Evaluating the Patient With Suspected Radiculopathy

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INTRODUCTION

Cervical and lumbosacral radiculopathies are conditions involving a pathological process affecting the spinal nerve root. Commonly, this is a herniated nucleus pulposis that anatomically compresses a nerve root within the spinal canal. Another common etiology for radiculopathy is spinal stenosis resulting from a combination of degenerative spondylosis, ligament hypertrophy, and spondylolisthesis. Inflammatory radiculitis is another pathophysiological process that can cause radiculopathy. It is important to remember, however, that other more ominous processes such as malignancy and infection can manifest the same symptoms and signs of radiculopathy as the more common causes.

This manuscript deals with the clinical approach used in an electrodiagnostic (EDX) laboratory to evaluate a person with neck pain, lumbar spine pain, or limb symptoms which are suggestive of radiculopathy. Given the large differential diagnosis for these symptoms, it is important for EDX physicians to develop a conceptual framework for evaluating these referrals with a standard focused history and physical examination and a tailored EDX approach. Accurately identifying radiculopathy by EDX whenever possible provides valuable information that informs treatment and minimizes other invasive and expensive diagnostic and therapeutic procedures.

SPINE AND NERVE ROOT ANATOMY: DEVIATIONS FROM THE EXPECTED

The anatomy of the bony spine, supporting ligamentous structures, and neural elements provides a unique biomechanical system that allows tremendous strength yet flexibility. The interested reader can consult standard anatomy texts for further discussions. The important structural issues that relate to radiculopathy are addressed in this article.

In the lumbar spine, the attachment and shape of the posterior longitudinal ligament predisposes the nucleus pulposis to herniation in a posterolateral direction where it is the weakest. The dorsal root ganglion (DRG) lies in the intervertebral foramen and this anatomical arrangement poses major implications for clinical EDX of radiculopathy. Intraspinal lesions can cause weakness due to their effects on the motor axons which originate in the anterior and lateral gray matter and pass through the lumbar spine as spinal roots. These roots form the “cauda equina,” or horse’s tail, the name used to describe this anatomic structure. Intraspinal lesions can also produce sensory loss by damaging the dorsal roots, which are composed of central processes from the sensory nerve cell bodies in the DRG, as they project to the spinal cord. Electrophysiologically, severe axonal damage intraspinally results in spontaneous activity on needle electromyography (needle EMG) and possibly reduced compound muscle action potentials (CMAPs). However, the sensory nerve action potentials (SNAPs) are preserved. This anatomical relationship provides a mechanism for further confirming whether or not a lesion is radicular (intraspinal). A destructive intramedullary (spinal cord) lesion at T11 can produce EMG findings in muscles innervated by any of the lumbosacral nerve roots and manifest the precise findings on needle EMG as those seen with a herniated nucleus pulposis at any of the lumbar disc levels. For this reason, the EDX physician cannot determine for certain the anatomic location of the lumbar intraspinal lesion producing distal muscle EMG findings in the lower limbs. Electromyography can only identify the root or roots that are physiologically involved, but not the precise anatomic site of pathology within the lumbar spinal canal.
In a prospective study of 100 patients with lumbosacral radiculopathy who underwent lumbar laminectomy, EMG precisely identified the involved root level 84% of the time. Electromyography failed to accurately identify the compressed root in 16% of patients. However, at least half of the failures were attributable to anomalies of innervation. Another component to this study involved stimulating the nerve roots intraoperatively with simultaneous recording of muscle activity in the lower limb using surface electrodes. These investigators demonstrated variations in root innervations, such as the L5 root innervating the soleus and medial gastrocnemius in 16% of a sample of 50 patients. Most subjects demonstrated dual innervations for most muscles.

Regarding the cervical nerve roots and the brachial plexus, there are many anatomic variations. Perneczky described an anatomic study of 40 cadavers. In all cases, there were deviations from accepted cervical root and brachial plexus anatomy. Levin, Maggiano, and Wilbourn examined the pattern of abnormalities on EMG in 50 cases of surgically proven cervical root lesions. A range of needle EMG patterns was found with EMG demonstrating less specificity for the C6 root level, but more specificity and consistent patterns for C8, C7, and C5 radiculopathies. In subjects with C6 radiculopathies, half the patients showed findings similar to those with C5 radiculopathies and the other half demonstrated C7 patterns.

These findings underscore the limitations of precise localization for root lesions by EMG. The EDX physician should maintain an understanding of these anatomic variations to better convey the level of certainty with respect to diagnostic conclusions.

### COMMON MUSCULOSKELETAL DISORDERS MIMICKING CERVICAL RADICULOPATHY

The symptoms of radiculopathy are nondescript and not specific for radiculopathy. Many other neurological and musculoskeletal conditions can produce pain, weakness, and sensory symptoms. In addition to the standard peripheral neurological examination, one of the most helpful maneuvers is to ask the patient where it hurts, then carefully palpate that area. If pain is reproduced by this palpation then the examiner should have a heightened suspicion for a musculoskeletal disorder. However, whereas a musculoskeletal disorder identified on examination makes a normal EDX study more likely, the presence of a musculoskeletal disorder does not exclude an abnormal EDX study with reliability or specificity. Common musculoskeletal disorders that produce symptoms similar to those produced by a cervical radiculopathy are shown in Table 1.

Shoulder impingement, lateral epicondylitis, and de Quervain's tenosynovitis are easily identifiable conditions that are extraordinarily common. Even with a positive EDX test showing an entrapment neuropathy or radiculopathy, treatment of a concomitant musculoskeletal disorder can often improve overall symptoms.

Common entrapment neuropathies can present with symptoms similar to radiculopathy. Median neuropathy at the wrist and ulnar neuropathy at the elbow are common conditions for which patients are referred for EDX, and complicate the EDX assessment for radiculopathy. Plexopathies such as idiopathic brachial neuritis can pose diagnostic dilemmas for the EDX consultant as pain, weakness, and sensory loss are all common symptoms in both plexopathies and radiculopathies.

### Table 1  Musculoskeletal conditions that commonly mimic cervical radiculopathy

<table>
<thead>
<tr>
<th>Condition</th>
<th>Clinical symptoms/signs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibromyalgia syndrome</td>
<td>Pain all over, female predominance, often sleep problems, tender to palpation in multiple areas</td>
</tr>
<tr>
<td>Polymyalgia rheumatica</td>
<td>&gt;50 years old, pain and stiffness in neck shoulders and hips, high ESR</td>
</tr>
<tr>
<td>Sternoclavicular joint arthropathy</td>
<td>Pain in anterior chest, pain with shoulder movement (adduction), pain on direct palpation</td>
</tr>
<tr>
<td>Acromioclavicular joint arthropathy</td>
<td>Pain in anterior chest, pain with shoulder movement (adduction), pain on direct palpation</td>
</tr>
<tr>
<td>Shoulder bursitis, impingement syndrome,</td>
<td>Pain with palpation, positive impingement signs, pain in C5 distribution</td>
</tr>
<tr>
<td>Lateral epicondylitis “tennis elbow”</td>
<td>bicipital tendinitis</td>
</tr>
<tr>
<td>De Quervain’s tenosynovitis</td>
<td>Lateral wrist and forearm pain, tender at abductor pollicis longus or extensor pollicis brevis tendons, positive Finkelstein test</td>
</tr>
<tr>
<td>Trigger finger, stenosing tenosynovitis</td>
<td>Intermittent pain and locking of a digit in flexion of finger flexor tendons</td>
</tr>
</tbody>
</table>

ESR = erythrocyte sedimentation rate
COMMON MUSCULOSKELETAL DISORDERS MIMICKING LUMBOSACRAL RADICULOPATHY

Conditions that present with symptoms similar to those of lumbo-sacral radiculopathy are shown in Table 2. In this author’s opinion, one of the most readily treatable, yet under-recognized conditions is trochanteric bursitis and illiotibial band syndrome. The illiotibial band originates at the iliac crest and has tendinous contributions from the gluteus maximus and tensor fascia latae. It runs the length of the thigh and crosses the knee joint inserting on the lateral condyle of the tibia. This band is part of the fascia lata, a layer of dense strong connective tissue enveloping the thigh like a stocking. It is extremely strong laterally where it becomes the illiotibial band. Where it crosses the hip, trochanteric bursitis can occur. The lateral femoral condyle of the knee can also be a site of tendinitis as well, particularly in runners. Trochanteric bursitis and illiotibial band syndrome are two conditions which respond well to corticosteroid injections and a rehabilitation program aimed at stretching this musculotendinous band. They are commonly mistaken for lumbo-sacral radiculopathy.

Pain at the bottom of the foot with symptoms of burning and tingling is frequently plantar fasciitis. Dorsiflexing the foot and palpating the plantar fascia will identify taut painful tendinous bands if plantar fasciitis is present.

Neuralgic amyotrophy from diabetes is a condition that is often difficult to distinguish from lumbosacral radiculopathy. It often presents with thigh pain and on EMG appears more like proximal lumbosacral plexus mononeuropathies with frequent involvement of the femoral nerve. Diabetic thoracic radiculopathy is a distinct syndrome with abdominal wall or thoracic wall pain, and weight loss, but has a good prognosis. In diabetic thoracic radiculopathy, intra-abdominal and intra-thoracic conditions must first be excluded. The EMG findings of denervation in the abdominal or thoracic wall musculature are consistent with this clinical entity.

Mononeuropathies such as peroneal, tibial, and femoral, pose diagnostic challenges and the EDX consultant should sample enough muscles with EMG in different peripheral nerve distributions to confirm that findings are not localized to a particular peripheral nerve distribution.

PHYSICAL EXAMINATION

The EDX examination is an extension of the standard clinical examination. The history and physical examination are vital initial steps in determining what conditions may be causing the patient’s symptoms. Most radiculopathies present with symptoms in one limb. Multiple radiculopathies such as are seen in cervical spinal stenosis or lumbar stenosis, may cause symptoms in more than one limb. A focused neuromuscular examination that assesses strength, reflexes, and sensation in the affected limb and the contralateral limb provides a framework for EDX assessment.

An algorithmic approach to utilizing physical examination and symptom information to tailor the EDX evaluation is shown in Figure 1. In this approach, the patient’s symptoms, and physical examination signs of sensory loss and weakness create a conceptual framework for approaching these sometimes daunting problems. Admittedly, there are many exceptions to this approach with considerable overlap in conditions which might fall in multiple categories. Radiculopathies and entrapment neuropathies are examples of such conditions with a variety of clinical presentations.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Clinical symptoms/signs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibromyalgia syndrome and polymyalgia rheumatica</td>
<td>As in Table 1</td>
</tr>
<tr>
<td>Hip arthritis</td>
<td>Pain in groin, anterior thigh, pain with weight bearing, positive Patrick’s test</td>
</tr>
<tr>
<td>Trochanteric bursitis</td>
<td>Lateral hip pain, pain with palpation on lateral and posterior hip</td>
</tr>
<tr>
<td>Iliotibial band syndrome</td>
<td>Pain along outer thigh, pain with palpation</td>
</tr>
<tr>
<td>Knee arthritis</td>
<td>Pain with weight bearing</td>
</tr>
<tr>
<td>Patellofemoral pain</td>
<td>Anterior knee pain, worsen with prolonged sitting</td>
</tr>
<tr>
<td>Pes anserinus bursitis</td>
<td>Medial proximal tibia pain, tender to palpation</td>
</tr>
<tr>
<td>Hamstring tendinitis, chronic strain</td>
<td>Posterior knee and thigh pain, can mimic positive straight leg raise, common in runners</td>
</tr>
<tr>
<td>Baker’s cyst</td>
<td>Posterior knee pain and swelling</td>
</tr>
<tr>
<td>Plantar fasciitis</td>
<td>Pain in sole of foot, worsened with weight bearing activities, tender to palpation</td>
</tr>
<tr>
<td>Gastrocnemius-soleus tendinitis,</td>
<td>Calf pain, worsened with sports activities, usually limited range of motion compared to asymptomatic limb, chronic strain</td>
</tr>
</tbody>
</table>
Evaluating the Patient With Suspected Radiculopathy

AANEM Course

and physical examination findings, such that they are included in both focal symptom categories with and without sensory loss. In the case of a person with lumbosacral radiculopathy, a positive straight leg raise test may be noted in the absence of motor, reflex, or sensory changes. Conditions such as myopathies and polyneuropathies better fit this algorithmic approach given that symptoms and physical examination signs are somewhat more specific. Figure 1 also contains musculoskeletal disorders and denotes how they fall into this conceptual framework. The EDX physician must be willing to modify the EDX examination in response to nerve conduction and EMG findings and adjust the focus of the examination in light of new information.

The implications of symptoms and signs on EDX findings were investigated by Lauder and colleagues for cohorts of patients with upper or lower limb symptoms as well suspected cervical and lumbosacral radiculopathies.35,36 Even though physical examination findings were better at predicting who would have a radiculopathy, many patients with normal examinations had abnormal EMG studies, indicating that clinicians should not curtail EDX testing simply because the physical examination is normal. For lower limb symptoms, loss of a reflex or weakness dramatically increased the likelihood of having a radiculopathy by EMG. Losing the Achilles reflex for instance, resulted in an odds ratio of 8.4 (p<0.01)—eight times the likelihood of having a radiculopathy (S1 level) by EMG with this physical examination finding.35 Weakness in any leg muscle group resulted in about 2.5 times greater chance of identifying a lumbosacral radiculopathy on EMG.35

Similar findings were noted for upper limb symptoms. For instance, if a reflex was lost or weakness was noted, the likelihood of having a cervical radiculopathy confirmed by EMG was about 4 times more likely.36 Combinations of findings, particularly weakness plus reflex changes, resulted in a nine-fold greater likelihood of cervical radiculopathy.36

Guidelines for Radiculopathy Evaluation

The American Association of Neuromuscular & Electrodiagnostic Medicine’s (AANEM) guidelines recommend that for an optimal evaluation of a patient with suspected radiculopathy, a needle EMG screen of a sufficient number of muscles and at least one motor and one sensory nerve conduction study (NCS) should be performed in the involved limb.1 The NCSs are necessary to exclude polyneuropathy. The sufficiency of the EMG screen and a recommended number of muscles is discussed in detail below. An EMG study is
considered confirmatory for a radiculopathy if EMG abnormalities are found in two or more muscles innervated by the same nerve root and different peripheral nerves, yet muscles innervated by adjacent nerve roots are normal. This definition assumes that other generalized conditions such as polyneuropathy are not present.

Bilateral limbs are often necessary to study, particularly if a single limb shows EMG findings suggestive of radiculopathy and the patient has symptoms in both the studied and the contralateral limb. If bilateral limbs are involved, the EDX physician should have a low threshold for studying selected muscles in an upper limb (if the lower limbs are abnormal on EMG) or a lower limb (if both upper limbs are abnormal), to exclude a generalized process such as polyneuropathy or motor neuron disease. Likewise, additional NCSs are appropriate to exclude other suspected conditions and the EDX consultant should have a low threshold for expanding the study.

**H REFLEXES, F WAVES, AND NERVE CONDUCTIONS**

Nerve conduction studies, H reflexes, and F waves are not very useful for confirming radiculopathy. They are useful, however, to exclude polyneuropathy or mononeuropathies.

**H Reflexes**

H reflexes have commonly been used to determine whether a radiculopathy demonstrates S1 involvement. It is a monosynaptic reflex that is an S1 mediated response and can differentiate to some extent L5 from S1 radiculopathy. Many researchers have evaluated their sensitivity and specificity with respect to lumbosacral radiculopathies and generally found a range of sensitivities from 32-88%. However, many of these studies suffered from lack of a control group, imprecise inclusion criteria, or small sample sizes.

Marin and colleagues prospectively examined the H reflex and the extensor digitorum brevis reflex in 53 normals, 17 patients with L5, and 18 patients with S1 radiculopathy. Patients included in the study had all of the following: (1) radiating low back pain into the leg, (2) reduced sensation or weakness or positive straight leg raise test, and (3) either EMG evidence of radiculopathy or structural causes of radiculopathy on magnetic resonance imaging (MRI) or computed tomography (CT) imaging. The H reflex maximal side-to-side latency difference was 1.8 ms as derived from the normal group. They analyzed the sensitivity of the H reflex for side-to-side differences greater than 1.8 ms or a unilaterally absent H reflex on the affected side. The H reflex only demonstrated a 50% sensitivity for S1 radiculopathy and 6% for L5 radiculopathy, but had a 91% specificity. Amplitudes were not assessed in this study. These results suggest that the H reflex has a low sensitivity for S1 root level involvement.

H reflexes may be useful to identify subtle S1 radiculopathy, yet there are a number of shortcomings related to these responses. They can be normal with radiculopathies, and because they are mediated over such a long physiological pathway, they can be abnormal due to polyneuropathy, sciatic neuropathy, or plexopathy. They are most useful in the assessment for polyneuropathy.

In order to interpret a latency or amplitude value and render a judgement as to the probability that it is abnormal, precise population-based normative values encompassing a large age range of normal subjects must be available for NCS comparisons. Falco and colleagues demonstrated in a group of healthy elderly subjects (60-88 years old), that the tibial H reflex was present and recorded bilaterally in 92%. Most elderly subjects are expected to have normal H-reflex studies and when abnormalities are found in these persons, the EDX consultant should critically evaluate these findings and the clinical scenario before attributing H-reflex abnormalities to the aging process.

**F Waves**

F waves are late responses involving the motor axons and axonal pool at the spinal cord level. They can be assessed and classified by using the minimal latency, mean latency, and chronodispersion or scatter. As in the case of H reflexes, they demonstrate low sensitivities and are not specific for radiculopathy, rather they are a better screen for polyneuropathy. Published sensitivities range from 13-69%, however these studies suffer from many of the shortcomings described for H-reflex studies.

London and England reported two cases of persons with neurogenic claudication from lumbosacral spinal stenosis. They demonstrated that the F-wave responses could be reversibly changed after 15 minutes of ambulation which provoked symptoms. This suggested an ischemia-induced conduction block in proximal motor neurons. A larger scale study of this type might find a use for F waves in the identification of lumbosacral spinal stenosis and delineate neurogenic from vascular claudication.

**Motor and Sensory Nerve Conduction Studies**

Standard motor and sensory NCS may not be helpful in identifying a cervical or lumbosacral radiculopathy, however they should be performed to screen for polyneuropathy and exclude common entrapment neuropathies if the patient’s symptoms could be explained by a focal entrapment.

Plexopathies often pose a diagnostic challenge, as they are similar to radiculopathies in symptoms and signs. In order to distinguish plexopathy from radiculopathy, sensory responses which are accessible in a limb should be tested. In plexopathy, they are likely to be reduced in amplitude, whereas in radiculopathy they are generally normal. If substantial axonal loss has occurred at the root level, the
CMAP recorded in muscles innervated by that root may be reduced in both plexopathies and radiculopathies. This is usually when severe axonal loss has occurred such as with cauda equina lesions or penetrating trauma that severely injures a nerve root. The distal motor latencies and conduction velocities are usually preserved as they reflect the fastest conducting nerve fibers.65

**SOMATOSENSORY EVOKED POTENTIALS, DERMATOMAL SOMATOSENSORY EVOKED POTENTIALS, AND MAGNETIC EVOKED POTENTIALS**

The AANEM guidelines examined the literature and concluded that somatosensory evoked potentials (SEPs) may be useful for cervical spondylosis with cord compression. Likewise, in lumbosacral spinal stenosis, dermatomal somatosensory evoked potentials (DSEPs) may be useful in defining levels of deficits.1

Physiological evidence of multiple or single root involvement in lumbosacral spinal stenosis can be documented with DSEPs and may be useful in the case where spinal canal narrowing is minimal and the patient has symptoms. This testing also complements standard needle EMG. Snowden and colleagues found that for single and multilevel lumbosacral spinal stenosis, DSEPs revealed 78% sensitivity relative to spinal imaging.23 In this well-designed prospective study, DSEP criteria as well as inclusion criteria were precisely defined. The predictive value for a positive test was 93%.

Yiannikas, Shahani, and Young demonstrated that SEPs may be useful for cervical myelopathy, all 10 had abnormal peroneal SEPs and 7 had abnormal median SEPs.

Maertens de Noordhout and colleagues examined motor and SEPs in 55 persons with unequivocal signs and symptoms of cervical spinal myelopathy.43 In this group 87% showed gait disturbances, and 82% showed hyperreflexia. Magnetic resonance imaging was not the diagnostic standard as these authors felt that MRI was prone to overdiagnosis; metrizamide myelography showed unequivocal signs of cervical cord compression for all patients. Magnetic stimulation of the cortex was performed and the responses measured with surface electrodes. In these subjects 89% demonstrated abnormalities in motor evoked potentials (MEP) to the first dorsal interosseus muscle and 93% had one MEP abnormality. At least one SEP abnormality was noted in 73%. This study demonstrated the potential usefulness of these techniques for identifying subtle cord compression.

Tavy and colleagues examined whether MEPs or SEPs assisted in identifying persons with radiological evidence of cervical cord compression but who were without clinical markers for myelopathy.60 All patients had clinical symptoms of cervical radiculopathy, but not myelopathy. In this group MEPs were normal in 92% and SEPs were normal in 96%. These investigators concluded that MEPs and SEPs are normal in most cases of persons with asymptomatic cervical stenosis. This indicates that abnormal MEPs and SEPs are likely to be true positive findings and not false positives related to mild asymptomatic cord compression. It is important to remember that cervical spondylosis is a process that causes a continuum of problems including both radiculopathy and myelopathy.

The inherent variability and difficulty in determinations as to what constitutes normal evoked potentials prompted investigation. Dumitru and colleagues examined the variations in latencies with SEPs.17 In 29 normal subjects, they examined the ipsilateral intertrial variations, arithmetic mean side-to-side differences and maximum potential side-to-side differences with stimulation of the superficial peroneal sensory nerve, sural nerve and L5 and S1 dermatomes with respect to P1 and N1 latencies and peak-to-peak amplitudes. Considerable ipsilateral intertrial variation was observed and side-to-side comparisons revealed a further increase in this inherent variation regarding the above measured parameters. They suggested an additional parameter with which to evaluate SEPs: the maximum side-to-side latency difference.

Dumitru and colleagues, in a study involving persons with unilateral and unilevel L5 and S1 radiculopathies, evaluated dermatomal and segmental somatosensory evoked potentials.35 History, physical examination, imaging studies, and EDX medicine evaluations clearly defined patients with unilateral/unilevel L5 or S1 nerve root compromise. Regression equation analysis for cortical P1 latencies evaluating age and height based on comparable patient and control reference populations revealed segmental and dermatomal sensitivities for L5 radiculopathies to be 70% and 50%, respectively, at 90% confidence intervals. Similar sensitivities were obtained for 2 standard deviation mean cortical P1 latencies. Side-to-side cortical P1 latency difference data revealed segmental and dermatomal sensitivities for S1 radiculopathies to be 50% and 10%, respectively, at two standard deviations. These investigators questioned the clinical utility of both segmental and dermatomal SEPs in the evaluation of patients with suspected unilateral/unilevel L5 and S1 nerve root compromise, finding little utility for these tests in persons with single level lumbosacral radiculopathy.

**PURPOSE OF ELECTRODIAGNOSTIC TESTING**

Electrodiagnostic testing is expensive and uncomfortable for patients, therefore, it is important to understand why it is performed and the expected outcomes. Electrodiagnostic testing serves several important purposes:

- It effectively excludes other conditions that mimic radiculopathy such as polyneuropathy or entrapment neuropathy. Haig and colleagues demonstrated that the referring diagnostic impression is often altered with EDX testing.23
- EDX testing can to some extent suggest severity, or extent of the disorder beyond the clinical symptoms. Involvement of other extremities can be delineated or the involvement of multiple roots may be demonstrated, such as in the case of lumbosacral spinal stenosis.
There is utility in solidifying a diagnosis. An unequivocal radiculopathy on EMG in an elderly patient with nonspecific or mild lumbar spondylosis or stenosis on MRI reduces diagnostic uncertainty and identifies avenues of management such as lumbar corticosteroid injections or decompression surgery in certain situations.

Outcome prediction may be possible. If surgical intervention is planned for a lumbosacral radiculopathy, a positive EMG preoperatively improves the likelihood of a successful outcome postoperatively. This is an area that deserves more research attention.

ELECTROMYOGRAPHY AND DIAGNOSTIC SENSITIVITIES

The need for EMG, particularly in relationship to imaging of the spine, has been recently highlighted. Needle EMG is particularly helpful in view of the fact that the false positive rates for MRI of the lumbar spine are high, with 27% of normal subjects having a disc protrusion. For the cervical spine the false positive rate for MRI is much lower with 19% of subjects demonstrating an abnormality, but only 10% showing a herniated or bulging disc. Radiculopathies can occur without structural findings on MRI, and likewise without EMG findings. The EMG only evaluates motor axonal loss or motor axon conduction block and for these reasons a radiculopathy affecting the sensory root will not yield abnormalities by EMG. If the rate of denervation is balanced by reinnervation in the muscle, then spontaneous activity is less likely to be found.

The sensitivity of EMG for cervical and lumbosacral radiculopathies has been examined in a number of studies. The results of some of these studies are tabulated in Table 3. Table 3 lists the "gold standards" against which these EMG findings were compared. Studies using a clinical standard may reflect a less severe group, whereas those using a surgical confirmation may indicate a more severely involved group. The sensitivity for EMG is unimpressive, ranging from 49-92% in these studies. Electromyography is not a sensitive test, yet it likely has a higher specificity. The issue of specificity and its value in EDX was underscored by Robinson. It is apparent that EMG is not a good screening test. In terms of screening tests, MRI is better for identifying subtle structural abnormalities, with EMG to assess their clinical relevance and exclude other disorders.

PARASPINAL MUSCLE EXAMINATION

Paraspinal muscles are important to study for a variety of reasons but there are some important caveats regarding their examination. In one study, Date and colleagues demonstrated that lumbar paraspinal muscles in asymptomatic subjects over 40 years old showed denervation potentials approximately 30% of the time. Nardin and colleagues similarly noted up to 48% of normal subjects having fibrillations or positive sharp waves in at least one site with the prevalence higher for those over 40 years of age. In sharp contrast to these findings, Dumitru, Diaz, and King examined the lumbosacral paraspinal muscles and intrinsic foot muscles with monopolar EMG. These investigators recorded potentials and found that there were irregularly firing potentials with similar waveform characteristics as fibrillations and positive sharp waves (PSW). By excluding irregularly firing potentials (atypical endplate spikes) they found much lower false positive paraspinal findings than the investigators above, with only 4% of their normal subjects showing regularly firing fibrillations or PSW potentials. They felt that the higher prevalences of spontaneous activity previously reported were due to not fully appreciating the similarity between innervated and denervated spontaneous single muscle fiber discharges. This quantitative study underscores the need to assess both firing rate and rhythm as well as discharge morphology when evaluating for fibrillations and positive waves in the lumbar paraspinal muscles. Electrodagnostic physicians should take care not to over-diagnose paraspinal muscle EMG findings by mistaking irregularly firing endplate spikes for fibrillations.

Paraspinal muscles (PM) may be abnormal in patients with spinal cancers, or amyotrophic lateral sclerosis, and following spinal surgery or lumbar puncture.

Investigations over the last decade have provided insights into better quantification and examination of lumbosacral paraspinal muscles. The lumbar paraspinal muscle examination has been refined through investigations that used a grading scale for the findings. The "mini PM" score provides a quantitative means of deriving the degree of paraspinal muscle denervation. It distinguishes normal findings from EMG findings in persons with radiculopathy. This novel and quantitative technique may prove to identify subtle radiculopathies or spinal stenosis with greater precision.

IDENTIFICATION AS A SEPARATE CONCEPT FROM SENSITIVITY

Because EDX is a composite assessment composed of various tests, a fundamental question is when the point of diminishing returns has been reached. Some radiculopathies cannot be confirmed by needle EMG, even though the signs and symptoms along with imaging results suggest that radiculopathy is the correct diagnosis. A screening EMG study involves determining whether or not the radiculopathy can be confirmed by EMG. If the radiculopathy cannot be confirmed, then presumably no amount of muscles can identify the radiculopathy. If it can be confirmed, then the screen should identify this possibility with a high probability. The process of identification can be conceptualized as a conditional probability: Given that a radiculopathy can be confirmed by needle EMG, what is the minimum number of muscles which must be examined in order to confidently recognize or exclude this possibility? This is a fundamentally different concept from sensitivity. It involves understanding and defining the limitations of a composite test (group of muscles).
Table 3  Selected studies evaluating the sensitivity of EMG relative to various “gold standards.” Unless otherwise stated the EMG parameters used in sensitivity calculations were fibrillation potentials.

<table>
<thead>
<tr>
<th>STUDY</th>
<th>SAMPLE SIZE</th>
<th>GOLD STANDARD</th>
<th>EMG SENSITIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LUMBOSACRAL (RADICULOPATHY)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weber and Albert(^{63})</td>
<td>42</td>
<td>Clinical + Imaging HNP</td>
<td>60%</td>
</tr>
<tr>
<td>Nardin and colleagues(^{47})</td>
<td>47</td>
<td>Clinical</td>
<td>55%</td>
</tr>
<tr>
<td>Kuruoglu and colleagues(^{31})</td>
<td>100</td>
<td>Clinical</td>
<td>86%</td>
</tr>
<tr>
<td>Khatri and colleagues(^{28})</td>
<td>95</td>
<td>Clinical</td>
<td>64%</td>
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<td>Tonzo and colleagues(^{41})</td>
<td>57</td>
<td>Clinical</td>
<td>49%</td>
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<tr>
<td>Schoedinger(^{23})</td>
<td>206</td>
<td>Surgically proven</td>
<td>56%</td>
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<tr>
<td>Young and colleagues(^{47})</td>
<td>100</td>
<td>Clinical and imaging</td>
<td>84%</td>
</tr>
<tr>
<td>Linden and Berlit(^{40})</td>
<td>19</td>
<td>Myelography and CT</td>
<td>78%</td>
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<tr>
<td><strong>LUMBOSACRAL (SPINAL STENOSIS)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hall and colleagues(^{24})</td>
<td>68</td>
<td>Clinical + myelogram</td>
<td>92%</td>
</tr>
<tr>
<td>Johnson and colleagues(^{27})</td>
<td>64</td>
<td>Clinical + myelogram</td>
<td>88%</td>
</tr>
<tr>
<td><strong>CERVICAL (RADICULOPATHY)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Berger and colleagues(^{2})</td>
<td>18</td>
<td>Clinical</td>
<td>61%</td>
</tr>
<tr>
<td>Partanen and colleagues(^{4})</td>
<td>77</td>
<td>Intraoperative</td>
<td>67%</td>
</tr>
<tr>
<td>Lelthub and colleagues(^{5})</td>
<td>24</td>
<td>Clinical + myelogram</td>
<td>67%</td>
</tr>
<tr>
<td>So and colleagues(^{6})</td>
<td>14</td>
<td>Clinical</td>
<td>71%</td>
</tr>
<tr>
<td>Yannikas and colleagues(^{6})</td>
<td>20</td>
<td>Clinical and/or radiographic</td>
<td>50%</td>
</tr>
<tr>
<td>Tackman and Radu(^{20})</td>
<td>20</td>
<td>Clinical</td>
<td>95%</td>
</tr>
<tr>
<td>Hong, Lee, and Lum(^{26})</td>
<td>108</td>
<td>Clinical</td>
<td>51%</td>
</tr>
</tbody>
</table>

* Both fibrillations or large motor units >8 mV were considered positive.
† This study assessed EMG parameters and used quantitative EMG with a unique grading scale not used in clinical practice. Fibrillations were infrequent. This limits the generalizability of this otherwise strong study.

CT = computerized tomography; EMG = electromyography; HNP = herniated nucleus pulposis

**HOW MANY AND WHICH MUSCLES TO STUDY**

The concept of a screening EMG encompasses identifying the possibility of an EDX-confirmable radiculopathy. If one of the muscles in the screen is abnormal, the screen must be expanded to exclude other diagnoses, and to fully delineate the radiculopathy level. Because of the screening nature of the EMG exam, EDX physicians with experience should look for more subtle signs of denervation, and if present in the screening muscles, then expand the study to determine if these findings are limited to a single myotome or peripheral nerve distribution. If they are limited to a single muscle, the clinical significance is uncertain.

**The Cervical Radiculopathy Screen**

Dillingham and colleagues conducted a prospective multi-center study evaluating patients referred to participating EDX laboratories with suspected cervical radiculopathy.\(^{10}\) A standard set of muscles were examined by needle EMG for all patients. Those with electrodiagnostically confirmed cervical radiculopathies, based upon EMG findings, were selected for analysis. The EMG findings in this prospective study also encompassed other neuropathic findings: (1) positive sharp waves, (2) fibrillation potentials, (3) complex repetitive discharges, (4) high-amplitude, long-duration motor unit action potentials, (5) increased polyphasic motor unit action potentials, or (6) reduced recruitment. There were 101 patients with EDX confirmed cervical radiculopathies representing all cervical root levels. When paraspinal muscles were one of the screening muscles and neuropathic findings were assessed, five muscle screens identified 90-98% of radiculopathies, six muscle screens identified 94-99% and seven muscle screens identified 96-100% (Tables 4 and 5). When paraspinal muscles were not part of the screen, eight distal limb muscles recognized 92-95% of radiculopathies. Without paraspinal muscles, the identification rates were consistently lower. If one only considers fibrillations and positive sharp waves in the EMG assessment, identification rates are lower. Six muscle screens including paraspinal muscles yielded consistently high identification rates and studying additional muscles lead to marginal increases in identification. Individual screens useful to the EDX physician are listed in Tables 4 and 5. In some instances a particular muscle cannot be studied due to wounds, skin grafts, dressings, or infections. In such cases the EDX physician can use an alternative screen with equally high identification. These findings were consistent with those derived from a large retrospective study.\(^{33}\)

**The Lumbosacral Radiculopathy Screen**

A prospective multicenter study was conducted at five institutions by Dillingham and colleagues.\(^{10}\) Patients referred to participating EDX laboratories with suspected lumbosacral radiculopathy were recruited and a standard set of muscles examined by needle EMG.
Patients with EDX-confirmed lumbosacral radiculopathies were selected for analysis. As described above for the prospective cervical study, neuropathic findings were analyzed along with spontaneous activity. There were 102 patients with EDX confirmed lumbosacral radiculopathies representing all lumbosacral root levels. When paraspinal muscles were not part of the screening muscles, 4 muscle screens identified 88-97%, 5 muscle screens identified 94-98%, and 6 muscle screens 98-100% (Tables 6, 7, and 8). When paraspinal muscles were not part of the screen, identification rates were lower for all screens and eight distal muscles were necessary to identify 90%. As with cervical radiculopathy screens, assessing for neuropathic findings increases identification rates. If only four muscles can be tested due to limited patient tolerance, as seen in Table 6, and if one of these muscles are the paraspinals, few EDX-confirmable radiculopathies will be missed. A large retrospective study noted similar findings, concluding that five muscles identified most electrodiagnostically confirmable radiculopathies.10

Dillingham and Dasher9 re-analyzed data from a study published by Knutsson almost forty years earlier.29 In this detailed study, 206 patients with sciatica, underwent lumbar surgical exploration. All subjects underwent a standardized 14 muscle EMG evaluation by the author (Knutsson) using concentric needles. The examiner was blinded to other test results and physical examination findings. In addition to the EMG and surgical information, myelogram and physical examination data were derived. In this re-analysis, screens of four muscles with one being the lumbosacral paraspinal muscle yielded (1) an identification rate of 100%, (2) a 92% sensitivity with respect to the intraoperative anatomical nerve root compressions, and (3) an 89% sensitivity with respect to the clinical inclusion criteria.9 This study, using data from 4 decades ago, confirmed that a 4 muscle screen provides high identification. These findings are consistent with contemporary work showing that screens with relatively few muscles (five or six) are sufficient.

As described above, recent research efforts were undertaken to refine and streamline the EMG examination. The strongest studies, contemporary prospective multicenter investigations, provide the best estimates of a sufficient number of muscles.10,11 In summary, for both cervical and lumbosacral radiculopathy screens the optimal number of muscles appears to be six muscles which include the paraspinal muscles and represent all root level innervations. When paraspinal muscles are not reliable, then eight nonparaspinal muscles must be examined. Another way to think of this:

To minimize harm, six in the leg and six in the arm.

If one of the six muscles studied in the screen is positive with a neuropathic finding, there exist the possibility of confirming EDX that a radiculopathy is present. In this case, the examiner must study additional muscles. Nerve conductions should be undertaken as well to determine if this muscle finding is due to a mononeuropathy. If more extensive EMG testing reveals that the findings are limited to a single muscle, and NCSs exclude mononeuropathy, then the single muscle finding remains inconclusive and of uncertain clinical relevance.

Table 4 Five muscle screen identifications of patients with cervical radiculopathies

<table>
<thead>
<tr>
<th>MUSCLE SCREEN</th>
<th>NEUROPATHIC</th>
<th>SPONTANEOUS ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Paraspinals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>deltoid, APB, FCU, triceps, PT</td>
<td>92%</td>
<td>65%</td>
</tr>
<tr>
<td>biceps, triceps, EDC, FCR, FDI</td>
<td>85%</td>
<td>54%</td>
</tr>
<tr>
<td>deltoid, triceps, EDC, FDI, FCR</td>
<td>84%</td>
<td>58%</td>
</tr>
<tr>
<td>biceps, triceps, PT, APB, FCU</td>
<td>91%</td>
<td>60%</td>
</tr>
<tr>
<td>With Paraspinals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>deltoid, triceps, PT, APB, PSM</td>
<td>98%</td>
<td>80%</td>
</tr>
<tr>
<td>biceps, triceps, EDC, FDI, PSM</td>
<td>95%</td>
<td>73%</td>
</tr>
<tr>
<td>deltoid, EDC, FDI, PSM, FCU</td>
<td>90%</td>
<td>73%</td>
</tr>
<tr>
<td>biceps, FCR, APB, PT, PSM</td>
<td>95%</td>
<td>77%</td>
</tr>
</tbody>
</table>

The screen detected the patient with cervical radiculopathy if any muscle in the screen was one of the muscles which were abnormal for that patient. Neuropathic findings for non-paraspinal muscles included positive waves, fibrillations, increased polyphasic potentials, neuropathic recruitment, increased insertional activity, CRDs, or large amplitude long duration motor unit action potentials. For paraspinal muscles the neuropathic category included fibrillations, increased insertional activity, positive waves, or CRDs. Spontaneous activity referred only to fibrillations or positive sharp waves.

APB = abductor pollicis brevis; CRD = complex repetitive discharge; EDC = extensor digitorum communis; FCR = flexor carpi radialis; FCU = flexor carpi ulnaris; FDI = first dorsal interosseous; PSM = cervical paraspinal muscles; PT = pronator teres. (Adapted with permission, Dillingham and colleagues:11)

If none of the six muscles are abnormal, the examiner can be confident in not missing the opportunity to confirm by EDX that a radiculopathy is present, and can curtail additional painful EMG studies. The patient may still have a radiculopathy, but other tests such as MRI will be necessary to confirm this clinical suspicion. This logic is illustrated in Figure 2.

**LUMBAR SPINAL STENOSIS**

There are fewer studies examining spinal stenosis and EMG. For lumbosacral spinal stenosis, Hall and colleagues showed that 92% of persons with imaging confirmed stenosis had a positive EMG.24 They also underscored the fact that 46% of persons with a positive...
EMG study did not demonstrate paraspinal muscle abnormalities, only distal muscle findings. For 76% of patients, the EMG showed bilateral myotomal involvement.²⁴

<table>
<thead>
<tr>
<th>MUSCLE SCREEN</th>
<th>NEUROPATHIC</th>
<th>SPONTANEOUS ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Without Paraspinals</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>deltoid, APB, FCU</td>
<td>93%</td>
<td>66%</td>
</tr>
<tr>
<td>triceps, PT, FCR</td>
<td>87%</td>
<td>55%</td>
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<tr>
<td>biceps, triceps, FCU</td>
<td>88%</td>
<td>64%</td>
</tr>
<tr>
<td>EDC, FCR, FDI</td>
<td>94%</td>
<td>64%</td>
</tr>
<tr>
<td><strong>With Paraspinals</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>deltoid, triceps, PT,</td>
<td>99%</td>
<td>83%</td>
</tr>
<tr>
<td>APB, EDC, PSM</td>
<td>96%</td>
<td>75%</td>
</tr>
<tr>
<td>biceps, triceps, EDC,</td>
<td>94%</td>
<td>77%</td>
</tr>
<tr>
<td>FDI, FCU, PSM</td>
<td>98%</td>
<td>79%</td>
</tr>
</tbody>
</table>

APB = abductor pollicis brevis; CRD = complex repetitive discharge; EDC = extensor digitorum communis; FCR = flexor carpi radialis; FCU = flexor carpi ulnaris; FDI = first dorsal interosseous; PSM = lumbosacral paraspinal muscles; PT = pronator teres.

**LIMITATIONS OF THE NEEDLE ELECTROMYOGRAPHY SCREEN**

These cervical and lumbosacral muscle screens should not substitute for a clinical evaluation and differential diagnosis formulation by the EDX physician. Rather, the information from investigations described earlier in the article allows the EDX consultant to streamline the EMG evaluation and make more informed clinical decisions regarding the probability of missing an EDX-confirmable radiculopathy when a given set of muscles are studied. Performing a focused history and physical examination is essential, and these screens should not supplant such clinical assessments or a more detailed EDX study when circumstances dictate.

It is important to remember that the EMG screens for cervical and lumbosacral radiculopathies were validated in a group of patients with limb symptoms suggestive of radiculopathies. These screens will not provide sufficient screening power if a brachial plexopathy is present or if a focal mononeuropathy such as a suprascapular neuropathy is the cause of the patient’s symptoms. The EDX physician should always perform EMG on weak muscles to increase the diagnostic yield. The six muscle EMG tests do not sufficiently screen for myopathies or motor neuron disease. It is incumbent upon the EDX physician to formulate a differential diagnosis and...
methodically evaluate for the diagnostic possibilities, further refining the examination as data are acquired.

**SYMPTOM DURATION AND THE PROBABILITY OF FIBRILLATIONS**

In the past, a well-defined temporal course of events was thought to occur with radiculopathies despite the absence of studies supporting such a relationship between symptom duration and the probability of spontaneous activity in a muscle. It was a commonly held notion that in acute lumbosacral radiculopathies, the paraspinal muscles denervated first followed by distal muscles, and that later reinnervation started with paraspinal muscles and then with distal muscles. This paradigm was recently challenged by a series of investigations. Diagnostic EMG findings, manifested as a result of these processes, cannot be predicted by this overly simplistic, symptom-duration explanation. Symptom duration should not be invoked to explain the presence or absence of paraspinal or limb muscle spontaneous activity in persons suspected of having a radiculopathy.

**IMPLICATIONS OF AN ELECTRODIagnostically CONFIRMED RADICULOPATHY**

It is important that the EDX physician not forget that EMG does not indicate the exact cause of the symptoms, only that axonal loss is taking place. A spine tumor, herniated disc, bony spinal stenosis, inflammatory radiculitis, or severe spondylolisthesis can all yield the same EMG findings. This underscores the need to image the spine with MRI to assess for significant structural causes.

![Suspected Radiculopathy]

- Six muscles (with PSM) - lumbar screen
- Six muscles (with PSM) - cervical screen

**If one muscle is positive, expand study**

Determine if EMG reflects:
1) Radiculopathy (which level),
2) Entrapment neuropathy,
3) Generalized condition, or
4) Findings that are of uncertain relevance

**If all muscles are negative, stop EMG exam in this limb**

*The patient will not have an electrodiagnostically confirmable radiculopathy*

They may:
1) Not have a radiculopathy, or
2) Have a radiculopathy but you will not confirm this with EMG. Other diagnostic tests must be utilized such as MRI.

Figure 2  Implications of an electromyography (EMG) screening evaluation.
Evaluating the Patient With Suspected Radiculopathy

AANEM Course

There are few studies that examine outcomes and the usefulness of EDX in predicting treatment success, the exception being surgical outcomes for lumbar discectomy. Tullberg and colleagues evaluated 20 patients with lumbosacral radicular syndromes who underwent unilevel surgery for disc herniations. They evaluated these patients before surgery and 1 year later with lower limb EMG, NCS, F waves, and SEPs. They showed that the EDX findings did not correlate with the level defined by computerized tomography for 15 patients. However, those patients in whom EDX testing preoperatively was normal were significantly more likely to have a poor surgical outcome (p<0.01). In spite of the fact that the sample size in this study was small, the significant correlation of a normal EDX study with poor outcome suggests that this may be a true relationship.

Spengler and Freeman described an objective approach to the assessment of patients preoperatively for laminectomy and discectomy for lumbosacral radiculopathy. Spengler and colleagues confirmed and underscored these previous findings regarding objective methods to assess the probability of surgical success preoperatively. In this preoperative screening evaluation, the EMG findings were combined with imaging, clinical, and psychological assessments. The EMG findings figured prominently (one quarter of the scale) — those patients with positive EMGs were more likely to have better surgical outcomes. This was particularly true when the EMG findings correlated with the spinal imaging findings in a person without psychological or dysfunctional personality issues.

It has become apparent over the last 2 decades that the natural history of both lumbosacral radiculopathy and cervical radiculopathy, with or without structural findings on MRI, is very favorable. A classic investigation by Henrik Weber showed that surgery for a herniated nucleus pulposis causing sciatica was more effective at pain control at one year, but beyond that conservative treatment had equal results compared to the surgically managed group. Of particular note was the fact that weakness did not correlate with outcome and even for persons with motor weakness, a good outcome with conservative treatment was the norm, and surgery did not improve motor return. Other investigators in cohort outcome studies demonstrated that the majority of persons suffer-
ing lumbosacral radiculopathy can resolve their symptoms.\textsuperscript{5,27,40,61} In fact, on follow-up MRI studies, lumbosacral disc herniations and disc fragments resolve in 76% of patients.\textsuperscript{5}

The outcomes for cervical radiculopathy are generally good in the absence of myelopathy.\textsuperscript{50}

Saal, Saal, and Yurth demonstrated that persons with cervical disc herniations have a similar favorable clinical course as persons with lumbosacral radiculopathy.\textsuperscript{50} These patients were managed with pain management strategies incorporating medications, rehabilitation with cervical traction and exercises, and epidural or selective nerve root injections if medications failed to control pain. In this series, the majority of patients (24 of 26) achieved successful outcomes.

**SUMMARY**

One cannot minimize the importance of the clinical evaluation and differential diagnosis formulation by the EDX physician to guide testing. The needle EMG examination is the most useful EDX test but is limited in sensitivity. Electromyography screening examinations using six muscles are possible that optimize identification yet minimize patient discomfort. Electrodiagnostic findings must be interpreted relative to the patient’s clinical presentation, and the consultant should tailor the EDX study to the clinical situation. Electromyography complements spinal imaging and often raises other diagnostic possibilities in addition to confirming clinical suspicions.

**REFERENCES**


