**Clinical Practice Guideline:** **Electrodiagnostic Testing**

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## *GUIDELINES*

### Medically Necessary

**Nerve Conduction/Electromyography: Performed Together**

American Specialty Health – Specialty (ASH) considers nerve conduction velocity (NCV) testing AND needle electromyography testing (NEMG) medically necessary when they are conducted and interpreted at the same time for **ANY of the following indications**:

- Myopathy, including but not limited to ANY of the following:
  - Inflammatory myopathy and myositis (i.e., polymyositis, dermatomyositis, inclusion body myositis)
  - Congenital and hereditary dystrophic and nondystrophic myopathies, including myotonic muscular dystrophy
  - Acquired myopathies (drug induced myopathy associated with statins, thyroid related)
  - Metabolic myopathies (such as McArdle disease)
- Disorder of brachial or lumbosacral plexus (e.g., inflammatory, idiopathic, traumatic, infiltrative plexopathy, thoracic outlet syndrome, Parsonage Turner syndrome)
- Motor or sensory neuronopathy or ganglionopathy (e.g., Amyotrophic lateral sclerosis, primary lateral sclerosis, progressive muscular atrophy or Kennedy's Disease)
- Multifocal motor neuropathy
- Neuromuscular junction disorder (e.g., myasthenia gravis, Lambert-Eaton myasthenic syndrome, botulism)
- Focal or generalized sensory and motor neuropathies including but not limited to ANY of the following after failure of 4-6 weeks of conservative care (e.g., physical therapy, exercise, bracing):
  - carpal tunnel syndrome
  - cubital tunnel syndrome or ulnar neuropathy

    - tarsal tunnel syndrome
    - cervical or lumbar radiculopathy
- Inflammatory/autoimmune polyneuropathy (e.g., Guillain-Barre syndrome, chronic inflammatory demyelinating polyneuropathy [CIDP], mononeuritis multiplex and neuropathy associated with rheumatologic disorders)
- Hereditary neuropathies (e.g., Charcot-Marie-Tooth disease, hereditary neuropathy with liability to pressure palsies, Friedreich's Ataxia)
- Diabetic polyneuropathy and diabetic radiculoplexus neuropathy (diabetic amyotrophy)
- Metabolic and nutritional neuropathy (e.g., vitamin B12 or thiamine deficiency)
- Toxic neuropathy (associate with drugs vincristine, amiodarone, or environmental toxins such as organophosphates)
- Infectious neuropathy (e.g., HIV, Lyme disease, Leprosy, polio)
- Cranial neuropathy (Bell's or facial palsy)
- Idiopathic peripheral neuropathy
- Symptom-based presentation suggesting nerve root, peripheral nerve, muscle, or neuromuscular junction involvement, when pre-test evaluations are inconclusive and clinical assessment supports the need for the study, such as for ANY of the following:
    - Muscle weakness
    - Muscle atrophy
    - Muscle fasciculation
    - Myokymia
    - Myotonia
    - Loss of dexterity
    - Spasticity
    - Hyperreflexia
    - Sensory deficits
    - Diplopia
    - Ptosis
    - Swallowing dysfunction
    - Dysarthria
    - Impaired bowel motility

**Nerve Conduction: Performed Alone**

Nerve conduction velocity (NCV) testing performed alone is considered medically necessary for ANY of the above indications, in ANY of the following clinical presentations:

- Current use of an anticoagulant
- Presence of significant lymphedema
- For facial nerve monitoring in Bells palsy
- Suspected peroneal/fibular nerve palsy
- Thoracic outlet syndrome
- Suspected tarsal tunnel syndrome
- Suspected acute nerve injury (within 3 weeks)
- Carpal tunnel syndrome with **BOTH** of the following:
    - with high pre-test probability (e.g., positive Tinel's, thenar muscle atrophy or paresthesia in the radial three digits)
    - after failure of 4-6 weeks of conservative care (e.g., physical therapy, exercise, bracing)

NEMG testing is considered medically necessary when performed for determination of precise muscle location for an injection (i.e., prior to botulism toxin injection for localization; prior to injection of phenol or other substances for nerve blocking or chemodenervation).

**Neuromuscular Junction Testing**

Neuromuscular junction testing is considered medically necessary for **ANY of the following indications**:

- Myopathy
- Motor neuropathy (e.g., ALS)
- Botulinum toxicity
- Myasthenia gravis
- Lambert Eaton myasthenic syndrome
- The presence of any of the following:
    - Diplopia
    - Dysphagia and dysarthria
    - Fatigue/weakness that progresses with repetitive activity

Single fiber EMG (SFEMG) is medically necessary for diagnosis of myasthenia gravis if repetitive nerve stimulation is negative or inconclusive.

**Somatosensory Evoked Potentials (SSEPs)**

Somatosensory evoked potentials (SSEPs) are considered medically necessary when prior diagnostic testing has failed to confirm a diagnosis for **ANY** of the following:

- Coma following traumatic, hypoxic/ischemic and other diffuse brain injuries
- Myoclonus
- Multiple sclerosis and other demyelinating diseases (e.g., adrenoleukodystrophy, adrenomyeloneuropathy, metachromatic leukodystrophy, and pelizaeus-merzbacher disease)
- Spinocerebellar degeneration
- Spinal cord lesions secondary to trauma when the need for surgical intervention is uncertain
- Acute (within 72 hours) anoxic encephalopathy
- To localize the cause of a central nervous system deficit seen on exam, but not explained by lesions seen on CT or MRI
- Suspected brain death

**Not Medically Necessary**

Neuromuscular junction testing for **ANY** other indication is considered not medically necessary.

Nerve conduction velocity testing when performed with NEMG testing for **ANY** other indication, including the following is considered not medically necessary:

- Screening of the general population, in the absence of related symptoms
- Screening, monitoring of disease intensity or monitoring of treatment efficacy for polyneuropathy of diabetes
- Screening, monitoring of disease intensity or monitoring of treatment efficacy for end stage renal disease

**Unproven**

The following electrodiagnostic tests are each considered unproven:

- Nerve conduction velocity (NCV) testing performed without needle electromyography, other than when performed for follow-up testing, with current use of anticoagulants, the presence of lymphedema, or for carpal tunnel syndrome
- Nerve conduction testing where the interpretation is delayed and not completed at the time of testing
- Nerve conduction velocity testing performed without the direct supervision of a trained electrodiagnostic physician
- Automated noninvasive nerve conduction testing (e.g., NC-stat System, Brevio® nerve conduction monitoring system)
- Macro electromyography (EMG)

- Surface electromyography (e.g., surface EMG [SEMG], surface scanning EMG, high-density SEMG, HD-SEMG) and macro EMGs
- Paraspinal SEMG
- Needle electromyography study performed without a nerve conduction velocity study and/or late response study for any indication, other than injection localization or intraoperative monitoring
- Exclusive testing of intrinsic foot muscles in the diagnosis of proximal lesions
- Definitive diagnostic conclusions based on paraspinal EMG in regions bearing scar of past surgeries (e.g., previous laminectomies)
- Pattern-setting limited limb muscle examinations, without paraspinal muscle testing for a diagnosis of radiculopathy
- EMG testing shortly after trauma, before EMG abnormalities would have reasonably had time to develop
- Multiple uses of EMG in the same patient at the same location of the same limb for the purpose of optimizing botulinum toxin injections

SSEPs are considered unproven for ANY indication other than those listed above; including the evaluation of disorders of the lumbosacral roots, such as radiculopathies, thoracic root disorders, or cervical root disorders.

Current Perception Threshold/Sensory Nerve Conduction Threshold TEST (sNCT) – is not covered by Medicare. This procedure is different and distinct from assessment of nerve conduction velocity, amplitude, and latency. It is also different from short-latency somatosensory evoked potentials.

| CPT®/HCPCS Code | CPT®/HCPCS Code Description |
|---|---|
| 95885 | Needle electromyography, each extremity, with related paraspinal areas, when performed, done with nerve conduction, amplitude and latency/velocity study; limited (List separately in addition to code for primary procedure) |
| 95886 | Needle electromyography, each extremity, with related paraspinal areas, when performed, done with nerve conduction, amplitude and latency/velocity study; complete, five or more muscles studied, innervated by three or more nerves or four or more spinal levels (List separately in addition to code for primary procedure) |
| 95887 | Needle electromyography, non-extremity (cranial nerve supplied or axial) muscle(s) done with nerve conduction, amplitude and latency/velocity study (List separately in addition to code for primary procedure) |

| CPT®/HCPCS Code | CPT®/HCPCS Code Description |
|---|---|
| 95905 | Motor and/or sensory nerve conduction, using preconfigured electrode array(s), amplitude and latency/velocity study, each limb, includes F-wave study when performed, with interpretation and report |
| 95907 | Nerve conduction studies; 1-2 studies |
| 95908 | Nerve conduction studies; 3-4 studies |
| 95909 | Nerve conduction studies; 5-6 studies |
| 95910 | Nerve conduction studies; 7-8 studies |
| 95911 | Nerve conduction studies; 9-10 studies |
| 95912 | Nerve conduction studies; 11-12 studies |
| 95913 | Nerve conduction studies; 13 or more studies |
| 95925 | Short-latency somatosensory evoked potential study, stimulation of any/all peripheral nerves or skin sites, recording from the central nervous system; in upper limbs |
| 95926 | Short-latency somatosensory evoked potential study, stimulation of any/all peripheral nerves or skin sites, recording from the central nervous system; in lower limbs |
| 95927 | Short-latency somatosensory evoked potential study, stimulation of any/all peripheral nerves or skin sites, recording from the central nervous system; in the trunk or head |
| 95937 | Neuromuscular junction testing (repetitive stimulation, paired stimuli), each nerve, any 1 method |
| 95938 | Short-latency somatosensory evoked potential study, stimulation of any/all peripheral nerves or skin sites, recording from the central nervous system; in upper and lower limbs |
| S3900 | Surface electromyography (EMG) |

## *DESCRIPTION/BACKGROUND*

This guideline addresses electrodiagnostic testing, including nerve conduction (NCV) studies, neuromuscular junction testing, electromyography (EMG) studies (including surface EMG). This guideline adopts many of the recommendations for the clinical necessity, contraindications, and proper performance of nerve conduction studies, needle electromyography, and somatosensory evoked potentials (SEPs) from the American Association of Neuromuscular & Electrodiagnostic Medicine (AANEM).

Electrodiagnostic studies are frequently used to evaluate a subset of patients with suspected neuromuscular disorders and include needle electromyography and other nerve stimulation tests such as nerve conduction studies. Electrodiagnostic testing may provide an important means of diagnosing conditions attributable to nerve, muscle, or neuromuscular junction weakness such as myopathies (muscle weakness), radiculopathies (nerve root disease), plexopathies (peripheral neuropathy), neuropathies (nerve disease), neuromuscular junction disorders, and nerve compression syndromes. In addition, electrodiagnostic testing may be indicated for symptom-based presentations, (e.g., pain in limb, muscle weakness) when appropriate pre-test evaluations are inconclusive and the clinical assessment unequivocally supports the need for the study (American Association of Neuromuscular and Electrodiagnostic Medicine [AANEM], 2010).

**Electrodiagnostic Testing Nerve Conduction/Needle Electromyography**

Nerve conduction studies (NCS), also referred to as nerve conduction velocity studies, are performed to diagnose disorders of the peripheral nervous system. Nerve conduction studies are used to measure action potentials resulting from peripheral nerve stimulation which are recordable over the nerve or from an innervated muscle. With this technique, responses are measured between two sites of stimulation, or between a stimulus and a recording site. Recording of the electrical response to stimulation of the nerve between these points along its route is conducted and compared to normal responses. The study measures speed (conduction velocity and/or latency), amplitude (size) and the shape of neurologic response for detecting demyelination and axon loss.

Nerve conduction studies are of two general types: sensory and motor. Either surface or needle electrodes can be used to stimulate the nerve or record the response. Axonal damage or dysfunction generally results in loss of nerve or muscle potential response amplitude; whereas demyelination leads to prolongation of conduction time and slowing of conduction velocity.

Obtaining and interpreting NCS results requires extensive interaction between the performing qualified health care professional and patient and is most effective when both obtaining raw data and interpretation are performed concurrently on a real-time basis. Results of the NCS reflect on the integrity and function of:

- The myelin sheath (Schwann cell derived insulation covering an axon)
- The axon (an extension of neuronal cell body) of a nerve

Interruption of axon and dysfunction of myelin will both affect NCS results. It is often also valuable to test conduction status in proximal segments of peripheral nerves. The stimulation of nerves is similar across all NCSs; the characteristics of motor, sensory, and mixed NCSs are different and are discussed separately below. In each case, an appropriate nerve is stimulated, and recording is made either from the appropriate nerves or from muscle supplied by the motor nerve.

Motor NCSs are performed by applying electrical stimulation at various points along the course of a motor nerve while recording the electrical response from an appropriate muscle. Response parameters include amplitude, latency, configuration, and motor conduction velocity.

Sensory NCSs are performed by applying electrical stimulation near a nerve and recording the response from a distant site along the nerve. Response parameters include amplitude, latency, and configuration.

Mixed NCSs are performed by applying electrical stimulation near a nerve containing both motor and sensory fibers (a mixed nerve) and recording from a different location along that nerve that also contains both motor and sensory nerve fibers. Response parameters include amplitude, latency, configuration, and motor conduction velocity."

Electromyography (EMG) is the study and recording of intrinsic electrical properties of skeletal muscles. This is carried out with a needle electrode. Generally, the needles are of two types: monopolar or concentric. EMG is undertaken together with NCS. Unlike NCS, however, EMG testing relies on both auditory and visual feedback to the electromyographer. This testing is also invasive in that it requires needle electrode insertion and adjustment at multiple sites, and at times anatomically critical sites. As in NCS during EMG studies the electromyographer depends on ongoing real-time interpretation-based knowledge of clinical diagnosis being evaluated to decide whether to continue, modify, or conclude a test. This process requires knowledge of anatomy, physiology, and neuromuscular diseases.

EMG results reflect not only on the integrity of the functioning connection between a nerve and its innervated muscle but also on the integrity of a muscle itself. The axon innervating a muscle is primarily responsible for the muscle's volitional contraction, survival, and trophic functions. Thus, interruption of the axon will alter the EMG. A few prime examples of conditions in which EMG is potentially helpful are disc disease producing spinal nerve dysfunction, advanced nerve compression in peripheral lesions, Amyotrophic Lateral Sclerosis (ALS), polyneuropathy, etc. After an acute neurogenic lesion, EMG changes may not appear for several days to weeks in the innervated muscles. Primary muscle disease such as polymyositis will also alter a normal EMG pattern. Myotonic disorders may show a pattern of spontaneous repetitive discharges on needle exploration.

NCS are generally performed with needle electromyogram (NEMG), enabling the presence and extent of peripheral nerve pathology to be determined (Katirji, 2002; North American Spine Society [NASS], 2003; Aminoff, 2003; Asbury, 2004; AANEM 2016). EMG studies measure the electrical activity of muscles. When performed together, they can be extremely helpful in detecting whether the pathology originates in the proximal or distal root ganglia and whether the neuromuscular dysfunction relates to peripheral nerve disease.

Both EMGs and NCSs are required for a clinical diagnosis of peripheral nervous system disorders. EMG results reflect on the integrity of the functioning connection between a nerve and its innervated muscle and also on the integrity of a muscle itself. Performance of one does not eliminate the need for the other. Without awareness of the patterns of abnormality expected in different diseases and knowledge that the results of nerve conduction studies and electromyography may be similar in different diseases, diagnosis solely by EMG-NCS findings may be both inadequate and ultimately be detrimental to the patient. For example, EMG-NCS findings may overlap in the following pairs of disorders: inflammatory myopathies and ALS, ALS and multi-level radiculopathies, myotonia of channelopathies (periodic paralyses) and myotonic dystrophies, focal neuropathies as Carpal Tunnel Syndrome and proximal plexopathies. Other instances where knowledge of disease behavior is crucial are Chronic Inflammatory Demyelinating Neuropathy (CIDP) and Multifocal Motor Neuropathy. These entities display electrodiagnostic features that resemble generalized polyneuropathies. Neuromuscular transmission disorders require separation based on clinical presentation and electrical features.

Without awareness of the disease spectrum, diagnosis solely by EMG-NCS findings may be either wrong or detrimental to the patient. Nerve conduction studies performed independent of needle electromyography (EMG) may only provide a portion of the information needed to diagnose muscle, nerve root, and most nerve disorders. When the nerve conduction study (NCS) is used on its own without integrating needle EMG findings or when an individual relies solely on a review of NCS data, the results can be misleading, and important diagnoses may be missed. For example, radiculopathies cannot be definitively diagnosed by NCS alone; EMG is performed to confirm the radiculopathy. According to the American Academy of Neurology (AAN), needle EMG (NEMG), in combination with nerve conduction studies, is the gold standard methodology for assessing the neurophysiologic characteristics of neuromuscular diseases (Pullman et al., 2000). In summary, axonal and muscle involvement are most sensitively detected by EMGs, and myelin and axonal involvement are best detected by NCSs.

EMG should always be performed by a physician or health care provider who is specially trained in electrodiagnostic medicine (neurologist, physiatrist, clinical neurophysiologist, board-certified physical therapist) with real-time interpretation (performed only by a physician) and is part of the complete electrodiagnostic examination (AANEM, 2022). EMG reports should include documentation of the muscle tested, the presence and type of spontaneous activity and the characteristics of the voluntary unit potentials.

NCS may be performed by a trained technologist under the direct supervision of a physician. Direct supervision implies that a physician is in close proximity to the patient undergoing testing, is immediately available to provide the trained technician with assistance and direction if necessary and is responsible for determining the nerve conduction studies that are appropriate. In general, a physician assesses the results of the degree of myelination or axonal loss.

**H-reflex/F-wave Testing**

Late response (H-reflex and F-wave testing) testing is a type of NCS usually performed on nerves more proximal to the spine. The H-reflex involves conduction from the periphery to and from the spinal cord. The H-reflex study involves the assessment of the gastrocnemius/soleus muscle complex in the calf and is usually performed bilaterally due to the need to assess symmetrical results in determining abnormalities. The F-wave study is a late response similar to the H-reflex. F-wave studies are used to assess the proximal segments of the motor nerve function and are performed in combination with the examination of motor nerves. Both studies are helpful in diagnosing conditions of radiculopathies, plexopathies, polyneuropathies, and proximal mononeuropathies (AANEM, 2022). Late response studies are additional studies complementary to NCV and are performed during the same patient evaluation.

Single Fiber EMG: Single fiber EMG uses a very highly selective electrode that can focus on a restricted number of muscle fibers. It is utilized to study neuromuscular jitter and muscle fiber density. Fiber density may be increased in neuromuscular disorders such as myasthenia gravis. Jitter is a measure of variation in neuromuscular transmission times and may be increased in some neuromuscular disorders (Sanders, Howard, 2008; Barboi and Barkhaus, 2004; Sanders, 2004). Single fiber EMG has many uses; however, it is most useful to confirm diagnosis for disorders of the neuromuscular junction in suspected myasthenia gravis when other tests are inconclusive or negative (Sanders, Howard, 2008; Gooch and Pullman, 2004).

**Macro EMG**

Macro EMG is less selective when compared to standard NEMG or single-fiber EMG and is primarily used in investigational settings. It is a method of analyzing the motor unit quantitatively. A surface electrode is used for reference, and motor unit action potentials (MUAP) are measured from a macro needle. Authors suggest that macro EMG evaluates a large recording area compared to other needle electrodes and is considered representative of the entire MUAP area (Barboi and Barkhous, 2004).

**Surface EMG (SEMG)**

In contrast to NEMG, SEMG, also referred to as surface scanning EMG, is a noninvasive, computer-based technique that records the electrical impulses using electrodes placed on the surface of the skin overlying the nerve at rest (i.e., static) and during activity (i.e.,

dynamic). The procedure studies the topography of the motor unit action potential (MUAP) and is assessed by computer analysis of the frequency spectrum, amplitude, or root mean square of the electrical action potential. The SEMG differs from the NEMG with respect to technical requirements and electrical properties. SEMG electrodes measure from a wide area of muscle, have a relatively narrow frequency band (range 20 to 500 Hz), have low-signal resolution, and are highly susceptible to movement artifact (Pullman, 2000). The proposed use for this type of EMG is to aid in the diagnosis of neuromuscular disorders and low back pain, and to aid in assessing the prognosis of disorders involving muscle lesions. The technology has also been used to monitor bruxism (i.e., grinding and clenching of teeth). The electrical activity of muscle may be recorded with surface EMG, although spontaneous electrical activity and voluntary motor units cannot be (Lange and Trojaborg, 2000). Although not widely used as a diagnostic tool, high-density SEMG (HD-sEMG) is a multichannel SEMG that records the input of multiple electrodes placed on one muscle and is being studied as a possible method of detecting single MU characteristics (Drost et al., 2006). Nonetheless, the clinical utility of surface EMG testing outside of the investigative setting has not been proven in the peer-reviewed scientific literature.

**Paraspinal EMG**

Paraspinal EMG scanning, a type of SEMG, also referred to as paraspinal SEMG, has been investigated as a method of assessing the paraspinal muscles of patients which provide support to the spinal column. Impairment of the paraspinal muscles may lead to abnormal motion and pain. The paraspinal SEMG is performed using a single electrode or an array of electrodes placed on the skin surface with recordings that are typically made at rest, in various positions, or after physical activity. The diagnostic utility of paraspinal EMG is not known, and its role in patient management has not been established.

**Somatosensory Evoked Potentials (SEPs)**

SEPs are an extension of the electrodiagnostic evaluation and can be used to test conduction in various sensory fibers of the peripheral and central nervous systems. SEPs may be used to assess the functional integrity of the central and peripheral sensory pathways. SEPs are noninvasive studies performed by repetitive submaximal stimulation of a sensory or mixed sensorimotor peripheral nerve and recording the averaged responses from electrodes placed over proximal portions of the nerve stimulated, plexus, spine, and scalp (AANEM, 2015). SSEPs are an extension of the electrodiagnostic evaluation and are used to evaluate nerves that cannot be studied by conventional nerve conduction studies, including electromyography. SEPs are typically elicited by stimulating mixed nerves (median, ulnar, tibial, and peroneal) to assess sensory pathways. Therefore, the application of standard SEPs to study radicular disease is necessarily limited to investigating the lumbar and cervical regions because of the limited number of sites to stimulate (AAN, 1997).

The evoked potential response depends on the functional integrity of the nerve that is stimulated. An abnormal SSEP points to a problem in the nerve conduction mechanism that carries the impulse to the brain, however, the SSEP abnormality is not disease specific—an abnormal SSEP indicates impairments associated with certain disorders. An abnormal SSEP signifies an impaired pathway, helps to localize it, and provides a prognostic guide. The SSEP does not provide any indication about the nature of the underlying pathological processes. Although evoked potentials offer additional information regarding function that can be clinically useful, magnetic resonance imaging (MRI) is often the preferred test to determine structural abnormalities and provides more specific information regarding neurologic structures.

SSEPs are altered by impairment of the somatosensory pathway which may occur as a result of both diffuse (e.g., diseases of myelin, hereditary system degenerations, coma) or local disorders (e.g., tumors, vascular lesions). SSEP abnormalities can be detected in a variety of different settings; therefore, the electrophysiologic findings should be interpreted in the clinical context in which they are obtained (e.g., assessing functional integrity, diagnostic purposes, determining the course of neurological disorders, determining pathological involvement). SSEPS are helpful in evaluating ill-defined complaints. A physician assesses the patient and determines a preliminary differential diagnosis; SSEP testing may then be performed by a trained technologist under the direct supervision of a trained electrodiagnostic physician. Direct supervision implies that a physician is in close proximity to the patient undergoing testing, is immediately available to provide the trained technician with assistance and direction if necessary and is responsible for determining the SSEP studies that are appropriate.

Evoked potentials are used to assist in diagnosing ill-defined neurological conditions and to categorize afferent pathways that may be responsible for the resulting symptoms experienced by the patient. Conditions for which SSEPS may offer clinical utility include (American Association of Neuromuscular and Electrodiagnostic Medicine [AANEM], 2015):

- Spinal cord trauma
- Subacute combined degeneration
- Non-traumatic spinal cord lesions (e.g., cervical spondylosis)
- Multiple sclerosis
- Spinocerebellar degeneration
- Myoclonus
- Coma

SSEPs have been utilized to evaluate other peripheral nerve disorders such as acute inflammatory demyelinating polyradiculoneuropathy and focal neuropathies (e.g., entrapment neuropathies, carpal tunnel syndrome, lateral femoral cutaneous neuropathy, medial and lateral plantar neuropathy, saphenous neuropathy, intercostals neuropathy,

trigeminal neuropathy, plexopathy) in addition to nerve root dysfunction (i.e., lumbosacral root [acute radiculopathies], thoracic root, cervical root). However, the diagnostic utility of SSEPs for these conditions remains controversial (AANEM, 2015). The AANEM reported that the available evidence is not convincing that SSEPs for these indications provide information that cannot be obtained with conventional nerve conduction studies or needle electromyography. SSEPS are rarely used to assess peripheral neuropathy as standard nerve conduction velocity studies are the preferred test. There are no data to suggest a role for SSEPs in the evaluation of behavioral health disorders. The usefulness of evoked potential testing in psychiatry, including SSEPs, is still under investigation (Guse and Love, 2005). Recordings of SSEP can be normal even in patients with extreme sensory deficits due to the presence of multiple parallel, afferent somatosensory pathways. This procedure is often performed to investigate patients with multiple sclerosis (MS); various coma states, such as those from post-traumatic injury or post-anoxia; suspected brain death; and to indicate the extensiveness of lesion damage in spinal cord injuries. The return or presence of a cortically-generated response to stimulation of a nerve below the injured portion of the cord indicates an incomplete lesion and therefore may offer a better prognosis. SSEP testing is typically performed bilaterally. Depending on the clinical situation being investigated, several nerves in one extremity may have to be tested and compared with the opposite limb. The physician's SSEP report should indicate which nerves were tested, latencies at various testing points and an evaluation of whether the results were normal or abnormal.

**Neuromuscular Junction Testing**

The neuromuscular unit is made up of four components: the anterior horn cells of the spinal cord, the peripheral nerve, the neuromuscular junction, and the muscle being innervated. The level of disease determines the signs and symptoms an individual develops. Neuromuscular junction testing involves the stimulation of an individual motor nerve by means of repetitive electrical impulses with measurement of the resulting electrical activity of a muscle supplied by that nerve. Supramaximal electrical stimuli are delivered to the nerve. A surface electrode over, or percutaneous electrode placed in, a corresponding muscle records the evoked muscle action potentials using standard nerve conduction study techniques. The nerve is then stimulated electrically in a repetitive train at 2-3 Hz, or in special circumstances at higher rates up to 50 Hz. Testing may be performed in addition to NCS of the same nerves and/or EMG. In diseases of the neuromuscular junction, characteristic changes of a progressive decrease (decrement) in the compound action potential amplitude may be seen during the repetitive stimulation. Testing is indicated for suspected diseases of the neuromuscular junction (generally associated with progressive motor fatigability) which include myopathy, focal neuropathy, myasthenia gravis and Lambert Eaton myasthenic syndrome. Another condition that testing may be indicated for, botulism, is associated with a decrease in the amount of acetycholine released, and results in weakness (Juel, 2012; Shearer, Jagoda, 2009).

**Automated Nerve Conduction Testing**

Proponents of automated nerve conduction tests suggest that they can be used in a variety of clinical settings, including a physician's office, without the need for specialized training or equipment, theoretically obtaining results within minutes. Portable, automated devices have been developed to provide nerve conduction studies at the point of care (e.g., primary care setting), particularly for carpal tunnel evaluation and evaluation of diabetic peripheral neuropathy, as an alternative to or as an adjunct to other conventional testing methods. Manufacturers state these devices have computational algorithms, provide delivery of stimulus, measure and analyze the patient's response, and provide a detailed report of study results.

The NC-stat System and ADVANCE™ NCS system (NEUROMetrix® Inc., Waltham, MA) are hand-held, noninvasive, automated nerve conduction testing systems that have been proposed as an alternative to conventional nerve conduction testing. The devices have been marketed for use in an office or clinic setting, to assess nerves of the upper and lower extremities assisting in the diagnosis of peripheral nerve disorders such as carpal tunnel syndrome, diabetic peripheral neuropathy, and sciatica. The manufacturer suggests that data can be analyzed and readily available within minutes and then transmitted to the physician via email, internet or as a faxed document. A computerized system interprets the data. The proposed benefits of these devices are ease of use and rapid results.

Another device proposed for automated testing of peripheral nerves is the Brevio nerve conduction monitoring system (Neurotron Medical, Inc., West Trenton, NJ). According to the manufacturer, the device calculates latency and amplitude for sensory, motor, and f-wave responses using a single noninvasive neuro-sensor for testing performed on the patient. Similar to the NC-stat device, when testing is performed, the results can be immediately sent to a printer in the office or through a Web service for an electronic report.

**Electrodiagnostic Testing General Principles**

Electrodiagnostic testing of nerve function is established as having diagnostic utility and is professionally recognized when such tests are ordered to clarify or confirm findings from history and physical examination including a neurological examination as described within this guideline. Current guidelines do not support the use of these tests for initial or routine screening of patients in the absence of findings from physical examination or when the results of such tests are unlikely to influence treatment planning or patient management.

In order to establish the necessity for special diagnostic testing, one needs to consider at least the following:

- Is there historical or chief complaint information that suggests a condition or lesion that can only be appropriately evaluated using special tests or was an appropriate physical examination performed that brought forth findings suggestive of a condition or lesion that can only be appropriately evaluated using special tests?

- For nerve function tests specifically, was a neurological examination of reflexes, sensory integrity, and motor function performed as part of the physical examination and were findings indicative of nerve insult (diminished reflexes, dermatome-specific sensory deficits, or nerve-root-specific muscle weakness)?
- Would the anticipated information or clarification from the results of the special tests influence treatment planning?
- If there is a strong indication for special testing because of suspicious findings on history or physical examination, would positive findings on special tests necessitate referral to a specialist where such testing might be repeated or duplicated; specifically, is the test most appropriately performed or ordered by the clinician evaluating the patient or by a specialist to whom the patient should be referred?

When patients present with neck or low back pain with associated extremity complaints of pain, numbness, or tingling it is hoped that a pattern match can be made between these complaints and objective physical examination demonstration of sensory loss, motor loss, or an associated deep tendon reflex decrease. Use of provocative maneuvers such as compression, distraction, or percussive maneuvers (e.g., Cervical Compression Test, Straight Leg Raise, Tinel's sign) may further clarify the diagnosis. Other sources of the complaint should also be evaluated including referral from trigger points or facet irritation. Management should be based on the suspected cause. Consideration of electrodiagnostic testing may be warranted when:

- The diagnosis and treatment plan are not confirmed by the history and physical examination;
- A preliminary diagnosis and trial of treatment are not resulting in improvement;
- The patient's condition does not respond to treatment or worsens; or
- In order to make a proper diagnosis and treatment plan.

However, in most cases, it would be appropriate to initiate conservative care (e.g., 4-6 weeks), being sure to monitor for worsening or non-response to care, prior to utilizing invasive electrodiagnostic procedures . The electrodiagnostic evaluation is an extension of the neurologic portion of the physical examination. Both require a detailed knowledge of a patient and their disease. The electrodiagnostic consultation provides useful information in the evaluation of motor, sensory and autonomic neurons, nerve roots, brachial and lumbar plexi, peripheral nerves, neuromuscular junction, and muscles. Electrodiagnostic studies should enhance, but not replace, a careful history and physical examination. Training in the performance of electrodiagnostic procedures in isolation of knowledge about clinical diagnostic and management aspects of neuromuscular diseases, may not be adequate for proper performance of an electrodiagnostic evaluation and correct interpretation of electrodiagnostic test results.

The broad diagnostic scope of NCS is recognizable by the foregoing description. There may be instances where questions about an indication, or need for a study, will arise. The clinical history and examination, carried out before the study, must always describe and document clearly and comprehensibly the need for the planned test. A "rule-out" diagnosis is typically not acceptable. Often, pain, paresthesia, or weakness in an extremity is the reason for an NCS or EMG. These common symptoms result not only from axonal and myelin dysfunction but also from systemic, non-neurological illnesses. EMG and NCV may help in making this distinction. Therefore, symptom-based diagnoses such as "pain in limb" weakness, disturbance in skin sensation or "paresthesia" are acceptable provided the clinical assessment unequivocally supports the need for a study. To cite but one example of many, an EMG or NCS is irrelevant as a first order diagnostic test for limb pain resulting from immediate antecedent trauma or acute bone injury.

The intensity and extent of testing with EMG and NCS are matters of clinical judgment developed after the initial pre-test evaluation, and later modified during the testing procedure. Decisions to continue, modify or conclude a test also rely on a knowledge base of anatomy, physiology, and neuromuscular diseases. There is a requirement for ongoing real-time clinical diagnostic evaluation, especially during EMG examination. Also, EMG examination is invasive. Needle placement in the exact muscle of interest is essential. It requires needle exploration near vital structures as the pleura, femoral neurovascular bundle, peritoneum, intraspinal spaces, carotid artery, orbit, and brachial plexus. Risk of infection from AIDS, Hepatitis B-E, Creutzfeldt-Jakob encephalopathy, and hemorrhage from anticoagulation can be managed by proper techniques. Needle EMG is relatively contraindicated in persons on anti-coagulant therapy with coumadin (Warfarin) or heparins that cannot be interrupted. Oh (2003) observed that patients with a variety of bleeding disorders may be referred for needle EMG. Oh (2003) recommended that the referring physician and the electromyographer examine each case individually, carefully weighing the potential risks and benefits. Cardiac pacemakers and implanted cardiac defibrillators (ICDs) are increasingly used in clinical practice, and no evidence exists indicating that performing routine electrodiagnostic studies on patients with these devices poses a safety hazard. However, there are theoretical concerns that electrical impulses of nerve conduction studies (NCSs) could be erroneously sensed by devices and result in unintended inhibition or triggering of output or reprogramming of the device (Schoeck, 2007). In general, the closer the stimulation site is to the pacemaker and pacing leads, the greater the chance for inducing a voltage of sufficient amplitude to inhibit the pacemaker. Despite such concerns, no immediate or delayed adverse effects have been reported with routine NCS (AANEM, 2014).

In patients with external cardiac pacemakers, the conductive lead, inserted into the heart (usually transvenously) and connected to the external cardiac pacemaker, presents a serious potential hazard of electric injury to the heart (Al-Shekhlee et al., 2003). NCSs are not

recommended in any patient with an external conductive lead terminating in or near the heart.

The nature of recurrent and frequent electrical impulses that may occur with repetitive stimulation or eliciting somatosensory evoked potentials (SEP) pose a special circumstance. Nerve stimulation in the lower extremities or in distal upper extremities would be unlikely to have untoward effects upon pacemakers or ICDs. Repetitive stimulation for assessing integrity of the neuromuscular junction typically necessitates study of proximal and/or cranial nerve-innervated muscles, which may place the stimulating electrode closer to the cardiac device. Nonetheless, as there are no data to determine the safety of performing these procedures in patients with pacemakers or ICDs, proximal upper extremity and cranial nerve stimulation sites should be avoided for repetitive and SEP stimulation (AANEM, 2014).

Needle EMG recording does not introduce electrical current into the body and, therefore, poses no risk of interference with implanted cardiac devices.

No known contraindications exist from performing needle EMG and NCSs on pregnant patients. In addition, no complications from these procedures have been reported in the literature. Evoked response testing, likewise, has not been reported to cause any problems when performed during pregnancy (AANEM, 2014).

The minimum standards recommended by the AANEM for electrodiagnostic testing (EDX) include the following:

1. EDX testing should be medically indicated.
2. Testing should be performed using EDX equipment that provides assessment of all parameters of the recorded signals. Studies performed with devices designed only for “screening purposes” rather than diagnosis are not acceptable.
3. The number of tests performed should be the minimum needed to establish an accurate diagnosis.
4. NCSs should be either (a) performed directly by a physician or (b) performed by a trained individual under the direct supervision of a physician. Direct supervision means that the physician is in close physical proximity to the EDX laboratory while testing is underway, is immediately available to provide the trained individual with assistance and direction and is responsible for selecting the appropriate NCSs to be performed.
5. The needle EMG examination must be performed by a physician specially trained in EDX medicine, as these tests are simultaneously performed and interpreted. The EDX laboratory must have the ability to perform needle EMG. The needle EMG must include evaluation of both resting and voluntary activities. NCSs should not be performed without needle EMG except in unique circumstances. EMG and NCSs should be performed together in the same EDX evaluation when possible.

6. It is appropriate for only 1 attending physician to perform or supervise all of the components of the EDX testing (e.g., history taking, physical evaluation, supervision and/or performance of the EDX test, and interpretation) for a given patient and for all the testing to occur on the same date of service. The reporting of NCS and needle EMG study results should be integrated into a unifying diagnostic impression.
7. In contrast, dissociation of NCS and needle EMG results into separate reports is inappropriate unless specifically explained by the physician. Performance and/or interpretation of NCSs separately from that of the needle EMG component of the test should clearly be the exception (e.g., when testing an acute nerve injury) rather than an established practice pattern for a given practitioner.

In a position statement published by the AANEM regarding the performance and interpretation of electrodiagnostic studies (AANEM, 2020), the AANEM states, "To reach a diagnosis based on EDX testing, it is imperative that the physician has obtained a history and examined the patient and designed the NCSs and EMG testing based on the information obtained from the patient. Using a predetermined or standardized battery of NCSs for all patients is inappropriate because it may be possible to obtain the data needed to reach a diagnosis with fewer studies. Alternatively, a pre-determined battery may not include the appropriate NCSs and/or EMG tests to determine the diagnosis. If the EDX studies are not based on the patient's history and physical examination findings, substandard care is being provided. If the NCS results a physician is relying on are interpreted offsite without integrating information from the needle EMG, substandard care is being provided. It is the opinion of the AANEM that relying on NCSs alone to make health care decisions is usually inadequate and inappropriate."

Except in limited clinical situations, performing nerve conduction studies (NCS) together with needle electromyography (NEMG) is required to diagnose peripheral nervous system disorders. According to the AANEM circumstances under which NCS and EMG should not be performed together include, but are not limited to, limited follow-up studies of neuromuscular structures that have undergone previous electrodiagnostic evaluation, the current use of anticoagulants, or the presence of lymphedema. In addition, the AANEM indicates that for suspected carpal tunnel syndrome, the extent of the needle EMG examination depends on the results of the NCSs and the differential diagnosis considered for the individual patient (AANEM, 2022). The AANEM (2022) does not support screening testing, monitoring disease intensity, or monitoring of treatment efficacy for polyneuropathy of diabetes or polyneuropathy of end stage renal disease (ESRD). NEMG is also not recommended for any of the following:

- Testing of intrinsic foot muscles in the diagnosis of proximal lesions
- Definitive diagnostic conclusion from paraspinal EMG in regions bearing scars of previous surgeries, such as previous laminectomy

- Pattern setting limited limb muscle examinations without paraspinal muscle testing for diagnosis of radiculopathy
- Needle EMG testing performed shortly after trauma

**Number of Services Recommended:** Table 1 summarizes the recommendations of the AANEM regarding the reasonable maximum number of studies per diagnostic category necessary for a physician to arrive at a diagnosis for 90% of patients with that final diagnosis, within a 12-month timeframe (AANEM, 2022).

**Table 1. Number of Services Recommended:**

| | **Limbs Studied by Needle Electromyography (95860-95864, 95867-95870, 95885-95887)** | **Nerve Conduction Studies (Total nerve studied, 95907-95913)** | **Neuromuscular Junction Testing (Repetitive Stimulation)** |
|---|---|---|---|
| **Indication** | **Number of Services (Tests)** | **Number of Services (Tests)** | **Number of Services (Tests)** |
| Carpal Tunnel (unilateral) | 1 | 7 | -- |
| Carpal Tunnel (bilateral) | 2 | 10 | -- |
| Radiculopathy | 2 | 7 | -- |
| Mononeuropathy | 1 | 8 | -- |
| Polyneuropathy/ Mononeuropathy Multiplex | 3 | 10 | -- |
| Myopathy | 2 | 4 | 2 |
| Motor Neuronopathy (e.g., ALS) | 4 | 6 | 2 |

| | Limbs Studied by Needle Electromyography (95860-95864, 95867-95870, 95885-95887) | Nerve Conduction Studies (Total nerve studied, 95907-95913) | Neuromuscular Junction Testing (Repetitive Stimulation) |
|---|---|---|---|
| **Indication** | **Number of Services (Tests)** | **Number of Services (Tests)** | **Number of Services (Tests)** |
| Plexopathy | 2 | 12 | -- |
| Neuromuscular Junction | 2 | 2 | 3 |
| Tarsal Tunnel Syndrome (unilateral) | 1 | 8 | -- |
| Tarsal Tunnel Syndrome (bilateral) | 2 | 11 | -- |
| Weakness, Fatigue, Cramps, or Twitching (focal) | 2 | 7 | 2 |
| Weakness, Fatigue, Cramps, or Twitching (general) | 4 | 8 | 2 |
| Pain, Numbness, or Tingling (unilateral) | 1 | 9 | -- |
| Pain, Numbness, or Tingling (bilateral) | 2 | 12 | -- |

## Carpal Tunnel Syndrome

For suspected carpal tunnel syndrome (CTS), bilateral median motor and sensory NCSs are often indicated. The studies in the contralateral asymptomatic limb serve as controls in cases where values are borderline and may establish the presence of bilateral CTS. Two to 4 additional sensory or mixed NCSs can be compared to the median sensory NCSs to increase the diagnostic sensitivity of the testing. The additional sensory NCSs and an additional motor NCS (usually ulnar) are indicated to exclude a generalized neuropathy or multiple mononeuropathies. If 2 sensitive sensory NCSs are performed at the beginning start, additional sensory testing on the same limb is rarely needed. For suspected bilateral CTS, bilateral median motor and sensory NCSs are indicated. Up to 2 additional motor and 2 additional sensory NCSs are often indicated. The extent of the needle EMG examination depends on the results of the NCSs and the differential diagnosis considered in the individual patient. Additional testing may be indicated in patients with a differential diagnosis which includes peripheral neuropathy, cervical radiculopathy, brachial plexopathy, or more proximal median neuropathy.

## Radiculopathy

A minimal evaluation for radiculopathy includes 1 motor and 1 sensory NCS and a needle EMG examination of the involved limb. However, the EDX testing can include up to 3 motor NCSs (in cases of an abnormal motor NCS, the same nerve in the contralateral limb and another motor nerve in the ipsilateral limb can be studied) and 2 sensory NCSs. Bilateral studies are often necessary to exclude a central disc herniation with bilateral radiculopathies or spinal stenosis or to differentiate between radiculopathy and plexopathy, polyneuropathy, or mononeuropathy. H reflexes and F waves may provide useful complementary information and assist in confirmation of root dysfunction Radiculopathies cannot be diagnosed by NCS alone; needle EMG must be performed to confirm a radiculopathy. Therefore, these studies should be performed together by 1 physician/qualified health care practitioner supervising and/or performing all aspects of the study.

## Polyneuropathy/Mononeuropathy Multiplex

In order to characterize the nature of the polyneuropathy (axonal or demyelinating, diffuse or multifocal) and in order to exclude polyradiculopathy, plexopathy, neuronopathy, or multiple mononeuropathies, it may be necessary to study 4 motor and 4 sensory nerves, consisting of 2 motor and 2 sensory NCSs in 1 leg, 1 motor and 1 sensory NCS in the opposite leg, and 1 motor and 1 sensory NCS in 1 arm. H-reflex studies and F-wave studies from 2 nerves may provide additional diagnostic information. At least 2 limbs should be studied by a needle EMG examination. Studies of related paraspinal muscles are indicated to exclude some conditions such as polyradiculopathy.

**Myopathy**

To diagnose a myopathy, a needle EMG examination of 2 limbs is indicated. To help exclude other disorders such as polyneuropathy or neuronopathy, 2 motor and 2 sensory NCSs are indicated. Two repetitive motor nerve stimulation studies may be performed to exclude a disorder of NM transmission.

**Motor Neuronopathy**

In order to establish the diagnosis of motor neuronopathy (e.g., amyotrophic lateral sclerosis and to exclude other disorders in the differential diagnosis, such as multifocal motor neuropathy or polyneuropathy, up to 4 motor nerves and 2 sensory nerves may be studied. Needle EMG of up to 4 extremities (or 3 limbs and facial or tongue muscles) is often necessary to document widespread denervation and to exclude a myopathy. One repetitive motor nerve stimulation study may be indicated to exclude a disorder affecting NMJ transmission.

**Plexopathy**

To characterize a brachial plexopathy and differentiate it from cervical radiculopathy and mononeuropathies it may be necessary to perform additional sensory studies (e.g., medial, and lateral antebrachial cutaneous nerves) for a total of up to 6 sensory studies. It may also be necessary to perform up to 4 motor studies.

To characterize a lumbosacral plexopathy and differentiate it from lumbosacral radiculopathy, mononeuropathies and polyneuropathy, it may be necessary to perform up to 4 sensory studies, up to 4 motor studies and up to 2 H-reflex studies.

For both brachial and lumbosacral plexopathies, up to 2 additional studies (sensory and/or motor) may be performed in the contralateral (at times asymptomatic) limb to better definite the diagnosis.

**Neuromuscular Junction**

To demonstrate and characterize abnormal NMJ transmission, repetitive nerve stimulation studies should be performed in up to 3 nerves and single fiber EMG (SFEMG) in up to 2 muscles. If any of these are abnormal, up to 2 motor and 2 sensory NCSs may be performed to exclude neuropathies that can be associated with abnormal NM transmission. At least 1 motor and 1 sensory NCS should be performed in a clinically involved limb, preferably in the distribution of a nerve studied with repetitive stimulation or SFEMG. At least 1 distal and 1 proximal muscle should be studied by a needle EMG examination to exclude a neuropathy or myopathy that can be associated with abnormal repetitive stimulation studies or SFEMG. At least 1 of the muscles should be clinically involved and both muscles should be in clinically involved limbs.

In combination, NCSs and a needle EMG examination may be most helpful when performed several weeks after the injury has occurred. However, NCSs are often useful acutely after nerve injury, for example, if there is concern that a nerve has been severed. In fact, if studies are delayed, the opportunity to precisely identify the region of injury or to intervene may be lost. In some cases, even needle EMG testing performed immediately after a nerve injury may demonstrate abnormal motor unit action potential (MUAP) recruitment and/or provide information that can be helpful to document preexisting conditions, date the injury, or serve as a baseline for comparison with later studies.

Because of the variability of different nerve injuries, a standard rule on the timing of EDX testing cannot easily be established, and the AANEM does not have specific recommendations in this regard. In all instances, the AANEM encourages dialogue between physicians and payers, and encourages the appropriate use of the physician's clinical judgment in determining when studies are most appropriately performed and what studies should be conducted.

**Frequency of Electrodiagnostic Testing in a Given Patient**

There are many clinical situations where good medical management requires repeat testing, such as in the following examples:

1. Second diagnosis. Where a single diagnosis is made on the first visit, but the patient subsequently develops a new set of symptoms, further evaluation is required for a second diagnosis before treatment can begin.
2. Inconclusive diagnosis. When a serious diagnosis (e.g., ALS) is suspected but the results of the needle EMG/NCS examination are insufficient to be conclusive, follow-up studies are needed to establish or exclude the diagnosis.
3. Rapidly evolving disease. Initial EDX testing in some diseases may not show any abnormality (e.g., Guillain-Barré syndrome) in the first 1 to 2 weeks. An early diagnosis confirmed by repeat electrodiagnosis must be made quickly so treatment can begin. Follow-up testing can be extremely useful in establishing prognosis and monitoring patient status.
4. Course of the disease. Certain treatable diseases such as polymyositis and myasthenia gravis follow a fluctuating course with variable response to treatment. The physician treating such patients needs to monitor the disease progress and the response to therapeutic interventions. The results of follow-up evaluations may be necessary to guide treatment decisions.
5. Unexpected disease course. In certain situations, management of a diagnosed condition may not yield expected results or new, questionably related problems may occur (e.g., failure to improve following surgery for radiculopathy). In these instances, reexamination is appropriate.

6. Recovery from injury. Repeat evaluations may be needed to monitor recovery, to help establish prognosis, and/or to determine the need for and timing of surgical intervention (e.g., traumatic nerve injury), and to assess recovery over time following peripheral nerve surgery.

Repeat EDX evaluation is, therefore, sometimes necessary and, when justifiable, should be reimbursed. Reasonable limits can be set concerning the frequency of repeat EDX testing per year in a given patient by a given EDX evaluation for a given diagnosis. The following numbers of tests per 12-month period per diagnosis per physician are acceptable:

1. Two tests for carpal tunnel-unilateral, carpal tunnel-bilateral, radiculopathy, mononeuropathy, polyneuropathy, myopathy, and neuromuscular junction (NMJ) disorders.
2. Three tests for motor neuronopathy, plexopathy, acute inflammatory demyelinating polyradiculoneuropathy/Guillain Barré Syndrome (AIDP/GBS) and following peripheral nerve surgery.

These limits should not apply if the patient requires evaluation by more than 1 EDX physician (i.e., a second opinion or an expert opinion at a tertiary care center) in a given year or if the patient requires evaluation for a second diagnosis in a given year. Additional studies then may be required or appropriate above these guidelines. In such situations, the reason for the repeat study should be included in the body of the report or in the patient's chart. Comparison with the previous test results should be documented. This additional documentation from the physician regarding the necessity for the additional repeat testing would be appropriate. Repeat EDX testing should not be necessary in a 12-month period in 80% of all cases.

The Professional Practice Committee of the AANEM developed the following recommendations as part of the ABIM Choosing Wisely Initiative (AANEM, 2015):

- Don’t do a needle electromyography (EMG) test for isolated neck or back pain after a motor vehicle accident, as a needle EMG is unlikely to be helpful.
- Don’t do a four-limb needle EMG/nerve conduction study (NCS) testing for neck and back pain after trauma.
- Don’t do nerve conduction studies without also doing a needle EMG for testing for radiculopathy, a pinched nerve in the neck or back.

Sensitivity and specificity reports for electrodiagnostic testing methods (in general) vary. A clearly established measure of comparison is lacking in the medical literature, making comparisons across studies difficult. Some studies have compared results with clinical examination findings, imaging studies such as magnetic resonance imaging, computed tomography, myelography, or the observation of nerve root compression during surgery. Interobserver differences, the variety of tests employed, the presence of symptoms that

may influence patient outcomes (e.g., pain), the presence of abnormal imaging studies in asymptomatic patients, and the subjectivity of the surgeon's interpretations may all lead to variances in sensitivity and specificity results. Despite these variances however, electrodiagnostic testing is commonly used to assist in diagnosing disorders involving the nerves, muscles, and neuromuscular junction. Sensitivity and specificity data for automated/portable devices, used instead of or as an adjunct to standard nerve conduction testing, is insufficient to draw conclusions regarding predictive value.

***DOCUMENTATION GUIDELINES***

**Documentation Required Justifying Electrodiagnostic Testing**

- Reason for the study, clinical history and examination findings are required
- Numerical values are required – latency, amplitude and nerve conduction
- Type of needle – monopolar or concentric
- When documentation is required submit hard copy of waveforms and complete written report, including test interpretation
- Name, signature, professional designation of all individuals performing, interpreting or supervising the test must be included

**Inadequate Documentation**

- Narrative reports alluding to 'normal' or 'abnormal' results without numerical data
- Description of F-wave without reference to corresponding motor conduction data
- Pattern-setting unilateral H-reflex measurements
- Absence of clinical history, preferably written by the referral source, indicating the need for the test
- Absence of documentation to support repeat testing on the same beneficiary or testing every beneficiary referred for pain

Nerve conduction studies must provide a number of response parameters in a real-time fashion to facilitate provider interpretation. Those parameters include amplitude, latency, configuration and conduction velocity, temperature of limb. Diagnostic studies that do not provide this information or those that provide delayed interpretation as substitutes for nerve conduction studies are not accepted. Raw measurement data obtained and transmitted trans-telephonically or over the Internet, therefore, does not qualify for the payment of the electrodiagnostic service codes included in this policy.

Claims for nerve conduction testing accomplished with discriminatory devices that use fixed anatomic templates and computer-generated reports used as an adjunct to physical examination routinely on all patients are not accepted.

The AANEM provides specific recommendations for reporting needle EMG and NCV results. According to the AANEM, the recommendation for documentation of nerve

conduction and EMG testing should include (but are not limited to) a description of the patient's clinical problem (demographics, reason for referral), the electrodiagnostic tests performed (techniques, distances, lab reference values, and temperature monitoring), all relevant data derived from these tests (nerves/muscles tested, numerical values for latencies and action potential), and the diagnostic interpretation of the data, including limitations. Complete NCV test measurements should also include amplitude measurements, normal reference values and criteria for abnormalities. The recommendations also include confirmation that limb temperature was monitored continuously during the NCS and repetitive stimulation and that (a) the hand temperature was maintained between 32°C and 36°C and (b) the foot temperature was maintained between 30°C and 36°C. NCS abnormalities such as prolonged distal sensory or motor latencies could otherwise be due to coolness of the limb. For repetitive stimulation, if the limb is not warmed, the results may be assessed inaccurately as normal (AANEM, 2019).

***EVIDENCE REVIEW***

**Automated Nerve Conduction Testing**

Evidence evaluating the diagnostic utility of the Brevio and Virtual Medical Systems VT 3000 nerve conduction monitor systems (Automated Nerve Conduction Testing) is lacking. Evidence evaluating the diagnostic utility of the NC-stat System consists mainly of case series, case control studies and retrospective reviews. Some of these studies compare results obtained using automated devices with results obtained from standard diagnostic testing (NCV testing and EMG), other studies did not have a comparison to conventional testing. Most of the published clinical studies have evaluated use of the NC-stat device for assessment of median and ulnar nerves (Dale et al., 2015; Megerian et al., 2007; Kong et al., 2006; Vinik et al., 2004); other published studies evaluated use of the device for disorders such as lumbosacral radiculopathies (Fisher et al., 2008) and sensorimotor polyneuropathy in diabetic patients (Perkins et al., 2008). In some of these studies a strong correlation has been demonstrated when comparing NC-stat with reference standards (Perkins et al., 2006; Kong et al., 2006). The diagnostic accuracy for other conditions, such as those involving the lower extremities, has not been sufficiently demonstrated in the literature. Data regarding diagnostic performance, sensitivity, and specificity of the automated NCV testing devices compared to standard testing is inconsistent and does not lead to strong conclusions; the studies are not well-designed, involve small populations and the results cannot be generalized. In some studies authors have reported high sensitivity and specificity when examining NC-stat accuracy for carpal tunnel syndrome compared to controls (Dale et al., 2015; Leffler et al., 2000; Rotman et al., 2004), other authors however have reported NC-stat is no more sensitive or specific than a traditionally performed distal motor latency for the diagnosis of carpal tunnel syndrome (Katz, 2006). In 2008, Armstrong and colleagues published the outcomes of a cohort study comparing the results obtained with the NC-stat device to traditional nerve conduction studies for carpal tunnel screening ($n$=33). All correlations were significant. The authors reported sensitivity, with respect to the traditional results, ranged from 93.8% to 100% and specificity ranged from

84.6% to 94.1%. Nonetheless, the authors did not address limitations such as lack of needle EMG testing and did not evaluate the clinical relevance to the results (Armstrong et al., 2008). In a longitudinal study (*n*=134), Dale and colleagues (2015) compared automated nerve conduction using the NC Stat device to traditional electrodiagnostic studies for 62 subjects, who had prior evaluation for carpal tunnel syndrome in the parent study (*n*=780). The authors reported that NC Stat results agreed with traditional electrodiagnostic studies for detecting median nerve conduction abnormalities within a general population of workers. Ulnar nerve testing results were not as favorable however median nerve testing results had high sensitivity and specificity (86-100%) for median motor and sensory latency. The study is limited by small sample population of industrial workers; results cannot be generalized to the standard population. A technology assessment conducted by the Washington State Department of Labor and Industries (2006) concluded that the scientific evidence does not show NC-stat to be equivalent to conventional methods for nerve conduction testing. Authors generally agree that further studies are needed to determine the role automated testing has as a component of clinical care. Furthermore, some concerns remain among specialists regarding lack of standard EMG testing and incomplete assessment when using automated NCV testing devices. The AANEM recommends electrodiagnostic studies be performed by properly trained physicians and that interpretation of nerve conduction study data alone, absent face-to-face patient interaction and control over the process, provides substandard care (AANEM, 2006). The AANEM (2010) does not support the following:

- Electrodiagnostic testing with automated, noninvasive nerve conduction testing devices
- Screening testing, monitoring disease intensity, or monitoring treatment efficacy for polyneuropathy of diabetes or polyneuropathy of end stage renal disease (ESRD)

Schmidt and colleagues (2011) reported on the use of an automated hand-held nerve conduction device compared to NCS or needle electrode examination (standard electrodiagnostic tests) in the evaluation of individuals with unilateral leg symptoms. A total of 50 participants with complaints of unilateral leg pain, numbness or weakness were included in the study and underwent history with physical exam and standard electrodiagnostic testing. The participants were then tested using an automated hand-held nerve conduction device. A total of 22 participants had findings consistent with radiculopathy on standard electrodiagnostic test and 28 participants had a normal electrodiagnostic exam or evidence of another distinct neuromuscular diagnosis. During initial data analysis, a significant discrepancy was revealed between the results of standard electrodiagnostic tests and the automated test. For this reason, another 25 participants were recruited to serve as the control group. The control group participants had upper limb symptoms such as cervical radiculopathy, carpal tunnel syndrome or ulnar neuropathy. Of the 50 participants initially recruited, 28 were found to have normal standard electrodiagnostic tests. The automated tests corroborated the findings in 4 cases only. In

the control group, all standard electrodiagnostic tests were normal, but the automated testing showed 18 of 25 participants had findings consistent with radiculopathy or polyneuropathy. Automated and standard testing correlated in 14 of 75 participants studied (11 of whom had normal exams with both testing methods). While this study has a small number of participants, the authors stated that "it is unlikely that larger study numbers would have increased specificity to acceptable levels of a clinically useful test, given the 95% confidence levels for the current data."

In a position statement on the Proper Performance and Interpretation of Electrodiagnostic Studies and the Recommended Use of Electrodiagnostic Medicine from the American Association of Neuromuscular and Electrodiagnostic Medicine (AANEM, 2006, 2014, 2020), although no specific reference to or recommendation for automated nerve conduction testing devices is made, it is noted that "Because needle EMG studies offer information needed for an accurate diagnosis, except in unique situations, it is the AANEM's position that NCSs and needle EMGs should be performed together in the same setting." The document also notes that using only NCS may provide incomplete diagnostic information which could lead to inadequate or inappropriate treatment. And: Individuals without a medical education in neuromuscular disorders and without special training in EDX procedures typically are not qualified to interpret the waveforms generated by NCSs and needle EMGs or to correlate the findings with other clinical information to reach a diagnosis. It is also the recommendation of the American Association of Neuromuscular and Electrodiagnostic Medicine (AANEM) that electrodiagnostic testing/consultations are conducted by physicians who have a comprehensive knowledge of neurological and neuromusculoskeletal diseases, and in the application of neurophysiologic techniques for evaluation of those disorders.

Although portable, automated, noninvasive testing of nerve conduction has been suggested as an easier method for providers to obtain rapid results, the AANEM recommended that EDX studies of EMG and NCS be performed "by physicians with medical education in neuromuscular disorders and special training in EDX testing" (AANEM, 2020). Currently, there is insufficient evidence in peer-reviewed published literature to demonstrate that automated nerve conduction testing devices provide better measures in the diagnosis of peripheral nerve disease. In addition, it remains unclear how testing with portable devices improves clinical outcomes for populations such as diabetics compared to clinical detection through neurological examination.

Since the clearance of the NC-stat, several other devices have also received FDA clearance listing the NC-stat as the predicate device. However, to date there has been very limited published evidence to demonstrate the safety and efficacy of automated, noninvasive nerve conduction testing devices, as compared to conventional "gold standard" electrodiagnostic testing using EMG and NCS. Most of the published clinical studies have evaluated use of

an automated device for assessment of the median and ulnar nerves only (Katz, 2006; Kong, 2006).

**Other Electrodiagnostic Testing**

Evidence in the peer reviewed scientific literature including textbook and professional society opinion supports clinical utility for electrodiagnostic testing, including neuromuscular junction testing, when used to assist in diagnosing disorders involving the nerves, muscles and neuromuscular junction. The AANEM has published guidance for the performance of nerve conduction studies and EMG. According to the AANEM a typical nerve conduction examination includes development of a differential diagnosis based upon appropriate history and physical exam, the NCV study (recording and studying of electrical responses from peripheral nerves or muscles) and the completion of indicated needle EMG studies to evaluate the differential diagnosis and to complement the nerve conduction study. In addition, the AANEM supports that when performing nerve conduction studies, the waveform must be reviewed on site and in real time, with reports prepared onsite by the examiner, consistent with current procedural terminology descriptions (AANEM, 2014). The AANEM defines the use of the term onsite as that where the history and physical, performance of NCV and EMG, analysis of electrodiagnostic data and determination of diagnosis occur in the same location, typically an electrodiagnostic laboratory. Similarly, real time is defined as that which allows for information from the physical and history to be integrated with the performance of testing, allowing for the testing of both NCV and EMG to be tailored/modified to the individual circumstance as needed before leaving the lab.

The use of nerve conduction studies including F-wave and H-reflex tests for the diagnosis of early stage polyneuropathies and proximal nerve lesions is confirmed in several reviews and studies (Choi and Maria, 2021; Maccabee et al., 2011; Kostera-Pruszczyk et al., 2004; Trujillo-Hernandez et al., 2005; Bal et al., 2006; Kocer et al., 2005; Mesrati and Vecchierini, 2004). The published scientific literature demonstrates somatosensory evoked potential (SEP) studies are useful when used to aid in the diagnosis of various neuromuscular disorders and have varying degrees of sensitivity and specificity.

Nerve conduction studies are indicated for the following conditions: peripheral nerve entrapment (Omejec, 2014; Park, 2014; Calfee, 2012; Kwon, 2008; Vij et al., 2021); generalized neuropathies (Choi and Maria, 2021; Holiner, 2013; Derr, 2009; Dyck, 2010; De Sousa, 2009); polyneuropathies (Choi and Maria, 2021; de Souza, 2015; Emeryk-Szajewska, 1998; Torvin Moller, 2009); plexopathy (Mullins, 2007); neuromuscular junction disorders (Meriggioli, 2005); myopathies including polymyositis, dermatomyositis, and congenital myopathies (Wang, 2010); motor neuron disease (Hammad, 2007); spine disorders and radiculopathy (Pawar, 2013; Alrawi, 2007; Haig, 2006); and guidance for botulinum toxin injection for spasmodic dysphonia or segmental dystonia, when it is difficult to isolate affected muscles (Molloy, 2002).

Karami-Mohajeri et al. (2014) presented a systematic review of the recent literature on the scientific support of EMG and NCV in diagnosing the exposure and toxicity of organophosphorus pesticides (OP). Specifically, this review focused on changes in EMG, NCV, occurrence of intermediate syndrome (IMS), and OP-induced delayed polyneuropathy (OPIDN) in human. All relevant bibliographic databases were searched for human studies using the key words "OP poisoning", "electromyography", "nerve conduction study," and "muscles disorders". Intermediate syndrome usually occurs after an acute cholinergic crisis, while OPIDN occurs after both acute and chronic exposures. Collection of these studies supported that IMS is a neuromuscular junction disorder and can be recorded upon the onset of respiratory failure. Due to heterogeneity of reports on outcomes of interest such as motor NCV and EMG amplitude in acute cases and inability to achieve precise estimation of effect in chronic cases meta-analysis was not helpful to this review. The OPIDN after both acute and low-level prolonged exposures develops peripheral neuropathy without preceding cholinergic toxicity and the progress of changes in EMG and NCV is parallel with the development of IMS and OPIDN. Persistent inhibition of acetylcholinesterase (AChE) is responsible for muscle weakness, but this is not the only factor involved in the incidence of this weakness in IMS or OPIDN suggestive of AChE assay not useful as an index of nerve and muscle impairment. The authors concluded that although several mechanisms for induction of this neurodegenerative disorder have been proposed, among them oxidative stress and resulting apoptosis can be emphasized. Nevertheless, they stated that there is little synchronized evidence on subclinical electrophysiological findings that limit these investigators to reach a strong conclusion on the diagnostic or prognostic use of EMG and NCV for acute and occupational exposures to OPs.

Asad et al. (2009) compared the nerve conduction studies in clinically undetectable and detectable sensorimotor polyneuropathy in type 2 diabetics. Diagnosed diabetics ($n$ = 60) were divided in two groups. Group 1 ($n$ 1 = 30) with clinically undetectable and group 2 ($n$ 2 = 30) with clinically detectable Diabetic Polyneuropathy. Detection of the sensorimotor neuropathy was done according to Diabetic Neuropathy Symptom Score and Diabetic Neuropathy Examination scores. The simplified nerve conduction studies protocol was followed in recording amplitudes, velocities and latencies of minimum two (Sural, Peroneal) and maximum six i.e., three sensory (Sural, Ulnar, Median) and three motor (Peroneal, Ulnar, Tibial) nerves. The comparisons were done between different parameters of nerve conduction studies with the neurological scores in undetectable and detectable groups using Pearson's chi square test. The amplitudes, velocities, latencies, outcome and grading of neuropathy in nerve conduction studies when compared with neurological detection scores showed a significant relation in each group regarding evaluation ($p = 0.005$, $p = 0.004$, $p = 0.05$, $p = 0.00001$, $p = 0.003$ respectively). Diabetic Neuropathy Symptom Score and Diabetic Neuropathy Examination Score together can help in prompt evaluation of the diabetic sensorimotor polyneuropathy though nerve conduction study is more powerful test and can help in diagnosing subclinical cases.

## Surface Electromyography (SEMG)

There is a wide variety of Surface Electromyography (SEMG) hardware and software that is used depending upon the specific clinical purpose intended. However, all SEMG hardware and software have in common the following:

- Electrical signals are measured from skeletal muscles.
- Sensing electrodes are placed on the skin overlying the muscle of interest.
- The electrical activity is measured when the muscle is active.
- SEMG records a narrow frequency of electrical activity (20-500 Hz).
- SEMG findings are based on computer analysis of either the frequency spectrum (spectral analysis), amplitude of signal, or root mean square of electrical action potentials.

### The Evaluation of Specific Neuromuscular Pathologies

The literature on the subject of SEMG use for neuromuscular disorders indicates that it is inferior in all parameters (sensitivity, specificity, spatial resolution, signal to noise ratio) to the invasive procedures such as needle electromyography (NEMG) or fine-wire electromyography (FWEMG) and thus cannot be used as a substitute for those procedures. Both systematic reviews of this subject explicitly reject SEMG for the diagnosis of neuromuscular disease.

The gold standard for this type of evaluation is either NEMG or FWEMG. Because these procedures are both invasive and painful, there is an obvious desire to find equally useful, but less onerous diagnostic tests. There are, however, several inherent limitations to the use of SEMG for the analysis of neuromuscular pathology. SEMG records input from a much wider spatial field than do either of the invasive procedures. Muscles adjacent to those of interest can produce signals that appear to originate from the target muscles (which are located immediately beneath the sensing electrodes). Thus, the specificity of SEMG findings is always in doubt. SEMG is also very susceptible to movement artifact. Even with the most careful procedural safeguards, small (and even imperceptible) body movements may produce spurious signals. There is a much poorer signal to noise ratio with SEMG. This is particularly a problem when target muscles are located more than 10 mm below the skin surface. Finally, the electrical activity that is recorded by SEMG is only of skeletal muscle origins. It is not possible to capture any electrical activity along motor neuron axons, as it is with NEMG or FWEMG.

### The Evaluation of Movement and Gait Disturbances

There are a variety of experimental applications such as studies of human movement, the study of nerve conduction velocities after electrical stimulation of peripheral nerves, etc., in which SEMG is considered standard. Because of its relative ease of use and non-invasive nature, SEMG is considered superior to NEMG and FWEMG for many of these applications. There are also thought to be advantages in using SEMG to evaluate/study movement disorders of CNS origins such as tremor, dystonia, dyskinesia, and myoclonus.

While it is thought that SEMG can accurately measure these disorders, it is less clear what the clinical utility of these measurements might be. This is the only application for which the American Medical Association (AMA) Current Procedural Terminology (CPT) coding committee has developed a procedure code.

**The Evaluation of Functional Back Pain**

There are a number of studies that have investigated the possibility that SEMG may differentiate between those with and those without back pain by evaluating muscle fatigue through "spectral shift". However, the findings are inconsistent and contradictory, the relationship between muscle fatigue and back pain is not established, and there may be unrelated factors affecting spectral shift.

The clinical context in which chiropractors are most likely to use SEMG is for the evaluation of functional low back pain and neck pain. There are two proposed mechanisms by which SEMG is thought to relate to back pain. First is the presumed relationship between muscle fatigue and back pain. The theory posits that excessive muscle fatigue, due to deconditioning, may result in back pain. Further, it has been shown that when muscles fatigue they produce a different set of electrical frequencies as measured by SEMG. This phenomenon has been dubbed the "spectral shift." Thus, it has been hypothesized that by using dynamic SEMG (recording muscle activity while exercising) it should be possible to differentiate those with back pain from those without back pain. There are a number of studies that have investigated this possibility, and some have had success in doing so. However, this success is tempered by several caveats. First, these findings are inconsistent and somewhat contradictory. Second, the exact nature of the relationship between muscle fatigue and back pain is uncertain. In fact, the direction of the relationship is uncertain—does muscle fatigue cause back pain or does back pain cause muscle fatigue? Third, it is unclear what other factors might cause a spectral shift making the specificity of such findings doubtful.

There is another mechanism by which it is proposed that SEMG can assist in the evaluation of back pain: the identification of hypertonic muscles. It is this mechanism that the leading chiropractic proponents of SEMG suggest is the most relevant to patient management. In effect, it is proposed that SEMG is a more objective and accurate tool than palpation in locating hypertonic muscles and thereby the identification of vertebral subluxations. The literature relative to this mechanism is even more limited and of much poorer quality than is the literature on muscle fatigue and SEMG. It is also speculated that the finding of SEMG asymmetry is an indication of spinal dysfunction. There is no literature that finds a relationship between back pain and such asymmetry and at least one study that casts doubt on this hypothesis. SEMG is not reliable for assessing spinal dysfunction or subluxation.

An analysis by Triano et al. (2013) examined the techniques and procedures used by chiropractors to identify the appropriate site for the application of spinal manipulation.

Consistent with previous reviews they found limited support for reliability of SEMG to identify cohorts of patients with abnormal neuromuscular control. However, the review concluded that there was no support for the use of SEMG to localize treatment to a specific site. Another area of research for SEMG is its use as a prognostic tool. Studies have looked at flexion and extension movements to determine the prognosis of the patient relative to their low back pain recovery. Hu et al. (2014) evaluated the prognostic value of quantitative SEMG topographic analysis and attempted to verify the accuracy of the performance of proposed time-varying topographic parameters for identifying the patients who have better response toward the rehabilitation program. Thirty-eight patients with chronic nonspecific LBP and 43 healthy subjects were included in the study. These patients suffered from chronic nonspecific LBP without the history of back surgery and any medical conditions causing acute exacerbation of LBP during the clinical test were enlisted to perform the clinical test during the 12-week physiotherapy (PT) treatment. Low back pain patients were classified into two groups: "responding" and "nonresponding" based on the clinical assessment. The responding group referred to the LBP patients who began to recover after the PT treatment, whereas the nonresponding group referred to some LBP patients who did not recover or got worse after the treatment. The quantitative time-varying analysis of SEMG topography showed significant difference between the healthy and LBP groups. The discrepancies in quantitative dynamic SEMG topography of LBP group from normal group, were able to identify those LBP subjects who would respond to a conservative rehabilitation program focused on functional restoration of lumbar muscle. More research is needed to confirm results and evaluate its utility clinically.

In assessing the appropriateness of SEMG for functional back pain, there are three levels of analysis to consider that remain pertinent:

1. **Technical performance of the instrument**. To what extent does the instrument accurately measure what it purports to measure (e.g., muscle fatigue, muscle spasm)? The above discussion regarding neuromuscular disorders identifies several inherent limitations in the technical performance of SEMG. All of those limitations (with the exception of the inability to measure axonal signals) are relevant to this issue as well. The lack of specificity, poor signal to noise ratio, and the problem of movement artifacts will all limit the accuracy and validity of SEMG for the evaluation of functional back pain.

2. **Whether and how the instrument findings can be used in patient management.** The use of SEMG as a “subluxation detector” that can help identify specific levels of spinal dysfunction has not been substantiated and is entirely speculative.

   If it has been determined that it is possible to identify hypo- or hypertonic muscles through the use of SEMG (keeping in mind the inherent technical limitations affecting specificity, accuracy, and validity), the question becomes how this information will be used in the management of the patient. To date, the only clinical

correlation that has been established is that there *may* be differences between subjects with back pain and control subjects in their muscle fatigability as measured by SEMG. In other words, it may be possible to differentiate those with and without back pain using SEMG. But as one of the systematic reviews points out, the gold standard for the presence or absence of back pain is the clinical history, and it is far easier and more reliable to simply ask the person whether he or she has back pain. While potentially, it might be possible to use SEMG to identify malingerers, the procedure is currently far too unreliable to permit any such determination to be predicated on SEMG findings. In addition, several established malingering tests are available as taught within standard orthopedic examination courses in chiropractic, osteopathic, and medical schools.

3. **Whether the use of an instrument results in better clinical outcomes.** There is no evidence (and very little theory) to indicate how specific SEMG findings should be used to manage individuals with back pain in order to produce better clinical outcomes.

   Ultimately what matters is whether or not the use of SEMG results in better clinical outcomes than does the management of back pain without the use of SEMG information. There have been no clinical trials that have addressed this question. In fact, there are no clinical trials of back pain that have used SEMG in any aspect of the diagnosis of subjects, in measuring outcomes of treatment, or otherwise evaluating the effectiveness of the therapeutic intervention (e.g., chiropractic treatment).

***PRACTITIONER SCOPE AND TRAINING***

Practitioners should practice only in the areas in which they are competent based on their education, training, and experience. Levels of education, experience, and proficiency may vary among individual practitioners. It is ethically and legally incumbent on a practitioner to determine where they have the knowledge and skills necessary to perform such services and whether the services are within their scope of practice.

It is best practice for the practitioner to appropriately render services to a member only if they are trained, equally skilled, and adequately competent to deliver a service compared to others trained to perform the same procedure. If the service would be most competently delivered by another health care practitioner who has more skill and training, it would be best practice to refer the member to the more expert practitioner.

Best practice can be defined as a clinical, scientific, or professional technique, method, or process that is typically evidence-based and consensus driven and is recognized by a majority of professionals in a particular field as more effective at delivering a particular

outcome than any other practice (Joint Commission International Accreditation Standards for Hospitals, 2020).

Depending on the practitioner's scope of practice, training, and experience, a member's condition and/or symptoms during examination or the course of treatment may indicate the need for referral to another practitioner or even emergency care. In such cases it is prudent for the practitioner to refer the member for appropriate co-management (e.g., to their primary care physician) or if immediate emergency care is warranted, to contact 911 as appropriate. See the *Managing Medical Emergencies (CPG 159 – S)* clinical practice guideline for information.

***References***

AANEM. AANEM's top five choosing wisely recommendations. Muscle Nerve. 2015;51(4):617-619. doi:10.1002/mus.24628

Ahern DK, Follick MJ, Council JR, Laser-Wolston N. Reliability of lumbar paravertebral EMG assessment in chronic low back pain. Arch Phys Med Rehabil. 1986;67(10):762-765. doi:10.1016/0003-9993(86)90014-6

Ahern DK, Follick MJ, Council JR, Laser-Wolston N, Litchman H. Comparison of lumbar paravertebral EMG patterns in chronic low back pain patients and non-patient controls. Pain. 1988;34(2):153-160. doi:10.1016/0304-3959(88)90160-1

Alemo S, Sayadipour A. Role of intraoperative neurophysiologic monitoring in lumbosacral spine fusion and instrumentation: a retrospective study. World Neurosurg. 2010;73(1):72-e7. doi:10.1016/j.surneu.2009.04.024

Alexiev AR. Some differences of the electromyographic erector spinae activity between normal subjects and low back pain patients during the generation of isometric trunk torque. Electromyogr Clin Neurophysiol. 1994;34(8):495-499

Alrawi MF, Khalil NM, Mitchell P, Hughes SP. The value of neurophysiological and imaging studies in predicting outcome in the surgical treatment of cervical radiculopathy. Eur Spine J. 2007;16(4):495-500. doi:10.1007/s00586-006-0189-6

Al-Shekhlee A, Shapiro BE, Preston DC. Iatrogenic complications and risks of nerve conduction studies and needle electromyography. Muscle Nerve. 2003;27(5):517-526. doi:10.1002/mus.10315

Ambroz C, Scott A, Ambroz A, Talbott EO. Chronic low back pain assessment using surface electromyography. J Occup Environ Med. 2000;42(6):660-669. doi:10.1097/00043764-200006000-00018

American Academy of Neurology (AAN). Position statement. Mobile electrodiagnostic laboratories provide substandard patient care. 2015. Updated and reapproved August 2020. Retrieved on July 4, 2024 from https://www.aanem.org/clinical-practice-resources/position-statements/position-statement/mobile-electrodiagnostic-laboratories-provide-substandard-patient-care

American Academy of Neurology (AAN). Principles of coding for intraoperative neurophysiologic monitoring (IOM) and testing model medical policy. 2012. Retrieved on July 4, 2024 from https://www.aan.com/siteassets/home-page/tools-and-resources/practicing-neurologist--administrators/billing-and-coding/model-coverage-policies/16iommodelpolicy_tr.pdf

American Association of Neuromuscular and Electrodiagnostic Medicine (AANEM). Definition of real time onsite. Position Statement. July 2014. Retrieved on July 4, 2024 from https://www.aanem.org/clinical-practice-resources/position-statements/position-statement/definition-of-real-time-onsite

American Association of Neuromuscular and Electrodiagnostic Medicine (AANEM). Model Policy for Nerve Conduction Studies and Needle Electromyography 2016. Retrieved on July 4, 2024 from https://www.aanem.org/clinical-practice-resources/position-statements/position-statement/model-policy-for-nerve-conduction-studies-and-needle-electromyography

American Association of Neuromuscular & Electrodiagnostic Medicine. Needle EMG in certain uncommon clinical contexts. Muscle Nerve. 2005;31(3):398-399. doi:10.1002/mus.20238

American Association of Neuromuscular and Electrodiagnostic Medicine (AANEM). Position Statement. Reporting the results of needle EMG and nerve conduction studies: and educational report. May 2014. Updated and reapproved July 2018. Retrieved on July 4, 2024 from: https://www.aanem.org/clinical-practice-resources/position-statements/position-statement/reporting-the-results-of-nerve-conduction-studies-and-needle-emg

American Association of Neuromuscular and Electrodiagnostic Medicine (AANEM). Position Statement. Technologist Performance Of Nerve Conduction Studies And Somatosensory Evoked Potentials Under Direct Edx Physician Supervision. Approved by the American Association of Electrodiagnostic Medicine May 1999b. Modified and approved August 2020. Retrieved on July 4, 2024 from https://www.aanem.org/docs/default-source/documents/aanem/advocacy/technologists-conducing-ncs_sep_2020.pdf?sfvrsn=132d3dd3_3

American Association of Neuromuscular and Electrodiagnostic Medicine (AANEM). Practice parameter for Repetitive Nerve Stimulation & Single Fiber EMG Evaluation of Adults w/Suspected Myasthenia Gravis. Reaffirmed October 2015. Retrieved on July 4, 2024 from https://www.aanem.org/clinical-practice-resources/guidelines/guideline/practice-parameter-for-rns-and-single-fiber-emg-eval-of-adults-with-suspected-mg

American Association of Neuromuscular and Electrodiagnostic Medicine (AANEM). Proper performance and interpretation of electrodiagnostic studies. Muscle Nerve. 2006 Mar;33(3):436-9. Reviewed and updated Jan 2020. Retrieved on July 4, 2024 from https://www.aanem.org/clinical-practice-resources/position-statements/position-statement/proper-performance-and-interpretation-of-electrodiagnostic-studies

American Association of Neuromuscular and Electrodiagnostic Medicine (AANEM). (2020). Risks in electrodiagnostic medicine. Retrieved on July 4, 2024 from https://www.aanem.org/clinical-practice-resources/position-statements/position-statement/risks-in-electrodiagnostic-medicine

American Association of Neuromuscular and Electrodiagnostic Medicine (AANEM). Somatosensory evoked potentials. Clinical uses. Chapter 5. Muscle Nerve 22: Supplement 8: S111-S118, 1999a. Retrieved on July 4, 2024 from https://www.aanem.org/clinical-practice-resources/guidelines/guideline/somatosensory-evoked-potentials-clinical-uses

American Association of Neuromuscular and Electrodiagnostic Medicine (AANEM). Who is qualified to practice electrodiagnostic medicine. Position statement. Updated and Re-approved: May 2012; November 2017, April 2024, Retrieved on July 4, 2024 from https://www.aanem.org/clinical-practice-resources/position-statements/position-statement/who-is-qualified-to-practice-electrodiagnostic-medicine

American Association of Neuromuscular and Electrodiagnostic Medicine (AANEM). Model Policy for Nerve Conduction Studies and Needle Electromyography. Updated and reapproved Dec 2022. Retrieved on July 4, 2024 from https://www.aanem.org/clinical-practice-resources/position-statements/position-statement/model-policy-for-nerve-conduction-studies-and-needle-electromyography

American Clinical Neurophysiology Society (ACNS). Guidelines for short latency somatosensory evoked potentials. Feb 10, 2006. Retrieved on July 4, 2024 from https://www.acns.org/practice/guidelines

American Medical Association. (current year) Current Procedural Terminology (CPT) Current year (rev. ed.), Chicago: AMA.

American Society of Electroneurodiagnostic Technologists (ASET). National competency skill standards for performing Intraoperative neurophysiologic monitoring. Retrieved on July 4, 2024 from https://www.aset.org/wp-content/uploads/2022/01/IONM_National_Competency_Skill_Standards_Approved_2011.pdf

American Society of Neurophysiological Monitoring (ASNM). Intraoperative monitoring using somatosensory evoked potentials. A position statement by the American Society of Neurophysiological Monitoring. J Clin Monit Comput. 2005 Jun;241-58 (18).

American Speech-Language-Hearing Association. Neurophysiologic Intraoperative Monitoring. Position Statement. Copyright©2013 American Language-Speech-Hearing Association. Retrieved on July 4, 2024 from http://www.asha.org/policy/PS1992-00036/

Aminoff MJ, Eisen A. Somatosensory Evoked Potentials. In: Aminoff's Electrodiagnosis in Clinical Neurology. Ch 26. Sixth Edition © 2012, Elsevier Inc.

Aminoff MJ. Electrophysiologic testing for the diagnosis of peripheral nerve injuries. Anesthesiology. 2004;100(5):1298-1303. doi:10.1097/00000542-200405000-00034

Armstrong TN, Dale AM, Al-Lozi MT, Franzblau A, Evanoff BA. Median and ulnar nerve conduction studies at the wrist: criterion validity of the NC-stat automated device. J Occup Environ Med. 2008;50(7):758-764. doi:10.1097/JOM.0b013e3181645425

Asad A, Hameed MA, Khan UA, Butt MU, Ahmed N, Nadeem A. Comparison of nerve conduction studies with diabetic neuropathy symptom score and diabetic neuropathy examination score in type-2 diabetics for detection of sensorimotor polyneuropathy. J Pak Med Assoc. 2009;59(9):594-598

Asbury AK. Approach to the patient with peripheral neuropathy. In: Harrison's Principles of Internal Medicine. Part 15: Neurologic disorders. Section 3: Nerve and muscle disorders. Chapter 363. Electrodiagnosis. Copyright 2004 by The McGraw-Hill Companies, Inc.

Assessment: dermatomal somatosensory evoked potentials. Report of the American Academy of Neurology's Therapeutics and Technology Assessments Subcommittee. Neurology. 1997;49(4):1127-1130

Assessment: intraoperative neurophysiology. Report of the Therapeutics and Technology Assessment Subcommittee of the American Academy of Neurology. Neurology. 1990;40(11):1644-1646

Bal S, Celiker R, Palaoglu S, Cila A. F wave studies of neurogenic intermittent claudication in lumbar spinal stenosis. Am J Phys Med Rehabil. 2006;85(2):135-140. doi:10.1097/01.phm.0000197586.91860.a1

Barboi AC, Barkhaus PE. Electrodiagnostic testing in neuromuscular disorders. Neurol Clin. 2004;22(3):619-vi. doi:10.1016/j.ncl.2004.03.007

Biedermann HJ, Shanks GL, Forrest WJ, Inglis J. Power spectrum analyses of electromyographic activity. Discriminators in the differential assessment of patients with chronic low-back pain. Spine (Phila Pa 1976). 1991;16(10):1179-1184

Bollu, PC. Single-fiber EMG. eMedicine Specialties. Neurology. Electromyography and Nerve Conduction Studies. Updated March 2019. Retrieved on July 4, 2024 from http://www.emedicine.com/neuro/topic343.htm

Bose B, Wierzbowski LR, Sestokas AK. Neurophysiologic monitoring of spinal nerve root function during instrumented posterior lumbar spine surgery. Spine (Phila Pa 1976). 2002;27(13):1444-1450. doi:10.1097/00007632-200207010-00014

Braunwald: Harrison's Principles of Internal Medicine. Electrophysiology studies of muscle and nerve: Electrophysiologic studies of the central and peripheral nervous systems. ©2001, The McGraw-Hill Companies, Inc. Chapter 357

Calfee RP, Dale AM, Ryan D, Descatha A, Franzblau A, Evanoff B. Performance of simplified scoring systems for hand diagrams in carpal tunnel syndrome screening. J Hand Surg Am. 2012;37(1):10-17. doi:10.1016/j.jhsa.2011.08.016

Centers for Medicare and Medicaid Services (CMS). Local Coverage Determination (LCD): NERVE CONDUCTION Studies and Electromyography (L36526). Retrieved on July 4, 2024 from https://www.cms.gov/medicare-coverage-database/view/lcd.aspx?lcdid=36526&ver=32&SearchType=Advanced&CoverageSelection=Both&NCSelection=NCA%7cCAL%7cNCD%7cMEDCAC%7cTA%7cMCD&ArticleType=Ed%7cKey%7cSAD%7cFAQ&PolicyType=Final&s=%26mdash%3b

Chang MH, Liu LH, Lee YC, Wei SJ, Chiang HL, Hsieh PF. Comparison of sensitivity of transcarpal median motor conduction velocity and conventional conduction techniques in electrodiagnosis of carpal tunnel syndrome. Clin Neurophysiol. 2006;117(5):984-991. doi:10.1016/j.clinph.2006.01.015

Chawla J, Burneo JG, Barkley GL. Clinical Applications of Somatosensory Evoked Potentials. Medscape. Updated Aug 2019. Retrieved on July 4, 2024 from http://emedicine.medscape.com/article/1139393-overview#showall

Chiappa K. Electrophysiologic monitoring during carotid endarterecteomies. In: Chiappa K, editor. Evoked potentials in clinical medicine. Third edition. ©1997. Lippincott-Raven Publishers. Philadelphia –New York. Ch. 19

Chiappa K, Cros D. Dermatomal somatosensory evoked potentials. In: Chiappa K, editor. Evoked potentials in clinical medicine. Third edition. ©1997. Lippincott-Raven Publishers. Philadelphia –New York. Ch. 12

Cho SC, Ferrante MA, Levin KH, Harmon RL, So YT. Utility of electrodiagnostic testing in evaluating patients with lumbosacral radiculopathy: An evidence-based review. Muscle Nerve. 2010;42(2):276-282. doi:10.1002/mus.21759

Choi JM, Di Maria G. Electrodiagnostic Testing for Disorders of Peripheral Nerves. Clin Geriatr Med. 2021;37(2):209-221. doi:10.1016/j.cger.2021.01.010

Collins GA, Cohen MJ, Naliboff BD, Schandler SL. Comparative analysis of paraspinal and frontalis EMG, heart rate and skin conductance in chronic low back pain patients and normals to various postures and stress. Scand J Rehabil Med. 1982;14(1):39-46

Cruccu G, Aminoff MJ, Curio G, et al. Recommendations for the clinical use of somatosensory-evoked potentials. Clin Neurophysiol. 2008;119(8):1705-1719. doi:10.1016/j.clinph.2008.03.016

Crum BA, Strommen JA. Peripheral nerve stimulation and monitoring during operative procedures. Muscle Nerve. 2007;35(2):159-170. doi:10.1002/mus.20707

Dale AM, Agboola F, Yun A, Zeringue A, Al-Lozi MT, Evanoff B. Comparison of automated versus traditional nerve conduction study methods for median nerve testing in a general worker population. PM R. 2015;7(3):276-282. doi:10.1016/j.pmrj.2014.10.003

Danneels LA, Cagnie BJ, Cools AM, et al. Intra-operator and inter-operator reliability of surface electromyography in the clinical evaluation of back muscles. Man Ther. 2001;6(3):145-153. doi:10.1054/math.2001.0396

DeGood DE, Stewart WR, Adams LE, Dale JA. Paraspinal EMG and autonomic reactivity of patients with back pain and controls to personally relevant stress. Percept Mot Skills. 1994;79(3 Pt 1):1399-1409. doi:10.2466/pms.1994.79.3.1399

Derr JJ, Micklesen PJ, Robinson LR. Predicting recovery after fibular nerve injury: which electrodiagnostic features are most useful?. Am J Phys Med Rehabil. 2009;88(7):547-553. doi:10.1097/PHM.0b013e3181a9f519

De Sousa EA, Chin RL, Sander HW, Latov N, Brannagan TH 3rd. Demyelinating findings in typical and atypical chronic inflammatory demyelinating polyneuropathy: sensitivity and specificity. J Clin Neuromuscul Dis. 2009;10(4):163-169. doi:10.1097/CND.0b013e31819a71e1

de Souza RJ, de Souza A, Nagvekar MD. Nerve conduction studies in diabetics presymptomatic and symptomatic for diabetic polyneuropathy. J Diabetes Complications. 2015;29(6):811-817. doi:10.1016/j.jdiacomp.2015.05.009

Devlin VJ, Schwartz DM. Intraoperative neurophysiologic monitoring during spinal surgery. J Am Acad Orthop Surg. 2007;15(9):549-560. doi:10.5435/00124635-200709000-00005

Drost G, Stegeman DF, van Engelen BG, Zwarts MJ. Clinical applications of high-density surface EMG: a systematic review. J Electromyogr Kinesiol. 2006;16(6):586-602. doi:10.1016/j.jelekin.2006.09.005

Dyck PJ, Overland CJ, Low PA, et al. Signs and symptoms versus nerve conduction studies to diagnose diabetic sensorimotor polyneuropathy: Cl vs. NPhys trial. Muscle Nerve. 2010;42(2):157-164. doi:10.1002/mus.21661

Eager M, Shimer A, Jahangiri FR, Shen F, Arlet V. Intraoperative neurophysiological monitoring (IONM): lessons learned from 32 case events in 2069 spine cases. Am J Electroneurodiagnostic Technol. 2011;51(4):247-263

Edwards BM, Kileny PR. Intraoperative neurophysiologic monitoring: indications and techniques for common procedures in otolaryngology-head and neck surgery. Otolaryngol Clin North Am. 2005;38(4):631-viii. doi:10.1016/j.otc.2005.03.002

Eisen and Fischer. The F Wave. Recommendations for the Practice of Clinical Neurophysiology: Guidelines of the International Federation of Clinical Physiology (EEG Suppl. 52) Editors: G. Deuschl and A. Eisen, 1999

Elkowitz SJ, Dubin NH, Richards BE, Wilgis EF. Clinical utility of portable versus traditional electrodiagnostic testing for diagnosing, evaluating, and treating carpal tunnel syndrome. Am J Orthop (Belle Mead NJ). 2005;34(8):362-364.

Emerson RG, Adams DC, Nagle KJ. Monitoring of spinal cord function intraoperatively using motor and somatosensory evoked potentials. In: Chiappa K, editor. Evoked potentials in clinical medicine. Third edition. ©1997. Lippincott-Raven Publishers. Philadelphia –New York. Ch 20

Emeryk-Szajewska B, Badurska B, Kostera-Pruszczyk A. Electrophysiological findings in hereditary motor and sensory neuropathy type I and II--a conduction velocity study. Electromyogr Clin Neurophysiol. 1998;38(2):95-101

England JD, Franklin GM. Automated hand-held nerve conduction devices: raw data, raw interpretations. Muscle Nerve. 2011;43(1):6-8. doi:10.1002/mus.21960

Erickson L, Costa V, McGregor M. Intraoperative neurophysiological monitoring during spinal surgery. Montreal: Technology Assessment Unit of the McGill University Health Centre (MUHC), 2005:39

Fehlings MG, Brodke DS, Norvell DC, Dettori JR. The evidence for intraoperative neurophysiological monitoring in spine surgery: does it make a difference?. Spine (Phila Pa 1976). 2010;35(9 Suppl):S37-S46. doi:10.1097/BRS.0b013e3181d8338e

Ferdjallah M, Wertsch JJ. Anatomical and technical considerations in surface electromyography. Phys Med Rehabil Clin N Am. 1998;9(4):925-931

Fisher MA. H reflexes and F waves. Fundamentals, normal and abnormal patterns. Neurol Clin. 2002;20(2):339-vi. doi:10.1016/s0733-8619(01)00004-4

Fisher MA, Bajwa R, Somashekar KN. Routine electrodiagnosis and a multiparameter technique in lumbosacral radiculopathies. Acta Neurol Scand. 2008;118(2):99-105. doi:10.1111/j.1600-0404.2007.00987.x

Geisser ME, Ranavaya M, Haig AJ, et al. A meta-analytic review of surface electromyography among persons with low back pain and normal, healthy controls. J Pain. 2005;6(11):711-726. doi:10.1016/j.jpain.2005.06.008

Gooch CL, Pullman S. Electromyography, nerve conduction studies, and magnetic stimulation. In: Rowland PL, editor. Merritt's Neurology. 11th edition. Lippincott Williams and Wilkins. Ch 15

Gooch CL, Weimer LH. The electrodiagnosis of neuropathy: basic principles and common pitfalls. Neurol Clin. 2007;25(1):1-28. doi:10.1016/j.ncl.2007.01.011

Grassme R, Arnold D, Anders Ch, et al. Improved evaluation of back muscle SEMG characteristics by modelling. Pathophysiology. 2005;12(4):307-312. doi:10.1016/j.pathophys.2005.09.011

Gunnarsson T, Krassioukov AV, Sarjeant R, Fehlings MG. Real-time continuous intraoperative electromyographic and somatosensory evoked potential recordings in spinal surgery: correlation of clinical and electrophysiologic findings in a prospective, consecutive series of 213 cases. Spine (Phila Pa 1976). 2004;29(6):677-684. doi:10.1097/01.brs.0000115144.30607.e9

Guse BH, Love MJ. Medical assessment and laboratory testing in psychiatry. In: Saydock BJ, Saydock VA, editors. Kaplan and Saydock's Comprehensive Textbook of Psychiatry. 8th ed, 2005. p. 919.

Haig AJ, Gelblum JB, Rechtien JJ, Gitter AJ. Technology assessment: the use of surface EMG in the diagnosis and treatment of nerve and muscle disorders. Muscle Nerve. 1996;19(3):392-395. doi:10.1002/(SICI)1097-4598(199603)19:3<392::AID-MUS21>3.0.CO;2-T

Haig AJ, Tong HC, Yamakawa KS, et al. Spinal stenosis, back pain, or no symptoms at all? A masked study comparing radiologic and electrodiagnostic diagnoses to the clinical impression. Arch Phys Med Rehabil. 2006;87(7):897-903. doi:10.1016/j.apmr.2006.03.016

Hammad M, Silva A, Glass J, Sladky JT, Benatar M. Clinical, electrophysiologic, and pathologic evidence for sensory abnormalities in ALS. Neurology. 2007;69(24):2236-2242. doi:10.1212/01.wnl.0000286948.99150.16

Heinonen P, Kautiainen H, Mikkelsson M. Erector spinae SEMG activity during forward flexion and re-extension in ankylosing spondylitis patients. Pathophysiology. 2005;12(4):289-293. doi:10.1016/j.pathophys.2005.09.010

Hilburn JW. General principles and use of electrodiagnostic studies in carpal and cubital tunnel syndromes. With special, attention to pitfalls and interpretation. Hand Clin. 1996;12(2):205-221.

Hogrel JY. Clinical applications of surface electromyography in neuromuscular disorders. Neurophysiol Clin. 2005;35(2-3):59-71. doi:10.1016/j.neucli.2005.03.001

Höliner I, Haslinger V, Lütschg J, et al. Validity of the neurological examination in diagnosing diabetic peripheral neuropathy. Pediatr Neurol. 2013;49(3):171-177. doi:10.1016/j.pediatrneurol.2013.03.014

Holland NR. Intraoperative electromyography. J Clin Neurophysiol. 2002;19(5):444-453. doi:10.1097/00004691-200210000-00007

Hu Y, Kwok JW, Tse JY, Luk KD. Time-varying surface electromyography topography as a prognostic tool for chronic low back pain rehabilitation. Spine J. 2014;14(6):1049-1056. doi:10.1016/j.spinee.2013.11.060

Jablecki CK, Andary MT, Floeter MK, et al. Practice parameter: Electrodiagnostic studies in carpal tunnel syndrome. Report of the American Association of Electrodiagnostic Medicine, American Academy of Neurology, and the American Academy of Physical Medicine and Rehabilitation (Retired). Neurology. 2002;58(11):1589-1592. doi:10.1212/wnl.58.11.1589

Jabre JF, Salzsieder BT, Gnemi KE. Criterion validity of the NC-stat automated nerve conduction measurement instrument. Physiol Meas. 2007;28(1):95-104. doi:10.1088/0967-3334/28/1/009

Jalovaara P, Niinimäki T, Vanharanta H. Pocket-size, portable surface EMG device in the differentiation of low back pain patients. Eur Spine J. 1995;4(4):210-212. doi:10.1007/BF00303412

Jameson LC, Janik DJ, Sloan TB. Electrophysiologic monitoring in neurosurgery. Anesthesiol Clin. 2007;25(3):605-x. doi:10.1016/j.anclin.2007.05.004

Juel VC. Evaluation of neuromuscular junction disorders in the electromyography laboratory. Neurol Clin. 2012;30(2):621-639. doi:10.1016/j.ncl.2011.12.012

Jurell KC. Surface EMG and fatigue. Phys Med Rehabil Clin N Am. 1998;9(4):933-ix

Karami-Mohajeri S, Nikfar S, Abdollahi M. A systematic review on the nerve-muscle electrophysiology in human organophosphorus pesticide exposure. Hum Exp Toxicol. 2014;33(1):92-102. doi:10.1177/0960327113489047

Katifi HA, Sedgwick EM. Evaluation of the dermatomal somatosensory evoked potential in the diagnosis of lumbo-sacral root compression. J Neurol Neurosurg Psychiatry. 1987;50(9):1204-1210. doi:10.1136/jnnp.50.9.1204

Katirji B. The clinical electromyography examination. An overview. Neurol Clin. 2002;20(2):291-v. doi:10.1016/s0733-8619(01)00002-0

Katz JN, Simmons BP. Clinical practice. Carpal tunnel syndrome. N Engl J Med. 2002;346(23):1807-1812. doi:10.1056/NEJMcp013018

Katz RT. NC-stat as a screening tool for carpal tunnel syndrome in industrial workers. J Occup Environ Med. 2006;48(4):414-418. doi:10.1097/01.jom.0000194151.30385.1a

Kaufman MA. Differential diagnosis and pitfalls in electrodiagnostic studies and special tests for diagnosing compressive neuropathies. Orthop Clin North Am. 1996;27(2):245-252

Kelleher MO, Tan G, Sarjeant R, Fehlings MG. Predictive value of intraoperative neurophysiological monitoring during cervical spine surgery: a prospective analysis of 1055 consecutive patients. J Neurosurg Spine. 2008;8(3):215-221. doi:10.3171/SPI/2008/8/3/215

Khan MH, Smith PN, Balzer JR, et al. Intraoperative somatosensory evoked potential monitoring during cervical spine corpectomy surgery: experience with 508 cases. Spine (Phila Pa 1976). 2006;31(4):E105-E113. doi:10.1097/01.brs.0000200163.71909.1f

Kong X, Gozani SN, Hayes MT, Weinberg DH. NC-stat sensory nerve conduction studies in the median and ulnar nerves of symptomatic patients. Clin Neurophysiol. 2006;117(2):405-413. doi:10.1016/j.clinph.2005.10.019

Kong X, Lesser EA, Megerian JT, Gozani SN. Repeatability of nerve conduction measurements using automation. J Clin Monit Comput. 2006;20(6):405-410. doi:10.1007/s10877-006-9046-8

Kostera-Pruszczyk A, Rowińska-Marcińska K, Owsiak S, Jezierski P, & Emeryk-Szajewska B. Amplituda fali F w uszkodzeniach obwodowego układu nerwowego [F-wave amplitude in peripheral nervous system lesions]. Neurologia i neurochirurgia polska. 2004;38(6):465–470

Kraft GH. Dermatomal somatosensory-evoked potentials in the evaluation of lumbosacral spinal stenosis. Phys Med Rehabil Clin N Am. 2003;14(1):71-75. doi:10.1016/s1047-9651(02)00080-3

Krassioukov AV, Sarjeant R, Arkia H, Fehlings MG. Multimodality intraoperative monitoring during complex lumbosacral procedures: indications, techniques, and long-term follow-up review of 61 consecutive cases. J Neurosurg Spine. 2004;1(3):243-253. doi:10.3171/spi.2004.1.3.0243

Krivickas LS. Electrodiagnosis in neuromuscular disease. Phys Med Rehabil Clin N Am. 1998;9(1):83-vi

Kwon BC, Jung KI, Baek GH. Comparison of sonography and electrodiagnostic testing in the diagnosis of carpal tunnel syndrome. J Hand Surg Am. 2008;33(1):65-71. doi:10.1016/j.jhsa.2007.10.014

Lall RR, Lall RR, Hauptman JS, et al. Intraoperative neurophysiological monitoring in spine surgery: indications, efficacy, and role of the preoperative checklist. Neurosurg Focus. 2012;33(5):E10. doi:10.3171/2012.9.FOCUS12235

Lange DJ, Trojaborg W. Electromyography and nerve conduction studies in neuromuscular disease. In: Merritt's Neurology. Chapter 15. Copyright 2000 by Lippincott Williams & Wilkins

Larivière C, Arsenault AB, Gravel D, Gagnon D, Loisel P. Evaluation of measurement strategies to increase the reliability of EMG indices to assess back muscle fatigue and recovery. J Electromyogr Kinesiol. 2002;12(2):91-102. doi:10.1016/s1050-6411(02)00011-1

Larivière C, Gagnon D, Loisel P. The comparison of trunk muscles EMG activation between subjects with and without chronic low back pain during flexion-extension and lateral bending tasks. J Electromyogr Kinesiol. 2000;10(2):79-91. doi:10.1016/s1050-6411(99)00027-9

Leffler CT, Gozani SN, Cros D. Median neuropathy at the wrist: diagnostic utility of clinical findings and an automated electrodiagnostic device. J Occup Environ Med. 2000;42(4):398-409. doi:10.1097/00043764-200004000-00015

Legatt AD. General Principles of Somatosensory Evoked Potentials: MedScape. Updated Feb 2019. Retrieved on July 4, 2024 from http://emedicine.medscape.com/article/1139906-overview

Lehman GJ, McGill SM. The importance of normalization in the interpretation of surface electromyography: a proof of principle. J Manipulative Physiol Ther. 1999;22(7):444-446. doi:10.1016/s0161-4754(99)70032-1

Lehman RM. A review of neurophysiological testing. Neurosurg Focus. 2004;16(4):ECP1. Published 2004 Apr 15. doi:10.3171/foc.2004.16.4.14

Lesser EA, Starr J, Kong X, Megerian JT, Gozani SN. Point-of-service nerve conduction studies: an example of industry-driven disruptive innovation in health care. Perspect Biol Med. 2007;50(1):40-53. doi:10.1353/pbm.2007.0007

Linden RD, Zappulla R, Shileds CB. Intraoperative evoked potential monitoring. In: Chiappa K, editor. Evoked potentials in clinical medicine. Third edition. ©1997. Lippincott-Raven Publishers. Philadelphia – New York. Ch. 18

Liu X, Aziz TZ, Bain PG. Intraoperative monitoring of motor symptoms using surface electromyography during stereotactic surgery for movement disorders. J Clin Neurophysiol. 2005;22(3):183-191

Lofland KR, Cassisi JE, Levin JB, Palumbo NL, Blonsky ER. The incremental validity of lumbar surface EMG, behavioral observation, and a symptom checklist in the assessment of patients with chronic low-back pain. Appl Psychophysiol Biofeedback. 2000;25(2):67-78. doi:10.1023/a:1009589524042

Maccabee PJ, Eberle LP, Stein IA, et al. Upper leg conduction time distinguishes demyelinating neuropathies. Muscle Nerve. 2011;43(4):518-530. doi:10.1002/mus.21909

Mahla ME, Black S, Cucchiara RF. Intraoperative monitoring of sensory evoked potentials. In: Miller RD, editor. Miller's Anesthesia, 6th ed. Ch 38. Neurologic monitoring. Copyright © 2005. Churchill Livingstone

Malhotra NR, Shaffrey CI. Intraoperative electrophysiological monitoring in spine surgery. Spine (Phila Pa 1976). 2010;35(25):2167-2179. doi:10.1097/BRS.0b013e3181f6f0d0

Marciniak C, Armon C, Wilson J, Miller R. Practice parameter: utility of electrodiagnostic techniques in evaluating patients with suspected peroneal neuropathy: an evidence-based review. Muscle Nerve. 2005;31(4):520-527. doi:10.1002/mus.20308

Meekins GD, So Y, Quan D. American Association of Neuromuscular & Electrodiagnostic Medicine evidenced-based review: use of surface electromyography in the diagnosis and study of neuromuscular disorders. Muscle Nerve. 2008;38(4):1219-1224. doi:10.1002/mus.21055

Megerian JT, Kong X, Gozani SN. Utility of nerve conduction studies for carpal tunnel syndrome by family medicine, primary care, and internal medicine physicians. J Am Board Fam Med. 2007;20(1):60-64. doi:10.3122/jabfm.2007.01.060111

Mendell JR, Sahenk Z. Clinical practice. Painful sensory neuropathy. N Engl J Med. 2003;348(13):1243-1255. doi:10.1056/NEJMcp022282

Meriggioli MN, Sanders DB. Advances in the diagnosis of neuromuscular junction disorders. Am J Phys Med Rehabil. 2005;84(8):627-638. doi:10.1097/01.phm.0000171169.79816.4c

Mesrati F, Vecchierini MF. F-waves: neurophysiology and clinical value. Neurophysiol Clin. 2004;34(5):217-243. doi:10.1016/j.neucli.2004.09.005

Mohseni Bandpei MA, Rahmani N, Majdoleslam B, Abdollahi I, Ali SS, Ahmad A. Reliability of surface electromyography in the assessment of paraspinal muscle fatigue: an updated systematic review. J Manipulative Physiol Ther. 2014;37(7):510-521. doi:10.1016/j.jmpt.2014.05.006

Molloy FM, Shill HA, Kaelin-Lang A, Karp BI. Accuracy of muscle localization without EMG: implications for treatment of limb dystonia. Neurology. 2002;58(5):805-807. doi:10.1212/wnl.58.5.805

Mondelli M, Aretini A, Arrigucci U, Ginanneschi F, Greco G, Sicurelli F. Clinical findings and electrodiagnostic testing in 108 consecutive cases of lumbosacral radiculopathy due to herniated disc. Neurophysiol Clin. 2013;43(4):205-215. doi:10.1016/j.neucli.2013.05.004

Mullins GM, O'Sullivan SS, Neligan A, et al. Non-traumatic brachial plexopathies, clinical, radiological and neurophysiological findings from a tertiary centre. Clin Neurol Neurosurg. 2007;109(8):661-666. doi:10.1016/j.clineuro.2007.05.010

NeuMed®, Inc. Brevio® Nerve Conduction Monitoring System. Retrieved on July 4, 2024from http://www.neumedinc.com/products/brevio.htm

NeuroMetrix®. Product Information NC-Stat®/ DPN Check®. Retrieved on July 4, 2024 from http://www.dpncheck.com/

Ney JP, van der Goes DN. Evidence-based guideline update: Intraoperative spinal monitoring with somatosensory and transcranial electrical motor evoked potentials. Report of the Therapeutics and Technology Assessment Subcommittee of the American Academy of Neurology and the American Clinical Neurophysiology Society. Neurology. 2012;79(3):292-294. doi:10.1212/WNL.0b013e3182637c24

Ng JK, Kippers V, Parnianpour M, Richardson CA. EMG activity normalization for trunk muscles in subjects with and without back pain. Med Sci Sports Exerc. 2002;34(7):1082-1086. doi:10.1097/00005768-200207000-00005

Ng JK, Richardson CA, Parnianpour M, Kippers V. EMG activity of trunk muscles and torque output during isometric axial rotation exertion: a comparison between back pain patients and matched controls. J Orthop Res. 2002;20(1):112-121. doi:10.1016/S0736-0266(01)00067-5

Ng JK, Richardson CA, Parnianpour M, Kippers V. Fatigue-related changes in torque output and electromyographic parameters of trunk muscles during isometric axial rotation exertion: an investigation in patients with back pain and in healthy subjects. Spine (Phila Pa 1976). 2002;27(6):637-646. doi:10.1097/00007632-200203150-00013

North American Spine Society. Electromyogram and nerve conduction study. North American Spine Society. Retrieved on July 4, 2024 from https://www.spine.org/KnowYourBack/Treatments/AssessmentTools/ElectrodiagnosticTesting

Nuwer MR, Emerson RG, Galloway G, et al. Evidence-based guideline update: intraoperative spinal monitoring with somatosensory and transcranial electrical motor evoked potentials: report of the Therapeutics and Technology Assessment Subcommittee of the American Academy of Neurology and the American Clinical Neurophysiology Society. Neurology. 2012;78(8):585-589. doi:10.1212/WNL.0b013e318247fa0e

Oddsson LI, Giphart JE, Buijs RJ, Roy SH, Taylor HP, De Luca CJ. Development of new protocols and analysis procedures for the assessment of LBP by surface EMG techniques. J Rehabil Res Dev. 1997;34(4):415-426

Oh SJ. Clinical Electromyography: Nerve Conduction Studies. 3d ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2003: 147-148

Omejec G, Žgur T, Podnar S. Diagnostic accuracy of ultrasonographic and nerve conduction studies in ulnar neuropathy at the elbow. Clin Neurophysiol. 2015;126(9):1797-1804. doi:10.1016/j.clinph.2014.12.001

Palmieri RM, Ingersoll CD, Hoffman MA. The hoffmann reflex: methodologic considerations and applications for use in sports medicine and athletic training research. J Athl Train. 2004;39(3):268-277

Park KM, Shin KJ, Park J, Ha SY, Kim SE. The usefulness of terminal latency index of median nerve and f-wave difference between median and ulnar nerves in assessing the severity of carpal tunnel syndrome. J Clin Neurophysiol. 2014;31(2):162-168. doi:10.1097/WNP.0000000000000041

Parker SL, Amin AG, Farber SH, et al. Ability of electromyographic monitoring to determine the presence of malpositioned pedicle screws in the lumbosacral spine: analysis of 2450 consecutively placed screws. J Neurosurg Spine. 2011;15(2):130-135. doi:10.3171/2011.3.SPINE101

Pawar S, Kashikar A, Shende V, Waghmare S. The study of diagnostic efficacy of nerve conduction study parameters in cervical radiculopathy. J Clin Diagn Res. 2013;7(12):2680-2682. doi:10.7860/JCDR/2013/7545.3731

Peach JP, McGill SM. Classification of low back pain with the use of spectral electromyogram parameters. Spine (Phila Pa 1976). 1998;23(10):1117-1123. doi:10.1097/00007632-199805150-00009

Pelosi L, Lamb J, Grevitt M, Mehdian SM, Webb JK, Blumhardt LD. Combined monitoring of motor and somatosensory evoked potentials in orthopaedic spinal surgery. Clin Neurophysiol. 2002;113(7):1082-1091. doi:10.1016/s1388-2457(02)00027-5

Perkins BA, Grewal J, Ng E, Ngo M, Bril V. Validation of a novel point-of-care nerve conduction device for the detection of diabetic sensorimotor polyneuropathy. Diabetes Care. 2006;29(9):2023-2027. doi:10.2337/dc08-0500

Perkins BA, Orszag A, Grewal J, Ng E, Ngo M, Bril V. Multi-site testing with a point-of-care nerve conduction device can be used in an algorithm to diagnose diabetic sensorimotor polyneuropathy. Diabetes Care. 2008;31(3):522-524. doi:10.2337/dc07-1227

Pullman SL, Goodin DS, Marquinez AI, Tabbal S, Rubin M. Clinical utility of surface EMG: report of the therapeutics and technology assessment subcommittee of the American Academy of Neurology (Retired). Neurology. 2000;55(2):171-177. doi:10.1212/wnl.55.2.171

Rau, G., Disselhorst-Klug, C., & Silny, J. (1997). Noninvasive approach to motor unit characterization: Muscle structure, membrane dynamics and neuronal control. Journal of Biomechanics, 30(5), 441-446

Raynor BL, Lenke LG, Bridwell KH, Taylor BA, Padberg AM. Correlation between low triggered electromyographic thresholds and lumbar pedicle screw malposition: analysis of 4857 screws. Spine (Phila Pa 1976). 2007;32(24):2673-2678. doi:10.1097/BRS.0b013e31815a524f

Resnick DK, Choudhri TF, Dailey AT, et al. Guidelines for the performance of fusion procedures for degenerative disease of the lumbar spine. Part 15: electrophysiological monitoring and lumbar fusion. J Neurosurg Spine. 2005;2(6):725-732. doi:10.3171/spi.2005.2.6.0725

Rotman MB, Enkvetchakul BV, Megerian JT, Gozani SN. Time course and predictors of median nerve conduction after carpal tunnel release. J Hand Surg Am. 2004;29(3):367-372. doi:10.1016/j.jhsa.2004.01.011

Ruddy: Kelley's Textbook of Rheumatology, 6th edition. Neurophysiology (electrodiagnostic studies). ©2001 W.B. Saunders Company. Page 470.

Sanders DB, Howard JF. Disorders of neuromuscular transmission. In: Bradley: Neurology in Clinical Practice, 5th edition. Ch 82. Copyright © 2008 Butterworth-Heinemann.

Schmidt K, Chinea NM, Sorenson EJ, Strommen JA, Boon AJ. Accuracy of diagnoses delivered by an automated hand-held nerve conduction device in comparison to standard electrophysiological testing in patients with unilateral leg symptoms. Muscle Nerve. 2011;43(1):9-13. doi:10.1002/mus.21911

Schoeck AP, Mellion ML, Gilchrist JM, Christian FV. Safety of nerve conduction studies in patients with implanted cardiac devices. Muscle Nerve. 2007;35(4):521-524. doi:10.1002/mus.20690

Seubert CN, Mahla ME. Neurologic monitoring. Ch 46. In: Miller's Anesthesia. 7th ed. Copyright © 2009 Churchill Livingstone

Sharan A, Groff MW, Dailey AT, et al. Guideline update for the performance of fusion procedures for degenerative disease of the lumbar spine. Part 15: electrophysiological monitoring and lumbar fusion. J Neurosurg Spine. 2014;21(1):102-105. doi:10.3171/2014.4.SPINE14324

Snowden ML, Haselkorn JK, Kraft GH, et al. Dermatomal somatosensory evoked potentials in the diagnosis of lumbosacral spinal stenosis: comparison with imaging studies. Muscle Nerve. 1992;15(9):1036-1044. doi:10.1002/mus.880150908

Souza, T. Differential Diagnosis and Management for the Chiropractor : Protocols and Algorithms. Fifth. Jones & Bartlett Learning; 2016

Stålberg E, Falck B. The role of electromyography in neurology. Electroencephalogr Clin Neurophysiol. 1997;103(6):579-598. doi:10.1016/s0013-4694(97)00138-7

Stegeman DF, Blok JH, Hermens HJ, Roeleveld K. Surface EMG models: properties and applications. J Electromyogr Kinesiol. 2000;10(5):313-326. doi:10.1016/s1050-6411(00)00023-7

Storm SA, Kraft GH. The clinical use of dermatomal somatosensory evoked potentials in lumbosacral spinal stenosis. Phys Med Rehabil Clin N Am. 2004;15(1):107-115. doi:10.1016/s1047-9651(03)00107-4

Sutter MA, Eggspuehler A, Grob D, Porchet F, Jeszenszky D, Dvorak J. Multimodal intraoperative monitoring (MIOM) during 409 lumbosacral surgical procedures in 409 patients. Eur Spine J. 2007;16 Suppl 2(Suppl 2):S221-S228. doi:10.1007/s00586-007-0432-9

Tankisi H, Pugdahl K, Fuglsang-Frederiksen A, et al. Pathophysiology inferred from electrodiagnostic nerve tests and classification of polyneuropathies. Suggested guidelines. Clin Neurophysiol. 2005;116(7):1571-1580. doi:10.1016/j.clinph.2005.04.003

Torvin Møller A, Winther Bach F, Feldt-Rasmussen U, et al. Functional and structural nerve fiber findings in heterozygote patients with Fabry disease. Pain. 2009;145(1-2):237-245. doi:10.1016/j.pain.2009.06.032

Triano JJ, Budgell B, Bagnulo A, et al. Review of methods used by chiropractors to determine the site for applying manipulation. Chiropr Man Therap. 2013;21(1):36. Published 2013 Oct 21. doi:10.1186/2045-709X-21-36

Trujillo-Hernández B, Huerta M, Trujillo X, Vásquez C, Pérez-Vargas D, Millán-Guerrero RO. F-wave and H-reflex alterations in recently diagnosed diabetic patients. J Clin Neurosci. 2005;12(7):763-766. doi:10.1016/j.jocn.2004.09.018

Tsai TM, Tsai CL, Lin TS, Lin CC, Jou IM. Value of dermatomal somatosensory evoked potentials in detecting acute nerve root injury: an experimental study with special emphasis on stimulus intensity. Spine (Phila Pa 1976). 2005;30(18):E540-E546. doi:10.1097/01.brs.0000179311.87137.0d

Urban MK. Anesthesia for Orthopedic Surgery. In: Miller: Miller's Anesthesia, 7th edition. Ch 70. Copyright © 2009 Churchill Livingstone

U.S. Food and Drug Administration (FDA). CFR Title 21. Part 882. Neurological Devices. Updated June 2023. Retrieved on July 4, 2024 from http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfCFR/CFRSearch.cfm?CFRPart=882

U.S. Food and Drug Administration. Brevio. 510(k) Summary K012069. June 29, 2001. Retrieved on July 4, 2024 from http://www.accessdata.fda.gov/cdrh_docs/pdf/k012069.pdf

Vij N, Kiernan H, Miller-Gutierrez S, et al. Etiology Diagnosis and Management of Radial Nerve Entrapment. Anesth Pain Med. 2021;11(1):e112823. Published 2021 Feb 14. doi:10.5812/aapm.112823

Wang Y, Cui LY, Chen L, et al. Nerve conduction studies in patients with dermatomyositis or polymyositis. Chin Med J (Engl). 2010;123(5):523-526

Watson PJ, Booker CK, Main CJ, Chen AC. Surface electromyography in the identification of chronic low back pain patients: the development of the flexion relaxation ratio. Clin Biomech (Bristol, Avon). 1997;12(3):165-171. doi:10.1016/s0268-0033(97)00065-x

Yiannikas C. Short-latency somatosensory evoked potentials in peripheral nerve lesions, plexopathies, and radiculopathies. In: Chiappa K, editor. Evoked potentials in clinical medicine. Third edition. Lippincott-Raven Publishers ©1997. Philadelphia –New York. Ch. 10

Zwarts MJ, Drost G, Stegeman DF. Recent progress in the diagnostic use of surface EMG for neurological diseases. J Electromyogr Kinesiol. 2000;10(5):287-291. doi:10.1016/s1050-6411(00)00020-1

Zwarts MJ, Stegeman DF. Multichannel surface EMG: basic aspects and clinical utility. Muscle Nerve. 2003;28(1):1-17. doi:10.1002/mus.10358