Electrodiagnostic Testing for Disorders of Peripheral Nerves

Joseph M. Choi, MD[a,b,*], Gianluca Di Maria, MD[c]

KEYWORDS

• Polyneuropathy • Nerve conduction studies • Electromyography • CTS
• Ulnar neuropathy • Radiculopathy

KEY POINTS

- Diagnosis of peripheral nerve disease can be clinically challenging, and electrodiagnostic study (EDX) is a valuable diagnostic tool to confirm diagnosis of polyneuropathy, compressive mononeuropathy, and radiculopathy.
- Nerve conduction studies have high sensitivity and specificity for compressive neuropathies.
- Needle electromyography has moderate sensitivity but very high specificity for diagnosing cervical and lumbosacral radiculopathy.
- The EDX study design is based on the referral question. The EDX referral form that has a clinical diagnosis (eg, left carpal tunnel syndrome) or symptom (right foot drop) will allow proper study design to achieve higher yield.
- Electrophysiological findings are best applied in the clinical context to correctly diagnose neuromuscular disease.

INTRODUCTION

Prevalence of neuropathies is 2% to 3% in the general population, but this increases to 8% when patients are older than 55 years.[1] Electrodiagnostic studies, such as nerve conduction studies (NCS) and electromyography (EMG), provide a tool for localization of disease and assessment of its disease severity. NCS are helpful in diagnosing various neuropathies, and needle EMG is more helpful with radiculopathies

[a] Georgetown University, Washington, DC, USA; [b] Department of Neurology, MedStar Washington Hospital Center, MedStar Georgetown University Hospital, 3800 Reservoir Road, PHC 7th Floor, Washington, DC 20007, USA; [c] Department of Neurology, MedStar Georgetown University Hospital, 3800 Reservoir Road, PHC 7th Floor, Washington, DC 20007, USA
* Corresponding author. Department of Neurology, MedStar Washington Hospital Center, MedStar Georgetown University Hospital, 3800 Reservoir Road, PHC 7th Floor, Washington, DC 20007.
E-mail address: joseph.m.choi@gunet.georgetown.edu

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and myopathies.[2–6] NCS and needle EMG are separate tests but are used in combination during routine neurophysiological testing.

As with all diagnostic studies, the results should be interpreted with the clinical history and examination in mind. An electrophysiological diagnosis does not necessarily give cause of the disease. For example, an EDX conclusion of axonal sensory polyneuropathy cannot distinguish if the polyneuropathy is due to diabetes or from B12 deficiency. The referring clinician needs to put the finding into clinical context.

EDX is a 2-part evaluation, and it is beneficial to explain to the patient what will happen during this study. The first part is the NCS and involves a patient receiving electrical impulses in their hand or hands or leg or legs. The electrical stimulations are very brief, and there are no residual side effects. Implanted cardiac pacemaker/defibrillator or left ventricular assist devices are not contraindicated.[7]

The second part of the test is the needle EMG. A small, sterile EMG needle will be inserted in the muscles. This insertion usually causes some transient pain and discomfort while the needle is in the muscle. There is a possibility of small bruising, but this can be reduced by applying pressure at the site. Patients can be on antiplatelet agents during the test, but higher risk exists for patients on anticoagulants.[6–8] If the patient is on an anticoagulant for a limited time, then it is generally advisable to wait until they have discontinued the anticoagulant before testing. If clinically necessary, the needle EMG can be conducted while on anticoagulants, but fewer muscles will be tested to reduce the chance of hematoma and other complications.[6–8] The test usually takes 30 to 60 minutes, and there is no activity restriction posttest.

Basics of Nerve Conduction Study and Electromyography

Diseases of the peripheral nervous system can affect muscles (myopathies), nerves (neuropathies), and neuromuscular junctions (myasthenia gravis), sometimes in combination. Peripheral neuropathies can impair sensory, motor, or autonomic function, either alone or in combination. They can affect the cell body (eg, neuronopathy or ganglionopathy), the myelin, and the axon (axonopathy). EDX allows the study of the sensory neuron, motor neuron, neuromuscular junction, and muscle individually by using a combination of NCS and needle EMG. Used together, they are a valuable diagnostic aid for neuromuscular disease.

Nerve conduction studies

NCS are used to assess peripheral nerves. There are 3 main types of peripheral nerves: sensory, motor, and autonomic nerves. On NCS, only large-fiber sensory and motor neurons are assessed. Motor nerve study is separate from sensory nerve study, so which type of nerves are affected can be differentiated. In addition to assessing different nerve types, the NCS can tell you what part of the nerve is affected, myelin versus axons.

In motor NCS, an electrical stimulus is applied on the surface of the skin above a given nerve, and an action potential of motor nerves (compound muscle action potential, CMAP) over a belly of a muscle is recorded. In sensory NCS, an electrical stimulation is applied on the surface of the skin and the response (sensory nerve action potential, SNAP) is recorded on the skin over a distal segment of the nerve.[9] This action potential represents the number of fibers that depolarize after an external electrical stimulus is applied. Three major features are observed and measured: Amplitude, distal latency, and conduction velocity (**Fig. 1**). By these 3 features, it can be distinguished whether the neuropathy is due to problems in the myelin sheath or the axons (**Table 1**).

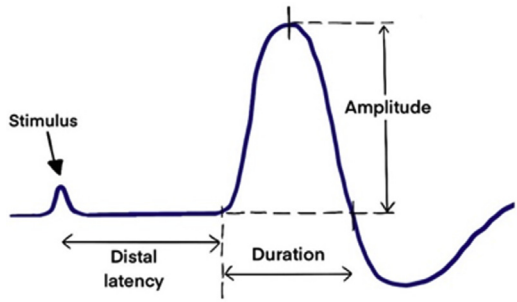

Fig. 1. Motor nerve conduction study. Three major features measured: amplitude, distal latency, and conduction velocity.

- Axonal neuropathy: Characterized by reduced amplitude of the CMAP, normal distal latency, and conduction velocity. If the axonal injury is severe, you can have preferential loss of faster nerve fibers where you can see mild slowing of nerve conduction velocity.[9] This can be reported as a mixed finding whereby there are minor demyelinating features seen on the NCS. The causes of axonal neuropathies are extensive, but some of the more common causes are *metabolic* (eg, diabetes), nutritional deficiencies (eg, B12), medications (eg, *chemotherapy*), infection (eg, HIV), and systemic disease (eg, uremia and hypothyroidism).
- *Demyelinating neuropathy*: Characterized by increased distal latency and decreased conduction velocity. Demyelinating polyneuropathy is less common than axonal neuropathy. The demyelinating disease generally has a more rapid course and usually responds to treatment. Urgent neurology evaluation is necessary. The most common acquired demyelinating polyneuropathies are Guillain-Barre syndrome (GBS) and chronic inflammatory demyelinating polyneuropathy (CIDP).

Electromyography

EMG can be very helpful in distinguishing myopathies from neuropathies, and it is essential in diagnosing radiculopathies.[1–7] In the needle EMG, the electromyographer inserts a small needle containing a recording electrode into a selected muscle. With needle EMG, you can clearly distinguish weakness caused by neuropathy or by myopathy (**Table 2**). The needle EMG is vital in localizing radiculopathy to specific myotomes.[9–13]

- Finding on radiculopathies: In radiculopathies older than 3 weeks, the needle EMG will show abnormal spontaneous activity in the form of fibrillations, positive sharp waves, and sometimes fasciculations. If the radiculopathy is older than 3 to 4 months, the motor unit action potential (MUAP) morphology will be of long-

Table 1
Nerve conduction studies: findings in axonal versus demyelinating disease

	Axonal Degeneration	Demyelination
Amplitude	Decreased or absent	Reduced or normal
Distal latency	Normal	Prolonged
Conduction velocity	Normal	Slowed

Table 2
Needle electromyography findings to differentiate neurogenic versus myopathic disease

	Spontaneous Activities		MUAP Morphology			
EMG Findings	Positive Sharp Waves or Fibrillation Potential	Fasciculations	Amplitude	Duration	Polyphasic	Recruitment
Neurogenic disease	Yes	Yes	Large	Long	Yes	Reduced
Myopathic disease	Yes	No	Small	Short	No	Early

duration, large-amplitude polyphasic units that show reduced recruitment. If the needle EMGs are done less than 3 weeks from onset of symptoms, you may not see any abnormalities.

- Findings on sensorimotor polyneuropathies: If the patient has mild distal sensorimotor polyneuropathy in the feet, the needle EMG can be normal. If the neuropathies are severe, the needle EMG can show abnormal spontaneous activity in the form of fibrillations and positive sharp waves. Similar to chronic radiculopathies, on longstanding chronic and severe polyneuropathies, the MUAP morphology will be of long-duration, large-amplitude polyphasic units that show reduced recruitment.
- Finding on myopathies: EMG may show abnormal spontaneous activity in the form of fibrillations and positive sharp waves. The MUAP morphology will be of short-duration and low-amplitude units that show early recruitment pattern.

Common Symptoms Where Electrodiagnostic Study Testing Will be Helpful in Clinical Practice

Numbness and tingling in the hands

Elderly patients coming in for hand pain or weakness is very common. The usual neurologic causes are median neuropathy across the wrist (carpal tunnel syndrome [CTS]) or ulnar neuropathy across the elbow or cervical radiculopathy. Electrodiagnostic testing is very helpful in differentiating these 3 diagnoses. In the elderly population, however, it is not unusual to find multiple abnormalities. The clinician must synthesize the electrodiagnostic information with the clinical findings to conclude which problem should be treated to address the patient's symptoms.

Median neuropathy across the wrist (CTS) is one of the most common reasons for referral for EDX. The study has high sensitivity and specificity for CTS, so it is a very useful test. In a compressive neuropathy like CTS, the abnormality is focal, and NCS will show slow nerve speed across the carpal tunnel space but not at other median nerve sites. The focal slowing is typically seen in both motor and sensory median nerve studies.

- Sensory NCS will reveal prolongation of distal peak latency and slowing of the conduction velocity across the wrist. **Fig. 2** shows an enlarged median sensory nerve at the carpal tunnel space, where the electrical impulse is traveling slower through that space.
- In motor NCS, there will also be prolongation of distal latency. **Fig. 3** shows an inflamed and enlarged median motor nerve at the carpal tunnel space, where

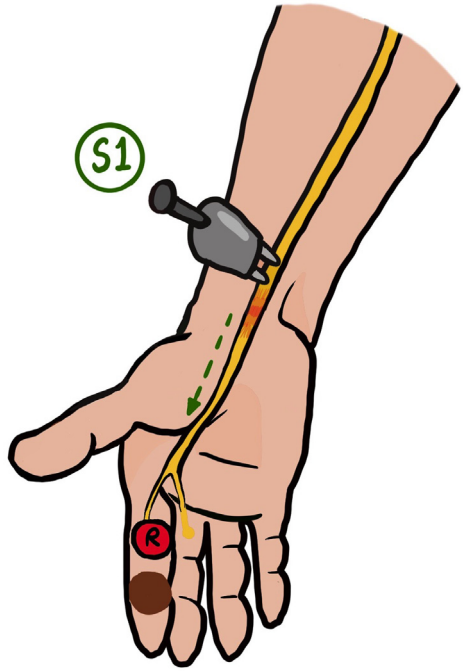

Fig. 2. Sensory study of the median nerve.

the electrical impulse is traveling slower, but speed of electrical impulse is normal at the forearm.

- In early and mild CTS, sensory nerve study may be the only part that is abnormal. As disease progresses, the motor nerve will eventually be affected.

When Should I Order Nerve Conduction Studies for Carpal Tunnel Syndrome?

If you are confident of the clinical diagnosis of CTS and the disease appears mild (episodic pain, no weakness or atrophy of thenar muscle), then it is reasonable to hold off on EDX and use conservative treatment, such as wrist splint and physical therapy. The authors recommend ordering the EDX if there is muscle atrophy or you are considering surgical evaluation. EDX will help confirm the diagnosis, assess the severity of the disease, and rule out other mimickers of CTS. You should consider performing EDX if a patient does not respond to CTS splints, if you have clinical uncertainty, or if you feel that there could be multiple causes for the patients' symptoms.

How Sensitive Is Electrodiagnostic Study in Detecting Carpal Tunnel Syndrome?

The sensitivity of NCS in detecting median neuropathy across the wrist is about 95%.[9] A small percentage of mild cases will not be diagnosed by NCS. Conservative treatment should still be initiated in patients with a normal NCS and clinical symptoms of CTS. If the symptoms worsen, repeat NCS would likely become diagnostic.

If you are suspecting CTS, it is best to put "evaluate for CTS" on the EDX referral form. An EDX test is designed for the specific disease. Correctly designing the study increases the sensitivity of the test. For example, mixed palmar nerve comparison study has high sensitivity for CTS (~95%), but this technique is not used on a routine

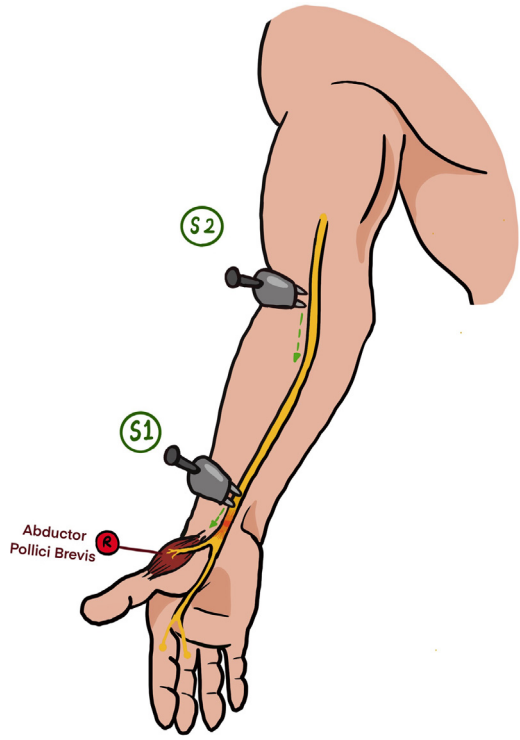

Fig. 3. Motor study of the median nerve.

screening study whereby CTS is not the referral question. If only the routine median nerve conductions are studied, the sensitivity will be lowered to about 70%.

ULNAR NEUROPATHY

Ulnar neuropathy patients primarily complain of hand weakness rather than pain. This complaint is not unusual because most of the intrinsic hand muscles are innervated by the ulnar nerve. When asked, they usually have more sensory complaints at the fourth and fifth digit, but do not be surprised if they say the sensation feels normal on all fingers.

Ulnar neuropathy: Compression at the elbow is more common than at the wrist.

- Sensory nerve study can be normal, or it can show reduced or absent SNAP amplitude.[9,11]
- Motor NCS will reveal focal slowing of ulnar motor nerve across the elbow. There should not be any slowing across the wrist or the forearm. **Fig. 4** shows an inflamed and enlarged ulnar nerve across the elbow. The speed across this compression site will be slow, but the speed of the nerve will be normal at the forearm and wrist.

What Is the Sensitivity of Electrodiagnostic Study on Ulnar Neuropathy Across the Elbow?

The sensitivity is about 50% to 80%, which is not as sensitive as EDX of CTS evaluation.[11] In addition, ulnar nerve study is technically challenging. False negative and

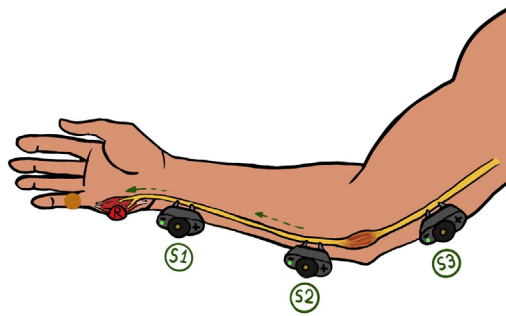

Fig. 4. Ulnar motor nerve study.

false positive results occur when there is operator error. Error on the ulnar nerve study is commonly seen on obese patients with extrasubcutaneous tissue, which makes it difficult to know the path of the ulnar nerve. Furthermore, incorrect measurements of distance can lead to wrong conclusions about velocity.

As stated before, there are many different techniques that can be used during EDX evaluation. Therefore, if the referral is for a specific disease process, such as ulnar neuropathy, this helps the electromyographer to correctly design a study to increase sensitivity. If the EDX referral does not state a specific diagnosis, then routine screening will be performed, and the diagnostic yield of the study may suffer.

What Should I Do if I Have High Clinical Suspicion of Ulnar Neuropathy Across the Elbow but the Electrodiagnostic Study Testing Result Is Normal?

In this scenario, alternative diagnoses should be considered, which include C8 radiculopathy or ulnar neuropathy across the wrist. Additional EDX testing may be needed to assess for these diagnoses.

Does my Patient Need to Have Repeat Electrodiagnostic Study After Surgical Decompression of Compressive Mononeuropathies?

If the patient's symptoms improve after surgical intervention, then repeat electrodiagnostic testing is not necessary. It is not uncommon to have continued slowing across the old compression site so repeat study will not be beneficial. If the patient's symptom returns, then repeat EDX testing should be done to check for reoccurrence of nerve entrapment. Ideally, you should have the repeat testing done with the same electromyographer so you can compare it to the prior test. Repeat tests done with the same provider will also reduce variability produced by different machine brands and different techniques used by the electromyographers.

Back and neck pain are very common problems in the elderly. There are many different medical conditions that can cause back or neck pain. A combination of musculoskeletal and neurogenic pain can occur. For diagnosis of cervical or lumbar radiculopathy, the authors commonly use the combination of history, physical examination, EDX, and imaging. Many times, the history is nonspecific, and examination is difficult to interpret because of pain, so the authors rely on EDX and imaging studies to guide them.

For example, if a patient has ipsilateral foot drop with low back pain, EDX help assess if the back pain with foot drop is caused by lumbosacral radiculopathy or by fibular (peroneal) neuropathy. Less common causes will be evaluated as well,

including sciatic neuropathy or lumbosacral plexopathy. Electrodiagnostic testing will help you localize from variable sites. Fig. 5 shows a cartoon drawing that shows potential sites of disease responsible for the patient's foot drop.

How Useful Is Electrodiagnostic Study for Diagnosis of Cervical or Lumbar Radiculopathy?

EDX is very specific in diagnosing radiculopathies. If the clinical localization and imaging levels do not match, then EDX can localize the level that is causing symptoms. This test will also search for other neurogenic cause of the patients' symptoms that may mimic radiculopathy. Last, EDX will reveal noncompressive radiculopathies when imaging is normal.

What Is the Ideal Time to Have Electrodiagnostic Study Done for a Radiculopathy?

Needle EMG is crucial for diagnosing radiculopathies. However, it takes time for Wallerian degeneration to occur before needle EMG shows the abnormalities. It is ideal to perform EMG 4 to 6 weeks after onset of symptoms.[3,9] If done earlier, findings such as spontaneous activities (positive sharp waves and fibrillations) may not be found. If the test is performed prematurely, then EMG may need to be repeated.

If the Initial Needle Electromyography Is Normal, Is There Any Utility in Repeating the Test or Performing Other Tests?

Repeating the study may be helpful. EMG has sensitivity of around 50% to 70% to detect radiculopathy. This sensitivity can be increased by sampling more muscles. For example, if you are suspecting an L5 radiculopathy, performing an EMG on multiple muscles with L5 myotomal innervation will increase the sensitivity.[12,13] Diagnoses are sometimes not initially made because of insufficient sampling of muscles. Furthermore, EMG findings change over time. Repeating a study in 3 to 6 months may reveal chronic findings that were initially not present.

If the EMG is normal, MRI would be a good complementary test. MRIs are very sensitive but have low specificity,[10] meaning there are many abnormalities on imaging that are asymptomatic. MRI and needle EMG are complementary when used together. MRI has high sensitivity, but low specificity. Needle EMG is the opposite, high in specificity but in moderate sensitivity.

What Does it Mean if MRI Is Normal, but Electromyography Indicates Radiculopathy?

In noncompressive radiculopathies, EMG will reveal physiologic abnormalities. The imaging study will be normal in noncompressive radiculopathies. Imaging studies are helpful for detecting structural abnormalities, but EMG is a dynamic test that

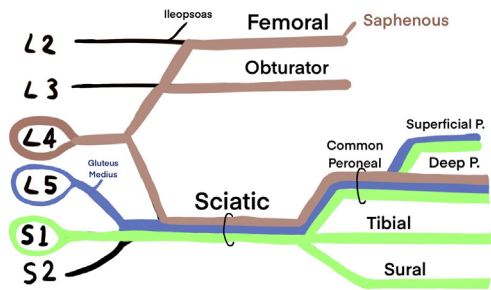

Fig. 5. Lumbosacral plexus and peripheral nerves.

reveals physiologic abnormalities. For example, varicella zoster and cytomegalovirus virus can cause infectious polyradiculitis, and MRI may not be as helpful in diagnosis.

Fibular (peroneal) neuropathy across the fibular head is a common compression site for causing foot drop in the elderly (Fig. 6); this could be confused for lumbar radiculopathy in patients with both foot drop and musculoskeletal back pain. The common fibular nerve is often subject to injury around the fibular head, where the nerve winds around the bone. This can occur with prolonged periods of leg crossing or be seen in hospitalized patients, where their legs are hanging off the bed and the lateral knee is pinned next to the bed railing.

Numbness and tingling in the feet

EDX is frequently ordered for symptoms of tingling and burning sensation in the feet. Tingling and burning sensation in the feet is typical early symptoms for sensory

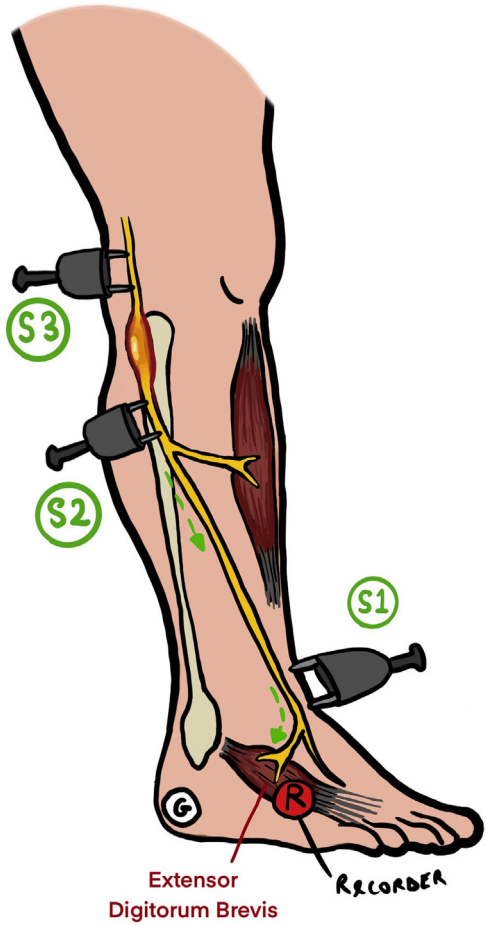

Fig. 6. The NCS done for foot drop. The recording is at the extensor digitorum brevis muscle, and stimulation is given on the fibular nerve at the ankle, distal to the head of the fibula and proximal to the head of the fibula. On typical fibular compression neuropathy, the focal slowing (compression site) occurs between the S2 and S3 stimulation sites. The slowing here proves that the entrapment is at that site.

neuropathy, and electrodiagnostic testing can be beneficial. The goal of the electrodiagnostic testing would be to find out if the neuropathy is axonal or demyelinating in nature. The test will also tell if the neuropathy involves sensory neurons, motor neurons, or both types of fiber. The electrophysiological finding will not provide the cause of the neuropathy, but it will narrow down the potential causes for the work up. In general, there are very few primary neurologic diseases that cause neuropathy. Particularly in the elderly, neuropathy is caused by systemic disease, toxic effects from medication, and nutritional deficiency. The neuropathy is analogous to a canary in a coal mine, an early warning of toxicity.

If a patient has symmetric symptoms on both feet, a study on both legs is not necessary. Thorough evaluation in 1 leg is usually adequate for symmetric leg symptoms. The limb tested will depend on the clinical findings and may expand based on the initial findings on EDX. This will show if the neuropathy is asymmetric, length dependent, or non–length dependent. Most neuropathies are axonal in nature. Acquired demyelinating polyneuropathy requires urgent evaluation. It is typical for most electromyographers to contact the referring physician for any concerning cases.

There is an inherent problem in performing EDX on elderly patients. In this population, particularly people older than 70 years, you can find absent or reduced sural sensory nerve responses in asymptomatic people.[14] The percentage of reduced response increases with age.[14–18] If the patient does not have any neuropathic symptoms, one can mistakenly diagnose sensory neuropathy in the legs. A mistakenly diagnosed sensory neuropathy will trigger unnecessary work up and worse yet result in unwanted treatment.

Can Someone Have Neuropathy in the Feet and Have Normal Electrodiagnostic Study?

Yes, if a patient only has small sensory fiber polyneuropathy, then the electrodiagnostic testing will be normal. The NCS test only detects large fibers, and if neuropathy is isolated to only small fibers, then the testing will be normal. For example, in early diabetes, patients may present with a burning sensation in their feet, which indicates small-fiber neuropathy. In these cases, the EDX will likely be normal.

Should I Use Nerve Conduction Studies to Track Clinical Progress in my Patient with Polyneuropathy?

No, EDX is a diagnostic tool, and there is no need to repeat unless there is unexpected clinical change or concern for additional superimposed disease that was not assessed on the initial study.

What Type of Patients Should I Refer for Neurology Consult Before Ordering an Electrodiagnostic Study?

If a patient has rapidly progressive disease of unknown cause or the patient has perplexing neurologic symptoms, it would be better to consult a neurologist before EDX testing. Neurologic consultation can clarify the potential diagnosis, which will increase the yield of EDX testing.

Demyelinating polyneuropathy is a mostly immune-mediated disease that improves with treatment. If you did not suspect demyelinating disease, but the EDX report suggests demyelinating polyneuropathy, then the patient will need to see a neurologist that specializes in neuromuscular disease for urgent evaluation.

What Is the Most Common Technical Error on Electrodiagnostic Study Testing?

Performing NCS on a cold limb is arguably the most common (and most troubling) occurrence in the EMG laboratory. Performing NCS on cold hands or feet will cause slowing of nerve conduction speed, because of the normal physiologic response to cold. NCS should be done on the hands at or greater than 34°C and in the legs at or greater than 32°C.[9,19] If the test is done on cold hands or feet, patients can mistakenly get diagnosed with median neuropathy across the wrist (eg, CTS), ulnar neuropathy across the wrist, or diffuse demyelinating sensorimotor polyneuropathy (eg, GBS or CIDP). The wrong diagnosis could cause unnecessary surgery for entrapment neuropathies or treatment with immunomodulating therapies for demyelinating sensorimotor polyneuropathy. This type of error is unfortunately not uncommon (**Fig. 7**).

Age also affects the nerve conduction speed. There can be a decrease in conduction velocity of 0.5 to 4 m/s per decade.[9] This factor is amplified in older patients that are tall. A person's height has inverse correlations with nerve conduction velocity. One can mistakenly misinterpret a tall elderly person to have slow nerve conduction velocity and incorrectly diagnose demyelinating neuropathy.

There are a few steps you can take to recognize this technical error. First, if EDX impression is multiple compressive mononeuropathies or demyelinating polyneuropathy, check on the report for measured skin temperature. The NCS technician should record and report skin temperature on every EDX report. If the temperature is less than 34°C and 32°C in the hands and feet, respectively, they should warm the hands before the study. Second, if there is truly demyelinating polyneuropathy or compressive mononeuropathies, the patient should have sensory complaints and show weakness on examination. If the patient has normal reflexes and normal sensory and motor examination, then it would be safe to state that the EDX diagnosis could be wrong. This

Stim Site	NR	Peak (ms)	Norm Peak (ms)	O-P Amp (μV)	Norm O-P Amp	Dist (cm)
Right Median 2nd Antidromic Sensory (2nd Digit)						
Wrist 34.2 degrees		2.7	<3.6	64.9	>20	13.0
wrist 25.8 degrees		3.2		69.3		

Waveforms:

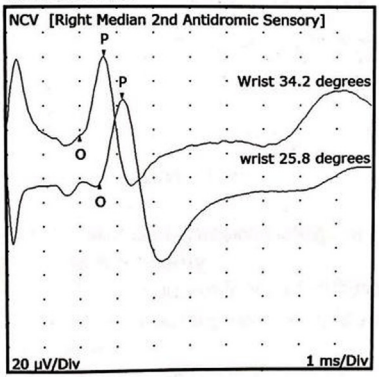

Fig. 7. The NCS of median sensory nerve study. First wave form shows normal hand temperature at 34°C, and distal peak latency is at 2.7 milliseconds. When the hand is colder than 25°C, you can see the distal peak latency is prolonged to 3.2 milliseconds. In median neuropathy across the wrist, a confirmatory finding is the prolongation of distal peak latency. Cold temperature can easily cause a false positive test result.

again illustrates that results cannot be interpreted independent of the clinical diagnosis.

SUMMARY

Electrodiagnostic testing is the primary diagnostic tool for evaluation of disease of peripheral nerve, neuromuscular junction, and muscle disease. EDX has 2 components, the NCS and needle EMG. These tests are complementary. The needle EMG is the more useful for diagnosing radiculopathy. The NCS is more useful in diagnosing entrapment neuropathies and sensorimotor polyneuropathies. NCS has relatively high sensitivity and specificity for compressive neuropathies and large-fiber sensorimotor polyneuropathies. Electrodiagnostic findings must be interpreted in context of the patient's clinical presentation. The EDX referral should have answerable questions posed to the electromyographer so that the test can be tailored to the clinical question. The EDX can provide diagnostic certainty only when used in the proper clinical context.

CLINICS CARE POINTS

- Electrodiagnostic study sensitivity is increased by electromyography referring, including clinical diagnosis, such as right carpal tunnel syndrome or left L5 radiculopathy.
- Timing is important when referring patients for electromyography evaluation for radiculopathy.
- Temperature is the most common technical error that can cause false positive test results.

DISCLOSURE

The authors have nothing to disclose.

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