Traumatic and Non-Traumatic Brachial Plexus Imaging: What the practicing radiologist needs to know

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• No relevant financial relationship to disclose
Objectives

- Review imaging protocol
- Review brachial plexus (BP) anatomy
- Illustrate direct and indirect imaging features of traumatic and non-traumatic brachial plexus pathology
- Demonstrate intra-operative findings
MR Imaging Protocol

Routine BP MR Scan on 1.5T and 3T includes the following basic 6 sequences:
Coronal T1 sequence is key for identifying normal anatomy, peri-neural and interscalene fat planes, and base of neck muscles.
Coronal STIR, and T2 FS sequences are useful for brachial plexus (bp) nerve size and signal with excellent contrast resolution for depicting pathology.
Post Contrast sequence imperative for tumor evaluation, and active inflammation.
* 3T imaging preferred for MR Neurography; we employ Dixon FS Technique to enhance BP evaluation / lesion conspicuity.
MR Imaging Protocol: Dixon FS Technique

Dixon technique: Modified spin echo sequence; separates water and fat images and generates fat suppressed (water only) and water suppressed (fat only) images. Allows for robust fat suppression and superior image quality, decreasing base of neck field inhomogeneity with enhanced nerve evaluation.

Sag T2 non FS sequence: included for enhanced depiction of muscle anatomy including variant muscle slips and fibromuscular bands (eg. accessory middle scalene muscle slip and Sibon’s fascial band), with improved BP nerve evaluation.
Brachial Plexus Anatomy

• Originates from the C5-T1 spinal nerve Roots

• Spinal nerves split into ventral and dorsal rami
  • Dorsal Rami (DR) - Innervate the paraspinal muscles
  • Ventral Rami (VR) - Form the Brachial Plexus Trunks located between the anterior (as) and middle scalene (ms) muscles
    • C5+C6 -- Superior or “Upper” Trunk
    • C7 -- Middle Trunk
    • C8+T1 -- Inferior or “Lower Trunk

More laterally within the posterior triangle of the neck each Trunk divides into 2 forming 3 anterior and 3 posterior Divisions
Brachial Plexus Anatomy

• The 3 anterior and 3 posterior **Divisions** --> 3 **Cords** which form just distal to the *lateral margin of the first rib*
  • *Lateral cord*: Anterior divisions of upper and middle trunks
  • *Posterior cord*: Posterior divisions of upper, middle and inferior trunks
  • *Medial cord*: Anterior division of inferior trunk

• At lateral border of pectoralis minor the 3 **cords** divide into five **Branches**:
  • Median
  • Ulnar
  • Radial
  • Axillary
  • Musculocutaneous
Brachial Plexus Anatomy

The 6 **Divisions** form just lateral to the inter-scalene triangle within the base of neck.

*Case of a 35 yo F with NF-1*
Brachial Plexus Anatomy

The 3 **Cords** form just distal to the lateral margin of the 1\(^{st}\) rib, named with respect to nerve proximity to the coursing axillary artery (AA)

*Case of a 35 yo F with NF-1*
The 5 terminal branches of the brachial plexus form at the border of the pectoralis minor muscle and include: the median, ulnar, musculocutaneous, axillary, and radial nerves.
Outline:

• **Traumatic brachial plexus pathology:**
  • Nerve root avulsion
    • Pre ganglionic nerve avulsion
    • Post ganglionic nerve avulsion
  • Obstetric brachial plexus palsy

• **Non-traumatic brachial plexus pathology**
  • Radiation plexopathy
  • Idiopathic neuritis (aka parsonage turner syndrome)
  • Thoracic outlet syndrome
  • Tumors
    • Neurofibromatosis / Neurofibroma / MPNST
    • Desmoid
Traumatic nerve avulsion: Pre-ganglionic injury

45 yo M s/p MVA with proximal rib and transverse process fx’s at C-T junction

Subacute pre-ganglionic nerve avulsions of the C7 and C8 nerves with pseudomeningocele formation at the C7/T1 level, lateralization of the C7 and C8 dorsal root ganglion (DRG), enlargement and edema of the avulsed nerve stump and indirect right hemi-cord atrophy and edema.
Traumatic nerve avulsion: Pre-ganglionic injury

Key Facts
- Traumatic BPI most commonly due to motor vehicle accidents >> gun shot wounds > sports injuries
- M >> F
- Pre-ganglionic BPI --> signifies avulsion of nerve roots and cannot be repaired
- Muscle functions are restored with nerve transfers; restoration of biceps muscle function and shoulder function is critical

MRI
- Direct findings: lateralized DRG with downstream BP edema, enlargement and signal heterogeneity.
  - Enhancement of the intradural nerve / nerve root signifies functional nerve impairment
- Indirect findings: Pseudomeningocele formation at level of avulsion; acute soft tissue denervation edema/ enhancement and chronic fatty muscle atrophy; acute spinal cord edema and chronic myelomalacia
Traumatic nerve avulsion: Post-ganglionic injury

35 yo M s/p motorcycle crash with T1 TP Fx presenting with neuropathic pain in shoulder and upper back

Sub-acute post-ganglionic nerve injury with focal neurotemesis of C6 with post-traumatic neuroma formation. Post-contrast enhancement of the C6 nerve and proximal most segment of the upper trunk signifies focal inflammation and scarring.
**Traumatic nerve avulsion: Post-ganglionic injury**

35 yo M s/p motorcycle crash with T1 TP Fx presenting with neuropathic pain in shoulder and upper back

**Key Facts**

- **Post-ganglionic BPI -->** Focal nerve fiber / nerve fascicle disruption distal to the DRG
- Injury ranges from stretch injury to full thickness laceration
- Most commonly due to MVA’s +/- C-spine or clavicle fractures
- Nerve fiber disruptions are repaired with nerve grafting (damaged nerve excision and autograft between two ends)

**MRI**

- Direct findings: edema and enlargement along any segment of the BP distal to the DRG +/- focal discontinuity, +/- hematoma and +/- resultant neuroma formation
- Indirect findings: acute denervation edema and chronic fatty muscle atrophy within the paraspinous muscles and/or shoulder girdle muscles.

**Coronal STIR**

*Denervation edema* is present within the rotator cuff muscles which are supplied by nerve branches of the upper trunk of the brachial plexus.
40 yo M s/p motorcycle crash with left sided clavicle fracture and C6 deficits --> laceration of the lateral cord
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Obstetric brachial plexus palsy (OBPP) – Case #1

3 month old with right arm *Erb palsy* since birth. Case shows C6 and C7 nerve root avulsions with pseudomeningocele formation.

| Key Facts | • Downward traction on the shoulder girdle during vaginal birth in setting of shoulder dystocia --> OBPP --> risk of permanent disability and limb deformity  
• Upper level injuries (C5-C7) are the most common; inferior extension of nerve injury occurs with more severe traction |
| MRI | • *Pseudomeningocele* with lateralized DRG when pre-ganglionic  
• Neuroma formation when traction injury distal to the DRG  
  • Range of pathology from stretch injury, to partial or complete nerve avulsion  
• Muscle denervation edema and subsequent fatty atrophy |
5 month old baby girl born full term weighing 9 lbs. who “got stuck”. Baby delivered after “manipulation”, and immediately had no movement of right arm. No functional recovery since birth. Mom reports baby has mild motion of hand and wrist but remains in ulnar deviated position.

- **Erb Palsy**: occurs with upper trunk C5 & C6 lesions — loss of shoulder abduction, shoulder external rotation, elbow flexion, and forearm supination.
- Involvement to middle trunk (C5–C7) — additional loss of wrist extension — waiter’s-tip posture of extended Erb palsy.
- Involvement of the entire brachial plexus (C5–T1) — flail arm that can be associated with Horner syndrome if the T1 contribution to the sympathetic chain is disrupted.
Obstetric brachial plexus palsy: Intra-op correlation

Case #2: Baby went on to surgical neurolysis, and decompression of the upper trunk with neuroma resection and grafting.
Obstetric brachial plexus palsy: Intra-op correlation

Normal view of the brachial plexus upper trunks from contralateral left upper extremity.
Non-traumatic pathology: Radiation plexopathy

65 year old M with RUL lung cancer s/p XRT with right arm pain, neck pain and weakness

**Key Facts**

- Most commonly occurs following axillary, lung apical or base of neck XRT treatment for breast cancer, lung cancer and/or lymphoma
- Sx’s of pain, parathesias, hyperthesias and weakness usually occur in an upper trunk distribution --> weakness of the arm flexors and shoulder abductors

**MRI**

- MR findings include: diffuse uniform swelling, thickening and mild enhancement of the involved BP without focal mass; +/- soft tissue denervation changes
- T2 FS and STIR --> show hyperintense signal of the BP within the XRT field
- Low signal on T1 and T2 FS --> suggests BP fibrosis --> downward BP traction/tethering
- Mild enhancement can be seen in both XRT plexopathy and tumor recurrence; tumor recurrence --> focal mass or asymmetric “mass like” enhancement of the BP

![MR neurogram images show abnormal supra- and infra-clavicluar BP enhancing edema, enlargement/thickening and downward tethering consistent with XRT fibrosis.](image)

Denervation muscle edema

Lung Mass
Non-traumatic pathology: Parsonage Turner Syndrome (PTS)

Key Facts

- PTS is a painful, non-traumatic self-limiting disorder involving the shoulder girdle
- Most patients present with sudden onset of pain +/- weakness, paresthesias and paralysis
- The etiology is unknown although recent viral illness, immunizations and auto-immune disease has been implicated
- The suprascapular nerve is almost always involved >>> axillary and subscapular nerves

MRI

- Smooth enlargement and hyperintense edema signal of the BP on T2 or STIR, most commonly involving the C5-C6 roots and upper trunk with downstream changes in the cords and peripheral nerves
- Multi-focal denervation muscle edema involving more than one nerve distribution

45 year old F with sudden onset L >R shoulder pain.

MR images show smooth, uniform edema of the bilateral BP worse on the left with downstream multi-focal denervation muscle edema in the supraspinatus >>> triceps muscle, deltoid and cranial subscapularis muscles.
Non-traumatic pathology: Thoracic outlet syndrome (TOS)

- **TOS Imaging protocol:** We perform a dedicated MR Neurogram of the BP, in combination with an MRA. Both are performed with dynamic maneuvers.
- **MRA dynamic maneuvers:** Patient is imaged in neutral position with the arms at the side and injected with ½ dose of gadolinium contrast. Subsequently, patient is imaged with the arms in abduction (placed over head) and given the remaining ½ dose of contrast to complete the MRA portion of the study.
- The non-contrast portion of the BP includes a Sag T2 non-FS which is obtained with the arms in neutral position at the patients side, AND again with the patients arms abducted, placed overhead. The Sag non-FS demonstrates nicely anatomy of the costo-clavicular (CC) space with clear definition of the coursing first rib, subclavian artery and subclavian vein and BP. The SCV normally compresses when then arms are abducted, however the SCA remains patent.
Non-traumatic pathology: Thoracic outlet syndrome (TOS)

35 y/o F with history of numbness and tingling during overhead maneuvers

**Key Facts**
- Dynamically induced compression of the neural, arterial, or venous structures crossing the interscalene triangle, costoclavicular space or retropectoralis minor space leads to thoracic outlet syndrome (TOS).
- Contributing soft tissue abnormalities include: Anterior scalene muscle hypertrophy, common origin of anterior and middle scalene muscles, broad middle scalene, post traumatic or post treatment scarring.
- Contributing osseous abnormalities include: cervical rib, elongated transverse process of C7, or abnormal first rib or clavicle deformity.

**MRI**
- Look for focal filling defect in SCV and SCA on Sag T2 FS and Sag T2 non-FS sequences and on concurrently performed MRA in setting of vascular compression.
- Look for loss of peri-neural fat surrounding the BP within the interscalene triangle and/or CC space, +/- close proximity of nerves to bony structures and any anomalous muscle slip or fibrous band (Cor T1, Sag T2 FS and Sag T2 non-FS are key)
Non-traumatic pathology: Thoracic outlet syndrome (TOS)

35 y/o F with history of numbness and tingling during overhead maneuvers

CXR with abnl ankylosis between the 1st - 2nd rib

Sag T2 with arms in neutral

Sagittal T2 with arms abducted

Cor T1 FS PC

★ Abnl rib ankylosis

Sag T2 FS images show a filling defect within the SCA with progressive CC space impingement / narrowing during arm abduction due to abnormal fusion mass between the 1st and 2nd ribs. The coursing distal BP trunks and proximal divisions are getting compressed just distal to the interscalene triangle --> upper extremity neurologic deficits. Cor T1 post contrast image demonstrates non-enhancing thrombus within the left SCA
Non-traumatic, tumor pathology: Neurofibroma

60 yo F with history of neurofibromatosis and a left sided BP plexiform neurofibroma

Key Facts
- Neurofibromas are the most common benign neural tumor to involve the BP
- 1/3 of these tumors occur in patients with NF-1; 2/3’s of cases are sporadic
- The majority are multiple, plexiform and diffusely involve the BP
  - Plexiform neurofibromas are pathopneumonic for NF-1, with increased risk of malignant txf

MRI
- MR best to characterize & define total extent; lesions are most conspicuous on STIR and T2 FS
- Focal neurofibroma --> well circumscribed fusiform mass, hypointense on T1, hyperintense on T2 +/- central low signal “target sign” with either avid or patchy/heterogeneous post contrast enhancement
- Plexiform neurofibroma --> Trans-spatial, multi-lobulated, “rope-like” expansion along a long nerve segment and its branches with T2 hyperintensity and heterogeneous post-contrast enhancement
- MPNST --> less common, usually > 5 cm, with heterogeneous T2 signal and heterogeneous contrast enhancement, +/- progressive invasion/infiltration into adjacent soft tissues.

MR images show an avidly enhancing plexiform neurofibroma involving the distal C5 and C6 nerve roots, upper trunk, anterior division and proximal cords.
35 yo F with NF-1 and diffuse involvement of the BP

MR image show marked enlargement, edema and stippled nodularity of the entire brachial plexus consistent with neurofibromatosis with multiple small nerve sheath tumors. DDx for diffuse nerve thickening includes chronic inflammatory demyelinating neuropathy and Charcot-Marie-tooth disease.

Cor STIR

40 yo F with NF-1 and MPNST

Coron T1WI C+ FS

MR demonstrate a lobulated MPNST (dashed arrow) engulfing the BP (solid arrow) inferolaterally & invading the upper mediastinum (white curved arrow).

** Imaging findings of benign vs. malignant nerve sheath tumors are difficult to distinguish. However, patients usually have increased pain with malignant tumor degeneration.

StatDx
Non-traumatic, tumor pathology: Desmoid

22 yo female with left upper extremity numbness, tingling and palpable neck mass

Pre contrast: classic iso-/hypointense T1 signal, and heterogeneous hyperintense T2/STIR signal with scattered low signal bands representing a mix of spindle cells and collagen stroma.

Desmoid tumors are a locally invasive, benign soft tissue tumor typically seen involving the abdominal wall; extra-abdominal desmoids in the head and neck can encase, and distort the BP --> neurologic deficits

Post contrast: desmoid tumors typically show avid post-contrast enhancement on MRI.

Treatment includes tamoxifen +/- NSAIDS, surgery, and/or XRT
Successful tx response --> decreased tumor size/volume, with decreased T2 hyperintensity and enhancement
Summary

• Understanding the complex anatomy of the brachial plexus is key to interpretation on MRI

• The brachial plexus provides both sensory and motor innervation to the upper extremity

• Recognizing location, and severity of brachial plexus traumatic injuries and non-traumatic pathology aids in early diagnosis, and significantly impacts patient management
References

References

Thank you!

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