Tiron C.M. Pechet, MD
Shields Health
—
Boston, MA

MR neurography imaging for all: providing a new service line using existing sequences and systems

Advancements in hardware and imaging techniques are propelling MR into new areas of clinical utility, from one-beat cardiac MR acquisitions to mapping neural connections in the brain using advanced diffusion and fMRI. In musculoskeletal (MSK) and neuro imaging, MR neurography (MRN) is emerging as a valuable tool to evaluate peripheral nerve pathology and investigate both traumatic and non-traumatic causes of neuropathy. While gaining in popularity, MRN is generally not widely used outside of academic hospitals and institutions.

"Neurography is a small but increasing part of the services we provide," says Tiron C.M. Pechet, MD, Assistant Medical Director of Shields Health, a leading provider of advanced, outpatient imaging services with more than 50 locations throughout New England. It is an important service, because for patients suffering from peripheral nerve damage or injury, MRN may be the best diagnostic tool for their neurologist, orthopedic surgeon or neurosurgeon to understand precisely what is causing their pain. Without MRN, the patient may not receive the correct diagnosis and, therefore, the appropriate treatment.

"Because high-quality MRN hasn't been widely available in the past, the referring community, including surgeons and neurologists, who addressed clinical issues with peripheral nerve pathology may not be accustomed to thinking about or ordering MRN. And that is part of the problem," Dr. Pechet says.

Now, with newer technologies such as AIR™ Recon DL 3D, MENSA Nerve, Cube STIR and AIR™ Coils, Dr. Pechet and the radiology team at Shields Health are achieving a high diagnostic success rate in patients referred for nerve trauma cases. Approximately 85% of these cases are abnormal. The radiologist can identify the pathology causing the problem, however, it is often in locations not suspected based on the clinical examination notes or EMG studies. This success in finding the injured nerves suggests to Dr. Pechet that MRN could be used earlier in the diagnosis of non-traumatic peripheral nerve disorders as well, for which the positivity rate on the initial study is often lower, but studies proximally and/or distally often disclose pathology.

"Ultrasound is an excellent tool for peripheral nerve imaging; however, it is challenged when viewing any nerve structure that's not superficial. We also find quite significant disagreement between ultrasound and MR," Dr. Pechet explains. "When we combine direct visualization of the nerves with what we call a 'visual EMG,' which is a careful analysis of muscle signal, our clinicians are generally finding MR more useful than ultrasound."

Ultrasound is also highly user dependent. Traditionally, so too was MRN when using 2D acquisition methods. The radiologist would need detailed knowledge of the clinical questions, including nerves involved, and then guide the technologist in real time to set the appropriate very thin slice imaging planes. For example, in elbow neurography, the 2D protocol would include acquiring multiple planes of thin-slice imaging of T1, STIR, T2 Flex, etc., all organized so they were both coplanar as well as orthogonal to the nerve of interest.

"You had to understand that patient's anatomy and the specific indication for the neurography examination to acquire images of the nerves in the right planes," Dr. Pechet says.

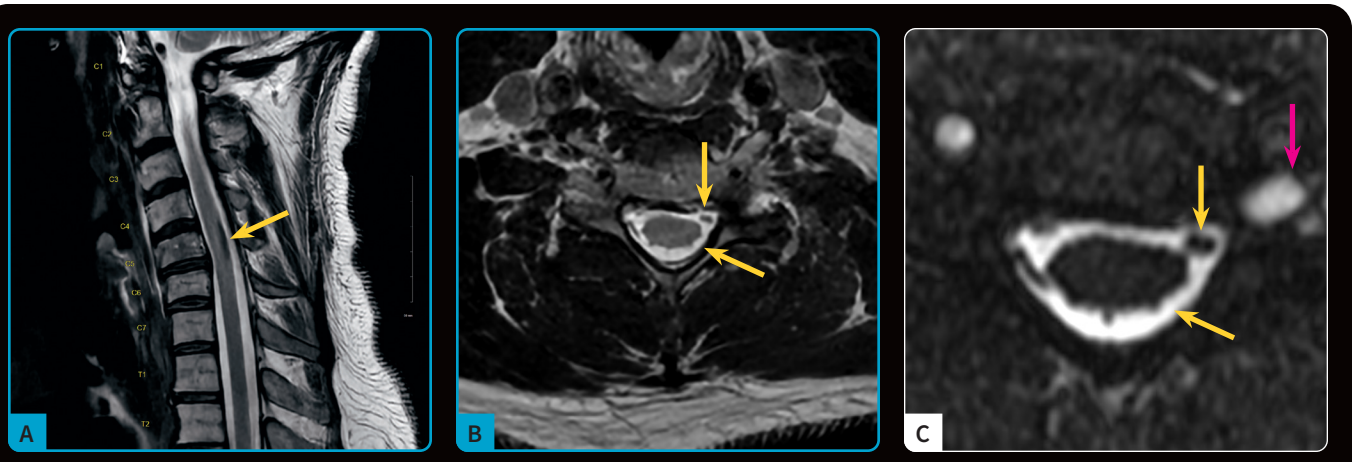

Figure 1. Patient referred after high-speed motor vehicle accident with right upper extremity paralysis. (A) Sagittal T2 PROPELLER depicts hemorrhage at dorsal root entry zones C6/C7 avulsed. (B) Axial T2 Cube 1 mm isotropic and (C) Axial FIESTA-C reformatted from an acquired coronal demonstrate the C7 ventral root scarred and thickened as well as a dorsal rootlet completely avulsed (yellow arrows). A pseudomeningocele is evident on the FIESTA-C (pink arrow).

AIR Recon DL 3D changes this paradigm and makes the examination much less technically challenging. The technologist does not need to locate and angle the imaging plane in relation to the nerve(s). Rather, they can include the relevant anatomy in the 3D imaging volume, e.g., the elbow, then acquire in the axial view. The radiologist can then post-process the appropriate planes and reconstruction and use 3D rendering tools.

"The protocol that we have developed at Shields makes very high-quality neurography feasible and successful in a non-academic setting," Dr. Pechet says. "The right combination of technology puts it in reach for most imaging centers with a 3.0T machine."

Building the protocol

MRN typically involves multiple anatomies and examinations, making it a long and complex acquisition. Shields has reduced scan times without impacting quality. A complete brachial plexus is now acquired in 25 minutes of scanning time, down from 50 minutes; a complete brachial plexus and arm in 50 minutes of scanning time, and a high-resolution C-spine, brachial plexus and the upper arm – three examinations – in 75 minutes of scanning time.

"The quality is so much higher than we could get without AIR Recon DL 3D," says Dr. Pechet. "We are really using the tools that GE HealthCare provides to make diagnoses that were, frankly, not within what we could do before."

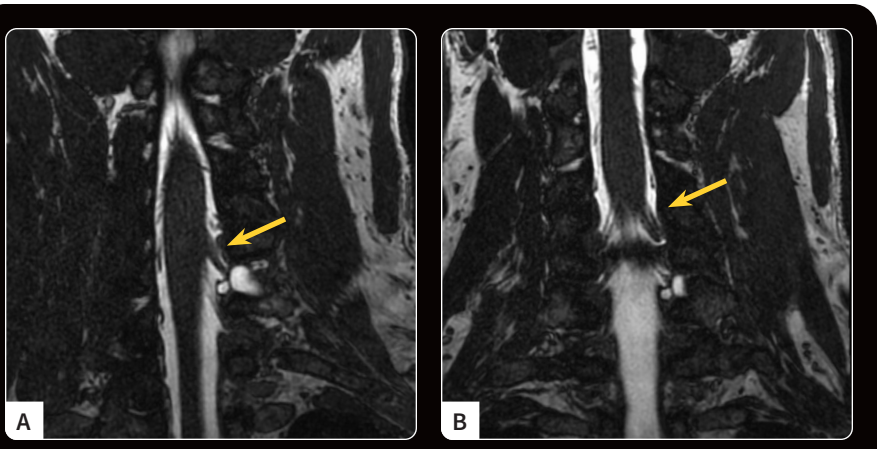

Figure 2. Same patient as in Figure 1. Coronal MPR of FIESTA-C showing on (A) the left C7 root/scar abruptly stopping at the pseudomeningocele. (B) Shows scarring and poor definition of the ventral rootlets one level above at C6 on the left versus normal appearing rootlets at C6 on the right.

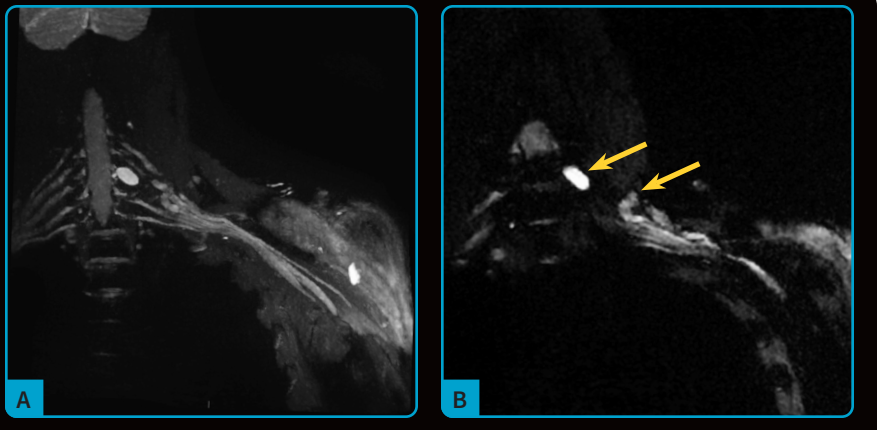

Figure 3. Same patient as in Figure 1. Coronal acquisition post-contrast injection of Cube STIR. (A) The MIP shows the brachial plexus as well as the pseudomeningocele, and (B) a very thin MIP showing the gap between the meningocele and the retracted, thick and hyperintense more distal C7 root. The use of HyperCube combined with HyperSense allows for high-quality imaging in an acceptable time frame and prevents folding in the image.

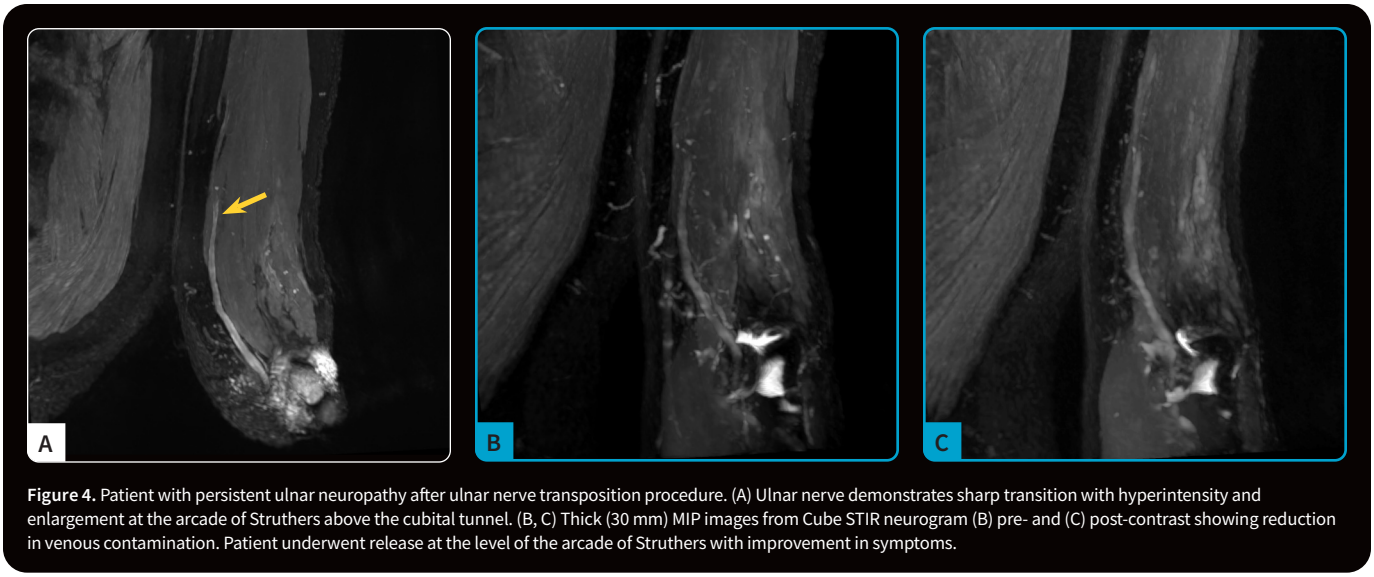

Figure 4. Patient with persistent ulnar neuropathy after ulnar nerve transposition procedure. (A) Ulnar nerve demonstrates sharp transition with hyperintensity and enlargement at the arcade of Struthers above the cubital tunnel. (B, C) Thick (30 mm) MIP images from Cube STIR neurogram (B) pre- and (C) post-contrast showing reduction in venous contamination. Patient underwent release at the level of the arcade of Struthers with improvement in symptoms.

Contrast enhancement is an important part of the protocol. With 3D Cube STIR, Dr. Pechet has noticed a significant improvement in the image quality for distinguishing nerves from vessels post-contrast, where most vessels have a very low signal. 3D LAVA Flex can identify neuromas in continuity or post-traumatic scar/granulation, which is important information for the surgeon, and can also be acquired in a volume without requiring the technologist to position planes. In cases of non-traumatic peripheral neuropathy, 3D Cube STIR – both without and with contrast – as well as the post-contrast 3D LAVA Flex can be very helpful in assessing neural/perineural inflammation.

In C-spine neurography, 3D T2 Cube with a 0.9 mm isotropic voxel is utilized to assess ventral and dorsal spinal nerve roots and morphology at each level in combination with 3D FIESTA-C.

High-quality sagittal PROPELLER T2 and axial T2 FSE acquisitions are used to interrogate subtle spinal cord signal abnormality at the root entry zones, which is important information for the clinicians. According to Dr. Pechet, identifying a pseudomeningocele is not sufficient. He typically looks for pruning of the rootlets, which can indicate a possible but less successful root to use for limb reanimation, especially in the ventral root.

"Robust 3D sequences with AIR Recon DL and FOCUS, and Flex imaging with AIR Recon DL are, in my mind, game changers," says Dr. Pechet. Cube should be acquired with FOCUS, he adds.

In addition to 3D Cube STIR, MENSA Nerve, a standard sequence available on MR30, is a fundamental sequence in the Shields protocol, along with 2D axial T1 and T2 Flex. On MENSA Nerve, Dr. Pechet recommends changing the FOV to accommodate the anatomy and adjusting the voxel size to keep resolution similar.

He has found MENSA Nerve to be useful for imaging nerve sheath tumors, such as schwannomas and neurofibromas. MUSE diffusion is also very helpful for following these cases and provides an accurate ADC map and measurements. Restricted diffusion below a b-value of 800 is typically considered concerning for malignancy.

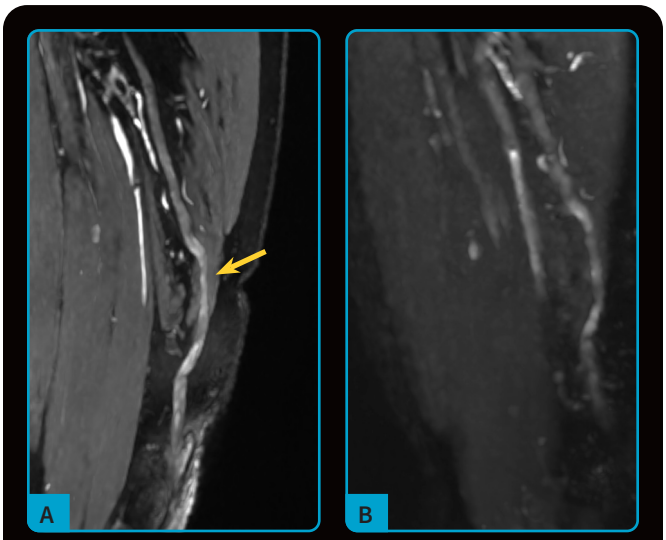

Figure 5. Another patient presenting with ulnar neuropathy with kinking at the arcade of Struthers. (A) MENSA Nerve showing a distal abnormality in terms of signal and caliber. (B) MIP MENSA Nerve highlighting the same distal abnormality.

"The axial T2 Flex isn't terribly useful without AIR Recon DL," says Dr. Pechet. "AIR Recon DL removes the noise – we always run it on high in these examinations – and it improves sharpness for any given matrix size. Without AIR Recon DL, we couldn't do these examinations in reasonable times, and they are still fairly long acquisitions."

For the 3D T2 Cube sequence, Shields uses isotropic 1 x 1 x 1 mm or smaller acquisitions and then reformats in any plane. Dr. Pechet says, "This is such a good sequence that we now do it standard as part of our routine C-spine examinations. Sagittal 3D T2 is faster, but the signal within neural foramina seems to be better when acquired in the axial plane."

With the Continuum upgrade path provided by GE HealthCare, nearly any MR system has the tools available to perform these studies, adds

Dr. Pechet. The use of AIR Coils is also very important at Shields.

"We find the 30-channel AIR Coil is the single most important coil for MRN," says Dr. Pechet. "You can use others, but this is our go-to coil because the fat suppression is better with it." He believes this is due to more coverage above and below the elbow by wrapping the AIR Coil around the arm and elbow. Plus, the elbow is typically acquired along with the upper arm or forearm, so wrapping/overlapping the AIR Coil eliminates the need to change or reposition the coil. The table coil should be turned off for cases where the AIR Coil is wrapped completely around the anatomy, he adds.

Shields is also using kaolin pectate and rice-filled bags placed around the patient's anatomy to improve B_0 homogeneity and image quality in brachial plexus imaging. Dr. Pechet believes these bags will also be helpful in pelvis imaging, including the femoral nerve and sports hernia protocols.

While 3.0T is preferred for the higher SNR, Shields has had success on 1.5T with lumbosacral neurography. Dr. Pechet also suggests 1.5T may be a better option in patients with implants. He receives referrals for shoulder and total hip arthroplasty patients with subsequent weakness to assess for perioperative nerve injury.

"Although MRN is getting much easier to perform, it remains a challenging examination that may need physician intervention, so it is important to have a knowledgeable radiologist available for these examinations," says Dr. Pechet. "I'm always looking at these cases in real time because we have that capability. Generally, however, I find that I'm removing sequences that won't help me rather than adding new ones or asking the technologist to repeat."

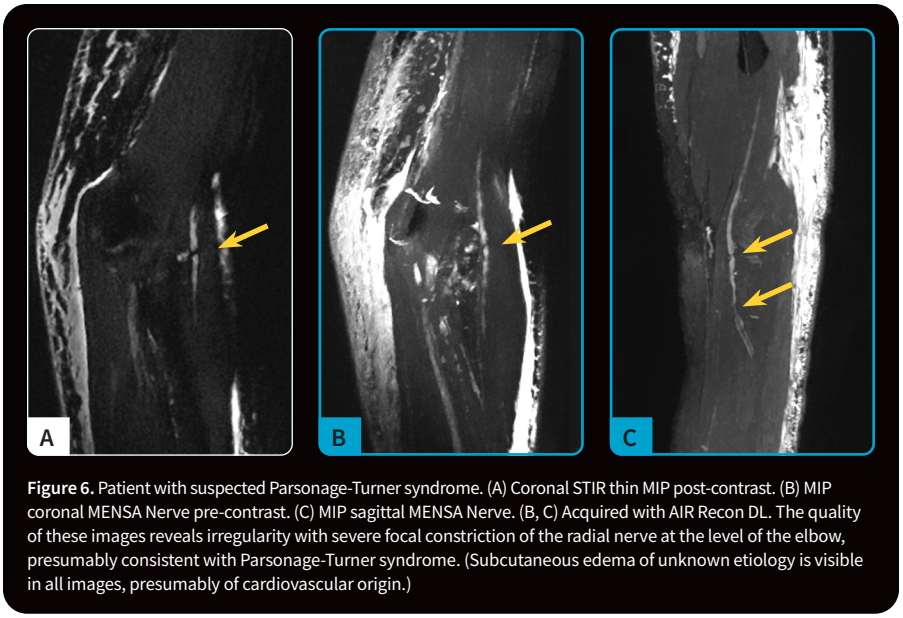

Figure 6. Patient with suspected Parsonage-Turner syndrome. (A) Coronal STIR thin MIP post-contrast. (B) MIP coronal MENSA Nerve pre-contrast. (C) MIP sagittal MENSA Nerve. (B, C) Acquired with AIR Recon DL. The quality of these images reveals irregularity with severe focal constriction of the radial nerve at the level of the elbow, presumably consistent with Parsonage-Turner syndrome. (Subcutaneous edema of unknown etiology is visible in all images, presumably of cardiovascular origin.)

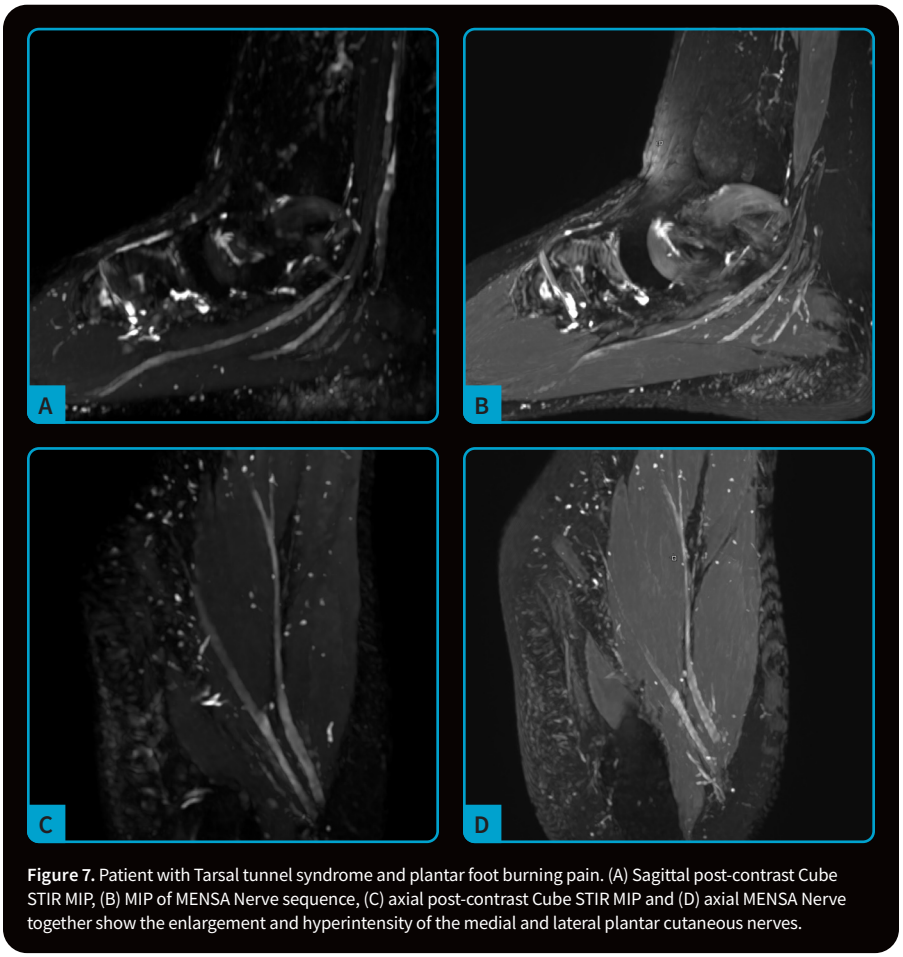

Figure 7. Patient with Tarsal tunnel syndrome and plantar foot burning pain. (A) Sagittal post-contrast Cube STIR MIP, (B) MIP of MENSA Nerve sequence, (C) axial post-contrast Cube STIR MIP and (D) axial MENSA Nerve together show the enlargement and hyperintensity of the medial and lateral plantar cutaneous nerves.

Building the referral base

The most important aspect of building a referral base is educating physicians on its value. Dr. Pechet believes MRN is underused because it is not widely available or known. He works closely with physicians to build relationships and referral patterns by having dedicated case reviews and clinics.

"This is very important because most clinicians don't have the software to perform the 3D data manipulations and they will really benefit from real-time review via secure videoconference," Dr. Pechet says.

Key specialties to target with education are neurologists and neurosurgeons who specialize in diseases of the peripheral nervous system and orthopedic surgeons, who may encounter challenges with preoperative planning or perioperative

nerve damage, especially in cases of total arthroplasty. MRN after total joint replacements of the hip and shoulder are also areas that Dr. Pechet and his colleagues are exploring, as some patients can develop neuropathy as a complication.

Dr. Pechet has frequently encountered multifocal disease in cases where a mononeuropathy was initially suspected. The MRN can help guide diagnosis and treatment, particularly when patients have abnormal nerves extending proximally and/or distally to the clinically suspected site of involvement. In some cases, for example a patient with left leg weakness, the neurologists may not know the main cause of the patient's issue or that MRN can help find the answer.

"The problem with scheduling MR neurography at our other centers isn't the acquisition of the data. It's the scheduling of the patient and figuring out exactly what examinations need to be done. We find that's the piece that really requires the knowledge of the radiologist and the technologist beforehand, not the actual acquisition," Dr. Pechet explains.

"We now go through the requisitions and find cases referred by primary care, family medicine and nurse practitioners for examinations that should actually be neurograms," Dr. Pechet says. "We steer and educate about neurography."

MRN information guides treatment planning and surgical precision for reconstructive neurosurgeons. Dr. Pechet explains they will often supplement the clinical examination, such as an EMG and other techniques, with MRN.

"I believe that MRN is now the cornerstone of imaging, with ultrasound being used only when MRN doesn't work well due to the presence of MR-Conditional implants or isn't available," Dr. Pechet adds.

One surgeon that Dr. Pechet frequently works with rarely performs peripheral neurosurgery without MRN imaging correlation.

"It guides the surgical procedure, there is much less exploration, and he has a better idea of what is going on with that patient and what to fix," says Dr. Pechet. "MRN really assists in the surgical planning and that helps the patient in many ways."

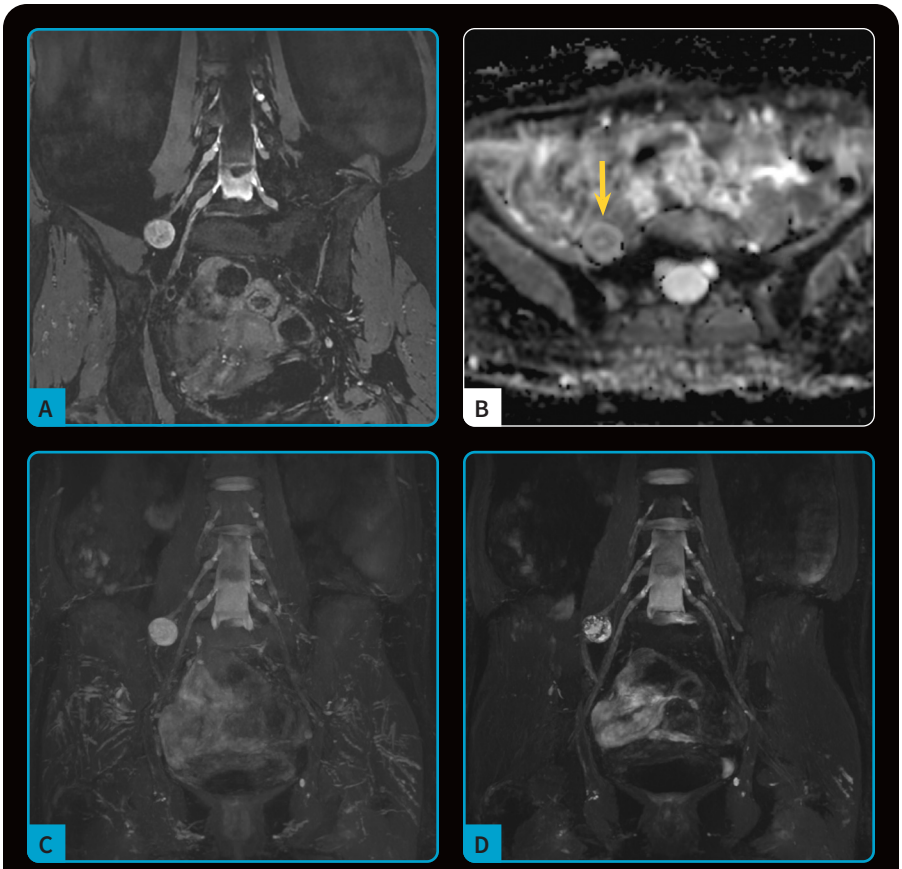

Figure 8. Right foot drop in patient with known lumbosacral plexus nerve sheath tumor to determine if L5 involvement or impingement is the cause of the foot drop. (A) MPR of MENSA Nerve showing known nerve sheath tumor arising from L4 and unambiguously not involving L5 (and not likely causing the foot drop). (B) MUSE diffusion sequence; lack of restricted diffusion consistent with likely benign lesion. (C, D) 20 mm MIP Cube STIR (C) pre- and (D) post-contrast showing reduction in venous contamination but also areas of signal loss in the lesion where it enhances, reinforcing importance of pre- and post-contrast imaging to help the radiologist not miss enhancing lesions on contrast-only images, where they may turn dark.

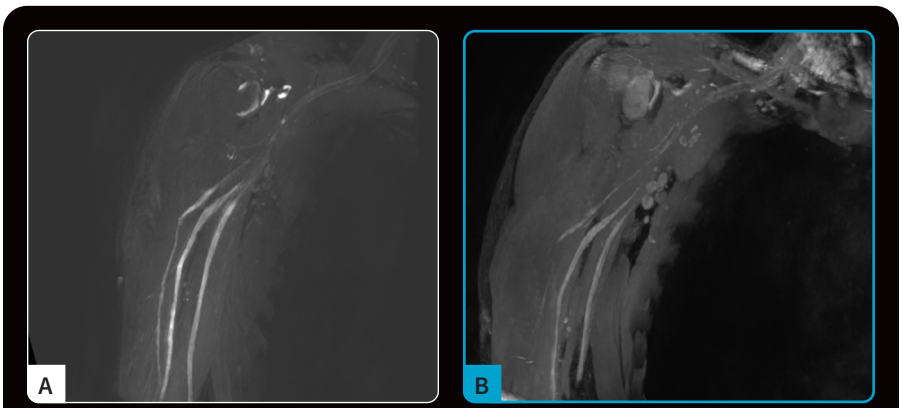

Figure 9. Patient with Saturday Night Palsy after falling asleep inebriated with arm over the back of a chair at the level of the axilla. (A) Post-contrast acquisition of Cube STIR with a thick MIP (50 mm) shows a normal brachial plexus and nerves marked by hyperintensity and enlargement distally to the level of the axillary injury. (B) MENSA Nerve with a thinner MIP (30 mm) aligns with the Cube STIR and is used complementary in our practice.