Electrodiagnosis

How to Read Electromyography Reports for the Nonneurophysiologist

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KEYWORDS

• Electrodiagnosis • Electromyography • EMG • Nerve conduction studies • Needle • Report interpretation

KEY POINTS

- An electrodiagnostic evaluation (EDX) is a neurodiagnostic study used in the diagnosis and evaluation of neuromuscular disorders, including motor neuron disorders, radiculopathies, mononeuropathies, peripheral neuropathies, neuromuscular junction disorders, and myopathies.
- An EDX study is composed of 2 parts:
  - Nerve conduction study, which uses surface electrical stimulation to record motor or sensory nerve responses.
  - Needle electromyography, which involves assessment of muscle activity via a needle electrode inserted into muscles.
- Knowledge of the fundamental components of the EDX evaluation allows the nonneurophysiologist to best determine if the study performed was technically reliable as well as sufficient to answer the clinical question posed.

GOALS OF ELECTRODIAGNOSIS

An electrodiagnostic evaluation study should be considered to achieve any of the following goals in a patient with a potential neuromuscular condition:

1. Confirm a diagnosis
2. Exclude alternative diagnosis
3. Define the anatomic extent of involvement
4. Localization of the abnormalities
5. Define severity
6. Determine pathophysiology
7. Follow temporal evolution of a clinical condition or treatment effects.

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INTRODUCTION

An electrodiagnostic evaluation (EDX) is a neurodiagnostic test but also a consultation used in the evaluation of peripheral nervous system disorders. Each study can provide useful information to aid in the diagnosis of common conditions, such as radiculopathies, mononeuropathies, and polyneuropathies, and uncommon disorders, such as myopathies, neuromuscular junction disorders, or motor neuron diseases. EDX can also be used to exclude neuromuscular conditions in patients presenting with vague or nonspecific symptoms, such as numbness or fatigue.

Most nonneuromuscular subspecialist providers, including neurologists, rely on the "clinical interpretation" portion of the report to provide them with the information they need to diagnose and manage their patients. An ideal report interpretation will include all necessary information to assist the referring provider in answering the clinical query posed for the study. Principal elements in the interpretation include localization, chronicity, and severity of a disorder and, in some cases, the specific neuromuscular disease. However, not all EDX findings and interpretations are reported similarly, and the details of the report may be confusing to a provider who does not perform or interpret EDX studies. A basic understanding of the essential components of a report, commonly termed the "EMG report", such as the significance of details within the data tables and what features inform the clinical interpretation, may be helpful to referring providers. Furthermore, because poorly performed EDX studies can lead to inaccurate data and interpretation, understanding the components constituting a reliable study is imperative.

This article will review the basic components of an EDX study and report, highlight general guidelines to understand the reported data, and review key features in reports related to certain diagnoses. A complete review of the methods and interpretations of EDX studies is beyond the scope of this article and can be found elsewhere.[1]

A typical EDX study consists of 2 components: nerve conduction studies (NCS) and needle EMG (nEMG). Because each provides complementary information necessary for an accurate interpretation, nearly every EDX study should include both components; the absence of one part should raise concern about the reliability of the study.

NERVE CONDUCTION STUDIES OVERVIEW

NCS are a technique where an individual nerve is stimulated with sufficient electrical current to depolarize all axons within the nerve.

When studying the integrity of the peripheral *motor* system, the action potentials propagate along the motor axons to the nerve terminal, releasing acetylcholine vesicles that diffuse across the synapse to the muscle endplate, yielding muscle fiber action potentials. The recording electrode is placed over a muscle, and the action potentials from all muscle fibers are recorded, producing a compound muscle action potential (CMAP) (**Fig. 1**). When the *sensory* nerves are studied, a large fiber mixed sensory/motor or pure sensory nerve is stimulated, and the action potentials are recorded at a distal (for antidromic studies) or proximal (for orthodromic studies) site along the nerve, resulting in a sensory nerve action potential (SNAP) (**Fig. 2**). The sensory modalities transmitted by small or unmyelinated sensory nerve fibers (serving pain/temperature or autonomic function) are not assessed with NCS.

NERVE CONDUCTION STUDIES IN AN ELECTROMYOGRAPHY REPORT

The results from each NCS, along with the laboratory reference values, are typically reported in a tabular format in an EMG report. In some laboratories, the NCS

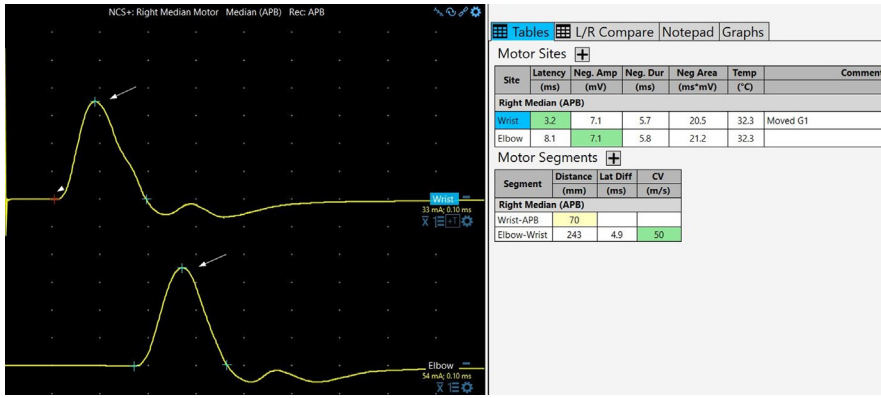


Fig. 1. Compound muscle action potential (CMAP). Typical CMAP recorded from the abductor pollicis brevis with stimulation of the median nerve. Note the waveform consistency in morphology and amplitude (*arrows*) at both sites of stimulation as well as the upward deflection from baseline (*arrowhead*) indicating a well-positioned recording electrode over the muscle endplate site of action potential generation.

waveforms themselves are included in the report. For the EDX specialist who is reviewing an EDX study performed by another provider, reviewing the actual waveforms allows for the assessment of reliability of the study by detecting technical factors that may be present. However, for the nonneurophysiologist, interpreting the waveforms may be difficult. The tabular numerical data provide valuable information

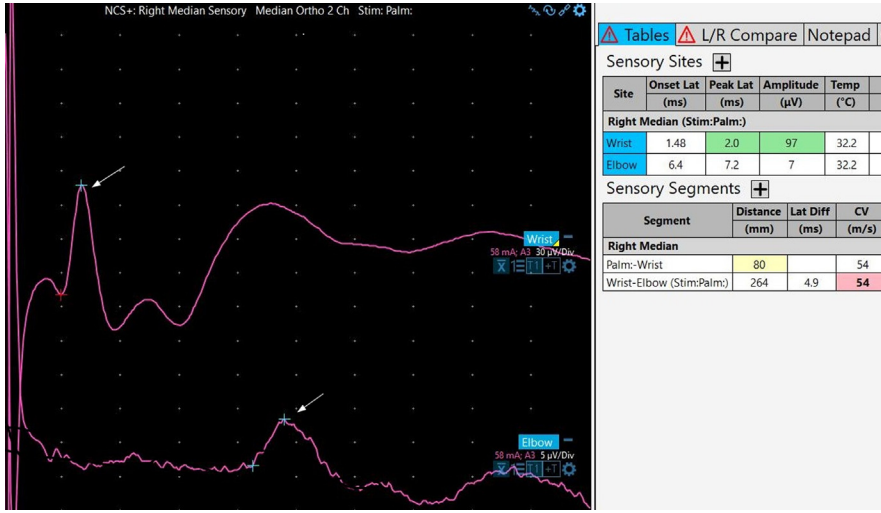


Fig. 2. Sensory nerve action potential (SNAP). Typical antidromic SNAP recorded from the second digit with stimulation of the median mixed nerve at the wrist and elbow. Unlike CMAPs, SNAPs demonstrate temporal dispersion of responses as one stimulates the nerve further from the recording site. The latency is marked at the peak of the response (*arrow*) not the onset. Note the SNAP is recorded at a much smaller sensitivity and therefore more prone to technical errors.

about the integrity and number of axons, as well as the integrity of the neuromuscular junction and muscle fibers for motor NCS. Each of the values reported for a nerve provides different types of information.[2]

REPORTED VALUES DURING MOTOR NERVE CONDUCTION STUDIES

The standard values reported during a motor NCS are (1) distal latency (DL), (2) amplitude, (3) conduction velocity (CV), and in some cases (4) F wave latencies. Each value provides information about the function of different components and sites along the nerve. Repetitive nerve stimulation (RNS) is an advanced technique performed on motor NCS to assess neuromuscular junction integrity (see **Fig. 1**).

Distal Latency

The distal latency reflects the conduction time along the distal segment of the nerve tested (usually distal to the wrist or ankle). Prolonged distal latencies suggest demyelination in the distal segment of the nerve, such as can occur with carpal tunnel syndrome. However, disorders associated with a loss of many fast-conducting large fiber axons may result in a secondary prolongation in the distal latency.

Amplitude

The CMAP amplitude measures the amplitude of the summated action potentials generated directly from the muscle(s) under the recording electrodes after nerve stimulation. Although this value directly reflects the number of muscle fibers, it indirectly reflects the number of motor axons and integrity of the neuromuscular junctions. A reduction in the CMAP amplitude can occur in disorders affecting motor nerves or axons (eg, motor neuron disease, severe mononeuropathy or polyneuropathy, severe radiculopathy), severe myopathies, and some neuromuscular junction disorders. For most motor nerves tested, the nerve is stimulated at 2 or more sites to assess the CV along the segment. In normal nerves, the CMAP amplitude and morphology should be similar at all sites of stimulation as motor axons conduct at similar rates (see **Fig. 1**). Although some EMG reports only report the amplitude at the proximal site of stimulation, others report the amplitude at all sites of stimulation. The latter is helpful to determine the presence of an abnormal drop (usually >20% in most nerves) in amplitude, which could represent focal conduction block or abnormal temporal dispersion, both of which are indicators of focal or multifocal demyelination. A thorough EMG report should also textually describe the presence and site of conduction block or temporal dispersion within the report Summary.

Conduction Velocity

The CV reflects the rate of conduction of action potentials along the nerve. It is calculated by dividing the latency differences at 2 or more stimulation sites by the distances between the sites. Abnormally slowed CV may suggest demyelination along the nerve. However, a process resulting in the loss of many large, fast-conducting axons may result in a mild slowing of CV. Therefore, the diagnosis of demyelinating neuropathies requires a degree of slowing that is disproportionately greater than what would be expected with amplitude reduction.

F Wave Latencies

F waves are late responses that are sometimes performed to assess the proximal segments of nerves. They are performed by stimulating a motor nerve at a distal site and recording the responses that propagate antidromically along the motor axon to the

anterior horn cell and then orthodromically back to the muscle. The time that the response takes to course through this pathway is the F wave latency (Fig. 3). The F wave latency may be compared with an absolute reference value, although limb length will affect the conduction time. Some laboratories compare the F wave latency to an estimated F wave latency (F estimate) based on the known distal motor CV. Prolongation of the actual F wave latency compared with the F estimate suggests more proximal slowing. Although F waves are insensitive at assessing radiculopathies and many other disorders, they are useful in the evaluation of demyelinating neuropathies or polyradiculopathies (such as chronic inflammatory demyelinating polyradiculopathy).

Repetitive Nerve Stimulation

RNS is an advanced technique in which a motor nerve is stimulated repetitively, usually at (slow) rates of 2 to 5 Hz in a short train (4–6 stimuli) to assess the integrity of neuromuscular transmission. When neuromuscular junctions are intact, the motor (CMAP) amplitude should remain the same with each stimulus. In conditions in which there is an impairment in neuromuscular junctions, there is a drop in amplitude (referred to as *decrement*) with each stimulus. The percent decrement between the first and each subsequent stimulus is calculated, and the maximum decrement between the first and last response is reported. The change in the decrement and CMAP amplitude following brief (10 seconds) or long (60 seconds) exercise is also reported. Some reports include the presence and degree of decrement within the NCS tables, whereas others describe this in a text format within the report Summary.[3]

REPORTED VALUES DURING SENSORY NERVE CONDUCTION STUDIES

As noted above, sensory responses are nerve-to-nerve recordings. Although the main values attained and reported during a sensory NCS are similar to motor NCS and include (1) distal latency (DL), (2) amplitude, and (3) CV, they differ slightly in their neurophysiology (see Fig. 2).

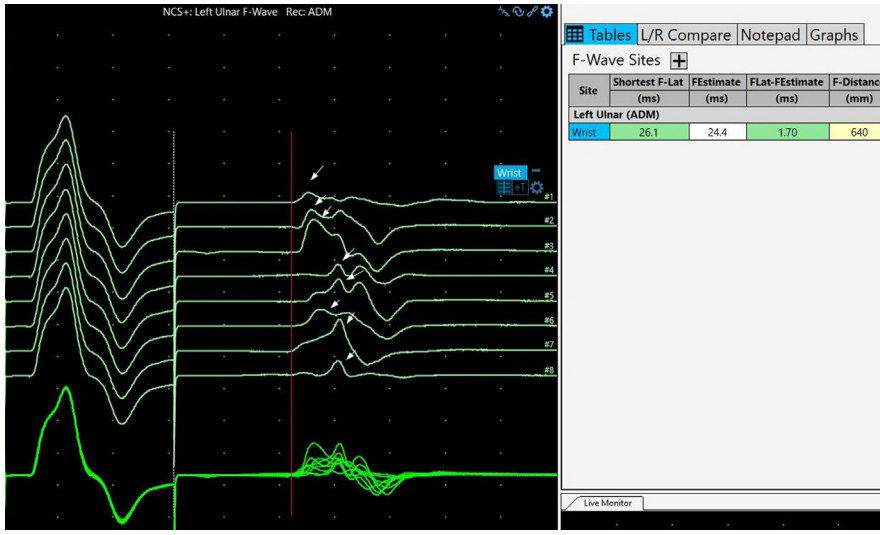


Fig. 3. F waves. F wave responses elicited by distal stimulation of the ulnar nerve. Note the expected variance in F wave latency and morphology with each stimulus (*arrowheads*) but the very uniform CMAP best depicted on the bottom trace (overlay).

Distal Latency

As in motor NCS, the reported distal latency refers to the time that it takes for the action potentials to travel from the stimulation site to the recording electrode. Unlike motor NCS in which the distal latency is marked at the onset of the waveform to assess the fastest fibers, most laboratories report the peak latency of sensory responses, thereby assessing the average speed of the fibers.

Amplitude

The sensory amplitude reflects the number of sensory axons under the recording electrode excited by nerve stimulation at that point. Since sensory axons have a wider variability in diameter and myelination than motor axons, they reach the recording electrode at variable times, resulting in "phase cancellation" and a decrease in the recorded amplitude over longer distance. Given this phenomenon and the fact that amplitudes are small (measured in microvolt rather than millivolt), distal amplitudes are reported and compared with reference values.

Conduction Velocity

CV is obtained in the same manner as in motor NCS, and it uses the onset latencies (measuring the conduction in the fastest fibers) for calculation.

NEEDLE ELECTROMYOGRAPHY OVERVIEW

nEMG is a technique that entails inserting a recording needle electrode into a muscle and recording the electrical signals that are generated directly from muscle fibers at rest and during voluntary contraction. The presence of spontaneous waveforms at rest may indicate certain types of neuromuscular disorders or pathologic conditions. The voluntary motor unit potentials (MUPs) recorded during contraction help to determine the presence and type (neurogenic, myopathic, neuromuscular junction) of neuromuscular disorder as well as the temporal course and severity of the disorder. A detailed review of the types and pathophysiology of changes of different waveforms is beyond the scope of this article and can be found in other sources.[4] However, the significance of each change that is reported in the needle EMG table in the EMG report will be briefly described below.

REPORTED FINDINGS DURING NEEDLE ELECTROMYOGRAPHY

The waveforms recorded during needle EMG are free running waveforms interpreted in real time as the muscle is being examined. Although buffers of EMG activity can be stored for future review, the actual waveforms are not included in an EMG report. The presence or absence of spontaneous waveforms for each muscle is documented and either graded in a table or described in the Summary. Similarly, multiple individual MUPs generated during voluntary contraction within each muscle are graded and the average qualitative grade of abnormality for different MUP parameters is entered into a table. Some laboratories perform quantitative EMG and report the mean numerical value of a given parameter as well.

Insertional Activity

When a needle is moved through a resting muscle, the needle irritates muscle fibers, resulting in brief bursts of action potentials. The bursts should last only while the needle is moved, and the baseline activity should become quiet once needle movement ceases. In disorders in which denervation or irritability of the muscle membranes is

present, insertional activity is *increased*, and there is persistent or recurrent firing of the action potentials after needle movement ceases. Increased insertion activity is nonspecific and can be seen in neurogenic or myopathic disorders.

Fibrillation Potentials

Fibrillation potentials are spontaneously firing action potentials of muscle fibers that have lost their innervation (ie, denervated). They are nonspecific and can be seen in neurogenic and some myopathic disorders. Their presence in neurogenic disorders typically occurs when there has been axon loss or degeneration, such as in axonal neuropathies, severe mononeuropathies involving loss of motor fibers, motor neuron diseases, and so forth. Fibrillation potentials occur in myopathies characterized pathologically by fiber necrosis, splitting, or vacuole injury to the fibers.[5] Although the presence of fibrillation potentials often indicates an "active" or ongoing disorder, they can persist in an old or inactive process if the muscle fibers are never fully reinnervated. Fibrillation potentials are graded on a qualitative (1–4+) scale based on the density of fibrillation potentials in the muscle.

Fasciculation Potentials

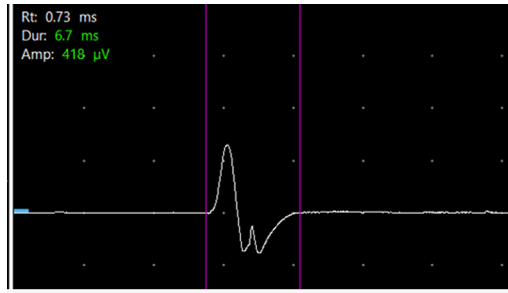
Fasciculation potentials are spontaneously firing MUPs. These can occur in normal individuals but are also frequently seen in patients with neurogenic disorders. Fasciculation potentials are graded qualitatively based on the number of potentials recorded per minute.

Several rarer spontaneous waveforms may be described in an EMG report. *Complex repetitive discharges* are nonspecific discharges seen in chronic neurogenic or myopathic disorders. *Myotonic discharges* are repetitive discharges that occur at rest or with needle movement because of abnormality of muscle membrane channels. They are nonspecific and can be seen in a variety of myopathies in isolated muscles but when diffusely recorded, suggest a myotonic myopathy or channelopathy. *Myokymic discharges* are grouped discharges, sometimes associated with clinical myokymia, seen in a variety of neurogenic disorders but most classically associated with radiation-induced nerve injury.[6]

Voluntary Motor Unit Potentials

Assessment of voluntary MUPs is necessary to determine the type and timing of a neuromuscular disorder. Each individual MUP is an electrical representation of a portion of the motor unit and extrapolation of the morphology of the MUPs helps to determine the fiber density and distribution of fibers of each motor unit within the muscle. Different MUP parameters are assessed, graded, and reported, and each provides information on the type of disorder, severity, and timing or chronicity of the disorder. Details of the pathophysiology of the parameters and changes can be found elsewhere.[4] A general overview of the significance of each parameter is described here (**Fig. 4**).

- *Recruitment*. Recruitment refers to the number of activated motor units and the firing rates of the motor units relative to the patient's effort of contraction. *Reduced recruitment* occurs when there is loss of motor units (eg, with axonal neurogenic disorders) or block of conduction along axons (eg, with focal demyelination). Reduced recruitment is often associated with clinical weakness. *Rapid (early) recruitment* occurs in myopathies associated with loss of muscle fibers; in this situation, more motor units fire with minimal effort to generate a needed force. *Poor activation* occurs with central (upper motor neuron) disorders or with poor voluntary effort.



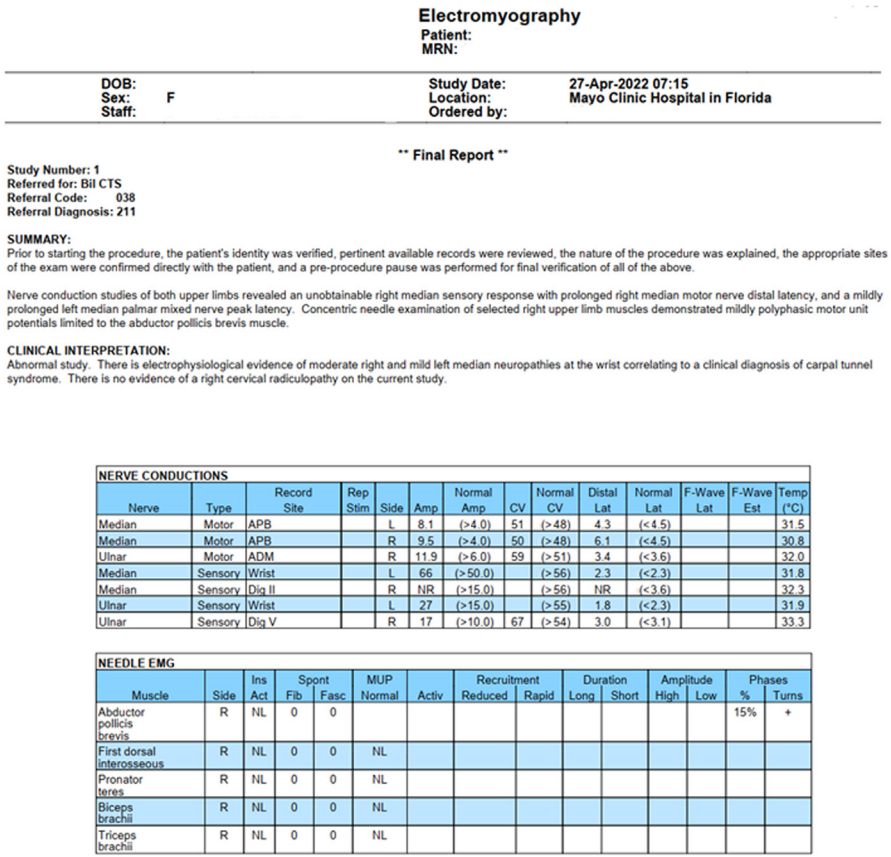
Results Table

	MUP
Duration (ms)	6.7
Thickness (ms)	1.43
Amplitude (µV)	418
Phases	2
Turns	4

Fig. 4. Motor unit potential (MUP). Example of a voluntary MUP. Top, the waveform of a single MUP (*purple vertical lines* mark the duration). Bottom, value of each parameter of the MUP.

- *Duration and Amplitude*. The duration (baseline to baseline) and amplitude (peak-to-peak) of a MUP are parameters that reflect the overall size of the motor unit, including the density and distribution of fibers in the region around the recording electrode (**Fig. 5**). These are the primary parameters used to help distinguish neurogenic from myopathic disorders. With reinnervation after axon loss, collateral sprouting results in increased fiber density and distribution, thereby resulting in higher amplitude and longer duration MUPs (**Table 1**). Myopathies characterized by loss of muscle fibers are associated with short duration, low amplitude MUPs. However, short duration, low amplitude MUPs can also occur in severe neuromuscular junction disorders and even severe neurogenic disorders where very early reinnervation has just begun (termed “nascent MUPs”).
- *Phases and Turns*. Phases and turns refer to the complexity of a MUP and are defined by the number of changes in direction of the MUP (phases cross the baseline and turns do not). Up to 15% of MUPs in a muscle may be polyphasic (>4 phases) or have excess turns. A higher percentage of complex (polyphasic) MUPs suggest less synchronous firing of the muscle fiber action potentials and is seen in early (weeks–months) reinnervation of neurogenic disorders or in myopathies. These parameters may be graded qualitatively or the percent of polyphasic MUPs may be estimated and reported.
- *Stability.* A motor unit with normally functioning neuromuscular junctions is stable; there is no moment-to-moment change in amplitude or morphology as it fires. An unstable MUP indicates impaired neuromuscular transmission and can be seen with neuromuscular junction disorders or with ongoing reinnervation. Stability is not commonly included in the needle EMG table but may be listed in a comment section by each muscle or in the Summary.

Interpreting each of these parameters helps to define the type and chronicity of the underlying process. Although variations occur, the classic findings of several disorders are shown in **Table 1**.



Electromyography

Patient:
MRN:

DOB:
Sex: F
Staff:

Study Date: 27-Apr-2022 07:15
Location: Mayo Clinic Hospital in Florida
Ordered by:

** Final Report **

Study Number: 1
Referred for: Bil CTS
Referral Code: 038
Referral Diagnosis: 211

SUMMARY:
Prior to starting the procedure, the patient's identity was verified, pertinent available records were reviewed, the nature of the procedure was explained, the appropriate sites of the exam were confirmed directly with the patient, and a pre-procedure pause was performed for final verification of all of the above.

Nerve conduction studies of both upper limbs revealed an unobtainable right median sensory response with prolonged right median motor nerve distal latency, and a mildly prolonged left median palmar mixed nerve peak latency. Concentric needle examination of selected right upper limb muscles demonstrated mildly polyphasic motor unit potentials limited to the abductor pollicis brevis muscle.

CLINICAL INTERPRETATION:
Abnormal study. There is electrophysiological evidence of moderate right and mild left median neuropathies at the wrist correlating to a clinical diagnosis of carpal tunnel syndrome. There is no evidence of a right cervical radiculopathy on the current study.

NERVE CONDUCTIONS

Nerve	Type	Record Site	Rep Stim	Side	Amp	Normal Amp	CV	Normal CV	Distal Lat	Normal Lat	F-Wave Lat	F-Wave Est	Temp (°C)
Median	Motor	APB		L	8.1	(>4.0)	51	(>48)	4.3	(<4.5)			31.5
Median	Motor	APB		R	9.5	(>4.0)	50	(>48)	6.1	(<4.5)			30.8
Ulnar	Motor	ADM		R	11.9	(>6.0)	59	(>51)	3.4	(<3.6)			32.0
Median	Sensory	Wrist		L	66	(>50.0)		(>56)	2.3	(<2.3)			31.8
Median	Sensory	Dig II		R	NR	(>15.0)		(>56)	NR	(<3.6)			32.3
Ulnar	Sensory	Wrist		L	27	(>15.0)		(>55)	1.8	(<2.3)			31.9
Ulnar	Sensory	Dig V		R	17	(>10.0)	67	(>54)	3.0	(<3.1)			33.3

NEEDLE EMG

Muscle	Side	Ins Act	Spont Fib	Spont Fasc	MUP Normal	Activ	Recruitment Reduced	Recruitment Rapid	Duration Long	Duration Short	Amplitude High	Amplitude Low	Phases %	Phases Turns
Abductor pollicis brevis	R	NL	0	0									15%	+
First dorsal interosseous	R	NL	0	0	NL									
Pronator teres	R	NL	0	0	NL									
Biceps brachii	R	NL	0	0	NL									
Triceps brachii	R	NL	0	0	NL									

Fig. 5. Standard electromyography (EMG) report example. Sample EMG report from an abnormal study in a patient referred for evaluation of carpal tunnel syndrome. Presented are the key elements of standard EMG report: Summary, interpretation, and tabular presentation of nerve conduction (including temperature reporting), and needle electromyography data.

COMPONENTS OF THE ELECTROMYOGRAPHY REPORT

The EMG report summarizes all the findings of NCS and EMG and provides an overall interpretation of those findings (see Fig. 5).[7] Most EMG reports consist of the following sections:

1. Demographics and Referral Indication or Clinical Summary. The report should list or describe the reason for the referral for the EDX study. Some reports will include a brief clinical history and examination findings, whereas others rely on the documentation in the electronic medical record. The EDX consultant should always perform a brief history and examination before the performance of the study.
2. NCS Table. This table lists details for each nerve studied, including the nerve, recording site, and numerical data. Because the studies are performed and data interpreted according to specific reference values and methods, the reference values should always be included in the report.
3. Temperature. Cool limb temperature has a significant impact on nerve conduction time and limbs that are too cold may result in slowed conduction velocities and/or prolonged distal latencies. Cooling will also increase amplitudes and can pseudonormalize neuromuscular junction disorders by facilitating neuromuscular transmission. Therefore, limb temperature should always be measured and maintained above a certain level throughout the study. An appropriate report should include skin temperature.
4. Needle Electromyography Table. This table lists each muscle that was examined and the findings for that muscle. The standard columns include insertional activity, the presence and grade of fibrillation and fasciculation potentials, and each of the voluntary MUP parameters.
5. Summary of Findings. This section summarizes the pertinent abnormalities or absence of abnormalities in a manner that supports the clinical interpretation. This section often includes specific information that may not be captured in the tables, such as the site of focal slowing or conduction block during short segment stimulation or the presence and degree of decrement during RNS.
6. Clinical Interpretation. This is the key part of the report in which the performing electromyographer interprets the EDX findings in the context of the clinical scenario and provides their insight into the patient's condition.

CLUES TO RELIABILITY OF THE ELECTRODIAGNOSTIC EVALUATION STUDY IN THE ELECTROMYOGRAPHY REPORT

Unlike reviewing radiographic images performed at a different location, it is difficult to completely determine reliability of the study simply by review of an EMG report. An EDX study may be fraught with technical situations that can result in data that mimics disease. Furthermore, although NCS waveforms can be included in a report, needle EMG findings are live waveforms that are not included. Thus, reliability of the interpretation depends on the reliability of the performing and interpreting EDX consultant. There are several clues to consider when reviewing the report for reliability.

1. Does the interpreting physician have board certification in clinical neurophysiology or electrodiagnostic medicine? Although subspecialty certification is not an absolute necessity to perform the studies, having sufficient training and successful certification in the field generally reflects a higher level of expertise.
2. Was limb temperature measured and documented in the report? If not, the results may not reliably reflect the integrity of the peripheral nervous system.

Table 1
Characteristics of common disorders noted on electromyography

Condition	Recruitment	Duration/ Amplitude	Phases/Turns	Stability
Acute (days) neurogenic	Reduced	Normal	Normal	Stable
Subacute (weeks) neurogenic	Reduced	Normal	Increased	Unstable
Chronic (months) neurogenic	Reduced	Increased	Increased (may decrease)	Stable
Myopathy	Rapid (early)	Decreased	Normal or increased	Stable
Neuromuscular junction disorder	Normal	Normal (decreased if severe)	Normal	Unstable

3. Were excessive numbers of nerves and muscles examined? The number of nerves and muscles tested varies widely depending on the clinical problem. However, in most uncomplicated studies, approximately 3 to 5 NCS and 5 to 7 muscles are necessary. Studies that include nearly all nerves and muscles in a limb should raise a red flag that the focus of the study was not based on a clinical hypothesis but more on random or algorithmic testing.

DISEASE-SPECIFIC ELECTROMYOGRAPHY REPORT CONSIDERATIONS

The EDX study can assist in making a diagnosis of many types of neuromuscular disorders. Although the final interpretation should indicate the type of disorder and aspects of the findings in each patient, certain specific report findings and considerations may provide additional helpful information.

ELECTROMYOGRAPHY REPORTS IN PERIPHERAL NEUROPATHIES

Peripheral neuropathy (PN) is among the most common indication for EDX testing. The goals of EDX testing in PN are to (1) confirm involvement of large fibers, (2) help elucidate pathophysiology, and (3) define the extent and distribution of abnormalities (length-dependent vs polyradiculoneuropathy). Both NCS and nEMG are necessary to adequately assess PN.[8]

- Most peripheral neuropathies are distal predominant and "length-dependent." In most cases, NCS will begin in the feet but will include the hands if abnormalities are identified in the lower limbs or if the patient is symptomatic in the hands.
- NCS, including F waves, are important in the assessment of PN because they can help to understand the underlying pathophysiology (axonal or demyelinating), which cannot be accomplished with a clinical examination.
  - In axonal neuropathies, the loss of axons results in a reduction of amplitudes. Usually, sensory nerves are affected before the motor nerves. Although this loss of axons can affect the fastest axons yielding slowing of DL and CV, the degree of slowing is mild compared with the degree of axonal loss (**Table 2**).
  - In demyelinating neuropathies, the axons are intact but injury to myelination slows the speed of nerve conduction, resulting in prolongation of DL and slowing of CV disproportionate to the degree of amplitude reduction. It is important that the interpretation of a demyelinating neuropathy incorporates established criteria for demyelination to avoid misdiagnoses (**Table 3**).[9,10]

- Conduction block and dispersion may not be evident in the tabular data in the report but should be summarized in the Summary text.
- Routine NCS are performed on distal limbs (hands and feet). Distal abnormalities can occur with proximal nerve involvement from axonal degeneration. Therefore, NCS alone are insufficient to exclude a process involving proximal nerves or roots, such as polyradiculopathies. A comprehensive EMG includes needle examination of proximal muscles if distal muscles are abnormal. Abnormalities in proximal muscles are unusual in length-dependent neuropathies and may suggest polyradiculopathy or polyradiculoneuropathy.
- Needle abnormalities in distal muscles may be the earliest or first abnormalities on EDX testing in PN because the NCS values are presented as a normal value related to a pooled population. Consequently, although the SNAP amplitude might be within normal range, it may represent a 50% reduction for that patient, which cannot be discerned without a prior comparative study performed in the same manner.
- EDX testing in the EMG laboratory cannot reliably assess for the presence of a small fiber neuropathy and is usually normal.

ELECTROMYOGRAPHY REPORTS IN RADICULOPATHIES

The role of EDX testing in radiculopathies is to (1) identify the presence of injury to one or more nerve roots, (2) localize the process to the specific root(s), (3) exclude other sites of pathologic condition, such as plexus or distal individual nerves, (4) determine whether the process is "active" (ie, ongoing injury to the root), (5) assess the chronicity of the process, and (6) assess the severity of root injury. The combination of NCS and needle EMG can often provide those answers.[11]

- EDX studies primarily assess the motor axons coursing through the root, and the preganglionic sensory roots cannot be reliably tested. Therefore, in root disorders that manifest primarily with pain and/or sensory disturbance or are due to irritation of the roots without axonal degeneration, the study will be normal. Referring physicians should understand that a normal EDX study does not exclude a process involving a root.
- Needle EMG is much more sensitive than NCS in identifying mild injury to the roots. Because abnormalities such as fibrillation potentials may occur even with the loss of only a few axons, changes on needle EMG may be identified when NCS remain normal. An EDX study for radiculopathy that does not include a careful needle examination is an incomplete study.[12,13]
- Fibrillation potentials in all muscles supplied by a specific root imply an "active" process. However, because fibrillation potentials take 2 to 3 weeks to develop,

Table 2
Nerve conduction studies in axonal peripheral neuropathy

CMAP Amplitude	Conduction Velocity	Distal Latency	Conduction Block or Temporal Dispersion
70%–99% normal	Normal to >70%	Normal	No
50%–70% normal	>70% normal	<130% normal	No
<50% normal	>50%	Any (indeterminate)	No

the EDX study should be performed at least 3 weeks after symptom onset to adequately assess for a recent onset radiculopathy.
- Although fibrillation potentials imply an active process, they can persist for months or years in an old, severe process with incomplete reinnervation. Therefore, the presence of fibrillation potentials, particularly in distal but not proximal muscles supplied by a root, may be the residua of an old process.

ELECTROMYOGRAPHY REPORTS IN MONONEUROPATHIES

EDX studies are often used to (1) confirm the presence of a mononeuropathy, (2) localize the focal areas of entrapment if possible, and (3) exclude alternative diagnoses (ie, cervical radiculopathy vs median neuropathy). The most common mononeuropathies (median nerve at the wrist, ulnar nerve at the elbow, and fibular nerve at the knee) are readily assessed by EDX testing but many other individual nerves can be assessed. The EDX evaluation of a mononeuropathy includes NCS and nEMG in most cases. For some nerves (eg, suprascapular, axillary, anterior interosseous, phrenic), there is not a sensory component to test but NCS can often be helpful to exclude a more diffuse process in suspected mononeuropathies (plexopathies, mononeuritis multiplex, and so forth).[14]

- Sensory NCS are typically affected first in compressive mononeuropathies that have motor and sensory axons.
- In compression mononeuropathies, NCS typically show slowing of latencies/CV before amplitude, implying that focal demyelination occurs first. With ongoing compression, axonal loss follows. Demyelination without axonal loss supports a better prognosis.
- In some nerves (ulnar neuropathy at the elbow, fibular neuropathy at knee), short segment stimulation can be helpful to precisely localize the area of focal conduction block or slowing. These stimulation sites are not typically presented in the tabular data but should be summarized in the report.

ELECTROMYOGRAPHY REPORTS IN MYOPATHIES

The goals of EDX studies in suspected myopathies are to (1) confirm the localization of a disorder to the muscle, (2) exclude other mimicking disorders (eg, neuromuscular junction disorders or motor neuron diseases), (3) identify the distribution of muscle involvement and subclinical muscle involvement, (4) provide clues to the underlying pathologic condition, and (5) help guide selection of muscle for potential biopsy.[15]

- Nerve conduction studies are usually normal in most myopathies, unless severe, because most myopathies are proximal in nature. Needle EMG is the most sensitive test to identify myopathy.
- The pattern of nEMG findings helps to define the differential diagnosis for causes of myopathy.
  - Fibrillation potentials are typically seen in myopathies characterized by muscle fiber necrosis, splitting, or vacuolar injury. These include inflammatory myopathies, muscular dystrophies, and toxic myopathies.[5]
  - Diffuse myotonic discharges are seen in myotonic dystrophies and muscle channelopathies (eg, myotonia congenita, hyperkalemic periodic paralysis).
- EDX testing may be normal in certain types of myopathies, including steroid-induced myopathy, metabolic myopathies, and some congenital myopathies.

Table 3
Nerve conduction studies in demyelinating peripheral neuropathy

CMAP Amplitude	Conduction Velocity	Distal Latency	Conduction Block/ Temporal Dispersion
Normal	<70% normal	>150% normal	
50%–99% normal	<50% normal	>150% normal	Yes, acquired*
<50% normal	If amplitude <50%, indeterminate		Yes, acquired*

* Some uncommon hereditary neuropathies can demonstrate conduction block (i.e. hereditary neuropathy with liability to pressure palsy)

ELECTROMYOGRAPHY REPORTS IN NEUROMUSCULAR JUNCTION DISORDERS

The goals of EDX studies in neuromuscular junction (NMJ) disorders are to (1) confirm a disorder of the NMJ, (2) determine whether the disorder involves the postsynaptic junction (eg, myasthenia gravis) or presynaptic junction (eg, Lambert Eaton myasthenic syndrome), (3) define severity, and (4) assess response to treatment.[3]

- RNS is a key component of the EDX study used to assess the NMJ integrity. The report should document which nerve–muscle combinations were studied, as well as the rate of stimulation and maximum degree of decrement or increment.
- Many technical factors during RNS can result in unreliable responses or falsely appearing decrement, which is difficult to discern when only reading a report. If the data are shown, 3 sets of RNS at rest should be performed, and the degree of decrement should be similar among each set. Wide variations in the degree of decrement should raise the suspicion for a technical problem. If the waveforms or percent decrement for each stimulus is included, the largest degree of decrement should always be between the first and second stimulus.
- RNS of proximal muscles are more often abnormal than distal muscles in myasthenia gravis and should be performed if there is a high clinical suspicion of disease.
- The only needle EMG feature indicates an NMJ disorders is MUP instability, which can easily be overlooked and not universally present on routine nEMG. An optimal study should comment on the presence or absence of MUP instability.
- The study should be performed with patients withholding their pyridostigmine (Mestinon) for at least 8 hours, and when the effects of other therapies (intravenous immunoglobulin, plasma exchange) are at their least impact to reduce false negative findings.

ANOMALOUS ANATOMY IN THE ELECTROMYOGRAPHY REPORT

There are several normal anatomic variants that may be reported in EMG reports. These have no clinical significance but can be misinterpreted as pathologic condition.

- Martin-Gruber anastomosis (or median-to-ulnar crossover). This is an anatomic variant in the forearm in which some ulnar innervated muscles are supplied by fibers that course with the median nerve in the upper arm but crossover to the ulnar nerve in the forearm. If not identified by the electromyographer, this could potentially mimic an ulnar neuropathy in the forearm.

- Riche-Cannieu anastomosis (or "all ulnar hand"). This is a rare anatomic variant by which the thenar muscles are supplied by the deep branch of the ulnar nerve such that all hand muscles are supplied by the ulnar nerve. This can produce an apparent low median motor amplitude on NCS.
- Accessory fibular (peroneal) nerve. An anatomic variant in the leg by which a portion of the extensor digitorum muscle is supplied by the superficial fibular (rather than deep fibular) branch. This finding does not mimic any disease.

SUMMARY

An EDX study provides depth to the evaluation in the neuromuscular patient beyond the clinical evaluation. Understanding the key components of an EMG report, including components of NCS and nEMG and common pitfalls and technical factors that can influence results is imperative for electromyographers. This knowledge is important for nonneurophysiologists who are ordering and using the EDX test to complement their history and examination.

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