Introduction

The ventral rami of the C5-8 and T1 nerve root unite to form the brachial plexus. It is a network of nerve convergences and divergences, which culminate into multiple terminal branches that provide motor and sensory innervation to the upper extremity. The plexus can be affected by a plethora of pathologies that may lead to serious and disabling complications leading to pain and limb weakness. A better radiological insight has a great potential in aiding the physicians render superior services to the patients affected by brachial plexopathy. Due to advancements in the three dimensional (3D) imaging, better fat suppression techniques and superior coil designs for magnetic resonance imaging (MRI) and increasing availability and usage of 3T magnets, the visualization of the complexity of brachial plexus has become facile. There is a steep learning curve to acquiring brachial plexus imaging and interpretation skills. In this session, the attendees will be able to learn the technical considerations, gain knowledge of the normal and abnormal appearance of the brachial plexus segments on high resolution MR Neurography (MRN) imaging, learn the role of 2D and 3D imaging in plexus evaluation and recognize the key imaging features of various pathologies.

Indications for MR Neurography

Magnetic resonance neurography (MRN) is indicated for a number of reasons in brachial plexus evaluation. MRN can be used to confirm the diagnosis of brachial plexopathy, exclude suspected plexopathy in patients presenting with non-specific symptoms, provide anatomic information for initial or failed thoracic outlet surgery, aid in depicting the extent and characterization of space occupying lesions, assess the degree of injury, differentiate radiation plexopathy from tumor recurrence and can be used for guidance for scalene muscle medication injections.

Pathologic conditions

Brachial plexus lesions can be prudently classified according to their location in relation to the clavicle, as supraclavicular, retroclavicular and infraclavicular lesions. Less commonly, panplexus lesions may result from severe trauma or radiation neuropathy.
Supraclavicular Lesions
These involve nerve roots and trunks in the scalene triangle and, generally the pathology is more commonly encountered as well as more severe than lesions at other sites. Erb-Duchenne palsy results from injury to the C5 and C6 roots or the upper trunk, and accounts for approximately 90% of obstetric brachial plexus injuries. Much less common is Dejerine-Klumpke palsy, which results from injury to the C8 and T1 roots or the lower trunk. Common pathologies in supraclavicular area include, brachial plexitis (Parsonage Turner syndrome), traumatic injury, iatrogenic injury, neoplasm (metastasis, nerve sheath tumor, neurocutaneous syndrome, pancoast tumor), and thoracic outlet syndrome.

Retroclavicular lesions
These involve the brachial plexus divisions. Isolated lesions to the divisions are rare and therefore, for practical purposes, these are included in the infraclavicular pathology.

Infraclavicular Lesions
These affect the cords and terminal branch nerves, and these are about 3 times less commonly seen than the supraclavicular lesions. These lesions also generally have better prognosis and earlier recovery than the supraclavicular lesions. Common causes include radiation neuropathy, humeral fracture, shoulder dislocation, gunshot injury and iatrogenic injuries, such as coronary artery procedure.

MRN technique and normal imaging appearances
Although, MRN can be performed at lower field strengths, we perform most of our exams on a 3T scanner (Trio, Verio, Siemens, Erlangen, Germany) due to the superior signal to noise ratio (SNR) and soft tissue contrast (Table 1). 3T imaging provides high quality 2D and 3D spin echo type imaging, essential for the optimal evaluation of the complex anatomy, frequent variations and small size of the brachial plexus segments. T1W images are most useful for anatomy of the nerves, surrounding fat planes, scalene and other regional muscles and the thoracic outlet. T2W images are obtained in a variety of contrasts for optimal assessment of the brachial plexus. Sagittal STIR imaging is useful for individual segmental assessment of the nerve segments, in terms of their relative signal, size and course. 3D STIR SPACE (sampling perfection with application optimized contrasts using variable flip angle evolutions, Siemens, Erlangen, Germany) sequence allows excellent background fat suppression as well as isotropic
multiplanar and curved planar reconstructions. The reconstructed images can be further enhanced with maximum intensity projection (MIP) to highlight the imaging abnormality and depiction along the longitudinal plane of the nerve. Finally, 3D T2 SPACE images focused on the cervical spine can be reformatted to generate isotropic spine images for evaluation of cervical spondylosis/injuries, which is a major confounder in brachial plexus pathology. Generally, all the brachial plexus studies are performed as unenhanced MRN exams, unless there is a suspicion of neoplasm, infection or diffuse polyneuropathy. Diffusion tensor imaging (DTI) is experimental at this stage. As the DTI protocols are being standardized and initial reliability studies are being performed, it is likely to play an important role in peripheral nerve imaging including brachial plexus.

**Table 1:** 3T MRN Examination Protocol for the Evaluation of the Brachial Plexus (FOV from C2 to T2).

<table>
<thead>
<tr>
<th>MR Sequence</th>
<th>FOV</th>
<th>Slice Thickness</th>
<th>TR/TE/TF</th>
<th>Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1 Coronal (T1 Axial)</td>
<td>30</td>
<td>4.0</td>
<td>881/11/7</td>
<td>512×512</td>
</tr>
<tr>
<td>3D Coronal STIR SPACE</td>
<td>30</td>
<td>1.0</td>
<td>1500/97/53</td>
<td>256×256</td>
</tr>
<tr>
<td>3D Sagittal T2 SPACE</td>
<td>25</td>
<td>1.0</td>
<td>1000/97/81</td>
<td>256×256</td>
</tr>
<tr>
<td>T1 Sagittal affected side</td>
<td>22-24</td>
<td>3.0</td>
<td>804/8/5</td>
<td>384×384</td>
</tr>
<tr>
<td>STIR Sagittal affected side</td>
<td>22-24</td>
<td>3.0</td>
<td>5210/18/22</td>
<td>256×256</td>
</tr>
<tr>
<td><strong>Additional arm Examination if desired</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Axial T1</td>
<td>20-22</td>
<td>3.0-4.0</td>
<td>550/7.9/6</td>
<td>256×384</td>
</tr>
<tr>
<td>Axial T2 SPAIR</td>
<td>20-22</td>
<td>3.0-4.0</td>
<td>2840/70/13</td>
<td>256×384</td>
</tr>
</tbody>
</table>

**Abnormal MRN findings in Brachial Plexus**

Abnormal brachial plexus findings may involve primary nerve imaging abnormality with or without associated anatomic variation, such as accessory scalene muscle belly or intramuscular course, surrounding fat plane changes, perineural space occupying lesions, cervical spondylosis or injury, regional denervation muscle changes, and often, a combination of all. Nerve findings include asymmetric T2 hyperintensity, enlargement, kinking of nerves by fibrosis...
flattening by intramuscular course / entrapment by the mass lesions and discontinuity / focal neuroma formation in injury. Generally, asymmetric T2 hyperintensity in the scalene triangle sparing the most proximal segment of the nerve root and dorsal nerve root ganglion usually distinguishes brachial plexopathy from cervical spondylosis related nerve impingement / irritation, which involves the most proximal portion of the nerve within and immediately distal to the neural foramen and additionally, the abnormality in the later case is usually restricted to the nerve corresponding to the most narrowed foramen. 3D images show the entire nerve extent and focal signal intensity changes, course deviations and size changes are easily appreciated. The degree of muscle fatty replacement and atrophy indicates chronicity of the lesions and is helpful to guide the surgical management in terms of nerve repair or tendon transfer procedures.

Questions to enhance your knowledge (answers will be covered in the session)

Questions:

1. Which sequence is most useful to correctly identify various segments of the brachial plexus?
   a. 3D T2 SPACE
   b. 2D STIR SPACE
   c. 3D STIR SPACE
   d. Axial T1W

2. Contrast enhanced MRN exam is useful for which of the following brachial plexus pathology:
   a. Neoplasm
   b. Infection
   c. Diffuse polyneuropathy
   d. All of the above

3. The brachial plexus cords are named on the basis of their position to which anatomic structure:
   a. Axillary artery
   b. First rib
   c. Shoulder joint
   d. Subclavian artery

4. Which is the least common nerve involved with brachial plexitis:
   a. Suprascapular nerve
b. Axillary nerve  
c. Ulnar nerve  
d. Musculocutaneous nerve

5. Which is the most severe form of nerve injury:  
a. Neurapraxia  
b. Axonotomesis  
c. Neurotomesis  
d. All are equally severe

6. Which of the following points should be kept in mind for accurate diagnosis of acute nerve injury:  
a. Partial obscuration of the nerve detail by hemorrhage and edema may occur in acute stage  
b. Avulsed nerve root with perineural scarring can mimic an appearance of partially intact nerve root  
c. It is important to distinguish pre-ganglionic from post-ganglionic nerve injury  
d. Nerve in continuity should be distinguished from nerve discontinuity  
e. All of the above

7. Which of the following is usually not a feature of a malignant peripheral nerve sheath tumor:  
a. Size >5cm  
b. Heterogeneous appearance and enhancement on MRN  
c. F18 FDG PET SUVmax uptake more than 3-4 and increasing uptake on delayed imaging  
d. Diffusion restriction with ADC value >1.2  
e. Target sign

8. Which of the following sign do not point to radiation plexopathy over tumor recurrence:  
a. Focal nodular enhancing lesion  
b. Diffuse nerve enlargement and enhancement  
c. Geographic involvement  
d. Kinking of nerve roots with T1 and T2 hypointense bands

9. Which nerve involvement may cause scapular winging:  
a. Long thoracic nerve  
b. Spinal accessory nerve  
c. Suprascapular nerve  
d. a and b


