MRI of Peripheral Nerves
And
Entrapment Syndromes

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Plan of Attack
- Nerve anatomy
- Basic classification of nerve injury
- Basic understanding of advantages of MR protocols
- Nerve disorders

Nerves
Enclosed, Cable-like Bundle of Axons

- Axon (nerve fiber) is a long, slender projection of a nerve cell that transmits electrical impulses
- Axon is one of 2 types of protoplasmic protrusions that extrude from the cell body of the neuron, the other being dendrite.
- Axons transmit signals away from the neuron's cell body, whereas dendrites receive signals.
- Axons make contact with other cells (usually other neurons) at junctions called synapses.
- Axons can be microscopic 1 to 20 microns in diameter but can be several feet in length.
- Axons are sheathed in myelin formed by glial cells (Schwann cells in peripheral nervous system/oligodendrocytes in the CNS).
- Along the myelinated axons, gaps in the sheath known as nodes of Ranvier occur at evenly spaced intervals.

Nerve Anatomy

PERINEURTIUM:
Multiple layers of perineurial cells, basal laminae, and extracellular matrix interspersed with a network of thin collagen fibers.
- The internal layer forms the BLOOD-NERVE BARRIER.

INTERNAL EPINEURITUM:
Thick, densely packed collagen fibers in a herringbone pattern in longitudinal orientation.
3T MR Extremity Neurography Protocol
High Resolution 3D MRI and Diffusion

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<th>3T MR Extremity Neurography Protocol</th>
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UTE MRI with Variable TI

Contrast Manipulation (TE 10 microseconds)

TI 280 ms
- Inversion pulse at 280 ms nulls the signal of the fascicles (neural tissue + perineurium)

TI 160 ms

Ultra High Field Nerve Evaluation

11.7 T Gradient echo

External epineurium
Internal epineurium
Perineurium
Endoneurium

Nerve Imaging Evaluation Features

- Size
  - Caliber similar to adjacent vascular structures
  - Decreases proximal to distal
- Signal
  - Normal signal isointense to muscle on T1- and T2-weighted images
- Fascicular appearance
  - Uniform in size
- Course
  - No focal deviation, smooth course
- Enhancement
  - Normal nerves do not enhance due to preserved blood nerve barrier

Nerve Imaging Evaluation Features

- Signal
  - Normal signal isointense to muscle on T1- and T2-weighted images (tibial nerve shown here)


Nerve Imaging Evaluation Features

- Fascicular appearance
  - Uniform in size (in this case, slightly increased SI consistent with mild injury)

MRN Interpretation Pitfalls

• Subject to magic angle phenomenon
  Kastel, et al., AJNR 2011 32: 821-827

• Suboptimal fat suppression and image blurring 1.5T STIR

• Suboptimal fat suppression and image blurring 1.5T STIR compared with 3T 3D STIR SPACE MIP reconstruction

MRN Interpretation Pitfalls

MR Characterization of Peripheral Nerve Injury

• Increased in signal
  • Depends on endoneurial fluid and background fat suppression
  • Causes of increased signal
    • Vascular congestion
    • Block of axoplasmic flow, leading to proximal accumulation of endoneurial fluid
    • Wallerian degeneration

MR Characterization of Peripheral Nerve Injury: Signal Changes

Traditional Classification of Nerve Injury

• Neurapraxia – Preserved fasciculation, subtle SI change
• Axonotmesis – Absent fasciculation, clear SI change
• Neurotmesis – Nerve transaction
Sunderland Classification

- I and II degree injuries correspond to neurapraxia and axonotmesis
- III degree injury involves endoneurium
- IV degree injury involves perineurium
  - MRI appearance typically shows neuroma in continuity
    - Regenerating nerve sprouts unable to grow down disrupted fascicles
tangle in conjunction with perifascicular and intrafascicular fibrosis to form neuroma (seen in continuity with proximal and distal uninvolved nerve segments)
- V degree injury involves epineurium
  - MRI appearance of complete nerve discontinuity

Neurapraxia
Preserved Fasciculation - Subtle SI Change

- Injury involves only the myelin sheath around the axon with resultant transient functional loss and associated with excellent prognosis
- MRI shows abnormal T2 hyperintensity and mild enlargement of the nerve
- Milder MR appearance seen in stretch injury, nerve entrapment (tunnel syndromes), compression from space-occupying lesions

Axonotmesis
Absent Fasciculation – Clear SI Change

- Axon suffers complete rupture resulting in wallerian degeneration of distal segment, however supporting structures including perineurium and epineurium remain intact
- Prognosis good, but axonal regeneration is limited
day
- MRI findings include effacement, enlargement or disruption of individual fascicles
- Similar appearance with moderate to severe nerve entrapment

Neuroma

- Any nerve lacerated, avulsed or traumatized may form a neuroma
- Classified into 2 basic types:
  - NIC – Neuroma in Continuity
    - Proximal spared nerve fascicles sprout in attempt to unite
    - Due to lattice disruption, reorganization, regeneration, hypertrophy of nerve fascicles, and associated fibrosis, proximal and distal nerve fibers at site of injury may fail to appose
  - End-bulb neuroma
    - Occur anywhere a nerve is completely divided and unopposed by another neural tissue

Neurotmesis
Nerve Transection

- Most severe type of injury and refers to complete severance of the nerve
- Functional loss complete and without surgical intervention no recovery anticipated
- MRI appearance acutely shows nerve discontinuity with fluid filled gap and granulation tissue
- Fibrosis at injury site typically seen in subacute and chronic stages as strandy hypointense soft tissue within the nerve gap on T2-weighted images


Chhabra, et al., AJNR 2010 31: 1363-1368

Chhabra, et al., Skeletal Radiol 2012 41: 257-271

Chhabra, et al., Skeletal Radiol 2012 41: 257-271

Chhabra, et al., Skeletal Radiol 2012 41: 257-271

Chhabra, et al., Skeletal Radiol 2012 41: 257-271

Chhabra, et al., Skeletal Radiol 2012 41: 257-271

Chhabra, et al., Skeletal Radiol 2012 41: 257-271
Neuroma in Continuity

- Distinguished from neurogenic tumors by presence of surrounding scarring, lack of a split fat or target sign and absence of abnormal enhancement

Chhabra, et al., AJNR 2010 31: 1363-1368

Secondary Findings Nerve Injury

- Muscle signal changes
  - Shown to represent shift between intra- and extracompartmental fluid components and do not reflect real edema
  - Edema-like SI may manifest as early as 24 hours after onset of neuropathy
  - Subacute changes, edematous SI and minimal fatty replacement, weeks to months
  - Chronic changes, fatty replacement and atrophy months to years after injury

Bendszus, et al., AJNR 2002 23: 1427-1431

Peripheral Nerve Disorders

- Injury or entrapment
  - Suprascapular and Axillary nerves
- Compressive
  - Suprascapular and Axillary nerves
- Intraneural ganglion
- Inflammatory/dysmyelinating
- Radiation

Intraneural Ganglion

- Theories of Pathogenesis
  - Degenerative
    - Mucoid degeneration of the epineurium leads to cyst formation
  - Articular
    - Fluid dissects through the epineurium from the joint
  - Tumoral
    - Tumor within the epineurium involutes with cystic degeneration


Intraneural Ganglion

- Synovial Theory of Pathogenesis
  - Cyst fluid dissects from a degenerative synovial joint along an articular nerve branch
  - Fluid follows path of least resistance
  - Pressure fluxes further alter cyst dimensions, configurations, and directionality >> waxing-waning clinical symptoms

http://www.backpain-guide.com
**Intraneural Ganglion**

**Synovial Theory of Pathogenesis**

**Imaging Findings – Popliteus Denervation**
- Popliteus changes
  - Edema (denervation change)
  - Tibial nerve - Articular branch

**Imaging Findings – J Sign**
- Tibial nerve
  - Posterior to anterior hook of articular branch

**Imaging Findings – Signet Ring**
- Eccentric displacement of nerve fascicles by cyst

**Imaging Findings – Clock Face Pathology**
- Tibial nerve articular branch – 9 o’clock
- Signet ring sign – 4-5 o’clock
- Transverse limb sign – 12:2 o’clock

**Entrapment Syndromes Upper Extremity**
- Brachial Plexus at the Thoracic Outlet
- Entrapment at the Shoulder
  - Musculocutaneous Nerve
  - Suprascapular Nerve
- Entrapment at the Arm and Elbow
  - Radial Nerve (Arm)
  - Ulnar Nerve (Elbow)
  - Radial Nerve and Posterior Interosseous Nerve (Elbow)
- Median Nerve and Anterior Interosseous Nerve (Elbow)
- Medial Nerve (Elbow)
- Median Nerve
- Palmar Cutaneous Branch of the Median Nerve
- Superficial Branch of the Radial Nerve

Entrapment Shoulder: Suprascapular Nerve

- From upper trunk of brachial plexus, C5 and C6 nerve roots
- Motor fibers to the supraspinatus and infraspinatus muscles
- Sensory fibers to the glenohumeral and A-C joints

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Entrapment Shoulder: Suprascapular Nerve

- Spinoglenoid notch perilabral cyst with secondary findings of infraspinatus edema

Shoulder: Suprascapular Nerve

Entrapment Thickened Transverse Scapular Ligament

Shoulder: Suprascapular Nerve

Entrapment Post-Traumatic Scar

- Coracoclavicular ligament injury with fibrous scar and tethered suprascapular nerve
Shoulder: Suprascapular Nerve
Entrapment Post-Traumatic Scar

- Coracoclavicular ligament injury with fibrous scar and tethered suprascapular nerve

Shoulder: Axillary Nerve

- Terminal branch of posterior cord of brachial plexus, contributions from C5 and C6
- Courses along anterior surface of subscapularis muscle, then sharp turn posteriorly to travel along the inferior glenohumeral joint and then enters the quadrilateral space
- Axillary nerve can be injured by trauma following anterior shoulder dislocation
- Axillary nerve can be compressed in the quadrilateral space

Axillary Nerve
Anterior Dislocation – Traction Phenomenon

- Edema deltoid and teres minor post reduction follow-up

Axillary Nerve
Quadrilateral Space

- Superior: Teres Minor
- Inferior: Teres Major
- Medial: Long head triceps
- Lateral: Humerus

Axillary Nerve
Quadrilateral Space Syndrome (Entrapment) – Fibrous Band

- Superior: Teres Minor
- Inferior: Teres Major
- Medial: Long head triceps
- Lateral: Humerus

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**Shoulder: Axillary Nerve**

**Quadilateral Space Syndrome (Compression) – Osteophyte**
- Prominent osteophytes can compress axillary nerve

**Shoulder: Axillary Nerve**

**Posterior Instability with Traction Phenomenon**
- POLPSA with edema teres minor

**Shoulder: Axillary Nerve**

**Posterior Instability with Traction Phenomenon**
- 3% incidence of isolated teres minor atrophy
- Associated findings
  - Rotator cuff 47/61
  - Posterior labral tear 31/61
  - GHJ OA 29/61
- Possible relationship to traction or rotator cuff injury during translational episode

**Elbow: Ulnar Nerve**

- At the midhumerus level, it pierces the intermuscular septum and enters the posterior compartment. The ulnar nerve may pass under the arcade of Struthers and follows a groove in the medial head of the triceps muscle, arriving at the cubital tunnel.
- Cubital tunnel is formed by:
  - Anterior: medial epicondyle
  - Lateral: olecranon
  - Roof: arcuate ligament
- Travels between the humeral and ulnar heads of FCU muscle and enters the anterior compartment of forearm after piercing flexor pronator aponeurosis

**Elbow: Ulnar Nerve**

- Cubital Tunnel Thickened Osborne’s Ligament (Arcuate Ligament)
- Posterior humerus, groove of triceps, proximal to cubital tunnel
- Abnormal caliber, SI and loss of fasciculation
Elbow: Ulnar Nerve
Cubital Tunnel Mass Effect from Anconeus Epitrochlearis/
Hypertrophied Medial Head Triceps

Elbow: Valgus Extension Overload
• With existing valgus instability, elbow slightly subluxed in
  valgus position as flexion occurs

Elbow: Valgus Extension Overload and Posteromedial Impingement
• Ulnar Nerve Injury
• Common Flexor Tendon Injury

Elbow: Radial and Posterior Interosseous Nerve
• SRN superficial to supinator
• PIN courses between heads of supinator

Elbow: Radial and Posterior Interosseous Nerve
• 5 potential sites of compression of PIN:
  Proximal edge of superficial portion of supinator "arcade of
  Frohse" (1)
  Fibrous bands of tissue anterior to radiocapitellar joint
  between brachialis and brachioradialis (2)
  Recurrent radial vessels aka "leash of Henry" (3)
  Edge of extensor carpi radialis brevis (ECRB) (4)
  Distal edge of supinator muscle (5)
**Elbow: Radial and Posterior Interosseous Nerve**

- Brachioradialis (ECRL)
- Extensor carpi radialis brevis
- Extensor digitorum communis
- Extensor carpi ulnaris
- Extensor digiti minimi
- Supinator
- Abductor pollicis longus
- Extensor pollicis brevis
- Extensor indicis proprius

**Elbow: Radial and Posterior Interosseous Nerve**

- Ganglion at level of Arcade of Frohse

**Elbow: Radial and Posterior Interosseous Nerve**

- Thickened ECRB Tendon
  - “Resistant Tennis elbow”
  - Motor neuropathy
  - Deep forearm pain
  - Weakness (loss of extension of all digits and decreased wrist extension)

**Elbow: Median Nerve**

- Crosses elbow, passes deep to bicipital aponeurosis
- Dives into antecubital fossa, medial to both biceps tendon and brachial artery, volar to the brachialis
- Then passes between 2 heads of pronator teres, deep to the humeral head and superficial to the ulnar head
Elbow: Median and Anterior Interosseous Nerve

• AIN courses off main trunk of the median nerve approximately 4 cm distal to medial epicondyle
• Supply: deep muscles of the forearm (flexor pollicis longus (FPL), FDP to the index and middle fingers, and the pronator quadratus)

Elbow: Median and Anterior Interosseous Nerve

Kiloh Nevin Syndrome

• Compression of anterior interosseous nerve in proximal forearm, purely motor
• Motor weakness of FPL, FDP of index and middle finger and Pronator Quadratus
• Unable to form a “O” with thumb and index finger
• Imaging of elbow and forearm: courses over FDP and interosseous membrane
• Causes: Direct trauma (most common), surgery, cast pressure, bulky tendinous origin of ulnar head of pronator teres, mass, accessory muscle

Upper Extremity Nerve Entrapment Take Home Points

• Nerve structure
• MR appearance
• Site specific anatomy
• Manifestations and Distribution of Findings