles were WNL.

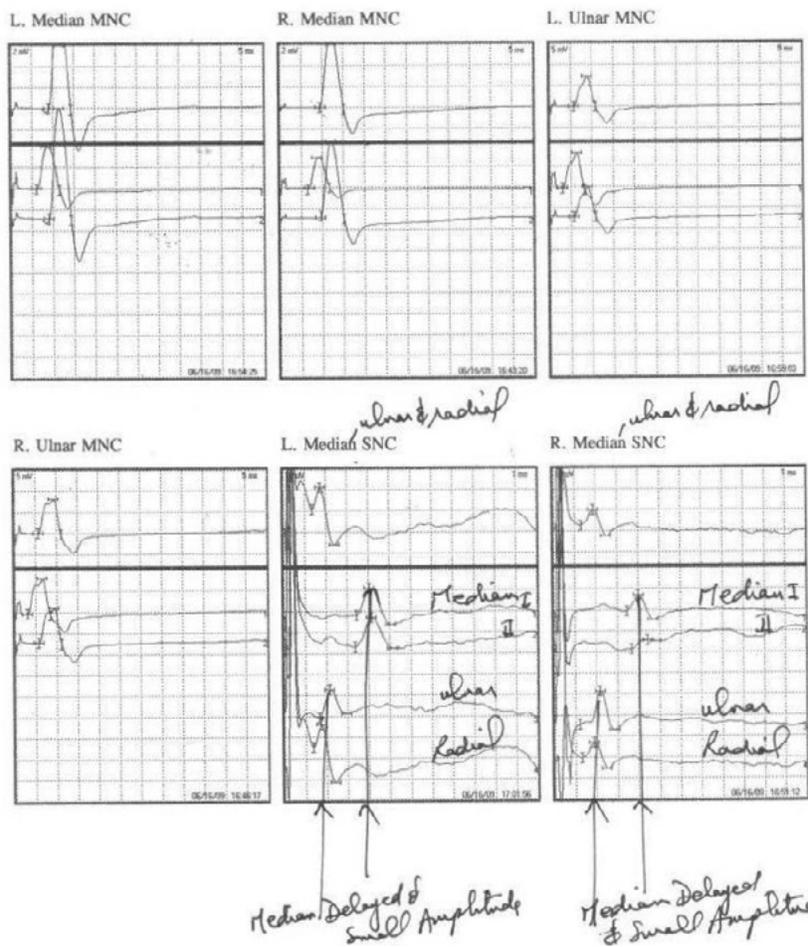
### CLINICAL IMPRESSION:

COMPATIBLE WITH COMPROMISED MEDIAN NERVE AT THE WRIST LEVEL OF BOTH HANDS, IN THE RIGHT MORE THAN LEFT SIDE, SIMILAR TO THOSE SEEN IN CARPAL TUNNEL SYNDROME OF MODERATE TO SEVERE DEGREE. THE COMPROMISE AFFECT THE MOTOR AS WELL AS THE SENSORY FASCICLES WITH DEMYELINATION AND AXONAL DAMAGE. THIS WAS ALSO ASSOCIATED WITH MILD C7-8 NERVE ROOT IRRITATION AFFECTING BOTH UPPER EXTERMITIES. CLINICAL CORRELATION IS NECESSARY. THANK YOU FOR THE REFRRAL OF THIS NICE PATIENT.

# Chapter 31: Electrophysiologic Testing

Mohamed Sabbahi, PT, PhD, ECS and Charles Costello, PT, PhD, CHT

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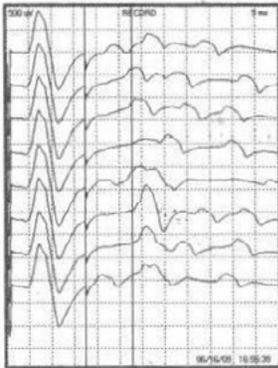
Note the differential latency values between the median, ulnar and radial nerves; as well as the small amplitude of the SNAP for the median nerve (right more so than left).

# Chapter 31: Electrophysiologic Testing

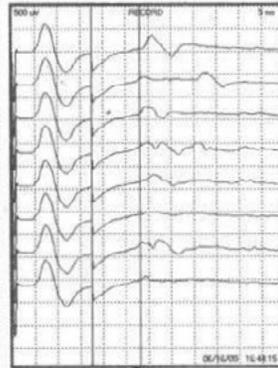
Mohamed Sabbahi, PT, PhD, ECS and Charles Costello, PT, PhD, CHT

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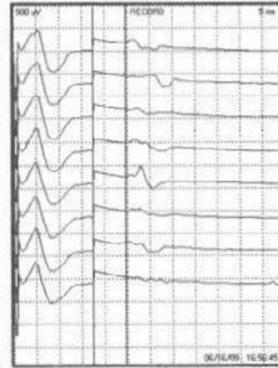
L. Median F-wave



R. Median F-wave

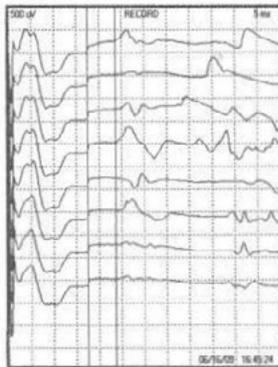


L. Ulnar F-wave

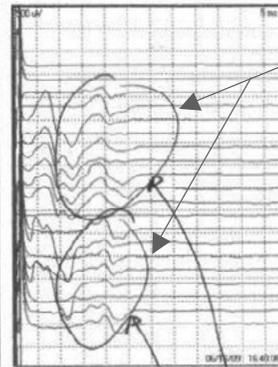


Note delayed F-waves for median nerve, compared to ulnar nerve. This is due to slowed F-wave conduction in the median nerve at the wrist during the orthodromic phase.

R. Ulnar F-wave



R. Median H-reflex



Note smaller amplitude H-reflexes for FCR (median).

Acknowledgement: We would like to thank Ms. Ambia Abdilahi for her clerical assistance.

## Chapter 31: Electrophysiologic Testing

*Mohamed Sabbahi, PT, PhD, ECS and Charles Costello, PT, PhD, CHT*

# References

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2. Sabbahi M, Sedgwick E. Age-related changes in monosynaptic reflex excitability. *J Gerontol.* 24-32, 1982.
3. Buch-Jaeger N, Foucher G: Correlation of clinical signs with nerve conduction tests in the diagnosis of carpal tunnel syndrome. *J Hand Surg Br.* 720-724, 1994.
4. Witt JC, Hentz JG, Stevens JC: Carpal tunnel syndrome with normal nerve conduction studies. *Muscle Nerve* 2004; 29(4):515-522.

## Multiple Choice Questions

1. Which of the following statements is correct about nerve conduction studies?
  - A. It tests muscle functions
  - B. It tests nerve conduction in the central nervous system
  - C. It tests the conduction along segments of peripheral nerves
  - D. It evaluates the excitability of the alpha motor neurons
2. Distal latency evaluation may be used to diagnose patients with:
  - A. Myasthenia gravis
  - B. Carpal tunnel syndrome
  - C. Muscle diseases
  - D. Cubital tunnel syndrome
3. During needle EMG exam, in which of the following would you normally find no electrical activity?
  - A. While the muscle is relaxed
  - B. During needle insertion
  - C. During mild muscle contraction
  - D. During strong muscle contraction
4. A complete EMG/NCV report should include the following, except:
  - A. Text information about the patient's physical condition and EMG/NCV findings
  - B. Numerical data of procedures carried out
  - C. A detailed description of the procedures
  - D. Sample traces of tested signal
5. In patients with mild Carpal Tunnel Syndrome, you would expect to see:
  - A. Increased distal sensory latency
  - B. Increased sensory or motor compound action potential
  - C. Reduced motor nerve conduction velocity
  - D. Increased H reflex latency for FCR
6. A denervation pattern in a muscle may be evident by the following, except:
  - A. Increased percentage of fibrillation potentials
  - B. Increased positive sharp waves
  - C. Increased amplitude of motor unit action potentials
  - D. Increased interference or recruitment pattern
7. Demyelinating disorders, such as diabetes, would be most evident by which of the following findings?
  - A. Reduced distal latency bilaterally in the median nerves only
  - B. Reduced distal latency bilaterally in both median and ulnar nerves.
  - C. Reduced conduction velocity in the proximal segments of both median and ulnar nerves bilaterally
  - D. Increased fibrillations and positive sharp waves on EMG needle examination

# Multiple Choice Questions

8. Long-term denervation would be evident by the presence of giant potentials, which would be identified as having:
  - A. Amplitude of 1000 – 3000  $\mu\text{v}$ ; duration 5 – 10 ms., triphasic
  - B. Amplitude of 100 – 3000  $\mu\text{v}$ ; duration 10 – 25 ms., polyphasic
  - C. Amplitude of 100 – 1000  $\mu\text{v}$ ; duration 1 – 10 ms., positive deflection, monophasic
  - D. Amplitude 3000 – 10,000  $\mu\text{v}$ ; duration 1000 – 6000 ms., triphasic
  
9. Which of the following statements is true regarding nerve conduction following a nerve transection injury?
  - A. Nerve conduction can be recorded in the distal segment, until Wallerian degeneration is complete
  - B. Nerve conduction can be recorded in the proximal segment, until Wallerian degeneration is complete
  - C. Nerve conduction can be recorded in the across the injured segment, until Wallerian degeneration is complete
  - D. Nerve conduction cannot be recorded in any segment of the nerve
  
10. Immediately following a nerve transection injury, which of the following is true regarding needle EMG evaluation?
  - A. Increased positive sharp waves will be seen
  - B. Fibrillation potentials will be seen
  - C. No activity will be seen with attempts at either mild or strong muscle contraction
  - D. Increased insertional activity will be seen
  
11. For a patient with myopathy, which of the following would be true regarding nerve conduction studies?
  - A. Motor conduction velocity would be reduced
  - B. The muscle action potential would show reduced amplitude
  - C. Motor conduction velocity would be greater
  - D. The muscle action potential amplitude would degrade from normal with repeated stimuli

## Multiple Choice Questions

12. You are seeing a patient who has been referred to you following a carpal tunnel release because of persistence of symptoms of paraesthesia radiating into the median nerve distribution of the right hand. You have an opportunity to review the presurgical electrodiagnostic studies report, and note the following relevant findings:

Median N.	Distal latency (ms.)	NCV across elbow (M/s)	NCV upper arm (M/s)	APB F-wave (ms.)	FCR H-reflex (ms.)
Right	5	55	60	28	22
Left	3	54	58	25	15

Additionally, the EMG findings report increased fibrillation potentials R cervical paraspinal, C6-C7. Based on these findings, what should you consider for intervention(s) for this patient?

- A. Include management for thoracic outlet, since this appears to be a double-crush situation
  - B. Include nerve gliding exercises, since this appears to be a double-crush situation involving another segment of the median nerve
  - C. Include management for cervical radiculopathy, since this appears to be a double-crush situation
  - D. Manage solely as a post-surgical carpal tunnel patient
13. Your patient is a glazier who received a complete laceration of the FCU, zone V ulnar side FDS & FDP and ulnar nerve and artery, 16 weeks ago. All structures were surgically repaired by a competent hand surgeon. The patient reports continued numbness affecting the pads of the small and ulnar side ring fingers. A recent EMG report includes the following findings: **ADM** – increased insertional activity, fibrillation potentials and polyphasic potentials, incomplete recruitment pattern; 1st **DI**– increased insertional activity, fibrillation potentials, no MUPs with attempted contraction. What conclusion can you make based on these findings?
- A. There has been progress of nerve recovery
  - B. There has been no progress in nerve recovery
  - C. Nerve recovery has stabilized
  - D. Only motor and no sensory recovery can be expected

# Multiple Choice Questions

14. You are seeing a patient who complains of dropping things from either hand. Her PCP suspects carpal tunnel syndrome, but is also evaluating her for diabetes. She reports no sensory deficit, but reports deep pain in both hands and has an evident rash/erythema affecting both hands. Both median and ulnar sensory distal latency is equal bilaterally, and within normal limits. Median and ulnar motor distal latency is normal, but MAP's are reduced. EMG examination of APB, 1st DI and ADM shows MUP's of 400  $\mu$ v, 3 ms.; complete recruitment pattern with reduced amplitude. All other conduction velocities and latencies are normal; no other relevant EMG findings. These findings are most consistent with which of the following diagnoses?
- A. Carpal tunnel syndrome
  - B. Cervical radiculopathy
  - C. Thoracic outlet syndrome
  - D. Dermatomyositis

### Multiple Choice Question Answer Key Chapter 31

1-C, 2-B, 3-A, 4-C, 5-A, 6-D, 7-B,  
8-D, 9-A, 10-C, 11-B, 12-C, 13-A, 14-D