High-Resolution 3T MR Neurography of the Lumbosacral Plexus

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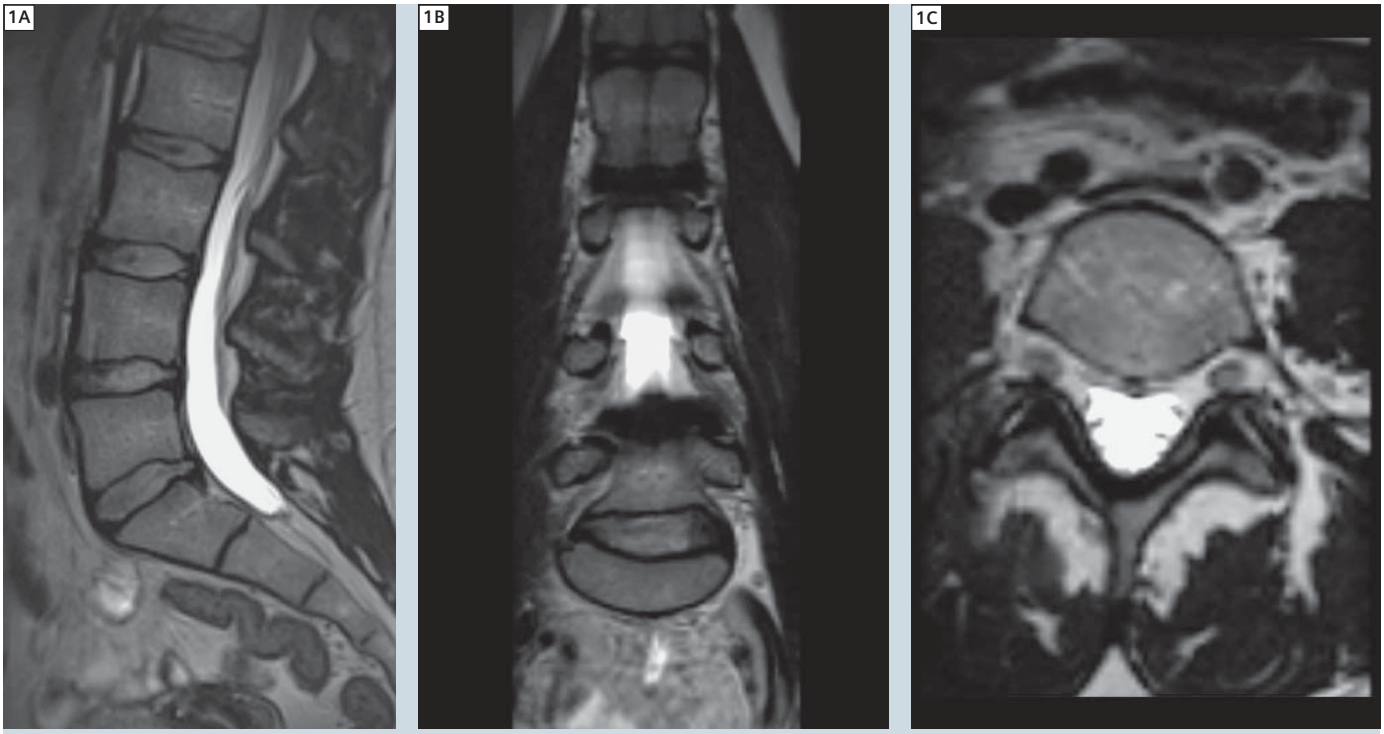


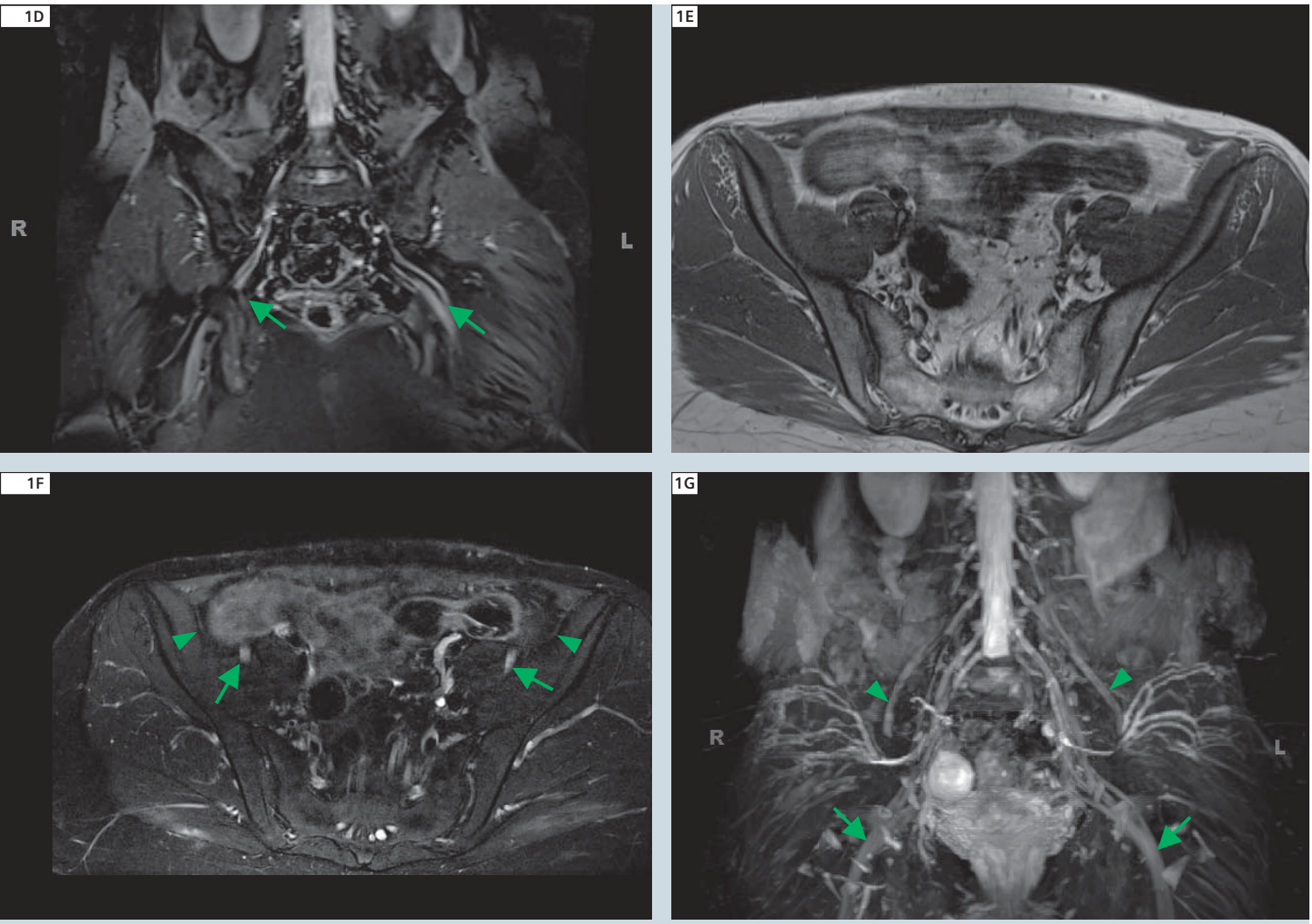
1A–C Lumbosacral Plexus 3T MR Neurography evaluation: Isotropic multiplanar reformats from 3D T2 SPACE **(1A–1C)**.

Abstract

The lumbosacral (LS) plexus is a series of nerve convergences and ramifications that provide motor and sensor innervation to pelvis and lower extremities. LS plexopathy is a serious condition caused by a variety of pathologies. Magnetic Resonance Neurography is an important modality for evaluation of LS plexopathy due to variable clinical presentations and deep location leading to suboptimal accessibility of the plexus to electrodiagnostic studies. This article describes the role of MR Neurography in evaluation of the LS plexus and illustrates the spectrum of pathologies along with their respective imaging findings using 3 Tesla MR Neurography.

Introduction

The lumbosacral (LS) plexus is comprised of an intricate architecture of nerves that supply the pelvis and lower extremity. It can be subject to a variety of pathologies, which may result in LS plexopathy, a clinical syndrome that includes motor and sensory disturbances. The diagnosis of LS plexopathy has traditionally relied on clinical findings and electrodiagnostic study results. However, differentiation of LS plexopathy from spine related abnormality and definition to type, location and extent of pathology often remains a diagnostic challenge due to deep location of the nerves and variable regional muscle innervation [1, 2]. With current high resolution 3 Tesla (T) Magnetic Resonance Neurography (MRN) techniques, diagnostic evaluation of large LS plexus branches, such as sciatic and femoral nerves, as well as smaller segments, such as nerve roots convergences and



1D–G Coronal reconstructed 3D STIR SPACE **(1D)** showing sciatic nerves (arrows). Axial T1w **(1E)** and T2 SPAIR **(1F)** images showing bilateral femoral nerves (arrows) and lateral femoral cutaneous nerves (arrowheads). MIP coronal 3D STIR SPACE **(1G)** image showing bilateral LS plexus nerve roots, femoral nerves (arrowheads) and sciatic nerves (arrows).

peripheral nerves is feasible, aiding in pre-surgical evaluation and appropriate patient management [3, 4]. This article provides a pertinent discussion of the LS plexus anatomy, current role of MRN in evaluation of plexopathy and describes the respective imaging findings of various pathologies using 3T MR Neurography.

Anatomic considerations

The LS plexus is comprised of lumbar plexus, sacral plexus and the pudendal plexus, with contributions from the ventral rami of lumbar (L1–4 +/– T12), sacral (S1–4 and LS trunk, L4–S1) and the lower sacrococcygeal (S2–4 and C1) nerves, respectively [5]. The plexus is formed lateral to the intervertebral foramina and various branches course through the psoas major muscle. The ventral rami are further split into anterior and posterior divisions. The anterior divisions give rise to the iliohypogastric (L1), ilioinguinal (L1), genitofemoral (L1-L2) and obturator nerves (L2–4). The posterior divisions combine to form the posterior branches [femoral (L2–4) and lateral femoral cutaneous nerves (L2, 3)]. All branches exit lateral to the psoas muscle and course under the inguinal ligament, except the obturator nerve and LS trunk, which exit medial to the psoas muscle. The sacral plexus gives rise to anterior branches, namely the tibial part of the sciatic nerve (L4–S3), pudendal nerve (S1–4) and medial part of the posterior femoral cutaneous nerve (S1–3) and, posterior branches, namely the common peroneal part of the sciatic nerve (L4–S2), superior (L4–S1) and inferior gluteal nerves (L5–S2),

Table 1: S The 3T MR imaging protocol employed in our institution of the evaluation of the lumbosacral plexus.

Sequence	Slice	Field-of-view (cm)	Voxel size (mm^3)	TR/TE (ms)	Turbo factor
Axial T1 TSE	BL	33	0.64	800/12	6
Axial T2 SPAIR	BL	33	1.00	4500/80	17
Coronal PD SPAIR	BL	36-38	0.6	4980/38	7
Coronal T1 TSE	BL	36-38	0.5	550/10	3
3D Coronal STIR SPACE	BL	36-38	1.45	1500/103	61
3D Sagittal T2 SPACE	Lumbar spine	28	1.45	1000/99	69
Coronal 3D VIBE *	BL	36-38	0.58	4.39/2.01	–

Abbreviations are: TSE = Turbo Spin Echo, SPAIR = spectral adiabatic inversion recovery, STIR = short tau inversion recovery, 3D SPACE = three-dimensional Sampling Perfection with Application optimized Contrasts using constantly varying flip angle Evolutions, VIBE = Volume Interpolated Breathhold Exam (* optional), BL = bilateral

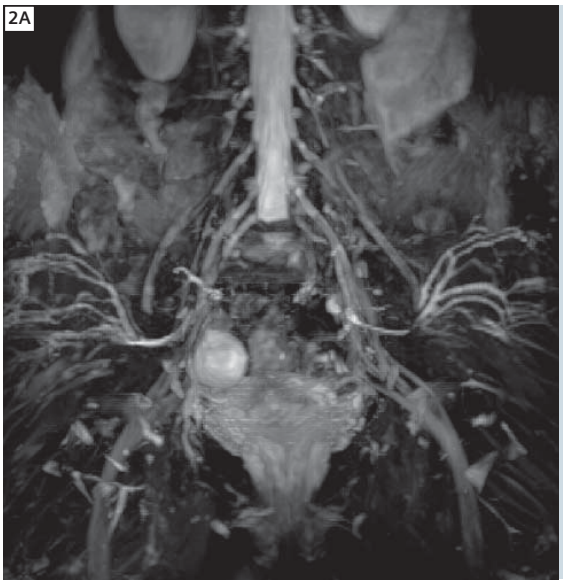
lateral part of the posterior femoral cutaneous nerve (S1–3) and the nerve to the piriformis muscle (L5, S2). The above two plexuses connect via the LS trunk to form the LS plexus [2, 5].

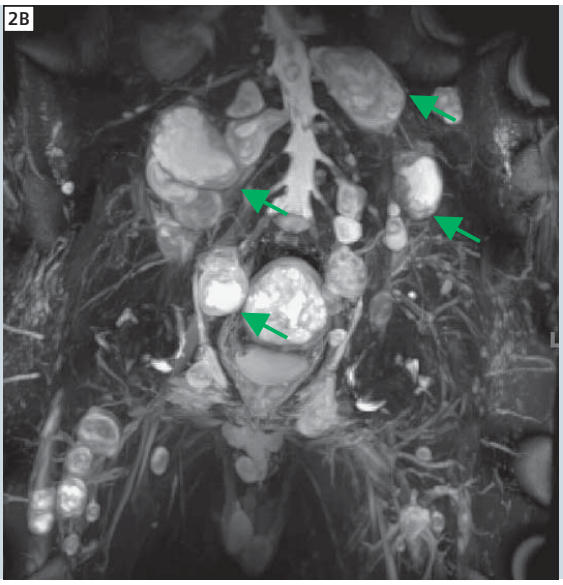
Pathologic conditions and indications of MRN

The LS plexus is relatively protected by the axial skeleton and entrapment neuropathy is much less common than brachial plexopathy. It is considered as the counterpart of the brachial plexus in the lower body and is affected by similar types of diseases. The LS plexus may be involved by local processes in the viscinity of the plexus, such as extrinsic compression by space occupying lesions, injury or infiltration by tumor / infectious process – which is an indication for MRN; or in systemic conditions, such as metabolic, autoimmune, vasculitis, ischemic or inflammatory disorders – which are usually diagnosed based on clinical and laboratory findings. MRN may be used in the latter case to confirm lumbar plexitis / plexopathy in clinically confusing presentation and underlying known systemic condition. In addition, a primary or idiopathic form of LS plexopathy may occur, possibly due to altered immunological response and is considered analogous to idiopathic brachial plexopathy [6–8]. The entity has a favorable outcome and spontaneous recovery, whereas its diagnosis is based upon exclusion of other etiologies and sometimes may require confirmation with MRN in case of indeterminate electrodiagnostic results. An important indication of MRN is in patients under consideration for surgery for peripheral nerve lesions (piriformis syndrome/meralgia paresthetica), post abdominal surgery entrapment of ilioinguinal/genitofemoral nerves, or after injury to a large branch (sciatic, femoral, obturator). Finally, MRN is increasingly used for guidance during perineural and intramuscular medication injection.

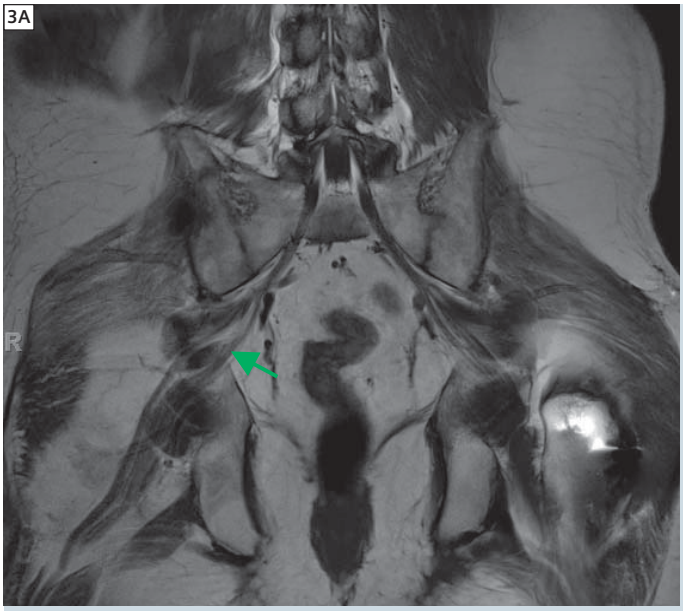
Clinical findings

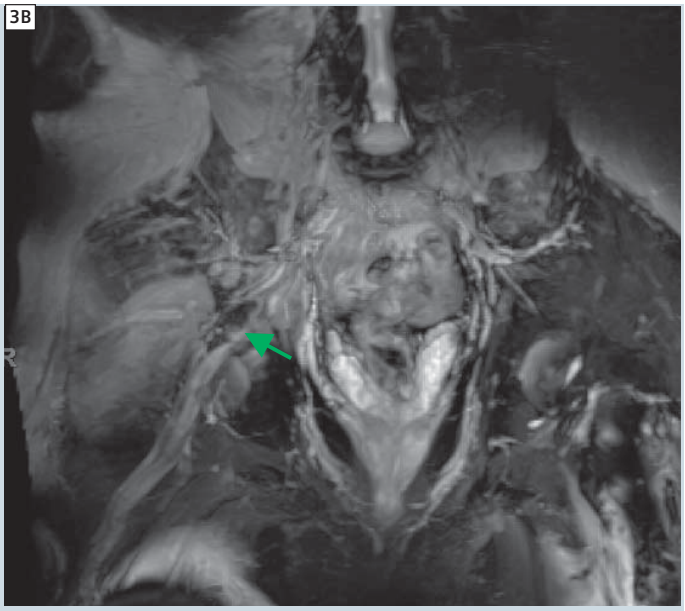
LS plexopathy most often presents with asymmetric weakness, pain and/or paresthesias in the lower extremities involving multiple contiguous LS nerve root distributions. Generally, unilateral localization of symptoms indicates a local pathology, whereas bilateral symptoms suggest a systemic process. The clinical picture often varies depending upon the location and degree of plexus involvement. In cases of involvement of the upper nerve roots, patients predominantly present with femoral and obturator nerve symptoms. LS trunk and upper sacral plexus lesions result in foot drop depending on the extent of involvement and weakness of knee flexion or hip abduction. Sensory symptoms may vary based on the individual nerves involved, which may include numbness or





2 Normal vs abnormal LS Plexus. Coronal MIP 3D STIR SPACE images in a normal subject **(2A)** and another subject with schwannomatosis (arrows in **2B**).





3 Piriformis syndrome – large LS plexus branch nerve abnormality. 33-year-old man with right buttock and pelvic pain, suspected piriformis syndrome. Coronal T1w **(3A)** and coronal MIP 3D STIR SPACE **(3B)** images through the pelvis show split right sciatic nerve by an accessory slip of the right piriformis muscle (arrow). Notice abnormal T2 hyperintensity of the sciatic nerve in keeping with entrapment neuropathy.

dysesthesia in the anterolateral thigh from lateral femoral cutaneous nerve involvement; in the mons and labia majora from genitofemoral nerve involvement and in the lower abdomen and inguinal area, upper medial thigh or pelvis from damage to the ilioinguinal, iliohypogastric, or pudendal nerves, respectively. Rarely, there may be associated bowel and bladder incontinence as well as sexual dysfunction [6–8].

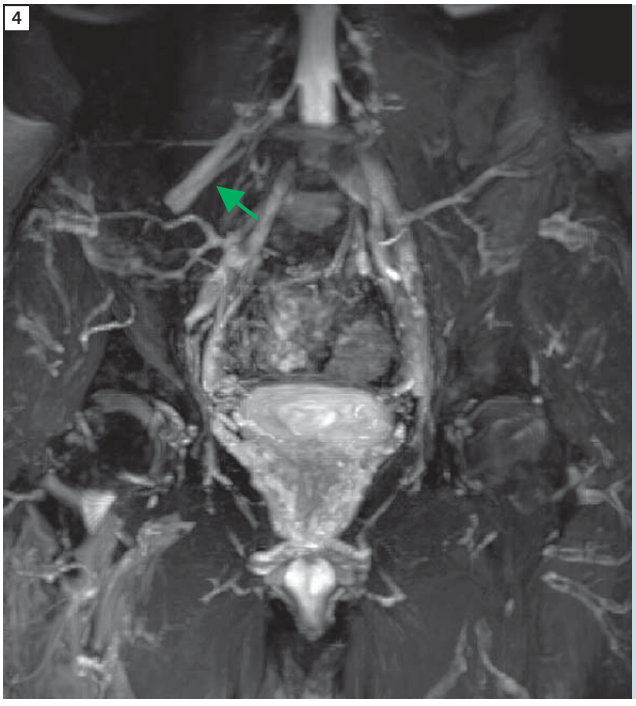
MRN technique and normal appearances

Compared to 1.5T systems 3 Tesla (MAGNETOM Verio and MAGNETOM Trio, Siemens, Erlangen, Germany) imaging is preferred for most MRN examinations by the authors due to high quality scans obtained by these systems due to better signal-to-noise ratio and contrast resolution available in short imaging times. Due to the relatively small nerve structures under interrogation, it is essential to use high resolution imaging with a combination of 2D (dimensional) and 3D isotropic spin echo type imaging for optimal assessment. In the presence of known metal* in the area of imaging, 1.5T imaging is preferred. Table 1 and Fig. 1 show the 3T MRN imaging protocol employed at Johns Hopkins for the evaluation of the LS plexus. For fascicular architecture and subtle signal intensity

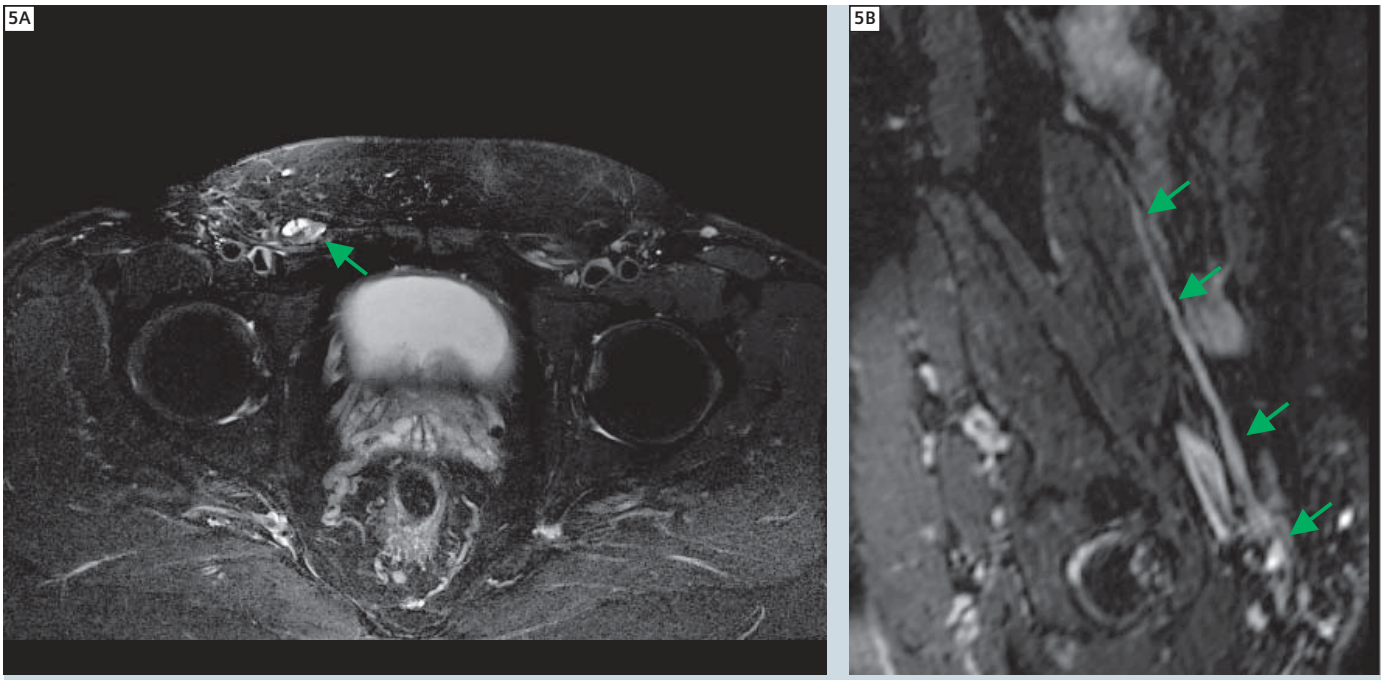
changes, high-resolution 2D axial T1w and T2 SPAIR (Spectral Adiabatic Inversion Recovery) images are ideal. Fascicular appearance of nerves is consistently seen with T2 SPAIR images in larger branches, such as femoral nerves and sciatic nerves, as well as in smaller nerves that are affected and enlarged due to neuropathy, such as lateral femoral cutaneous and genitofemoral nerves. 2D imaging is complemented by isotropic 3D images reconstructed in planes perpendicular and longitudinal to the nerves in question. 3D imaging (SPACE – Sampling Perfection with Application optimized Contrasts using constantly varying flip angle Evolutions) allows multiplanar and curved planar reformations. Two types of 3D imaging are performed, focusing in two different locations with two different purposes, 3D STIR SPACE for the LS plexus (from L2-3 level to lesser trochanter of femurs), while T2 SPACE (from L2-S2) is used for the lumbar spine, as spondylosis is a major confounder in the diagnosis of peripheral nerve pathology (Fig. 1). 3D imaging shows the lesions along the long axis of the nerve, course deviations, focal neuroma, nerve gap in cases of injury, etc. for better pre-operative planning and understanding of the referring physicians. Side-side imaging differences of the nerves can also be highlighted on maximum intensity projection (MIP) images. Gadolinium administration is reserved for cases of suspected neoplasm, inflammation, diffuse polyneuropathy, neurocutaneous syndrome, or post-operative complication [9–13]. Additional coronal T1w and STIR/PD SPAIR images aid in detection of lesions along the long axis of the nerves, side-to-side comparison of the nerve morphology and signal intensity (generally symmetrical), as well as for depiction of other incidental findings in relation to hips or spine. SPAIR produces higher SNR and is less prone to pulsation artifacts than STIR imaging, and is also more SAR favorable at 3T imaging [3, 4].

MR Neurography findings of LS plexopathy

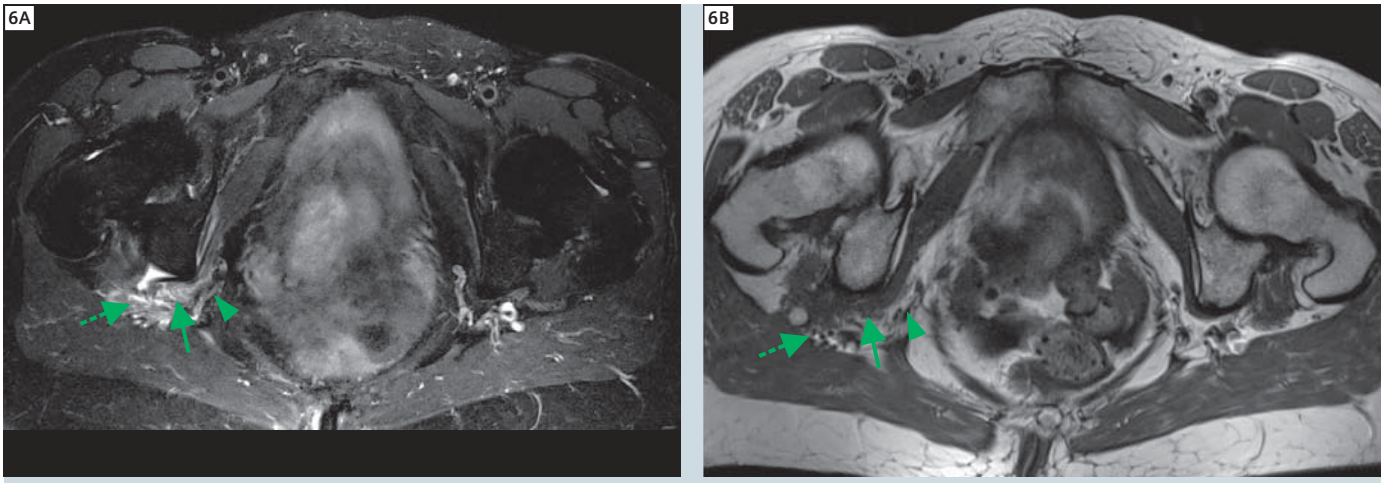
MRN assessment of the LS plexus relies on the evaluation of direct morphologic features, such as altered nerve size, abnormal fascicular morphology (disrupted, effaced or enlarged) and focal or diffuse deviations in nerve course. T2 signal intensity (SI) changes (signal alterations approaching the adjacent vascular signal intensity, or asymmetric SI to the other side, given variations due to non-uniform fat saturation); as well as indirect features such as effacement of perineural fat planes due to focal fibrosis/mass lesions (Figs. 2, 3) and regional muscle denervation changes (edema like T2 signal alteration in acute and subacute cases to fatty replacement and atrophy in chronic cases). MRN is useful for detecting the individual segmental nerve abnormalities (enlarged or asymmetrically T2 hyperintense) in cases of plexitis/plexopathy or nerve injury. Similar to brachial plexus imaging, minimal increased nerve T2 signal intensity alone should be perceived with caution, as magic-angle artifact is a well-recognized artifact in LS plexus MR imaging [3, 4]. MRN is also useful in differentiating the plexopathy (nerve abnormality starting distal to the neural foramina, and often involving multiple nerve roots) from lumbar spondylosis (presence of substantial spondylosis, disc herniations, intraspinal mass, and nerve abnormality starting from within and immediately distal to the neural foraminal level in a distribution of the narrowed foramina). It is also worth mentioning that MRN may help exclude LS plexopathy in clinically confusing cases by demonstrating normal symmetrical appearance of bilateral nerve segments. In trauma cases, it is critical to demonstrate whether the injury is merely a stretch injury (merely T2 signal alterations) with nerve continuity; or if there is neuroma formation (focal enlargement of the nerve with effaced fascicular appearance) or nerve root avulsion or nerve discontinuity, which may be indications for surgery (Fig. 4). Peripheral nerve sheath tumors are depicted as focal or fusiform enlargements of the nerves, and may variably demonstrate classic signs, such as the tail, target, fascicular, bag of worms and split-fat signs. Differentiation between benign and malignant peripheral nerve sheath tumors is generally not reliable by imaging, although large size, ill-defined margins, peritumoral edema, significant interval growth and internal heterogeneity,



4 Right femoral nerve transection – large LS plexus branch nerve abnormality. 64-year-old man with right leg weakness following recent surgery. Coronal MIP 3D STIR SPACE image through the pelvis shows abrupt termination of the right femoral nerve in keeping with transection (arrow) (Sunderland Grade V injury).



5 Genitofemoral nerve entrapment – small LS plexus branch nerve abnormality. 50-year-old man with right inguinal and scrotal pain, following a prior right inguinal hernia repair. Axial T2 SPAIR **(5A)** and oblique coronal MIP 3D STIR SPACE **(5B)** images through the pelvis show abnormally enlarged and hyperintense right genitofemoral nerve (arrows), with most abnormality at the site of previous hernia repair in keeping with entrapment neuropathy.



6 Right pudendal and sciatic Neuropathy – small LS plexus branch nerve abnormality. 61-year-old man with right pelvic pain, suspected pudendal neuralgia. Axial T2 SPAIR image through the pelvis shows grade I/II strain of the right obturator internus muscle (large arrow) with mild hyperintensity of the right pudendal nerve (small arrow) and right sciatic nerve (dotted arrows) in keeping with acute neuropathy.

especially in neurofibromas, are suspicious for malignancy. In those cases, a combination of clinical (new onset or increasing pain/ neurological deficit), MRN imaging findings (as above), as well as ^{18}F FDG PET uptake (SUV_{max} >3–4 and increased uptake on delayed imaging) are used to make a clinical decision about percutaneous biopsy/surgical biopsy/ resection. Finally, MRN aids in differentiation of radiation neuropathy (diffuse nerve signal intensity alterations and enhancement in a geographic distribution corresponding to the radiation field) from recurrent mass lesion (focal enhancing lesions) [11–14].

Lumbosacral plexus branch anatomy and pathology

Current high-resolution 3T techniques allow depiction of internal nerve pathology of normal sized large branches, such as sciatic (Fig. 3), obturator, femoral (Fig. 4), various lumbosacral nerve roots as well as enlarged smaller branches,

such as ilioinguinal, genitofemoral (Fig. 5) and pudendal (Figs. 6, 7) nerves. Many of the smaller nerves are sensory nerves, and electrodiagnostic studies are usually not useful for their assessment. Nerve blocks have also been variably used, more so for therapeutic effect rather than for diagnosis of pathology. MRN may detect lesions within (diffuse enlargement proximal to entrapment, neuroma, etc.) or surrounding these nerves (focal fibrosis/mass lesion), thereby impacting patient management. Iatrogenic insults, such as during laparotomy, lymph node dissection, difficult parturition, hernia repair, etc are the leading cause of injury to these fine nerves. MRN may be used to detect focal fibrosis along the course of these nerves and their branches, which may be used to guide neurolysis. Such a procedure may give back patients' necessary sensation or provide pain relief. Finally, MRN may be used to provide guidance for perineural (local anesthetic and steroids) and intramuscular medication (e.g. Botulinium Toxin) injections. It is important to know that an appropriately performed image guided negative block / placebo controlled or graded positive nerve block confers more specificity to the diagnosis rather than a single positive block. Few studies have however, shown the therapeutic value of these blocks [15–22].

Conclusion

In the evaluation of LS plexopathy, 3T MRN provides high quality imaging and is a valuable adjunct to clinical examination and electrodiagnostic tests as it can offer anatomic information and lesion assessment otherwise unattainable by other modalities.

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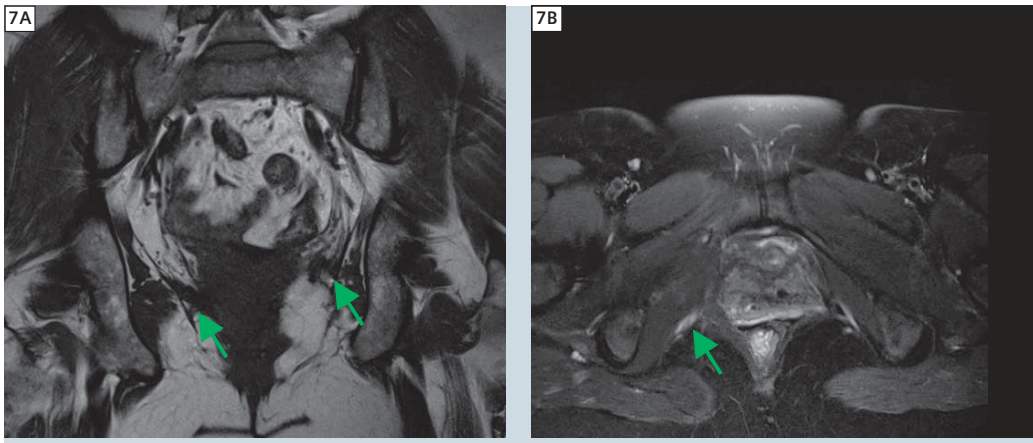

7 Chronic pudendal Neuralgia – small LS plexus branch nerve abnormality. 41-year-old woman with pelvic pain, right > left for many months. Coronal T1w **(7A)** and axial T2 SPAIR **(7B)** images through the pelvis show bilateral pelvic scarring (right > left), along the expected course of the pudendal nerves, causing entrapment (arrows). Notice asymmetrically prominent right pudendal neurovascular bundle (arrow).

*In the US, metal near or in the MR system must be labeled as MR-safe or conditional (with conditions stated).

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