Magnetic Resonance Neurography

Number: 0387

Policy

*Please see amendment for Pennsylvania Medicaid at the end of this CPB.*

Aetna considers magnetic resonance neurography experimental and investigational because the medical literature on the application of this technology in clinical situations remains in early stages of development.

Background

Currently, diagnosis and management of nerve injury due to compression or trauma are generally undertaken without images of the nerves themselves. Although nerves can sometimes be seen in standard magnetic resonance imaging (MRI), the method is so unreliable that nerve images have never played a significant role in diagnosis and clinical usefulness. Magnetic resonance neurography is a new MRI technology requiring special software and hardware upgrades, which are not widely available; currently, this test is only available at a very limited number of medical centers.
Magnetic resonance neurography is capable of generating high resolution longitudinal and cross-sectional images of major peripheral nerves, and has been studied to supplement diagnostic evaluations by electromyography (EMG) and nerve conduction studies in patients with suspected peripheral nerve tumors, traumatic injury, post-irradiation neuritis, chronic compression, and pain syndromes where an anatomic lesion is suspected. Although current evidence supports MR neurography as a promising technique, the outcome data that would determine the efficacy of this technology is limited to studies involving a small number of patients, making it premature to offer conclusions regarding its effectiveness for the general population. Additionally, large-scale, well-conducted, controlled studies with this approach are warranted to determine its efficacy in imaging neurofibromas and distinguishing benign from malignant lesions.

In a prospective observational study of patients with sciatica, Zhang and colleagues (2009) investigated the effectiveness of three-dimensional (3-D) high-spatial resolution diffusion-weighted MR neurography based on steady state free precession (3-D diffusion-weighted steady-state free precession [DW-SSFP]) in the diagnosis of sciatica. The 3-D DW-SSFP sequence was performed on 137 patients with sciatica and 32 patients in control group. The post-processing techniques were used to generate images of lumbo-sacral plexus and sciatic nerve, and the images acquired were assessed based on the presence or absence of nerve abnormality. The certainty of identifying the lumbo-sacral plexus and main branches from all cases was determined in each of the reconstruction planes for each case individually and assessed by using a 3-score scale. The sciatic nerve and its main branches were differentiated and a clear picture was obtained in all subjects. Compared with the control group, the presence of nerve root compression or increased T2 signal intensity changes can be observed in all patients. The mean score of certainty of identifying the sciatic nerve and main branches was 1.76 +/- 0.4, which indicates that the sciatic
nerve and main branches can be identified with certainty. The authors concluded that the 3-D DW-SSFP MR neurography with high spatial and sufficient contrast is an excellent technique to define the nature of sciatica and assists in prognostication and possibly in management.

Du et al (2010) analyzed the role of MR neurography in the evaluation of spinal and peripheral nerve lesions. Imaging studies, medical records, and EMG/nerve conduction studies (NCS) results were analyzed retrospectively in a consecutive series of 191 patients who underwent MR neurography for spinal and peripheral nerve disorders; 91 (47.6 %) of these patients also underwent EMG/NCS studies. In those who underwent both MR neurography and EMG/NCS, MR neurography provided the same or additional diagnostic information in 32 % and 45 % of patients, respectively. Magnetic resonance neurograms were obtained at a median of 12 months after the onset of symptoms. The utility of MR neurography correlated with the interval between the onset of symptoms to MR neurography. Twelve patients underwent repeated MR neurography for serial evaluation. The decrease in abnormal signal detected on subsequent MR neurography correlated with time from onset of symptoms and the time interval between MR neurography, but not with resolution of symptoms. Twenty-one patients underwent MR neurography post-operatively to assess persistent, recurrent, or new symptoms; of these 3 (14.3 %) required a subsequent surgery. The authors concluded that MR neurography is a valuable adjunct to conventional MRI and EMG/NCS in the evaluation and localization of nerve root, brachial plexus, and peripheral nerve lesions. They found that MR neurography is indicated in patients: (i) in whom EMG and traditional MR imaging are inconclusive; (ii) who present with brachial plexopathy who have previously received radiation therapy to the brachial plexus region; (iii) who present with brachial plexopathy and have systemic tumors; and (iv) in patients under consideration for surgery for peripheral nerve disorders.
lesions or after trauma. The authors also noted that MR neurography is limited by the size of the nerve trunk imaged and the timing of the study.

In a review on new approaches in imaging of the brachial plexus, Vargas et al (2010) stated that imaging plays an essential role for the detection and analysis of pathologic conditions of the brachial plexus. Currently, several new techniques are used in addition to conventional 2-D MR sequences to study the brachial plexus: the 3-D STIR SPACE sequence, 3-D heavily T2w MR myelography sequences (balanced SSFP=CISS 3-D, True FISP 3-D, bFFE and FIESTA), and the diffusion-weighted (DW) neurography sequence with fiber tracking reconstruction (tractography). The 3-D STIR sequence offers complete anatomical coverage of the brachial plexus and the ability to slice through the volume helps to analyze fiber course modification and structure alteration. It allows precise assessment of distortion, compression and interruption of post-ganglionic nerve fibers thanks to the capability of performing maximum intensity projections (MIP) and multi-planar reconstructions (MPRs).

The CISS 3D, b-SSFP sequences allow good visualization of nerve roots within the spinal canal and may be used for MR myelography in traumatic plexus injuries. The DW neurography sequence with tractography is still a work in progress, able to demonstrate nerves tracts, their structure alteration or deformation due to pathologic processes surrounding or located along the post-ganglionic brachial plexus. It may become a precious tool for the understanding of the underlying molecular pathophysiologic mechanisms in diseases affecting the brachial plexus and may play a role for surgical planning procedures in the near future.

Eguchi et al (2011) stated that DW imaging (DWI) can provide valuable structural information that may be useful for evaluating pathological changes of the lumbar nerve root. Diffusion-weighted MR neurography has recently been
introduced as an alternative way to visualize nerves, but to
date, quantitative DWI and MR neurography have not been
applied to evaluate the pathology of lumbar nerve roots.
These researchers visualized lumbar nerve roots and
analyzed their morphology by MR neurography, and measured
the apparent diffusion coefficient (ADC) of lumbar nerve roots
compressed by herniated disks using 1.5-T MR imaging. A
total of 10 consecutive patients (median age of 48.0 and
range of 20 to 72 years) with mono-radicular symptoms
caused by a lumbar herniated disk and 14 healthy volunteers
were studied. Regions of interests (ROIs) were placed on the
lumbar roots at dorsal root ganglia (DRG) and distal spinal
nerves on DWI to quantify mean ADC values. The spinal
nerve roots were also visualized by MR neurography. In the
patients, mean ADC values were significantly greater in the
compressed DRG and distal spinal nerves than in intact
nerves. Magnetic resonance neurography also showed
abnormalities such as nerve swelling at and below the
compression in the symptomatic nerve root. Increased ADC
values were considered to be because of edema and
Wallerian degeneration of compressed nerve roots. The
authors concluded that DWI is a potential tool for analysis of
the pathophysiology of lumbar nerve roots compressed by
herniated disks.

Merlini et al (2011) assessed the feasibility of MR neurography
in children, and the potential roles of DWI and fiber-tracking
(FT) techniques. A total of 5 pediatric patients (age range of 6
to 12 years) underwent MRI for various clinical indications:
neurogenic bladder (case 1); persistent hand pain following
minor trauma (case 2); progressive atrophy of the lower left
extremity muscles (case 3); bilateral hip pain (case 4); and
palpable left supraclavicular mass (case 5). All studies were
performed using a 1.5-T Avanto MRI scanner. The protocol
included 3D T2-weighted STIR and SPACE imaging, T1-
weighted fat-saturation post-gadolinium imaging and diffusion
tensor imaging (DTI) with tractography. ADC (N×10(-3) mm
(2)/s) and FA values were calculated from ROIs centered on
the nerves. Nerve-fiber tracks were calculated using a 4th-order Runge-Kutta algorithm (NeuroD software). Magnetic resonance neurography allowed satisfactory visualization of all neural structures, and FA and ADC measurements were feasible. The final diagnoses were Tarlov cysts, median-nerve compression, sciatic perineurioma, Charcot-Marie-Tooth disease and plexiform neurofibroma in a patient with NF-1.

The authors noted that measurements of FA and ADC are of little value because of the lack of normal reference values. Nerve-fiber tractography (FT) may be of value in the characterization of tumor pathology, and is also helpful in the planning of surgical treatments. They concluded that MR neurography is feasible in pediatric patients. However, a considerable amount of work has yet to be done to establish its role in the clinical management of the wide range of peripheral nerve diseases.

The Work Loss Data Institute’s clinical guideline on acute and chronic low back pain (2011) listed magnetic resonance neurography as one of the interventions/procedures that are under study and not specifically recommended. Guidelines on ulnar neuropathy from the Washington State Department of Labor and Industries (2010) considered but did not recommend magnetic resonance neurography. Guidelines on radial nerve entrapment from the Washington State Department of Labor and Industries (2010) recommended use of magnetic resonance neurography only in research settings.

The American College of Radiology’s Appropriateness Criteria® on “Plexopathy” (2012) stated that “Magnetic resonance neurography, diffusion tensor imaging (DTI), and tractography are exciting developments currently under investigation”.

Chung et al (2014) noted that magnetic resonance neurography (MRN) has utility in the diagnosis of many focal peripheral nerve lesions. The authors stated that when combined with history, examination, electrophysiology, and
laboratory data, future advancements in high-field MRN may play an increasingly important role in the evaluation of patients with peripheral neuropathy.

Thawait et al (2014) stated that MRN is a specialized technique that is rapidly becoming part of the diagnostic algorithm of peripheral nerve pathology. However, in order for this modality to be considered appropriate, its value compared with current methods of diagnosis should be established. Therefore, radiologists involved in MRN research should use appropriate methodology to evaluate MRN's effectiveness with a multi-disciplinary approach.

The Work Loss Data Institute's clinical guideline on "Shoulder (acute & chronic)" (2013) listed MRN as one of the interventions/procedures that was considered and not recommended.

Birnbaum et al (2014) stated that the diagnosis and treatment of patients with Sjogren syndrome (SS) with neuropathic pain pose several challenges. Patients with SS may experience unorthodox patterns of burning pain not conforming to a traditional "stocking-and-glove" distribution, which can affect the face, torso, and proximal extremities. This distribution of neuropathic pain may reflect mechanisms targeting the proximal-most element of the peripheral nervous system—the dorsal root ganglia (DRG). Skin biopsy can diagnose such a small-fiber neuropathy and is a surrogate marker of DRG neuronal cell loss. However, SS patients have been reported who have similar patterns of proximal neuropathic pain, despite having normal skin biopsy studies. In such cases, DRGs may be targeted by mechanisms not associated with neuronal cell loss. Thus, alternative approaches are needed to help characterize abnormal DRGs in SS patients with proximal neuropathic pain. These researchers performed a systematic review of the literature to define the frequency and spectrum of SS peripheral neuropathies, and to better understand the attribution of SS neuropathic pain to peripheral neuropathies.
They found that the frequency of SS neuropathic pain exceeded the prevalence of peripheral neuropathies, and that painful peripheral neuropathies occurred less frequently than neuropathies not always associated with pain. The investigators developed a novel MRN protocol to evaluate DRG abnormalities. A total of 10 SS patients with proximal neuropathic pain were evaluated by this MRN protocol, as well as by punch skin biopsies evaluating for intra-epidermal nerve fiber density (IENFD) of unmyelinated nerves; 5 patients had radiographic evidence of DRG abnormalities. Patients with MRN DRG abnormalities had increased IENFD of unmyelinated nerves compared to patients without MRN DRG abnormalities (30.2 [interquartile range, 4.4] fibers/mm versus 11.0 [4.1] fibers/mm, respectively; p = 0.03). Two of these 5 SS patients whose neuropathic pain resolved with intravenous immunoglobulin (IVIG) therapy had improvement of MRN DRG abnormalities. These researchers developed a novel MRN protocol that can detect DRG abnormalities in SS patients with neuropathic pain who do not have markers of peripheral neuropathy. They found that SS patients with MRN DRG abnormalities had statistically significant, increased IENFD on skin biopsy studies, which may suggest a relationship between trophic mediators and neuropathic pain. The authors concluded that given that this literature review has demonstrated that many SS neuropathic pain patients do not exhibit neuropathies; these findings suggested an important niche for this MRN DRG technique in the evaluation of broader subsets of SS neuropathic pain patients who may not have underlying neuropathies. The improvement of MRN DRG abnormalities in patients with IVIG-induced remission of neuropathic pain suggested that this MRN protocol may be capturing reversible, immune-mediated mechanisms targeting the DRG. The findings of this small case-series study need to be validated by well-designed studies.

Kitazume et al (2014) examined the feasibility of diffusion-weighted MRN (DW-MNR) for determining the originating nerve of para-pharyngeal schwannomas pre-operatively. A
total of 6 patients who underwent DW-MRN pre-operatively for a para-pharyngeal schwannoma were studied. Prediction of the originating nerve was performed. With the conventional method, a tumor showing "separation" between the internal jugular vein and carotid artery was determined to originate from the vagus nerve, with "no separation" from the sympathetic chain. With DW-MRN, the relationships between the vagus nerve and sympathetic chain to the tumor were characterized as "connected" or "dislocated". A nerve connected to the tumor was determined as the origin. Surgeries revealed that the origins included 1 vagus nerve and 5 sympathetic chains. Using a conventional method, all 6 cases were diagnosed correctly, whereas DW-MRN successfully predicted only 4 cases with a sympathetic chain origin. The authors concluded that DW-MRN is a feasible approach for determining an originating nerve.

Wang et al (2014) measured relevant anatomical variables of lumbosacral nerve root and adjacent structures by MRN and analyzed operative safety of transforaminal lumbar interbody fusion (TLIF) in Chinese subjects. A total of 12 normal healthy volunteers (6 men and 6 women) underwent MRN of lumbosacral nerve roots at 3.0 T. Three-dimensional imaging was reconstructed with Osirix software and the following anatomic variables measured: (i) distance between nerve root and upper pedicle; (ii) distance between nerve root and lower pedicle; (iii) angle between nerve root and sagittal plane; (iv) distance between upper and lower nerve roots; and (v) distance between upper and lower pedicles. Good images of the L1 to L5 nerve roots were obtained by MRN technology in all 12 volunteers. The distance between nerve root and upper pedicle and the angle between nerve roots and the sagittal plane gradually diminished from L1 to L5. However, there were no significant variations in the distance between nerve root and lower pedicle or between upper and lower pedicles. From L1 to L2 to L4 to L5, the distances between upper and lower pedicles, which are
closely related to the operating space for TLIF in Chinese men and women, were less than 10 mm in most subjects and were significantly smaller in women than in men. The variables did not differ significantly between the left and right sides of the same segment. The authors concluded that based on the above anatomical study and measurement analysis, they believed that TLIF puts the upper nerve root at risk in some Chinese patients. Moreover, they stated that this conclusion requires confirmation by anatomical study of large samples and clinical validation.

Yoshida et al (2015) noted that there have been no reports of the use of 3-Tesla MRN (3T MRN) to characterize cervical radiculopathy. In particular, there are no reports of MRN of brachial plexus involvement in patients with cervical radiculopathy. These investigators reviewed retrospectively 12 consecutive patients with cervical radiculopathy who underwent 3T MRN. The median age was 54.5 years; 11 of 12 patients were men. The distribution of nerve-root signal abnormality was correlated with intervertebral foraminal stenosis and the presence of muscles that exhibited weakness and/or signs of denervation on EMG. Abnormalities in MRN were found to extend into the distal part of the brachial plexus in 10 patients. The authors concluded that the findings of this study demonstrated that MRN is potentially useful for diagnosis in patients with suspected cervical radiculopathy. Moreover, they stated that the finding of brachial plexus involvement on MRN may indicate a possible pathophysiological relationship between cervical radiculopathy and brachial plexopathy.

Menezes et al (2015) examined the use of DW-MRN in visualizing the lumbar plexus during pre-operative planning of lateral transpsoas surgery. A total of 94 (188 lumbar plexuses) spine patients underwent a DW-MR examination of the lumbar plexus in relation to the L3 to L4 and L4 to L5 disc spaces and superior third of the L5 vertebral body. Images were reconstructed in the axial plane using high-resolution
Maximum Intensity projection (MIP) overlay templates at the disc space and L3 to L4 and L4 to L5 interspaces; 10 and 22 mm MIP templates were chosen to mimic the working zone of standard lateral access retractors. The positions of the L4 nerve root and femoral nerve were analyzed relative to the L4 to L5 disc in axial and sagittal planes. Third-party radiologists and a senior spine surgeon performed the evaluations, with inter- and intra-observer testing performed. In all subjects, the plexus was successfully mapped. At L3 to L4, in all but 1 case, the components of the plexus (except the genito-femoral nerve) were located in the most posterior quadrant (zone IV). The L3 and L4 roots coalesced into the femoral nerve below the L4 to L5 disc space in all subjects. Side-to-side variation was noted, with the plexus occurring in zone IV in 86.2 % right and only 78.7 % of left sides. At the superior third of L5, the plexus was found in zone III in 27.7 % of right and 36.2 % of left sides; and in zone II in 4.3 % right and 2.1 % left sides. Significant inter- and intra-observer agreement was found. The authors concluded that by providing the surgeon with a pre-operative roadmap of the lumbar plexus, DW-MRN may improve the safety profile of lateral access procedures. These findings need to be validated by well-designed studies.

In an observational study, Quinn and colleagues (2015) demonstrated use of MRN to visualize the course of the lumbar plexus at the L4 to L5 disc space. Consecutive lumbar plexus MR neurograms (n = 35 patients, 70 sides) were studied. Scans were obtained on a Siemens 3T Skyra magnetic resonance imaging scanner. T1- and T2-color-coded fusion maps were generated along with 3-D models of the lumbosacral plexus with attention to the L4 to L5 interspace. The position of the plexus and the shape of the psoas muscle at the L4 to L5 interspace were evaluated and recorded. Direct imaging of the lumbar plexus using MRN revealed a substantial variability in the position of the lumbar plexus relative to the L4 to L5 disc space. The left-side plexus was identified in zone 2 (5.7 %), zone 3 (54.3 %), and zone 4 (40 %) (p = 0.0014); on the right, zone 2 (8.6 %), zone 3 (42.9 %).
or zone 4 (45.7 %), and zone 5 (2.9 %) (p = 0.01). Right-left symmetry was found in 18 of 35 subjects (51.4 %) (p = 0.865). There was no association between the position of the plexus and the shape of the overlying psoas muscle identified. In patients with an elevated psoas (n = 12), the lumbar plexus was identified in zone 3 in 75 % and 66 % (left and right) compared with patients without psoas elevation (n = 23), 30.4 % and 43.5 % (left and right). The authors concluded that the course of the lumbosacral plexus traversing the L4 to L5 disc space may be more variable than has been suggested by previous studies. They stated that MRN may provide a more reliable means of pre-operatively identifying the plexus when compared with current methods. These findings need to be validated by well-designed studies.

In a prospective study, Chhabra and colleagues (2016a) tested the incremental value of 3T MRN in a series of unilateral radiculopathy patients with non-contributory MRI. A total of 10 subjects (3 men and 7 women; mean age of 54 years; range of 22 to 74) with unilateral lumbar radiculopathy and with previous non-contributory lumbar spine MRI underwent lumbo-sacral (LS) plexus MRN over a period of 1 year. Lumbar spine MRI performed as part of the MRN LS protocol as well as bilateral L4 to S1 nerves, sciatic, femoral and lateral femoral cutaneous nerves were evaluated in each subject for neuropathy findings on both anatomic (nerve signal, course and caliber alterations) and DTI tensor maps (nerve signal and caliber alterations). Minimum fractional anisotropy (FA) and mean ADC of L4 to S2 nerve roots, sciatic and femoral nerves were recorded. All anatomic studies and 80 % of DTI imaging received a good-excellent imaging quality grading. In a blinded evaluation, all 10 examinations demonstrated neural and/or neuromuscular abnormality corresponding to the site of radiculopathy. A number of contributory neuropathy findings including double crush syndrome were observed. On DTI tensor maps, nerve signal and caliber alterations were more conspicuous. Although individual differences were observed among neuropathic
appearing nerve (lower FA and increased ADC) as compared to its contralateral counterpart, there were no significant mean differences on statistical comparison of LS plexus nerves, femoral and sciatic nerves (p > 0.05). The authors concluded that MRN of LS plexus was useful for the evaluation of patients with non-contributory MRI of lumbar spine as it could incrementally delineate the etiology and provided direct objective and non-invasive evidence of neuromuscular pathology.

This study has several limitations: (i) being a small pilot study, the authors did not obtain inter- or intra-observer performance assessment, (ii) although there was good correlation of imaging findings, it is not an accuracy study and the authors do not yet have outcomes data, which remains a topic for further research, (iii) there is a spectrum and selection bias, but it could not be avoided, since these researchers wanted to study incremental value of MRN over MR spine studies, and (iv) the authors did not test cervical radiculopathy cases, thus, they could not comment on whether MRN provided any incremental value over MRI in those cases.

Chhabra and colleagues (2016b) examined the feasibility of whole-body MRN (WB-MRN) in polyneuropathy for technical feasibility, distribution of nerve abnormalities, and differentiation. A total of 20 WB-MRN examinations were performed on a 3T scanner over 2 years. Patient demographics including history of hereditary and acquired neuropathy were recorded. The images were evaluated by 2 independent readers with nerve imaging experience for quality. The nerve signal and size alterations were measured in the brachial plexus, LS plexus, and femoral and sciatic nerves; DTI parameters (FA and ADC) were determined in plexuses, and tractography was performed. Non-parametric Wilcoxon rank sum test, receiver operating characteristic (ROC) analysis, and intra-class correlation coefficients (ICCs)
were obtained. Excellent image quality was obtained for the majority of LS plexus (18/20) and 50% of brachial plexus (10/20) regions. Qualitatively among cases, the nerve hyper-intensity and/or thickening involved the brachial plexus (11/11), LS plexus (7/11), and both plexuses (7/11), with most nerve thickenings observed in Charcot-Marie-Tooth (CMT) disease type 1. The nerve signal intensity alterations were significantly different for both brachial (p < 0.05) and LS (p < 0.05) plexuses in cases versus controls. The femoral and sciatic nerve size alterations were different (p < 0.05), while signal intensity differences were not significant (p = 0.1-0.97). Transverse dimensions of C8 (4 mm), L5 (6.2 mm) and S1 (5.1 mm) nerve roots, and sciatic nerves (10.2 mm) were the most accurate diagnostic performance measures in distinguishing cases from controls. The authors concluded that WB-MRN is feasible for use in the clinical practice for the identification and potential characterization of polyneuropathy. Well-designed studies are needed to ascertain the safety and effectiveness of WB-MRN in the management of patients with polyneuropathy and CMT disease.

Mizuma and colleagues (2016) stated that metastasis of breast cancer is often detected through a long-term course and difficult to diagnose. These investigators reported a case of brachial plexopathy suspected to be the initial lesion of breast cancer metastasis, which was only detected by MRN. A 61-year old woman was admitted to the authors’ hospital within 2 years after operation for breast cancer because of progressive dysesthesia and motor weakness initially in the upper limb on the affected side and subsequently on the contralateral side. Enhanced computed tomography (CT), axillary lymph node echo, gallium scintigraphy, and short tau inversion recovery MR images showed no abnormalities; MRN revealed a swollen region in the left brachial plexus. These investigators suspected neuralgic amyotrophy and initiated treatment with intravenous immunoglobulin (IVIG) therapy and steroid therapy. However, there was no improvement, and the progression of motor weakness in the bilateral lower limbs
appeared over 4 years. Concomitant elevation of carbohydrate antigen 15-3 level (58.9 U/ml) led to suspect breast cancer metastasis, which was associated with the worsening of neurological findings, although gallium scintigraphy and bone scintigraphy showed no inflammatory and metastatic lesions. Swelling of the cauda equina in enhanced lumbar MRI and abnormal accumulation at the brachial plexus and cervical spinal cord in positron-emission tomography (PET) were newly detected contrary to the normal findings on the gallium scintigraphy, which suggested cerebrospinal fluid seeding. The authors suspected breast cancer metastasis about the initial brachial plexopathy based on the clinical course. They stated that MRN may be a helpful tool to detect metastatic lesion, especially in nerve roots.

Bao and colleagues (2017a) examined the feasibility of DW-MRN in the visualization of extremity nerves in the wrist and palm. A total of 32 volunteers and 21 patients underwent imaging of the wrist and palm on a 3T MR scanner. In all subjects, 2 radiologists evaluated the image quality on DW-MRN using a 4-point grading scale. Kappa statistics were obtained for inter-observer performance. In volunteers, the Chi-squared test was used to assess the differences in nerve visualization on DW-MRN and axial fat-suppressed proton density weighted imaging (FS-PDWI). In volunteers, the mean image quality scores for the median nerve (MN) and ulnar nerve (UN) were 3.71 ± 0.46 and 3.23 ± 0.67 for observer 1, and 3.70 ± 0.46 and 3.22 ± 0.71 for observer 2, respectively. The inter-observer agreement was excellent (k = 0.843) and good (k = 0.788), respectively. DW-MRN provided significantly improved visualizations of the 2nd and the 3rd common palmar digital nerves and 3 branches of UN compared with FS-PDWI (p < 0.05). In patients, the mean image quality scores for the 2 observers were 3.24 ± 0.62 and 3.10 ± 0.83, inter-observer performance was excellent (k = 0.842). The authors concluded that DW-MRN is feasible for improving visualization of extremity nerves and their lesions in the wrist and palm with adequate image quality, thereby providing a
supplementary method to conventional MR imaging. Well-designed studies are needed to ascertain the safety and effectiveness of DW-MRN in the evaluation of median and ulnar nerves in the wrist and palm.

Wadhwa and co-workers (2017) stated that pudendal neuralgia is being increasingly recognized as a cause of chronic pelvic pain, which may be related to nerve injury or entrapment. Due to its complex anatomy and branching patterns, the pudendal nerve abnormalities are challenging to illustrate. The authors noted that high-resolution 3T MRN is a promising technique for the evaluation of peripheral neuropathies.

Yamashita and associates (2017) evaluated the potential of readout-segmented echo-planar DW-MRN (RS-EPI DW-MRN) for the selective visualization of pelvic splanchnic nerve and pelvic plexus in healthy male volunteers. Institutional review board approval and written informed consent were obtained; RS-EPI DW-MRN images were acquired from 13 healthy male volunteers aged 25 to 48 years between September 2013 and December 2013. For RS-EPI DW-MRN, the following parameters were used: spatial resolution, 1.1×1.1×2.5 mm; b-value, 250 s/mm²; number of readout-segments, 7; and acquisition time, 7 minutes 45 seconds. For qualitative assessment, 2 abdominal radiologists independently evaluated the visibility of the pelvic splanchnic nerves and pelvic plexuses bilaterally in each subject on oblique coronal thin-slab 10-mm-thick maximum intensity projection images and scored it with a 4-point grading scale (excellent, good, fair, poor). Both readers scored twice at 6-month intervals. Inter-observer and intra-observer variability were evaluated using Cohen's quadratically weighted κ statistics. Image artifact level was scored on a 4-point grading scale by other 2 abdominal radiologists in order to evaluate the correlation between the nerve visibility and the severity of imaging artifacts using the Spearman's correlation coefficient. Qualitative grading showed the following success rate (number
of nerves qualitatively scored as excellent or good divided by total number of nerves): reader 1 (first set), 73 % (19/26); reader 2 (first set), 77 % (20/26); reader 1 (second set), 81 % (21/26); and reader 2 (second set), 77 % (20/26). Inter-observer agreement between readers 1 and 2 was excellent: \( \kappa = 0.947 \) (first set) and 0.845 (second set). Intra-observer agreement was also excellent: \( \kappa = 0.810 \) (reader 1) and 0.946 (reader 2). The visibility of pelvic splanchnic nerve and pelvic plexus showed a moderate correlation with the image artifact level (\( \rho = 0.54, p = 0.004 \)). The authors concluded that the findings of this study demonstrated that RS-EPI DW-MRN is a promising approach for selectively visualizing the pelvic splanchnic nerve and pelvic plexus.

In a pilot study, Bao and co-workers (2017b) examined the applicability of DW-MRN in the diagnosis of carpal tunnel syndrome (CTS). A total of 47 patients with CTS (69 wrists) and 19 normal participants (38 wrists) were included in this study. Cross-sectional area (CSA) and ADC values of the median nerves in the carpal tunnel were determined using DW-MRN; ROC analysis was performed. No significant differences in age or body mass index (BMI) were observed between the control and CTS groups. DW-MRN imaging showed obvious hyper-intensity in the lesions in CTS wrists, while other nerve regions were related to slight hyper-intensity. Inter-observer variability analysis indicated excellent agreement regarding both the CSA and ADC measurements for the control and CTS groups. Both the mean CSA and ADC values of the median nerves in carpal tunnel in the CTS group were significantly higher than the control group. According to the ROC analysis, the CSA cut-off value was 11.7 mm2, and sensitivity and specificity were 66.7 % and 89.5 %, respectively. In contrast, the median nerve ADC cut-off value was 1.047×10-3 mm2/s. The sensitivity and specificity were 91.3 % and 76.3.9 %, respectively. The authors concluded that DW-MRN represents a highly reproducible diagnostic
technique for CTS. The ADC value of median nerves in the carpal tunnel was significantly higher in CTS patients, which provides a potential powerful tool for the disease diagnosis.

Currently, the sensitivity, specificity, as well as positive predictive value (PPV) and negative predictive value (NPV) of MRN in the diagnosis and management of patients with peripheral nerve disorders remain unclear. Thus, the accuracy and clinical value of MR neurography has yet to be established.

Jende and co-workers (2017) quantified peripheral nerve lesions in multiple sclerosis (MS) by MRN. A total of 36 patients diagnosed with MS based on the 2010 McDonald criteria (34 with the relapsing-remitting form, 2 with clinically isolated syndrome) with and without disease-modifying treatment were compared to 35 healthy age- and sex-matched volunteers. All patients underwent detailed neurological and electrophysiological examinations. Three Tesla MRN with large anatomical coverage of both legs and the lumbosacral plexus was performed by using 2-dimensional (2D) fat-saturated, T2-weighted (T2w) and dual echo turbo spin echo sequences as well as a 3D T2-weighted, fat-saturated SPACE sequence. Besides qualitative visual nerve assessment, a T2w signal quantification was performed by calculation of proton spin density (PSD) and T2 relaxation time. Nerve diameter was measured as a morphometric criterion. T2w hyper-intense nerve lesions were detectable in all MS patients, with a mean lesion number at thigh level of 151.5 ± 5.7 versus 19.1 ± 2.4 in controls (p < 0.0001). Nerve PSD was higher in MS (tibial/peroneal: 371.8 ± 7.7/368.9 ± 8.2) versus controls (tibial/peroneal: 266.0 ± 11.0/276.8 ± 9.7, p < 0.0001). In contrast, T2 relaxation time was significantly higher in controls (tibial/peroneal: 82.0 ± 2.1/78.3 ± 1.7) versus MS (tibial/peroneal: 64.3 ± 1.0/61.2 ± 0.9, p < 0.0001). Proximal tibial and peroneal nerve caliber was higher in MS (tibial: 52.4 ± 2.1 mm², peroneal: 25.4 ± 1.3 mm²) versus controls (tibial: 45.2 ± 1.4 mm², p < 0.0015; peroneal: 21.3 ± 0.7 mm², p =
The authors concluded that peripheral nerve lesions could be visualized and quantified in MS in-vivo by high-resolution MRN. Lesions were defined by an increase of PSD and a decrease of T2 relaxation time, indicating changes in the microstructural organization of the extracellular matrix in peripheral nerve tissue in MS. They stated that by showing involvement of the peripheral nervous system in MS, this proof-of-concept study may offer new insights into the pathophysiology and treatment of MS.

Petrasic and colleagues (2017) stated that chronic cauda equina syndrome, defined as persistent damage of the cauda equina nerve roots within the spinal canal can be a challenging diagnosis with varied presentations. These researchers evaluated the impact of lumbo-sacral plexus MRN in the diagnostic thinking and therapeutic management of patients presenting with chronic pelvic pain and dysfunction and suspected chronic cauda equina syndrome. Consecutive MRN lumbosacral plexus examinations at the authors’ institution were reviewed retrospectively. Relevant data collected included the following: patient demographics, clinical history, pertinent physical examination findings, pre-imaging diagnostic impression, prior MR imaging lumbar spine findings, MRN findings, post-imaging diagnosis, and post-imaging treatment plan. The impact of imaging on the pre-imaging clinical diagnosis and therapeutic management was evaluated. Of 185 studies of patients who presented with chronic pelvic pain and/or dysfunction, 23 with clinically suspected chronic cauda equina syndrome and imaging findings were included in the study (2 subjects were lost to follow-up). The mean ages were 53 ± 12 years and 53 ± 16 years for men and women, respectively. The common etiologies included arachnoiditis (n = 8), tethered cord (n = 2), and simple/Tarlov cysts (n = 3); 18 of 23 (78 %) subjects had a change in diagnosis resulting from MRN findings, and 5/23 (22 %) had no change; 17 of 21 (81 %) subjects had a change in
management, and 4/21 (19 %) had no change. The authors concluded that MRN impacted the diagnosis and therapeutic management of patients with suspected chronic cauda equina

The authors noted that this study had several limitations. The analysis, including the retrospective methodology and, to some degree, the categorization of “no” or “yes” with regard to change in management, was somewhat subjective, leaving it open to bias. A few patients were lost to follow-up; thus, these investigators did not have complete imaging or clinical management data for these subjects. Due to the retrospective nature of this study, no inter-observer performance in repeat readings of the MRN examinations was obtained (all studies were ultimately interpreted by one of the authors), stressing the need for an increase in the number of radiologists qualified to read these studies. They stated that future directions include performance of a larger, prospective randomized clinical trial looking at the clinical impact of MRN on this and other neurologic diseases. A multi-center trial would be ideal to decrease potential bias, given the relative paucity of specialized radiologists qualified to read these studies. Performing a cost-effectiveness analysis on the impact of MRN results would also be helpful in identifying how these studies impact standard practice economy

Hilgenfeld and associates (2017) examined if high-resolution brachial plexus (BP) MRN is capable of distinguishing patients with compressive neuropathy or non-compressive plexopathy from age- and sex-matched controls, discriminating between patients with compressive neuropathy and non-compressive plexopathy, and detecting spatial lesion patterns suggesting somatotopic organization of the BP. A total of 36 patients (50.9 ± 12.7 years) with clinical symptoms, nerve conduction studies, and needle EMG findings suggestive of BP and 36 control subjects matched for age and sex (50.8 ± 12.6 years) underwent high-resolution MRN of the BP. Lesion determination and localization was performed by 2 blinded neuro-radiologists at the anatomical levels of the plexus trunks
and cords. By applying defined criteria of structural plexus lesions on high-resolution MRN, all patients were correctly rated as affected, whereas 34 of 36 controls were correctly rated as unaffected by independent and blinded reading from 2 neuro-radiologists with overall good to excellent inter-rater reliability. In all cases, plexopathies with a compressive etiology (n = 12) were correctly distinguished from non-compressive plexopathies with inflammatory origin (n = 24). Patho-anatomical contiguity of lesion from trunk into cord level allowed recognition of distinct somato-topical patterns of fascicular involvement, which correlated closely with the spatial distribution of clinical symptoms and electrophysiological data. The authors concluded that BP MRN was highly accurate for differentiating patients with symptomatic plexopathy from healthy controls and for distinguishing patients with compressive neuropathy and non-compressive plexopathy. Furthermore, BP MRN revealed evidence for somatotopic organization of the BP. Therefore, as an addition to functional information of electro-diagnostic studies, anatomical information gained by BP MRN may help to improve the efficiency and accuracy of patient care. These preliminary findings need to be validated by well-designed studies.

In a prospective study, Kronlage and colleagues (2019) evaluated large coverage MRN in chronic inflammatory demyelinating polyneuropathy (CIDP). A total of 18 patients with CIDP and 18 healthy controls were examined by a standardized MRN protocol at 3 T. Lumbo-sacral plexus was imaged by a T2-weighted 3D sequence and peripheral nerves of the upper and lower extremity by axial T2-weighted turbo spin-echo sequences. Lesions were characterized by nerve cross-sectional area (CSA) and T2-weighted signal (nT2). Additionally, T2 relaxometry of the sciatic nerve was performed using a multi-spin-echo sequence. All patients received a complementary electrophysiological examination. Patients with CIDP exhibited increased nerve CSA and nT2 compared to controls (p < 0.05) in a proximally predominating
pattern; ROC analysis revealed the best diagnostic accuracy for CSA of the lumbo-sacral plexus (AUC = 0.88) and nT2 of the sciatic nerve (AUC = 0.88); CSA correlated with multiple electrophysiological parameters of demyelinating neuropathy (F wave latency, nerve conduction velocity) of sciatic and median nerve, while nT2 only correlated with F wave latency of sciatic and not median nerve. T2 relaxometry indicated that MR signal increase in CIDP was due to an increase in PSD (p < 0.05), and not due to the increase in T2 relaxation time. The authors concluded that both nT2 and CSA might aid in the diagnosis of CIDP, but CSA correlated more robustly with established electrophysiological parameters for CIDP. They stated that since the best diagnostic accuracy was shown for proximal nerve locations, MRN may be a useful complementary tool in selected CIDP cases.

In a prospective, observational, cohort study, Lichtenstein et al (2017) evaluated the utility of nerve diffusion tensor imaging (DTI), nerve cross-sectional area, and muscle MRI multi-echo Dixon for assessing proximal nerve injury in CIDP. A total of 11 patients with CIDP and 11 healthy controls underwent a multi-parametric MRI protocol with DTI of the sciatic nerve and assessment of muscle proton-density fat fraction of the biceps femoris and the quadriceps femoris muscles by multi-echo Dixon MRI. Patients were longitudinally evaluated by MRI, clinical examination, and nerve conduction studies at baseline and after 6 months. In sciatic nerves of CIDP patients, mean CSA was significantly higher and fractional anisotropy value was significantly lower, compared to controls. In contrast, muscle proton-density fat fraction was significantly higher in thigh muscles of patients with CIDP, compared to controls; MRI parameters showed high reproducibility at baseline and 6 months. The authors concluded that advanced MRI parameters demonstrated subclinical proximal nerve damage and intra-muscular fat accumulation in CIDP. They stated that these findings suggested that MRN of lower proximal limbs including nerve DTI and muscle fat Dixon imaging could be a useful tool for quantifying the subclinical burden of axonal
degeneration and neurogenic muscle changes in patients with CIDP. However further studies with patients with CIDP that are more severely affected in terms of proximal weakness are needed to determine the utility of these MR-based measures to serve as biomarkers in therapeutic trials.

Martín Noguerol and colleagues (2017) noted that traumatic conditions of peripheral nerves (PN) and plexus have been classically evaluated by morphological imaging techniques and electrophysiological tests. New MRI studies based on 3D fat-suppressed techniques are providing high accuracy for peripheral nerve injury evaluation from a qualitative point of view. However, these techniques do not provide quantitative information. Diffusion weighted imaging (DWI) and diffusion tensor imaging (DTI) are functional MRI techniques that are able to evaluate and quantify the movement of water molecules within different biological structures. These techniques have been successfully applied in other anatomical areas, especially in the assessment of central nervous system, and now are being imported, with promising results for PN and plexus evaluation. DWI and DTI allow performing a qualitative and quantitative PN analysis, providing valuable pathophysiological information about functional integrity of these structures. In the field of trauma and PN or plexus injury, several derived parameters from DWI and DTI studies such as apparent diffusion coefficient (ADC) or fractional anisotropy (FA) among others, can be used as potential biomarkers of neural damage providing information about fiber organization, axonal flow or myelin integrity. A proper knowledge of physical basis of these techniques and their limitations is important for an optimal interpretation of the imaging findings and derived data. The authors concluded that DTI and DWI neurographic studies provide both valuable morphological and functional information in several clinical scenarios, that helps to understand the different pathophysiological process that occurs in PN injury related lesions. Parametric data derived from these sequences add quantitative information to PN study, helping in the detection
and characterization of neural damage and grading its severity. In addition, these data can help to determine the most appropriate therapeutic option, as well as to monitoring the response to conservative or surgical treatment. In spite of the time penalty, the introduction of these techniques in routine MRI protocols for PN injury evaluation should be strongly considered. However, they stated that further prospective multi-center studies are needed to confirm parameters such as FA or RD as real biomarkers of neural damage. Finally, the standardization of both the acquisition and analysis protocols is key to obtain more reproducible and robust results.

Weissman and co-workers (2017) stated that chronic pelvic pain syndrome is commonly caused by nerve injury, inflammation, or entrapment. Owing to the complex anatomy and branching patterns of pelvic nerves, pelvic neuropathies are often difficult to illustrate and diagnose. High-resolution 3-T MRN is a promising technique for the evaluation of peripheral neuropathy.

Kronlage and associates (2018) established normal values and identified demographic determinants of quantitative biomarkers in MRN. A total of 60 healthy individuals (5 men and 5 women of every decade between 20 and 80 years) were examined according to a standardized MRN protocol at 3 T, including multi-echo T2 relaxometry. Nerve CSA, transverse relaxation time (T2), and PSD were assessed for the sciatic, tibial, median, ulnar, and radial nerves. Correlation with demographic variables, such as height, weight, body mass index (BMI), and age was expressed by Pearson coefficients and t-tests were used to compare MRN biomarkers between men and women with and without normalization to body weight and BMI by linear regression. The average nerve CSA correlated moderately with height ($r = 0.28$, $p = 0.04$), weight ($r = 0.40$, $p = 0.002$), and BMI ($r = 0.35$, $p = 0.008$), but not with age ($r = 0.23$, $p = 0.09$). While T2 did not correlate with demographic parameters, PSD was strongly inversely associated with BMI ($r = -0.64$, $p < 0.001$) and weight ($r =
-0.557, p < 0.001). Sex-dependent differences in imaging marker values were found for CSA but became negligible after normalization to body weight. The authors concluded that quantitative biomarkers of MRN co-varied with demographic variables. As particularly important determinants, these researchers identified body weight for nerve CSA and BMI for PSD. They stated that the presented normal values and demographic determinants may assist investigations into the potential of MRN biomarkers in further disease-specific studies.

In a prospective study, Schwarz and co-workers (2018) evaluated the imaging appearance and diagnostic value of plexus and peripheral nerve MRN in cervical radiculopathy. A total of 24 patients were included with a diagnosis of cervical radiculopathy based on clinical examination, supporting electrophysiological examinations and spinal imaging consistent with the clinical syndrome. All patients then underwent a high-resolution MRN protocol including the brachial plexus from nerve roots to plexus cords using a 3D turbo spin echo with variable flip angle short tau inversion recovery and sagittal-oblique T2w spectral adiabatic inversion recovery sequence, and ulnar, median, and radial nerves at the upper arm and elbow in T2w fat saturated sequences. Two readers independently rated plexus elements regarding the presence of lesions at neuro-foraminal levels, roots, trunks, and cord segments. Median, ulnar, and radial nerves were likewise rated. Findings were then compared to a referenced standard of cervical radiculopathy that was defined as the combined diagnosis of clinical syndrome including supporting electrophysiological exams and matching positive spinal imaging, and diagnostic performance parameters were calculated. Additional quantitative and qualitative analysis assessed peripheral nerve caliber and normalized T2-signal at arm level in cervical radiculopathy and compared them to 25 inflammatory neuropathy controls. Cervical radiculopathy resulted in distinct plexus lesion patterns for each level of neuro-foraminal stenosis. Overall, brachial plexus MRN in
cervical radiculopathy reached a sensitivity of 81 %, a specificity of 96 %, a PPV of 87 %, and overall diagnostic accuracy of 87 %. Initial spinal MRI showed multiple positive findings for clinically unaffected root levels and resulted in a specificity of 69 %, a PPV of 54 %, and an overall diagnostic accuracy of 78 %; T2w peripheral nerve lesions were detected in 79 % of cervical radiculopathy cases and imitated imaging appearance of inflammatory neuropathies both quantitatively and qualitatively. The authors concluded that complementing spine imaging in cervical radiculopathy with brachial plexus MRN can improve diagnostic accuracy by increasing specificity and PPV; T2w lesions of peripheral nerves can be caused by cervical radiculopathy, which must be considered a relevant diagnostic pitfall in MRN of peripheral neuropathies.

Vaeggemose and associates (2017) examined if DTI-MRN, T2 relaxation time, and PSD can detect and grade neuropathic abnormalities in patients with type 1 diabetes (T1D). Patients with T1D (n = 49) were included -- 11 with severe polyneuropathy (sDPN), 13 with mild polyneuropathy (mDPN), and 25 without polyneuropathy (nDPN) -- along with 30 healthy control subjects (HCs). Clinical examinations, nerve conduction studies, and vibratory perception thresholds determined the presence and severity of DPN. DTI-MRN covered proximal (sciatic nerve) and distal (tibial nerve) nerve segments of the lower extremity. Fractional anisotropy (FA) and the apparent diffusion coefficient (ADC) were calculated, as were T2 relaxation time and PSD obtained from DTI-MRN.

All magnetic resonance findings were related to the presence and severity of neuropathy; FA of the sciatic and tibial nerves was lowest in the sDPN group. Corresponding with this, proximal and distal ADCs were highest in patients with sDPN compared with patients with mDPN and nDPN, as well as the HCs. DTI-MRN correlated closely with the severity of neuropathy, demonstrating strong associations with sciatic and tibial nerve findings. Quantitative group differences in PSD were also significant, but less pronounced than those for DTI-MRN. The authors concluded that DTI-MRN enabled
detection in peripheral nerves of abnormalities related to DPN, more so than PSD or T2 relaxation time. They stated that these abnormalities are likely to reflect pathology in sciatic and tibial nerve fibers.

The authors stated that this study had several drawbacks. First, this was a cross-sectional study, and thus how DTI findings developed over time remained unknown. Second, axial and radial diffusivities were not calculated in this study, which in HCs provided additional information about axonal and myelin sheath integrity. Third, MRN coverage of the sciatic and tibial nerves consisted of 16 slices (2 × 4.80 cm), evaluating only small parts of the nerve. MRN covering the entire nerve would enable detection of multi-focal lesions in DPN; however, this would considerably increase examination time. Also, these researchers did not include the upper-limb nerve to serve as a control for the lower limb, which could have further substantiated these findings; this would, however, also increase the examination time. Finally, the study did not include an assessment of peripheral limb vascular status to evaluate any influence of multi-focal ischemic neuropathy on the DTI-MRN findings.

Jende and colleagues (2018) quantified differences of microstructural nerve damage in distal symmetric diabetic neuropathy (DPN) between T1D and type 2 diabetes (T2D), and detected correlations between neuropathic symptoms and serological risk factors. 3T MRN of the sciatic nerve was performed in 120 patients (n = 35 for T1D; n = 85 for T2D) with either DPN (n = 84) or no DPN (NDPN; n = 36). Results were subsequently correlated with clinical, serological, and electrophysiological patient data. T2-weighted hyper-intense lesions correlated negatively with tibial compound motor action potential (r = -0.58; p < 0.0001) and peroneal nerve conduction (r = 0.51; p = 0.0002), and positively with neuropathy disability (NDS; r = -0.54; p < 0.0001) and severity score (NSS; r = 0.52; p < 0.0001), and HbA1c levels (r = 0.23; p = 0.014). T2w-hypo-intense lesions correlated positively with NDS, NSS (r =
0.28; p = 0.002; r = 0.36; p < 0.0001), and serum triglycerides (r = 0.34; p = 0.0003), and negatively with serum HDL (r = -0.48; p < 0.0001). For DPN in T1D, elevated values of T2w-hyperintense lesions (19.67 % ± 4.13 versus 12.49 % ± 1.23; p = 0.027) and HbA1c (8.74 % ± 0.29 versus 7.11 % ± 0.16; p < 0.0001) were found when compared to T2D. For DPN in T2D, elevated T2w-hypo-intense lesions (23.41 mm3 ± 2.69 versus 11.43 mm3 ± 1.74; p = 0.046), triglycerides (220.70 mg/dL ± 23.70 versus 106.60 mg/dL ± 14.51; p < 0.0001), and lower serum HDL (51.29 mg/dL ± 3.02 versus 70.79 mg/dL ± 4.65; p < 0.0001) were found when compared to T1D. The authors concluded that the predominant type of nerve lesions in DPN differed between T1D and T2D. Correlations found between lesion type and serological parameters indicated that predominant nerve lesions in T1D were associated with poor glycemic control and loss of nerve conduction, whereas predominant lesions in T2D were associated with changes in lipid metabolism. The researchers stated that these findings may be helpful for future studies on the underlying pathophysiological pathways and possible treatments for DPN in T1D and T2D.

Chaves and associates (2018) noted that disorders affecting the lumbo-sacral plexus (LSP) could alter root diameter. These investigators determined normal LSP nerve root dimensions using MRN. A total of 11 asymptomatic patients (ages: 18 to 53, mean of 34 years) underwent MRN of the LSP on a 3 T scanner with an 8-channel torso-PA coil. IDEAL T2-weighted images were acquired and nerve root dimensions were measured from the 2nd lumbar (L2) to the 1st sacral (S1) vertebrae on the coronal plane, 5 mm from the dorsal root ganglion (DRG). Root size was recorded by 3 separate groups of radiologists with different levels of expertise. Additional LSP-MRN images were acquired from a fresh-frozen cadaver specimen using the same scanner and parameters identical to those described above. Subsequently, 2 experienced anatomists dissected and measured the LSP roots at exactly the same distance from the DRG, using an
electronic caliper. Mean root size values recorded (± standard deviation) in the asymptomatic patients were as follows: L2: 3.12 mm (± 0.92), L3: 4.29 mm (± 0.95), L4: 5.13 mm (± 0.79), L5: 5.29 mm (± 0.9), and S1: 5.38 mm (± 0.7). The correlation coefficients were 0.72 between the patient and cadaver MRN results and 0.79 between the patient and dissected cadaver MRN results. Inter-observer agreements were 0.73 among the radiologist groups and 0.87 between the anatomists conducting dissections. The authors believed MRN provided reliable assessments of LSP root thickness; they stated that more extensive studies should be performed to confirm these findings.

Newhart and colleagues (2019) stated that MRN is a newer imaging technique that is increasingly used for detailed visualization of peripheral nerves not reliably achieved with conventional imaging modalities. Although MRN has been previously characterized in the literature, few studies have assessed its utility to neurosurgery, where there is potentially substantial impact particularly with pre-operative assessment. These investigators carried out a retrospective review of cases in which MRN was used for clinical evaluation and surgical decision-making. Clinical assessment, MRN, and operative decision-making were retrospectively assessed in 206 consecutive patients at the authors’ institution between 2015 and 2018. MRN was determined to lead to a change in diagnosis or surgical decision-making in 44 patients (21.4 %: 27 female, 17 male). These were classified into 6 major diagnostic categories: trauma, post-surgical evaluation, compressive/degenerative conditions, tumors, neuritis/inflammation, and other neurogenic lesions; 9 representative cases were selected from these categories to highlight the range of neurosurgical pathologies in which MRN was useful in diagnostic assessment and surgical decision-making. The authors concluded that MRN is an under-used resource with great potential value in the diagnoses, surgical planning, and post-operative assessment of various
neurosurgical conditions. These presented incremental utility to the neurosurgeon as well as socio-economic benefit in the detection of potentially surgically treatable lesions.

**Magnetic Resonance Neurography Biomarkers to Characterize Peripheral Neuropathy in AL Amyloidosis**

Kollmer and colleagues (2018) detected, localized, and quantified peripheral nerve lesions in amyloid light chain (AL) amyloidosis by MRN in correlation with clinical and electrophysiologic findings. These researchers prospectively examined 20 patients with AL-polyneuropathy (PNP) and 25 age- and sex-matched healthy volunteers. After detailed neurologic and electrophysiologic testing, the patient group was sub-divided into mild and moderate PNP; MRN in a 3.0 tesla scanner with anatomical coverage from the lumbo-sacral plexus and proximal thigh down to the tibio-talar joint was performed by using T2-weighted and dual-echo 2-dimensional sequences with spectral fat saturation and a 3D, T2-weighted inversion recovery sequence. Besides evaluation of nerve T2-weighted signal, detailed quantification of nerve injury by morphometric (nerve caliber) and microstructural MRN markers (proton spin density, T2 relaxation time) was conducted. Nerve T2-weighted signal increase correlated with disease severity: moderate (420.2 ± 60.1) versus mild AL-PNP (307.2 ± 17.9; p = 0.0003) versus controls (207.0 ± 6.4; p < 0.0001). Proton spin density was also higher in moderate (tibial: 525.5 ± 53.0; peroneal: 553.6 ± 64.5; sural: 492.0 ± 56.6) and mild AL-PNP (tibial: 431.6 ± 22.0; peroneal: 457.6 ± 21.7; sural: 404.8 ± 25.2) versus controls (tibial: 310.5 ± 14.1; peroneal: 313.6 ± 11.6; sural: 261.7 ± 11.0; p < 0.0001 for all nerves). T2 relaxation time was elevated in moderate AL-PNP only (tibial: p = 0.0106; peroneal: p = 0.0070; sural: p = 0.0190). Tibial nerve caliber was higher in moderate (58.0 ± 8.8 mm3) versus mild AL-PNP (46.5 ± 2.5 mm3; p = 0.008) versus controls (39.1 ± 1.2 mm3; p < 0.0001). The authors concluded that MRN detected and quantified peripheral nerve injury in AL-PNP in-vivo with high sensitivity and in close...
correlation with the clinical stage. Quantitative parameters were feasible new imaging biomarkers for the detection of early AL-PNP and might help to monitor microstructural nerve tissue changes under treatment. These researchers stated that proton spin density could serve as a promising imaging biomarker for the monitoring of structural nerve damage under therapy by providing a direct inside view into nerve tissue integrity in-vivo. They noted that in absence of competing biomarkers, scientific findings generated from this study might influence future therapeutic decision-making in individual patients.

Magnetic Resonance Neurography of the Lumbosacral Plexus in Failed Back Surgery Syndrome

In a retrospective, case-series study, Dessouky and colleagues (2018) examined the role of MRN of the LSP in management of patients with failed back surgery syndrome (FBSS). From 203 consecutive 3 T MRN studies of lumbosacral plexus in 1 year, 12 % (25/203) presented as FBSS. Demographic data, number of previous lumbar MRIs and their findings, MRN findings, interval between MRI and MRN, pre- and post-MRN diagnosis, pain levels, and treatments were recorded. Changes in diagnosis, treatment, and outcomes after MRN were determined. The final sample of 25 patients had a mean age 62±15 and male to female ratio 1:1.08. Approximately 88 % (22/25) had previous lumbar MRI, of which 27 % had 3 or more. Most common imaging findings were neuro-foraminal stenosis 22.6 % (7/31) on MRI and neuropathy 22.9 % (19/83) on MRN. Mean interval between MRI and MRN was 13.9±28.3 months. Lumbar MRIs were inconclusive in 36 % (8/22); MRN detected 63 % (52/83) more findings and changed the diagnosis and treatment in 12 % and 48 % of FBSS cases, respectively. Favorable outcomes were recorded in 40 % to 67 % of patients following MRN-guided treatments. The authors concluded that FBSS is a complex problem and MRN of LSP impacted its management by better directing source of symptoms. Level of evidence = IV.
Magnetic Resonance Neurography for Evaluation of Chronic Inflammatory Demyelinating Polyradiculoneuropathy

In a retrospective study, Hiwatashi and colleagues (2019) examined the usefulness of simultaneous apparent T2 mapping and MRN with nerve-sheath signal increased with inked rest-tissue rapid acquisition of relaxation enhancement imaging (SHINKEI) to distinguish patients with chronic inflammatory demyelinating polyneuropathy (CIDP) from healthy subjects. This trial included 13 patients with CIDP and 5 healthy subjects. The T2 relaxation time and the size of the cervical ganglia and roots of the brachial plexus were measured. Statistical analyses were performed with the Mann-Whitney U test and receiver operating characteristics (ROC) analysis. The T2 relaxation times of the ganglia and roots were longer in patients with CIDP (119.31 ± 35.53 msec and 111.15 ± 33.82 msec) than in healthy subjects (101.42 ± 26.42 msec and 85.29 ± 13.22 msec, p = 0.0007 and p < 0.0001, respectively). The sizes of the ganglia and the roots were larger in patients with CIDP (6.25 ± 1.56 mm and 4.37 ± 1.71 mm) than in healthy subjects (5.59 ± 1.08 mm and 3.50 ± 0.62 mm, p = 0.0114 and p = 0.0014, respectively); ROC analysis revealed that T2 relaxation time of the roots was best at distinguishing CIDP patients from healthy subjects (the area under the curve = 0.748). The authors concluded that patients with CIDP could be distinguished from healthy subjects using simultaneous apparent T2 mapping and MRN with SHINKEI.

The authors stated that this study had several drawbacks. These researchers quantified T2 relaxation time with 2 iMSDE duration times, because the other parameters were exactly the same in these 2 acquisitions. T2 quantification with 3 or more points might be better, which needs longer acquisition time and might cause image degradation due to motion. A simulation in which the accuracy of T2 estimation is plotted as function of T1 and T2 might be useful to verify this technique, however it might be difficult because of field inhomogeneity.
especially at 3T. These investigators did not evaluate the entire length of the brachial plexus because of its complex form. They should establish the other analysis method such as automatic tracking of the nerves in future. Lack of contrast material might be another limitation. Because most of the patients included had stable symptoms, they did not want a contrast agent on follow-up MR examination. The small number of patients included (n = 13) and the lack of the evaluation of the other nerves might be other limitations. The authors are continuing to gather patients with more robust fat suppression techniques with SHINKEI. They did not compare their new technique with a classic SHINKEI showing only neurography because they did not observe a critical difference between these techniques clinically. These researchers stated that comparison with clinical assessment of specific nerves involved and other imaging findings might be preferable, however, it is also difficult to define specific nerves involved because of the various symptoms in patients included in this study.

### CPT Codes / HCPCS Codes / ICD-10 Codes

Information in the [brackets] below has been added for clarification purposes. Codes requiring a 7th character are represented by "+":

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The above policy is based on the following references:


   Neurography of the brachial plexus in the thoracic 
13. Cornwall R, Radomisli TE. Nerve injury in traumatic 
   neurography: Magnetic resonance imaging of 
   peripheral nerves. Neuroimaging Clin N Am. 2001;11 
   (1):viii, 131-146.
   resonance neurography studies of the median nerve 
   before and after carpal tunnel decompression. J 
   acute nerve compression injury with magnetic 
17. Spratt JD, Stanley AJ, Grainger AJ, et al. The role of 
   diagnostic radiology in compressive and entrapment 
   intraneural ganglia: The importance of the articular 
   329.
19. Zhou L, Yousem DM, Chaudhry V. Role of magnetic 
   resonance neurography in brachial plexus lesions. 
   Characterization of genetically defined types of Charcot-
   Marie-Tooth neuropathies by using magnetic resonance 
   composite magnetic resonance neurography of the 
   brachial plexus: Implications for infraclavicular block 


31. Washington State Department of Labor and Industries. Work-related ulnar neuropathy at the elbow (UNE):


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Amendment to
Aetna Clinical Policy Bulletin Number: 0387 Magnetic Resonance Neurography

There are no amendments for Medicaid.