Magnetic Resonance Neurography – Techniques and Interpretation

Avneesh Chhabra, M.D.[1]; Abraham Padua Jr., Ph.D.[2]; Aaron Flammang, MBA[2]; Wesley Gilson, Ph.D.[2]; John A. Carrino, M.D., M.P.H.[1]

[1]*Department of Radiology & Radiological Science, Johns Hopkins University, Baltimore, MD, USA*
[2]*Siemens Healthcare, Malvern, PA, USA and Erlangen, Germany*

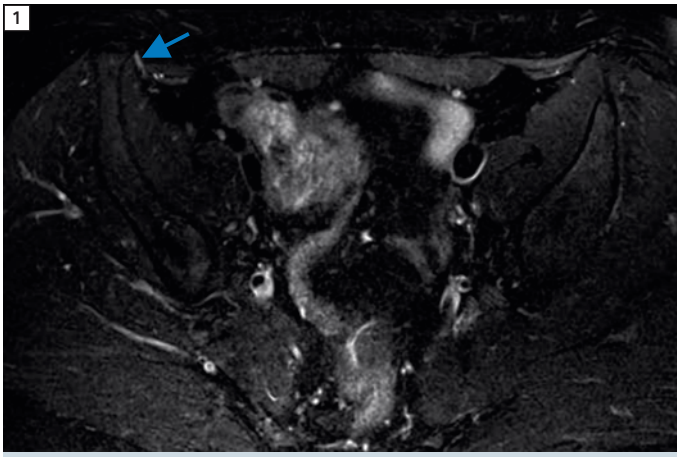
Introduction

Magnetic resonance neurography (MRN), akin to angiography, is an ever-advancing technology for multiplanar depiction of normal and abnormal peripheral nerves. This article will highlight various 2D and 3D pulse sequences available for non-selective and selective nerve visualization as well as their functional evaluation. Related interpretation pearls and pitfalls are discussed.

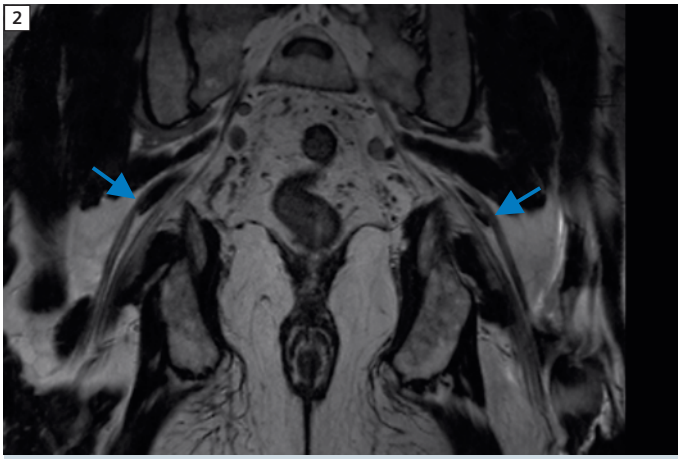
Techniques

MRN is best performed on 3 Tesla (T) scanners with dedicated extremity or wrap around flex coils as they can provide higher signal-to-noise ratio (SNR), which is essential to enhance the smallest structure in the neurovascular bundle, namely the peripheral nerves [1].

On current 1.5T scanners (MAGNETOM Aera, MAGNETOM Avanto), 2D (dimensional) imaging can be performed with near-similar resolution as on 3T scanners, however 3D imaging is often limited, especially if smaller voxels are used or fat suppression is applied. On the other hand, if there is metal in the field-of-view, in order to mitigate susceptibility artifacts and for superior nerve visualization, 1.5T imaging is often favored.
2D pulse sequences include high resolution (base resolution 256 or higher, in plane resolution 0.3–0.4 mm) T1-weighted and fat suppressed T2w images. Uniform fat suppression is essential to avoid artifactual increase in nerve signal intensity. Options include frequency selective fat suppression (fsT2w), short tau inversion recovery (STIR), and spectral adiabatic inversion recovery (SPAIR), or 2-point or 3-point Dixon techniques. fsT2w is often limited due to loss of fat saturation along the curvatures of extremities, especially in large subjects. STIR works well for 3D imaging with excellent fat suppression, however for 2D imaging it is often marred by poor SNR, excessive SAR (specific absorption rate) deposition and pulsation artifacts. SPAIR works well as it provides better fat suppression than fsT2w and higher SNR than STIR. It has virtually no pulsation artifacts and is also relatively SAR favorable (Fig. 1). It comes in weak and strong contrast versions. The authors prefer the strong version as it provides isointense signal in normal nerves [2].

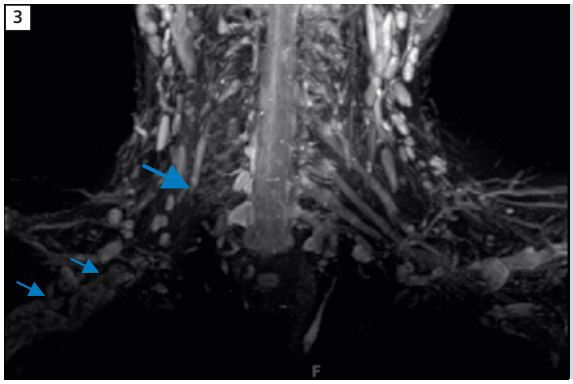


1 Meralgia Paresthetica. Young woman with right anterolateral thigh pain and suspected lateral femoral cutaneous (LFCN) nerve abnormality. Axial T2 SPAIR image shows uniform fat suppression and abnormally hyperintense right LFCN (arrow) in keeping with clinical diagnosis of meralgia paresthetica.

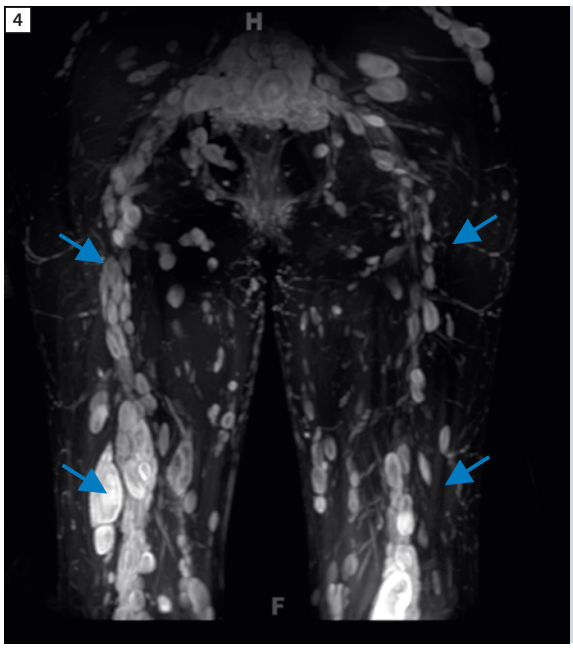


2 T2 SPACE. Coronal non-fat suppressed T2 SPACE image through the pelvis shows bilaterally split sciatic nerves (arrows) in this patient with no symptoms of sciatica.

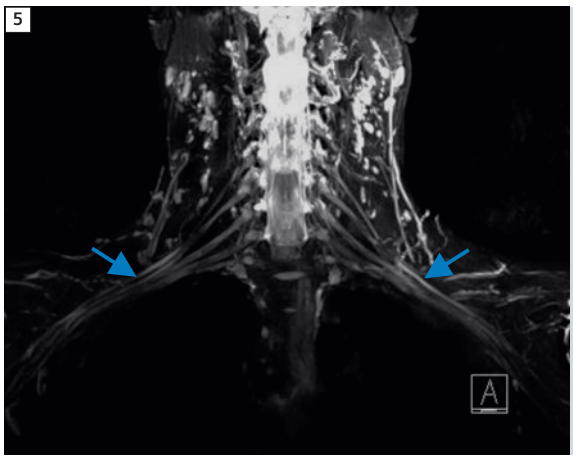
Dixon technique applied with T2w imaging gives separate water and fat images and also provides excellent fat suppression with higher SNR and contrast-to-noise ratio than STIR or SPAIR.
3D pulse sequences can be divided into anatomic and functional techniques. Anatomic techniques are further divided into nerve non-selective and nerve selective sequences. Nerve non-selective techniques include T1w imaging, namely VIBE (volume interpolated breathhold examination, T1 3DGRE) or MPRAGE (3D GRE); and T2w multislab acquisition, namely SPACE (sampling perfection with application optimized contrasts using varying flip angle evolutions) [3]. SPACE is heavily used in MRN examinations as isotropic spine echo type imaging can obtained using SPACE in a variety of contrasts (T1, PD, T2, STIR, and SPAIR) with constant or variable echo times (Fig. 2). The authors use VIBE for pre- and post-contrast imaging, and otherwise mostly use 3D imaging with fluid sensitive contrast. 3D STIR SPACE provides best fat suppression for the brachial and LS plexus while 3D SPAIR SPACE provides higher SNR along with good fat suppression for extremity imaging (Figs. 3, 4). Dixon T2w imaging also provides excellent images of the brachial plexus, however currently can be acquired in 2D mode only (Fig. 5). Others such as 3D PD SPACE with variable echo time can produce similar image quality and allows multiplanar reconstruction (Fig. 6). Currently, 3D STIR SPACE and SPAIR SPACE sequences are most widely used and are time tested. Maximum intensity projections (MIP) of acquired images or their curved planar reformats produce excellent quality nerve images along their long axis. It remains to be seen if other techniques, such as Dixon with SPACE, can be obtained within acceptable time periods and provide the necessary isotropic spatial and good contrast resolution.
3D nerve selective imaging includes diffusion-weighting (DW) with a small b-value (80–200 s/mm^2) to suppress flowing blood. It is a fine balance as one adds diffusion gradient to the 3D imaging, as it reduces SNR and can degrade image quality while providing the benefit of vascular flow signal suppression for selec-



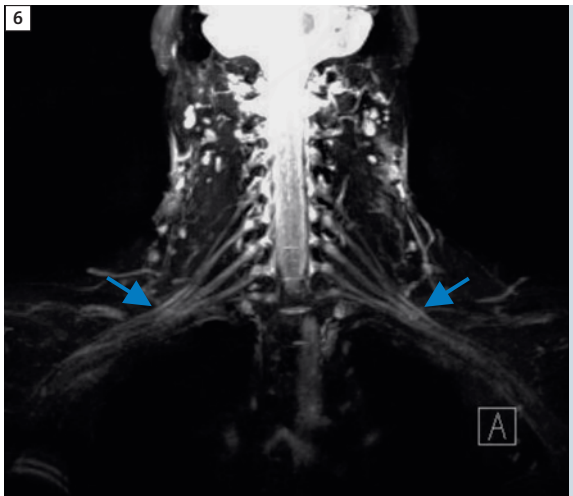
3 3D STIR SPACE. 24-year-old man with recent motor vehicle accident and flail right arm. MIP image from coronal 3D STIR SPACE sequence shows transected right L5 nerve (large arrow). Notice torn, retracted and bunched up remaining right brachial plexus (small arrows).



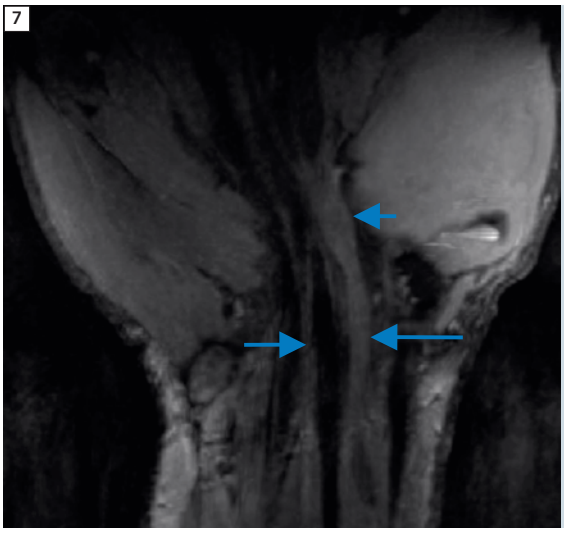
4 SPAIR SPACE. MIP image from coronal 3D SPAIR SPACE sequence shows multifocal nodular enlargement of bilateral sciatic nerves, infiltrated by numerous neurofibromas (arrows) in this known case of NF type I.



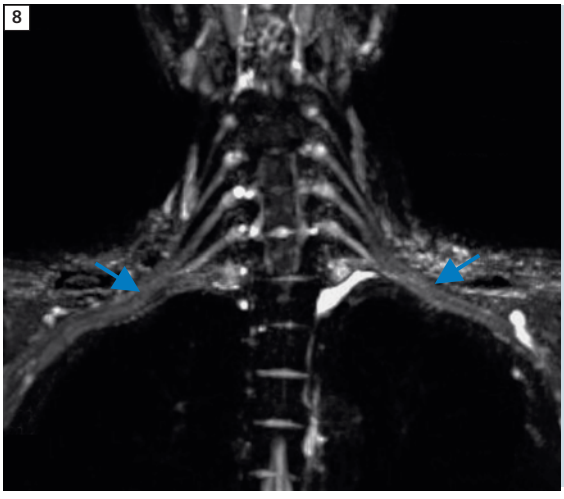
5 T2 Dixon. MIP image from coronal 2D T2 Dixon sequence shows excellent depiction of normal bilateral brachial plexuses (arrows) in a healthy volunteer.



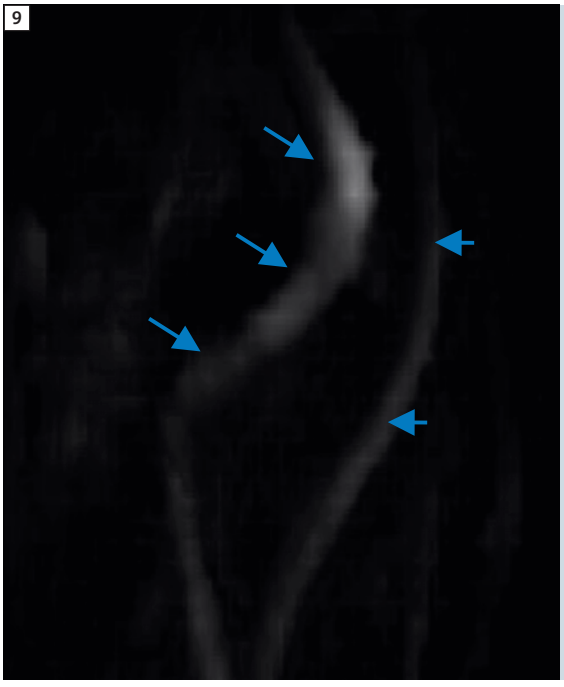
6 PD variable 3D SPACE. MIP image from coronal PD variable 3D SPACE sequence shows excellent depiction of normal bilateral brachial plexuses (arrows) in a healthy volunteer.



7 3D DW PSIF. Young woman with persistent carpal tunnel symptoms following a prior transverse carpal ligament release. Notice normal median (large arrow) and ulnar nerves (medium arrow) proximal to the carpal tunnel. A neuroma in continuity is seen along the distal aspect of the carpal tunnel (smallest arrow). Notice selective nerve depiction with excellent vascular signal suppression



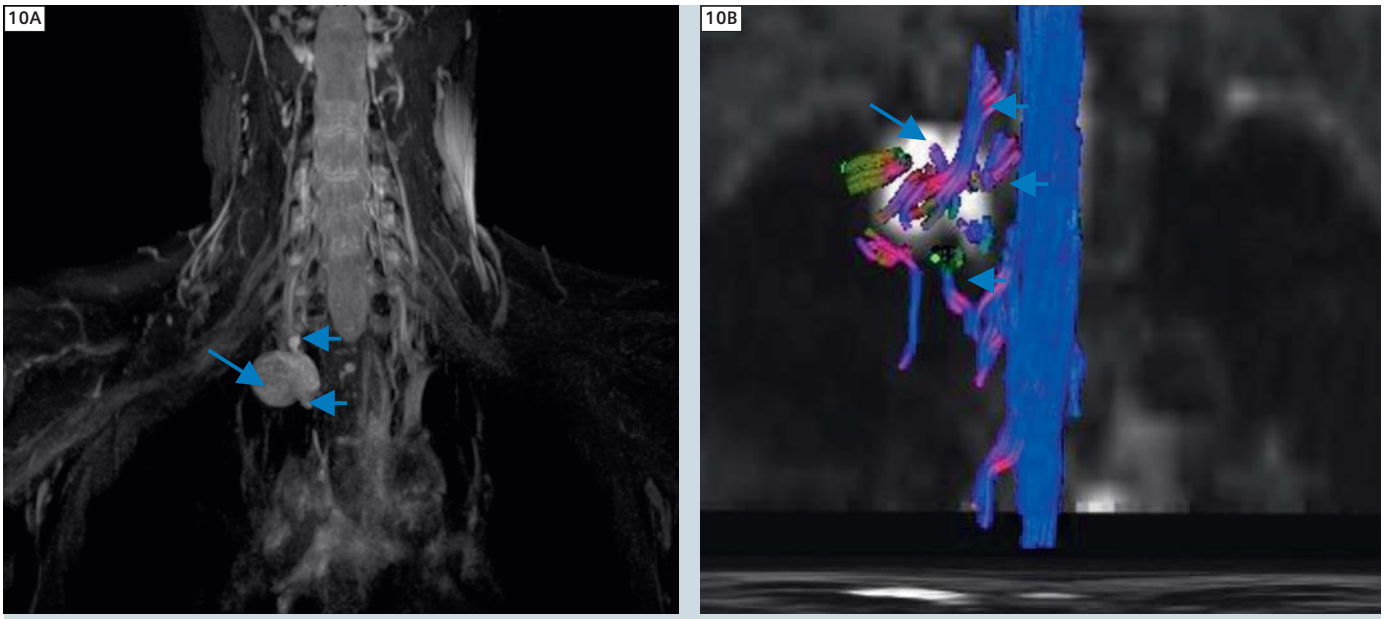
8 3D DW SPACE. MIP image from coronal DW 3D STIR SPACE sequence shows selective depiction of normal bilateral brachial plexuses (arrows) in a healthy volunteer. However note decreased SNR due to added diffusion component.



9 DTI. MIP coronal tensor image with inverted grey scale from axial DTI sequence shows enlarged ulnar nerve with abnormally low FA and high ADC values in this case of re-entrapped ulnar nerve at the site of prior anterior transposition (large arrows). Notice normal median nerve (small arrows).

tive nerve imaging. The sequences include 3D DW PSIF (reversed steady state free precession) and DW STIR SPACE. 3D DW PSIF is very susceptible to local inhomogeneity, motion artifacts, breathing artifacts, and poor fat suppression. Water selective fat suppression currently works well with PSIF [4, 5]. With appropriate technique, it provides excellent nerve selective images (Fig. 7). MIP images from DW PSIF and DW SPACE provide good nerve selective depiction (Fig. 8). With further pulse sequence development, one can look at adding Dixon to DW PSIF or try to improve DW SPACE sequence that can be obtained in acceptable time periods while keep the advantages of nerve selectivity. A typical lumbosacral plexus protocol has been highlighted in Table 1. Normal nerves do not enhance as they are outside the blood-nerve barrier. Contrast imaging (gadolinium based agent) does not add much in trauma or entrapment neuropathy cases as these are mostly subacute cases. In these cases, only denervated muscles enhance, the demonstration of which is already visible on T1w and fat suppressed fluid sensitive images. Contrast administration is, however, recommended in other cases, such as suspected neural and perineural mass lesions, polyneuropathy conditions including lymphoma, amyloidosis, demyelinating neuropathies, hereditary neuropathies, etc.

Functional imaging of the peripheral nerves primarily includes diffusion tensor imaging (DTI). It has been exploited in various extremity and plexus peripheral nerves in the last few years and continuous refinements are being made. Single shot echo planar imaging (EPI) is the technique used in most centers and multiple diffusion moments (b-values) are applied to obtain functional parameter of apparent diffusion coefficient (ADC) [6]. At least 6 directions of interrogation are needed for DTI, although most authors have used 12–20 directions to obtain reproducible data. The authors use 3 diffusion moments (0, 800, 1000 s/mm^2) and 12 directions of interrogation. Tight echo spacing, frequency selective fat suppression, auto-shimming before image acquisition and no motion degradation



10 3D STIR SPACE and DTI. MIP image from coronal 3D STIR SPACE sequence **(10A)** shows normal depiction of normal bilateral brachial plexuses in a 39-year-old woman with incidentally detected lesion on chest CT (not shown). A peripheral nerve sheath tumor (large arrow) is nicely depicted in close relation to paraspinal T1 and T2 ganglia (small arrows). The lesion showed high ADC values in keeping with a benign lesion. Tractography image from DTI **(10B)** shows the nerve roots (small arrows) draped over the lesion (large arrow) without involvement.

Table 1: The imaging protocol employed in the magnetic resonance neurography examination for the LS plexus.

MR sequence	Slice thickness (mm)	TR / TE (ms)	TF	Base resolution (pixels)
Axial T1	4	800/12	6	832
Coronal T1	4	960/12	5	384
Axial T2 SPAIR	4	4890/80	22	256
Sagittal T2 3D SPACE	1	1000/97	81	256
Sagittal STIR	4	3700/18	22	256
Coronal STIR 3D SPACE	1.5	1500/91	41	256

are essential to obtain good and reproducible DTI data. Axial images obtained with 4–5 mm slice thickness with 0 gap can be reconstructed in multiple planes without artifacts (Fig. 9). These images then allow accurate tensor calculation, fractional anisotropy (FA) measurements and tractography. DTI has proven useful in non-invasive pre- and post-operative evaluation of carpal tunnel syndrome patients and peripheral nerve sheath tumors (PNST) as the involved nerves show reduced FA values that improve over time with treatment [7]. The benign PNSTs show higher ADC values than their malignant counterparts and tractography differences exist among different tumor types depending upon internal fascicular involvement or mere displacement [8] (Fig. 10). Further investigations are underway to evaluate the role of DTI in other types of neuropathies.

Interpretation pearls and pitfalls

While image generation is getting easier with high field MR techniques, the radiologists should learn to correctly interpret these high quality examinations. There is a steep learning curve for those who spend time with attention to detail, since nerve architecture is easily visible to the fascicular and perineurium level. One should learn normal nerve anatomy, variations, diagnostic pearls and pitfalls while obtaining all the information possible from clinical findings and available electrodiagnostic test results. Electrodiagnostic tests are also limited by false negative or indeterminate results, especially in deeply located nerves. So, while these results are helpful, one

should not get biased by negative results. The reader should follow a stepwise approach to imaging diagnosis:

1. Image quality – is it adequate and is fat suppression uniform? Are the nerves visible adequately and can the nerves be separately evaluated from adjacent vessels or compared side to side if the contralateral portion of body is available, such as in pelvic imaging. Recognize normal nerves and their variations (bifid nerve, split nerve with muscle belly intervening, intramuscular course of the nerve, etc.)
2. Look for orthopedic internal derangements which can mimic similar neuropathic symptoms or are potential cause of traction neuropathy, such as spondylosis, plantar fasciitis, tibialis posterior dysfunction, etc.
3. Look for clues of disseminated or systemic causes of neuropathy: one nerve abnormal over long distance away from entrapment sites or multiple regional nerves abnormal. This may happen in diabetic neuropathy, demyelinating neuropathies, hereditary neuropathy, vasculitis or toxic metabolic conditions. Usually hereditary neuropathy results in symmetric disease as compared to acquired conditions. Clinical findings should be correlated for insights into above diagnoses.
4. Look for focal area of nerve abnormality, abnormal T2 hyperintensity (approaching adjacent venous signal intensity) and / or fascicular abnormality (enlargement / effacement from edema / discontinuity) indicating entrapment or injury in the correct clinical scenario. If the nerve is really abnormal, the signal intensity will persist over few to many sections along its length versus signal change from a magic angle artifact. The nerve further enlarges with worsening neuropathy forming a pseudoneuroma in entrapment and neuroma in injury (lost partial or complete fascicular continuity with heterogeneous appearance) [9]. The nerve abnormality is generally worst at the site of insult and it fades gradually proximally and distally. Abrupt change in nerve intensity from bright-black-bright signal (Triple B sign) usually means severe focal neuropathy and a potential surgical case. Painful neuroma in continuity and nerve discontinuity in functionally important nerves also require surgical repair/reconstruction. Long standing neuropathy, such as in diabetes, can lead to atrophic appearance of the nerve with fascicular atrophy and intra-epineurial fatty proliferation / replacement.
5. Evaluate regional muscles. As a rule, the muscle denervation changes are distal to the site of insult. If muscle changes are patchy or widespread in different nerve territories or associated with fascial edema, the diagnosis could be myopathy / myositis rather than denervation change. The diagnosis can be made with confidence if regional nerves are normal.
6. In case of a mass lesion, further characterize the lesion into neural or perineural masses. Age, clinical findings and anatomic MRN plus DTI are useful in the imaging evaluation of neural masses. Perineural lesions are further evaluated based on anatomic imaging and contrast evaluation into lipoma, ganglion cyst, hematoma, and abscess etc.
7. Finally, look for prior local surgical changes or nerve repair/reconstruction changes. The signal alteration may persist but in successful cases, the signal decreases within the nerves and denervation changes in the muscle resolve. In worsening nerve degeneration cases, the nerve signal approaches fluid signal and persists till the nerve atrophy starts, while the regional muscles undergo continued fatty replacement and atrophy [10]. Correlation with prior imaging studies is essential in these cases.

To conclude, magnetic resonance neurography is an exciting imaging technique that affords multiplanar anatomic and functional depiction of peripheral nerves and their related lesions. Appropriate imaging and accurate interpretation are essential components of successful performance of this ever advancing technique.

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Contact
Avneesh Chhabra, M.D.
Assistant Professor Radiology &
Orthopedic Surgery
Russell H Morgan Department
of Radiology & Radiological Science
Johns Hopkins University, Baltimore, MD
USA
achhabr6@jhmi.edu