The Role of EMG/NCV in the Evaluation of Spinal Nerve Root Lesions/Radiculopathies
Learning Objectives:

• At the end of this session the learner should be able to:
  – State anatomical considerations in root lesions
  – State the basic findings for nerve conduction studies in nerve root lesions
  – State the basic findings for electromyography in nerve root lesions
  – State the optimal screening for lumbar and cervical radiculopathies
  – State the advantages and limitations in electrophysiological studies in evaluating nerve root lesions

The Main Points

• Exam findings in radiculopathy:
  – + needle EMG changes
  – Normal sensory studies, normal motor studies *
  – Prolonged H reflex in S1 radiculopathies [possibly in C7 (6)]
  – Good sensitivity, high specificity (low false +)

• Needle EMG
  – Directly assesses physiologic integrity of roots (prognostic and diagnostic)
  – Tests the MOTOR (ventral ramus) side of a root injury only for axon loss pathology (demyelination not testable by needle exam! - may be testable by NCS late responses)
  – Will most likely be positive only if two or more clinical signs of root injury are present but...
  – May reveal changes in the face of a normal/confusing clinical exam

• EMG/NCV can’t be used to EXCLUDE a radiculopathy
  – Time sensitive (not early > 21 days, not too late < 6 mos c-spine, 18 mos L-spine, (ie false negatives increase)
  – Needle exam frequently normalizes with persistent sensory complaint

• Etiology and anatomic site of pathology is not determined by EMG/NCV
• Optimal screen for C/L spine radiculopathy is 6 muscle to include PVMS
Anatomy

Cross Section Spinal Cord and Meninges

Location of N root compression

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Vertebral Components

- Note borders of the Intervertebral Foramen (IvF)
- Roots/Spinal nerve secured to superior portion of IvF and zygapophyseal joint by connective tissues
- Spinal nerve occupies 7-22% of IvF space (25-30% at L5 IvF)

Ligamentous Components

- Lumbar PLL
  - Cruciform shape
  - Narrow across posterior disc with broad attachments to vertebral bodies
- LF covers laminar gap – can hypertrophy
Transforaminal Ligaments

- Spans exterior of IvF
  - Divides IvF
  - Approx. 47% incidence
  - (A) most common
  - Ossification and entrapment possible
  - Mostly documented in L-spine

A = Superior corporotransverse ligament

Spinal Column

- Note how spinal cord (SC) segment levels and spinal nerve (SN) exit points differ proximal to distal
  - Due to differential growth rates of cord and column
  - SC ends at ~ L1 (conus medullaris) continues as the cauda equina (CE) – a group of nerve roots (not SNs)
  - DRGs are within IvF – CE lesions are thus sensory preganglionic
  - 8 cervical SNs and 7 vertebrae
  - C1-7 SNs exit above the corresponding vertebra and C8-S5 exit below
Intracanal Arrangement of Lumbosacral Roots

- Upper roots more lateral and lower roots more medial (esp. L4-S1)
- Symmetric for left & right sides
- For each root motor fibers anteromedial; sensory fibers posterolateral

- DRGs: 90% inf. to pedicle, 8% lateral, 2% medial in lateral recess
- S1>L5 DRGs: 32% overlay some aspect of the intervertebral disc

Nerve Root

Medial protrusion at disc level L4–5 rarely affects 4th lumbar nerve but may affect 5th lumbar nerve and sometimes 1st–4th sacral nerves
Nerve Root

Lumbar disc protrusion does not usually affect nerve exiting above disc. Lateral protrusion at disc level L4–5 affects 5th lumbar nerve, not 4th lumbar nerve. Protrusion at disc level L5–S1 affects 1st sacral nerve, not 5th lumbar nerve.

Lumbar Root Anomalies

- Possible to implicate involvement of two roots
- Improper example: “Evidence of L4 and L5 HNP”
- ** EMG/NCS is a physiological test not anatomical
Nerve Root

- Discogenic
  - HNP vs. chemical radiculitis
- Degenerative
  - Central stenosis – inferior facet osteophytes
  - Lateral stenosis – loss of disc height or facet subluxation
  - Spondylosis, spondylolysis, spondylolisthesis

Nerve Root - History

- Back pain accompanied by a radiating pain down the posterior or lateral leg, past the knee
  - “sharp, burning, stabbing, or electrical”
- Superficial, well-localized
- Associated w/ numbness or paresthesias
- Subjective and /or objective weakness
- Aggravating factors (cough, sneeze, strain)
Pathophysiology of Radiculopathies

- Root compression typically due to disc degeneration, bony hypertrophy or hypermobility
  - Additionally: ischemia and inflammatory response
- Varying clinical presentation
  1. Most common: S&S of sensory fiber compromise alone
  2. Motor + sensory
  3. Motor alone

Pathology dependent on type and amount of pressure (L/S spine)

- Most HNPs are posterolateral toward IvF
- Root adhered to disc material; elevated superiorly against facet joints; encroached by bony facet joint hypertrophy
- Ventral root involved to a greater degree than DRG and SN – slight compression affected DRG more
  - Microscopically DRG (w/in 1 cm of SN) exact site of compression
- Usually due to series of small insults – maybe due to root “tension” in the L/S spine
- Extra/Intraneural edema compromises vasculature
  - Deleterious to DRG; roots lack protective tissue
- Rapid onset: > fnx affect, < recovery
- High Force: > fnx affect, < recovery, sensory > motor
Pathophysiology (cont)

• Axon loss lesion
  – May result in spontaneous potentials in the appropriate myotome, which may be detected with needle examination
  – In chronic lesions, detection may depend on MUP changes
  – Electrophysiological testing is preferential to detecting axonal loss

Pathophysiology (cont)

• Focal demyelination
  – Can result in complete or partial conduction block with resultant weakness
  – Reflex changes
  – Not “seen” with EMG! – Possibly seen with abnormal H-reflex and F-wave late responses but can not be definitively identified
  – NCS tests large myelinated fibers
  – However, pain is mediated by smaller myelinated and unmyelinated fibers
Electrophysiological Procedures Used in Diagnosis of Radiculopathies

- Sensory nerve conduction studies
- Motor nerve conduction studies
- H reflex
- F wave
- Needle EMG
- Minimal obligation: 1 MNCS, 1 SNCS, H-reflex in L/S lesions, 1 extremity EMG w/ paraspinal mm.

Sensory Studies in Radiculopathy

- Typically **normal** even with fixed sensory deficit on clinical exam
- Due to lesion being proximal to DRG
- Normal finding is **useful diagnostically** as it implies any lesion is proximal to DRG (i.e. excludes plexopathy)
- When abn usually dec amplitude or absent
  - Compare to contralateral
- Remember, however, in the L-spine it’s possible the DRG can reside proximal to lVf and thus may be affected (esp. L5)
- Likewise, DRGs can be affected in polyradic/ganglionopathies (e.g. DM polyradic)
Sensory Studies in Radiculopathy

• Cervical Radiculopathies:
  – D1/2 – C6, Med n., LC, UT
  – D3 – C7, Med n., LC, MT
  – D5 – C8, Ul n., MC, LT
  – LABC – C6, MusCut nn., LC, UT
  – Sup. Rad. – C6, Rad n. PC, UT
  – MABC – C8/T1, MC, LT

• Lumbosacral Radiculopathies:
  – Sup. Fib. – L5, Fib n., Fib portion of sciatic n., post. div. of sacral plexus
  – Sural – S1, Fib and Tib nn., Fib/Tib portions of sciatic n. post./ant. div. of sacral plexus
  – Saph. – L4 (ankle) L3/4 (knee)*, femoral n., post. div. of lumbar plexus
  – Lat. Fem. Cut.* – L2/3, post. div. of lumbar plexus
    • * caution

Motor Conduction Studies in Radiculopathy

• Typically normal, but...
  – Amplitude may be affected in extreme axonal loss injuries
    • Reflection of loss of viable fibers supplying the muscle
    • More likely in CE/multi-level lesions
  – Amplitude loss is uncommon due to:
    1. Multiple root level innervations
    2. Incomplete root compromise
    3. Focal demyelinating pathology
  – NCV/latency remain normal
H Reflex

- Miller et al, 1999 *Muscle & Nerve*, showed Sn/Sp for cervical H reflex (multiple levels) at 72/85%, respectively..... technically challenging
- Most consistent in gastroc-soleus, less consistent in FCR
- Tibial considered a sensitive measure for evaluating S1 radiculopathies, Median – C7>6
- Typically, long latency is the major abnormality, some have suggested amplitude changes but not reliable
- Advantage: evaluates proximal sensory root fibers
- Normal side-to-side comparison latency values:
  - Tibial <1.2 ms; Median <1.0 ms
- Disadvantage:
  - Tibial most reliable study; Median more inconsistent
  - Pathology anywhere along the pathway may be source of the slowing (motor or sensory)
  - Often absent in cases of polyneuropathy and in elderly
Nerve Root - EDx

- Late responses
  - H-reflex
    - 50% sensitive for S1 radiculopathy
    - 6% sensitive for L5 radiculopathy
    - Specificity of 91%
  - F-wave
    - Screening exam for polyneuropathy, plexopathy, or sciatic neuropathy

F-wave

- Gamma motor: eff/aff
- Stim
- Muscle
- 8cm
- F wave
- 30 ms UE
- 50 ms LE
F wave

- Maximal stimulation, activates AHC’s, orthodromic action potential to the muscle
- Yields a low amplitude, variable response
- Minimal latency most often utilized
- Widely used but its effectiveness for root injuries questionable
- Commonly done for median/ulnar/tibial/peroneal
- Advantage: test of long loop
- Disadvantages:
  1. Assesses only motor fibers
  2. Slowing may be obscured due to the long pathway
  3. Multiple root innervation may mask problems at single root

Needle Electrode Examination (EMG)

- Single most useful electrophysiologic method for radiculopathy
- Several muscles assessed in adjacent myotomes
- Positive if abnormalities are present in two or more muscles from same root and different peripheral nerves
- Paraspinals routinely assessed, but absence of findings does not rule out radiculopathy - why?
- Assesses only motor root fibers
Abnormalities

• Spontaneous activity - Fibs, PSWs (CRDs, Fasics in chronic lesions)
• Polyphasic MUP, or timing problems show that there has been previous damage and axon regeneration
• Motor unit drop out - Fast firing rates
• Decreased interference patterns

Summary of Electrophysiological Findings in Radiculopathy

• +/- Normal motor studies (decreased amplitude possible, but rare)
• Normal sensory studies
• +/- Prolonged F wave
• +/- Prolonged H reflexes
• Abnormal EMG in muscles sharing the same root innervation, different peripheral innervation
Diagnostic Aim of EMG Examination in Radiculopathy

• Four fold:
  1. Exclude a more distal lesion (plexopathy, common Fibular n. at fibular head...)
  2. Confirm evidence of root compression
  3. Localize compression to either single or multiple roots or myotomes (anterior horn cells)
  4. “Quantify” extent and severity of lesion

Sensitivity of Needle Exam

• Sensitivity: 50-71%
  – Berger AR. Neurology. 1987. 34 patients, Compared root stimulation to needle EMG. 47/61% (grouping)
  – Waylonis. Arch Phys Med. 1968. 113 patients, 72%
  – Hong et al. Ortho Review. 1986. Retrospective study. Reviewed clinical exam, XR, needle EMG. 51%
  – AAEM Review, Muscle Nerve 1999. 50-71%
• Specificity: “Likely high” AAEM. Poorly reported.
  – Hong et al. In 404 normal myotomes, 1.5% abnormal rate
  – Estimated at approx 80% (2001, M&N, Comparison of Needle EMG and MRI in L-S radiculopathy)
Cervical Radiculopathy Screen

- Six Muscle Screen w/ PVMs identified 94-96% of all cervical radiculopathies (not the specific level)
  - Delt, Tri, PT, APB, EDC, PVMs
    - 99% showed neuropathic changes; 83% spontaneous potentials
  - With PVMs: 5 muscles = 90-98%; 7 muscles = 96-100%
  - Without PVMs: 8 muscles = 92-95%


Lumbar Radiculopathy Screen

- Six Muscle Screen w/ PVMs identified 98-100% of all lumbar radiculopathies (not the specific level)
  - Add, MGas, PTib, Atib, ShBF, PVMs
    - 100% showed neuropathic changes; 93% spontaneous potentials
  - With PVMs: 4 muscles = 88-97%; 5 muscles = 94-98%; 7 muscles = 99-100%
  - Without PVMs: 8 muscles = 87-90%

EMG of Paravertebral Muscles
“To be or Not to be”

- PVMs are not an ABSOLUTE requirement for the identification of a root lesion
  - If no findings in PVMs you can not definitively rule out a root lesion
    - If cervical lesion suspected eval serratus anterior
    - Reinnervation may be complete or keeping pace w/ denervation
    - Patient unable to relax

- If only findings in PVMs you can not definitively rule in a root lesion
  - Could have entrapment MB of the dorsal primary rami, anterior horn cell disease, muscle fiber disease, polyradiculopathy
  - 25-40% of radics have findings only in PVMs*
  - Some evidence suggests that radiating and non-radiating LBP can be from a compromise of the dorsal primary rami due to segmental hypermobility
  - Previous spinal surgery?
  - Chronicity of the symptoms
EMG of Paravertebral Muscles

• Multifidi musculature (deepest PVM layer) is the least polysegmentally innervated
• MUST attempt to evaluate the multifidi
• See handout for proper technique

When EMG/NCS findings do not conform what’s anticipated

• WHY?
• Individual variations in muscle innervation
• Variations in myotomal charts used by examiner
• Few nerve fibers are affected - mild compromise
• Reinnervation is keeping pace with or exceeding denervation
• Pre or Post-fixed innervations and other anatomical variations
• Chronicity of the lesion
• Examiner error
Cervical Radiculopathy

• 2nd most common area for root involvement
• Frequency:
  – C7: 69% Marinacci, Yoss
  – C6: 19-25%
  – C8: 4-10%
  – C5: 2-12%


Findings

• C3/4 – rare; EMG/NCS of little value; clinical dx
• C5/6
  – Can be difficult to differentiate
  – Biceps (C5-6), Brachioradialis & supinator(C5-6), deltoid (C5-6), infraspinatus (C5-6), ECR (C6-7)
  – + Rhomboids implicates C5
  – + pronator teres (C6-7), FCR (C6-7) likely C6, serratus anterior (C5-6-7), likely 6
  – Normal motor/sensory studies, normal F waves
  – Abnormal Median/FCR H-reflex implicates C6
  – Often C5/6 grouped together – physiological limitation of the study
C7
  - Most common
  - Triceps (C-6-7-8), anconeus (C7-8), pronator teres (C6-7), FCR (C6-7), EDS (C7-8), Latissimus Dorsi (C6-7-8), serratus anterior (C5-6-7), likely 7
  - ? Has been suggested if Triceps normal after careful exam then C7 unlikely?
  - Normal motor/sensory studies, normal F wave
  - Possible abnormal H reflex (FCR)

C8/T1
  - Difficult to differentiate, C8 more often
  - + ulnar muscles, + median APB (C8-T1), FPL(C7-8), FCU (C8-T1)
  - * additional findings in radial C7-8 muscles such as EIP (C7-8) & EPL (C7-8), likely C8
  - * no findings in APB might suggest C8
  - + findings in serratus anterior likely not solely C8
  - Normal motor and sensory studies
  - +/- F wave

* has been suggested by some that radial has some T1 and that ABP is pure T1

Lumbosacral Radiculopathy

- L5, S1 roots most commonly affected
- Findings often restricted to muscles below the knee due to reinnervation patterns
- Differences from cervical compressions:
  - Most compressions occur in the intraspinal canal vice foramen
  - Multiple levels may be affected by single disc herniation
  - “Essential” to check contralateral limb even if asymptomatic (AAEM guideline)
- Knowledge of root affected has less predictive value as to anatomic level of compromise
- L4 disc herniation:
  - Post lateral = L5 root
  - Far lateral = L4 root
  - Central = S1 root
L2,3,4

- Uncommon
- Evaluation is suboptimal
  - Limited limb representation
  - More proximally located muscles, tend to reinnervate sooner
  - Majority of muscles = femoral nerve, differentiation difficult
  - No reliable SNAP to differentiate from plexopathy
- Findings:
  1. Vastii, thigh adductors, iliacus, tib anterior
  2. Normal saphenous SNAP
  3. +/- paraspinals

L5 Radiculopathy

- + EMG findings (abnormalities)
  - +/- paraspinals
  - peroneal muscles
    - Per longus, tib anterior
  - Tibial muscles
    - Tib posterior, FDL, medial hamstrings, TFL, glut medius
- Normal motor studies
- Normal sup peroneal SNAP (deep fibular)
- Must differentiate from compression of common peroneal nerve (fibular n) at fibular head
  - Motor studies across fibular head
  - Needle study of SH of biceps, tib posterior, FHL

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S1 Radiculopathy

- + EMG findings
  - +/- paraspinals
  - Med gastroc, foot intrinsics, flex digitorum longus, EDB, lateral hamstrings, glut maximus
  - Abnormal H reflex
  - Normal sural SNAP (< age 60)
- Often bilateral due to midline orientation of sacral fibers in cauda equina

Lumbar Canal Stenosis

- Diverse EMG changes
- Normal, to bilateral and severe changes
- Assess H reflex and EMG bilaterally
- Most common findings:
  - Bilateral and asymmetrical L-S radiculopathies affecting L5, S1 and S2 roots
  - Severe axon loss with reduced motor amplitudes
Limitations

- If dorsal root is the only root compressed, EMG examination is normal. Normal EMG does NOT exclude a root compression.
- Time dependence
  1. Most sensitive finding are fibrillations in a myotomal distribution
  2. These don’t occur until 14-21 days post injury, recede proximal to distal
  3. Reinnervation occurs proximal to distal, and occurs even if decompression doesn’t occur
  4. Needle exam then normalizes, even in the face of persistent clinical symptoms, especially sensory component
  5. Many false negative exams for cervical compression > 6 months, lumbosacral > 12-18 months
- Lower extremity SNAP frequently absent in elderly, differentiating pre from post ganglionic lesion is difficult
- Anatomic site of the lesion in regards to disc levels unknown

Benefits

- Only study that directly assesses the physiologic integrity of the roots
  - Diagnostic and prognostic
- Helps determine if anatomic abnormalities are functionally or clinically relevant
- EMG may reveal changes in the presence of a normal clinical examination
- EMG may reveal changes in the presence of other normal studies (radiologic etc)
- False positive rate is low
- Low morbidity, can be used to follow course over time
- Rules out other confusing factors; peripheral neuropathies
Summary:

- Differences between electromyography and nerve conduction studies
- Basic findings for nerve conduction studies in nerve root injuries
- Basic findings for electromyography in nerve root injuries
- Advantages and limitations in electrophysiological studies in evaluating nerve root injuries