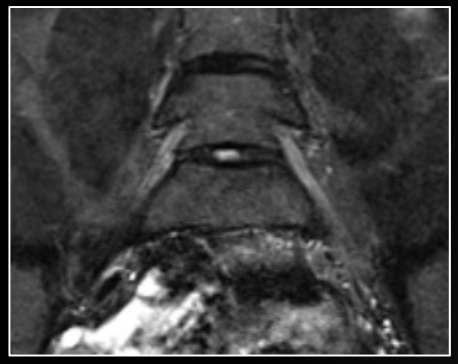
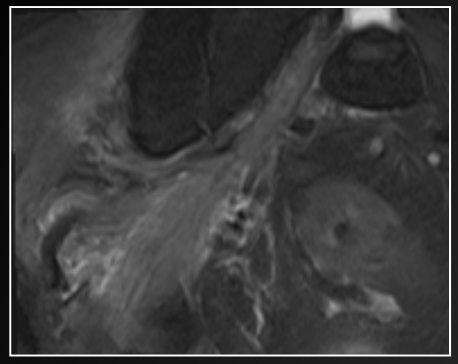
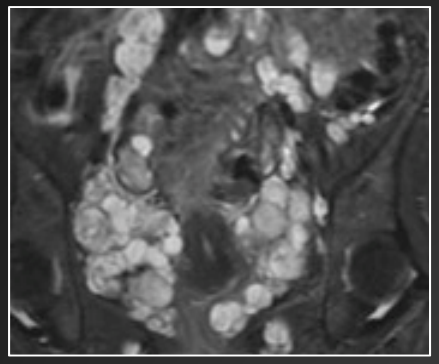
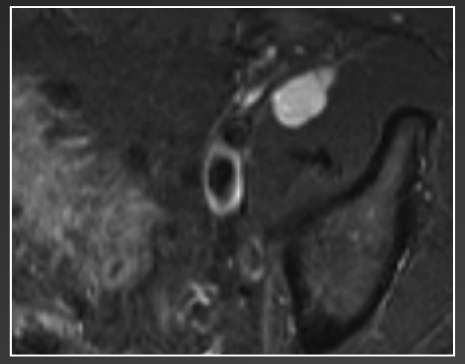
MRI of the Lumbosacral Plexus

What the Practicing Radiologist Needs to Know

HEALTH
UNIVERSITY OF UTAH

DEPARTMENT OF RADIOLOGY
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NOTHING TO DISCLOSE

LEARNING OBJECTIVES

After review of this exhibit, the learner will:

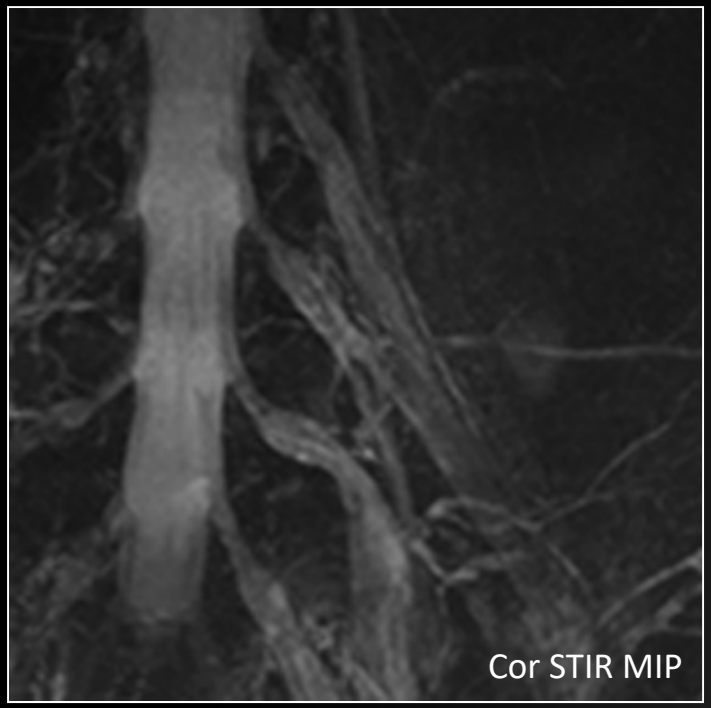
- Be familiar with normal lumbosacral plexus anatomy, in addition to transitional lumbosacral nerve anatomy
- Understand the key MRI sequences utilized to adequately image patients with suspected lumbosacral nerve pathology
- Recognize both the normal and abnormal MRI appearance of peripheral nerves
- Have a robust and practical differential diagnosis for abnormalities associated with the lumbosacral plexus on MRI

OUTLINE

- Discuss role of MR imaging of the lumbosacral plexus in clinical practice
- Review lumbosacral plexus normal anatomy and important normal variant anatomy
- Discuss key MRI sequences and present an MRI sequence-based search pattern
- Review the MRI appearance of normal and abnormal peripheral nerves

- Case-based imaging review of the following topics:
  - Neuropathy
  - Tumor and Tumor-Like Conditions
  - Infectious and Inflammatory Pathology
  - Trauma

ROLE OF LUMBOSACRAL PLEXUS MRI



- Increased accuracy for diagnosis of the exact location, type, extent and cause of peripheral neuropathy / plexopathy
- Excellent distinction of traumatic and atraumatic lumbosacral plexus pathology from spine related abnormalities, which can be a clinical conundrum
- Provides fine detail anatomic information given high spatial and contrast resolution for pre-surgical planning

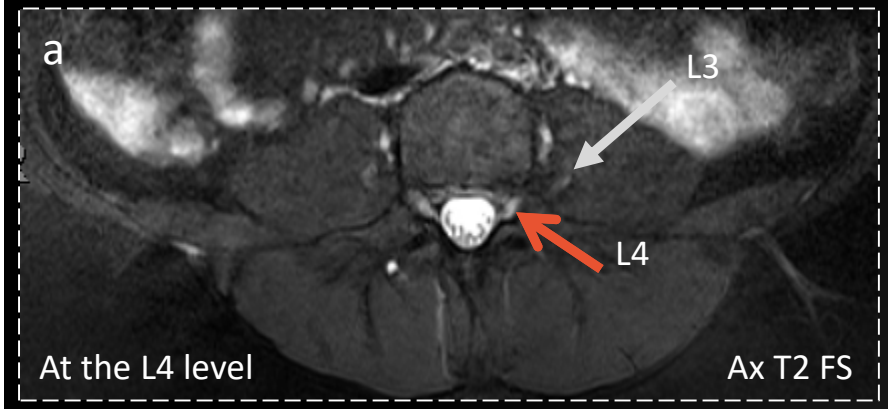
ACR APPROPRIATENESS CRITERIA: PLEXOPATHY

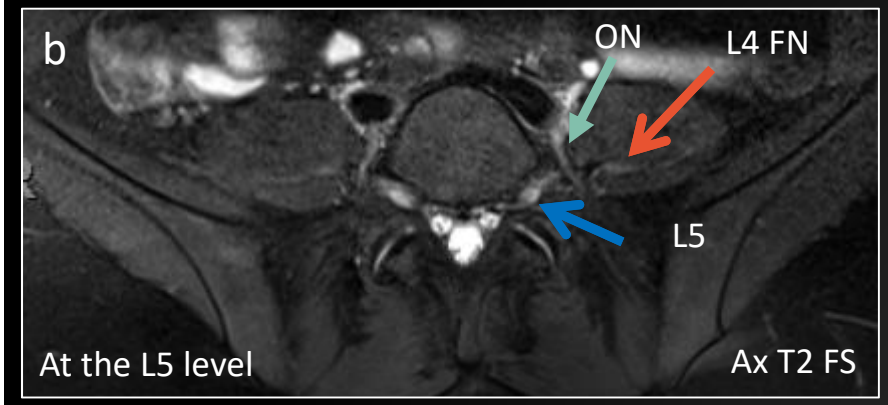
- In 2017, the American College of Radiology released guidelines regarding the clinical use of lumbosacral plexus MRI
- The panel consensus gives its highest rating to contrast enhanced MRI of the plexus for patients with suspected acute or chronic plexopathy with or without a history of trauma or in the setting of malignancy or prior radiation
- In patients who cannot undergo MRI, alternative imaging modalities such as CT or FDG-PET/CT can be considered

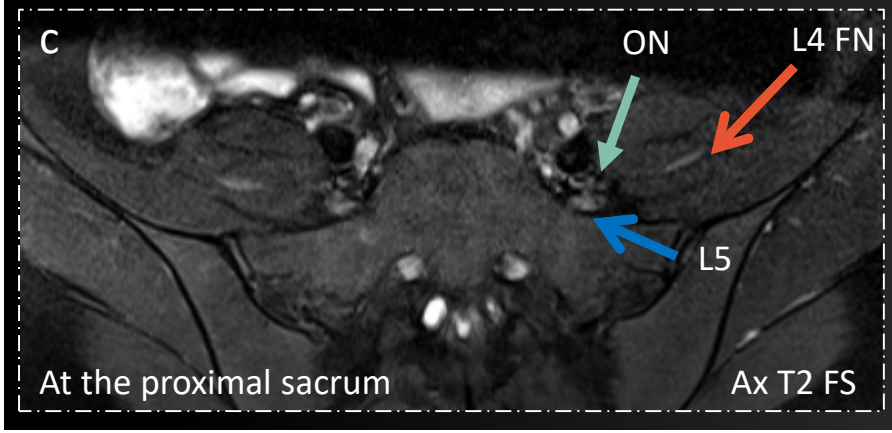
ACR Appropriateness Criteria® Plexopathy

Expert Panel on Neurologic Imaging: *Julie Bykowski, MD[a], Joseph M. Aulino, MD[b], Kevin L. Berger, MD[c], R. Carter Cassidy, MD[d], Asim F. Choudhri, MD[e], A. Tuba Kendi, MD[f], Claudia F. E. Kirsch, MD[g], Michael D. Luttrull, MD[h], Aseem Sharma, MD[i], Vilaas S. Shetty, MD[j], Khoi Than, MD[k], Christopher J. Winfree, MD[l], Rebecca S. Cornelius, MD[m]*

Approach to Normal Anatomy







Lumbosacral plexus:

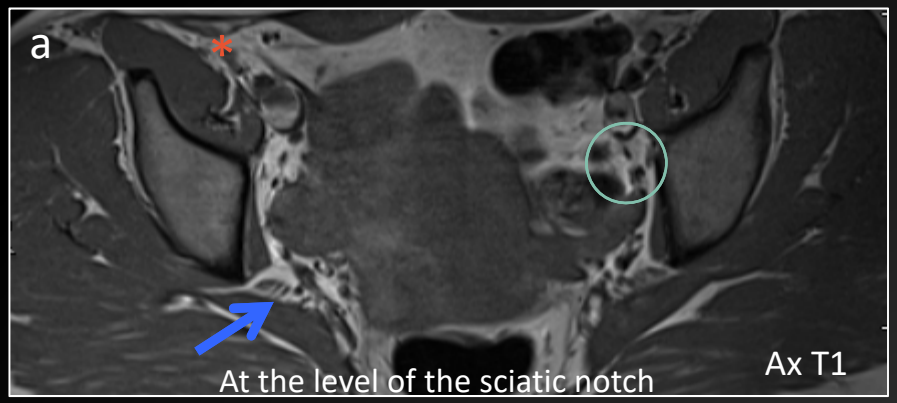
- Formed by the coalescence of the ventral rami of the lumbar plexus (T12, L1-L4) and the sacral plexus (L4-S4) to form the lumbosacral (LS) trunk

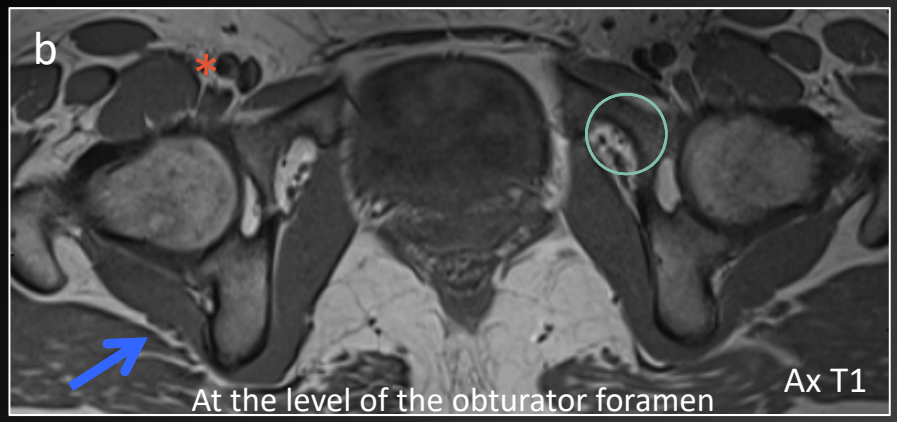
- (a) The extra-foraminal L3 segment is seen diving deep into the psoas major muscle
- (b) The obturator nerve (ON, L2-L4 nerve roots) runs medial to the psoas. The L4 femoral nerve component (FN) lies more posterior and lateral within / along the psoas major muscle
- (c) The L5 nerve hugs the sacral promontory and then combines with the peroneal component of the L4 nerve to form the lumbosacral trunk . The LS trunk joins S1-S3 just proximal to the sciatic notch --> forming the sciatic nerve

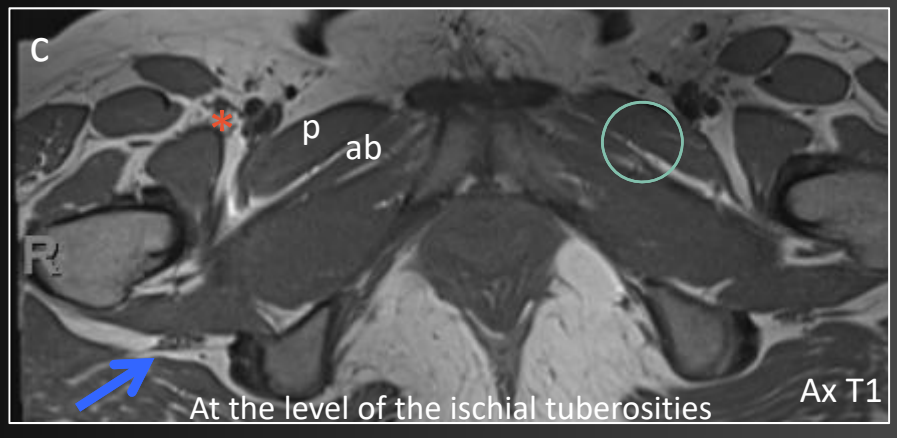
Approach to Normal Anatomy

- The femoral nerve is formed by the L2-L4 nerve roots and extends inferiorly between the psoas major and iliacus muscles (see previous slide), emerging beneath the inguinal ligament (a) and into the thigh, where it splits into anterior and posterior divisions (b,c)

- The sciatic nerve is formed by the coalescence of L4-S3 nerve roots. It courses anterior to the piriformis muscle (a), then posterior to it extending from the pelvis through the greater sciatic notch, deep to the gluteus maximus muscle, and into the posterior compartment of the thigh (b,c)



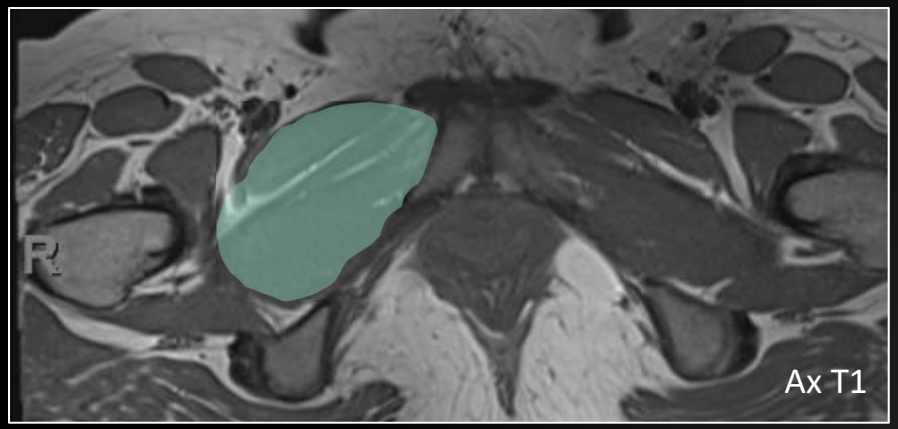




- The obturator nerve is formed by the L2–L4 nerve roots and seen coursing along the medial border of the psoas major muscle (see previous slide) deep to the common iliac vessels, and lateral to the sacrum. It has a straight course, extending along the lateral pelvic side wall (a) to enter the obturator foramen (b). It pierces the fascia between the pectineus (p) and adductor brevis (ab) muscles (c) where it splits into anterior and posterior divisons

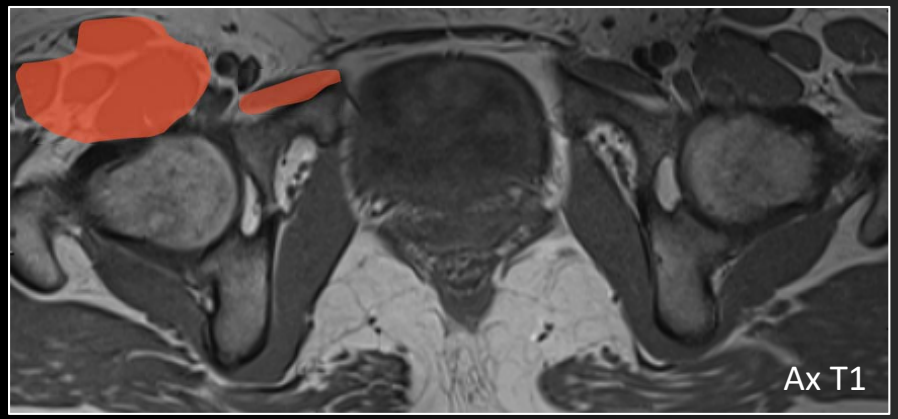
Muscle Innervation Patterns

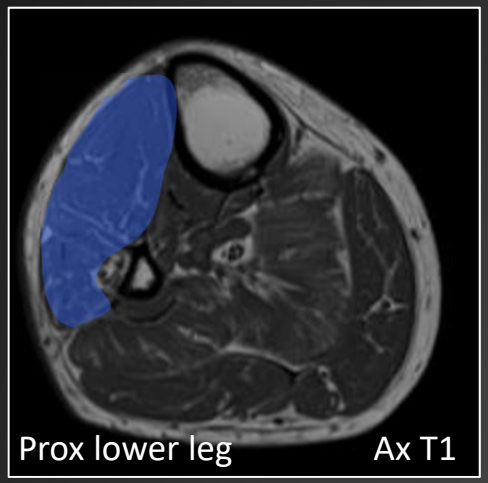
- Obturator nerve --> motor innervation includes external obturator, adductor compartment muscles, gracilis, and pectineus

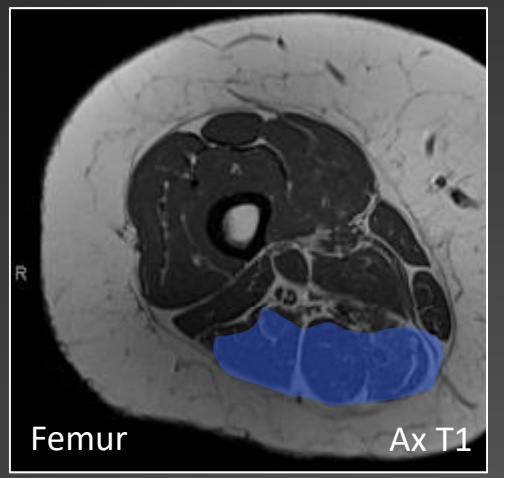


- Sciatic nerve --> provides motor innervation of the anterior and lateral compartments of the lower leg via the peroneal nerve (mostly L5) and provides motor innervation of the hamstring muscles via the tibial component (mostly S1)

- Femoral nerve --> motor innervation of quadriceps, pectineus, proximal anterior thigh muscles including sartorius

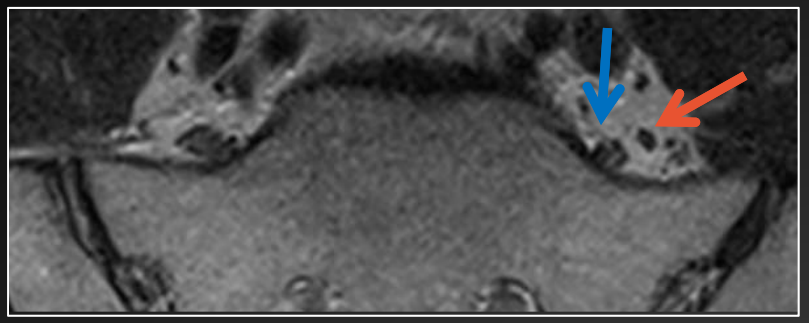


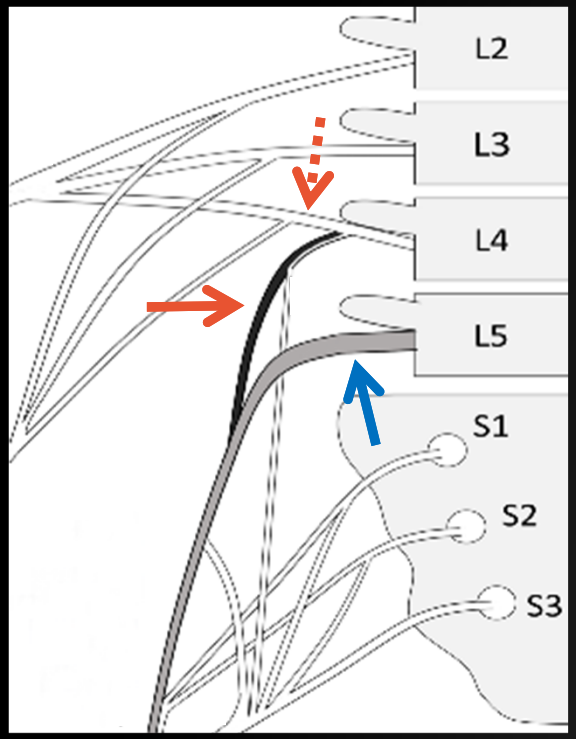




Approach to Normal Anatomy

Identification of L5 Nerve: Neuroanatomic Method





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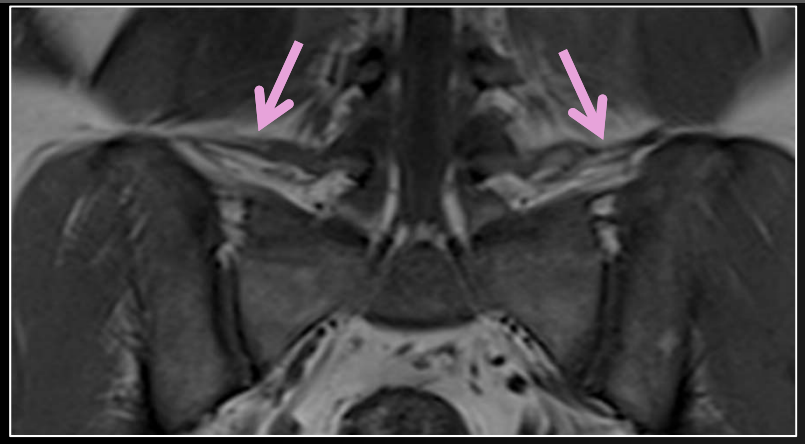
- After exiting the neural foramen, L4 splits into peroneal and tibial branches (orange solid and dashed arrows, respectively)
- L5 is the only lumbar nerve which does not branch (blue arrows)
- The peroneal branch (solid orange arrow) of L4 typically joins the L5 nerve (blue arrows) root at the level of the sacrum
- The L5 nerve root is typically twice the size of the L4 peroneal branch

Approach to Transitional Anatomy

Identification of L5: The Iliolumbar Ligament Method

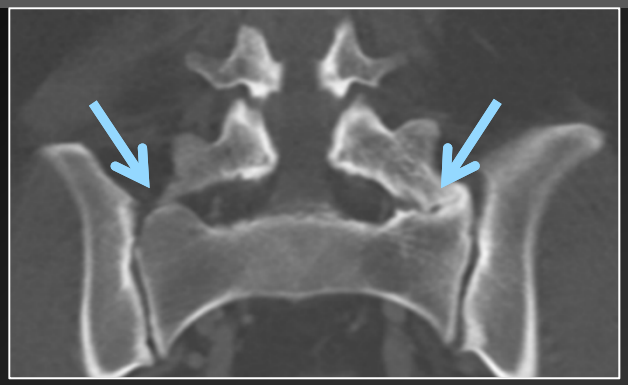


- The iliolumbar ligament (pink arrows) typically arises from the L5 transverse process and inserts onto the iliac crest
- This method accurately identifies the L5 vertebra in *83% of cases*

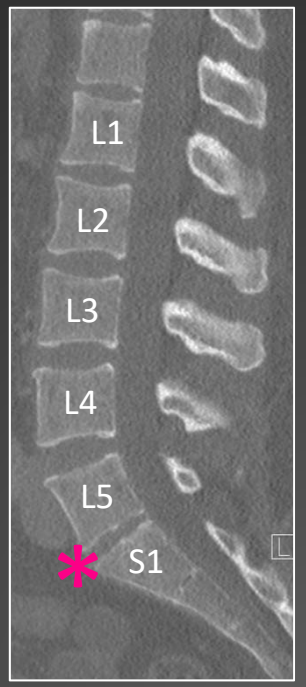
Vertebral Numeric Variation

% of Population	# of Presacral Vertebral Bodies	# of Lumbar Type Vertebral Bodies
89	24	5
8	25	6
3	23	4

Lumbosacral Transitional Vertebrae:

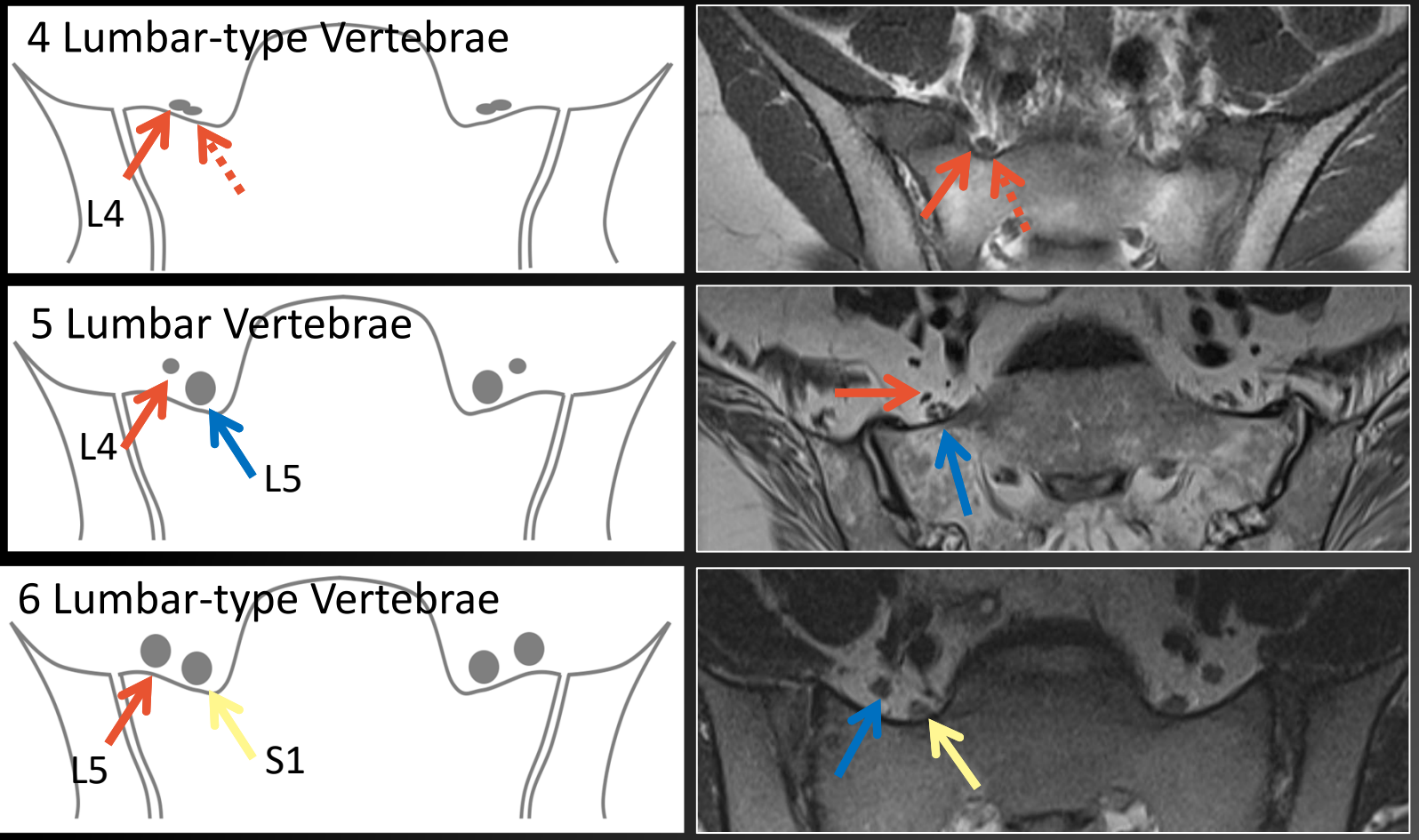


- Defined by variable elongation of the transverse process of the last lumbar vertebrae to fuse, in whole or in part, with the sacrum (blue arrows)
- 5% of the population has both transitional vertebrae and a variant number (6 or 4) of lumbar type vertebral bodies
- Sacralization of L5 results in a rudimentary L5-S1 disk (asterisk)



Approach to Transitional Anatomy

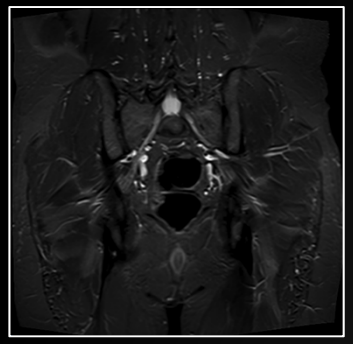
Identification of L5 Nerve: Neuroanatomic Method



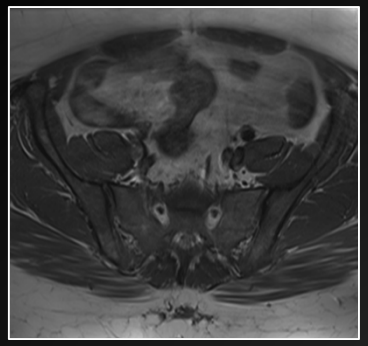
- *At the level of the sacrum* :
  - In patients with 4 lumbar type vertebrae, L4 splits into peroneal and tibial branches (solid and dashed orange arrows)
  - In patients with 6 lumbar type vertebrae, two large nerves of similar caliber are present, representing L5 (blue arrow) and S1 (yellow arrow)

MRI Protocol Overview

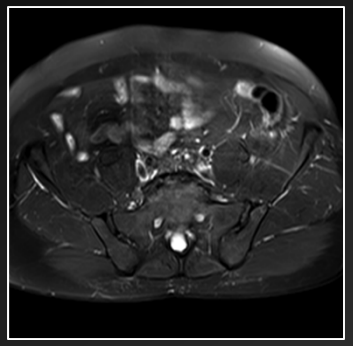
Coronal T1



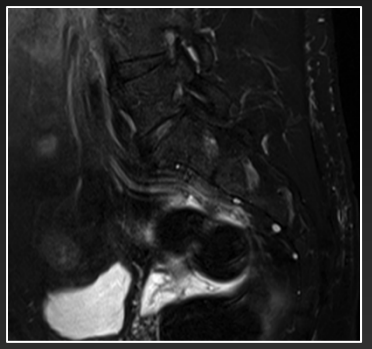
Coronal STIR



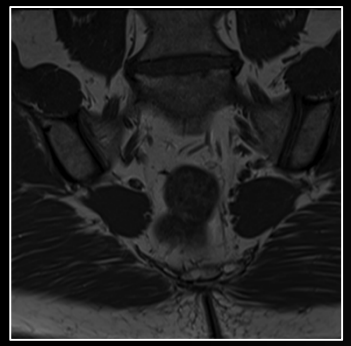
Axial T1



Axial T2 FS



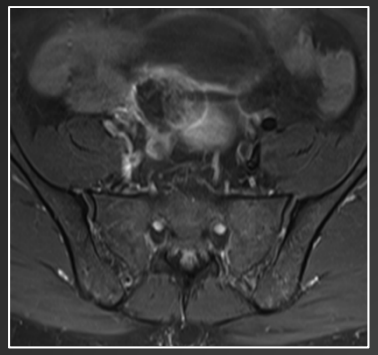
Sagittal PD FS



Oblique
Coronal T1

Oblique
Coronal T2 FS

Coronal T1 FS
+ Contrast



Axial T1 FS
+ Contrast

2D or 3D
Coronal STIR
SPACE

- Imaging at 3.0T field strength results in images with higher signal-to-noise
- Patients with surgical hardware in the lower back or pelvis are imaged at 1.5T field strength to minimize susceptibility artifact
- Field of view includes from L3 level extending though the proximal thigh. Axial slice thickness = 5 mm

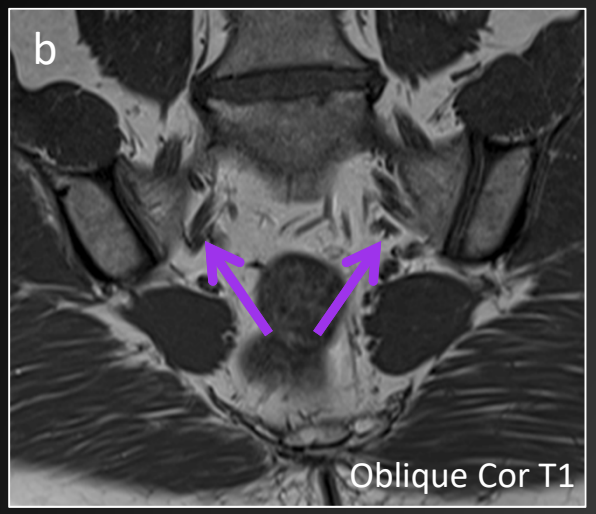
MRI Protocol and Search Pattern

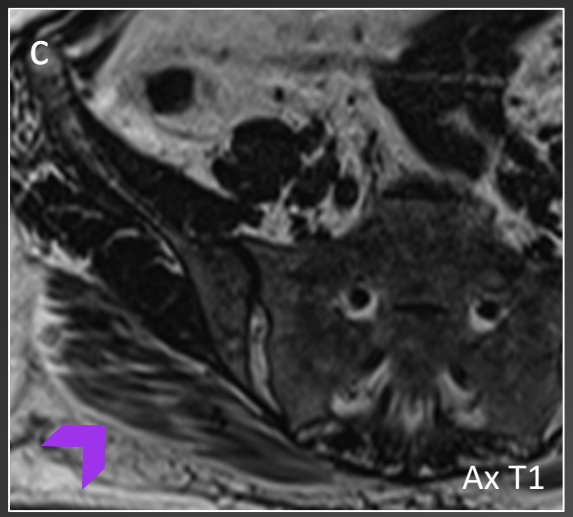
T1 Sequence: Key Facts

Well suited for assessment of:

- Perineural and intermuscular fat
- Chronic fatty muscle infiltration
- Met-Hgb blood products
- Marrow signal

- Coronal oblique images are acquired in a plane coronal to the sacrum





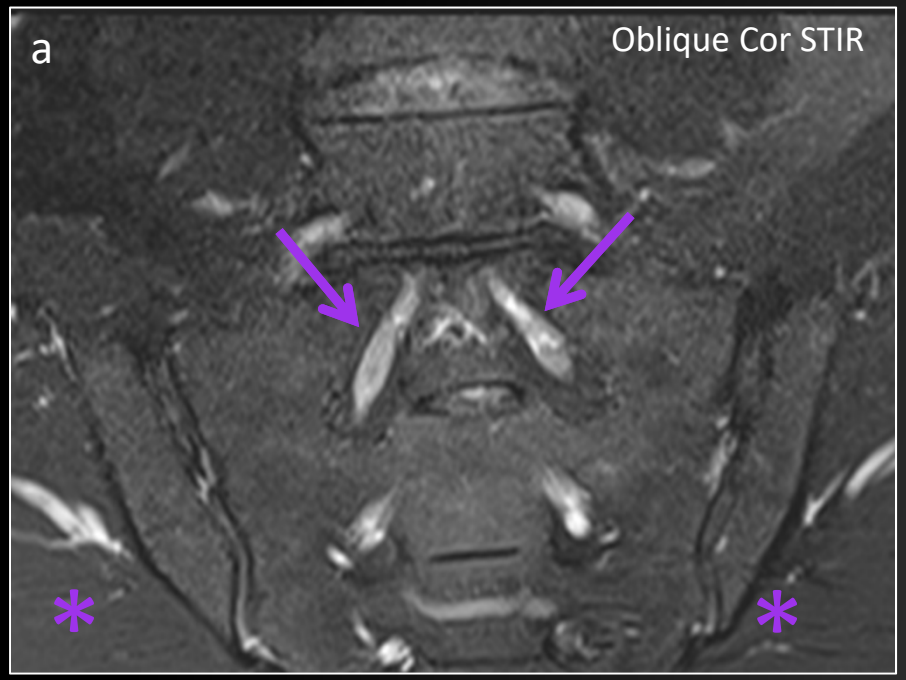
(a,b) Images from a normal lumbosacral plexus MRI demonstrate symmetric muscle bulk with no significant fatty infiltration (asterisks). The visualized proximal coursing lumbar and sacral nerves (arrows) are surrounded by homogeneous fat signal. (c) Marked disproportionate fatty atrophy of the right gluteus maximus muscle (chevron)

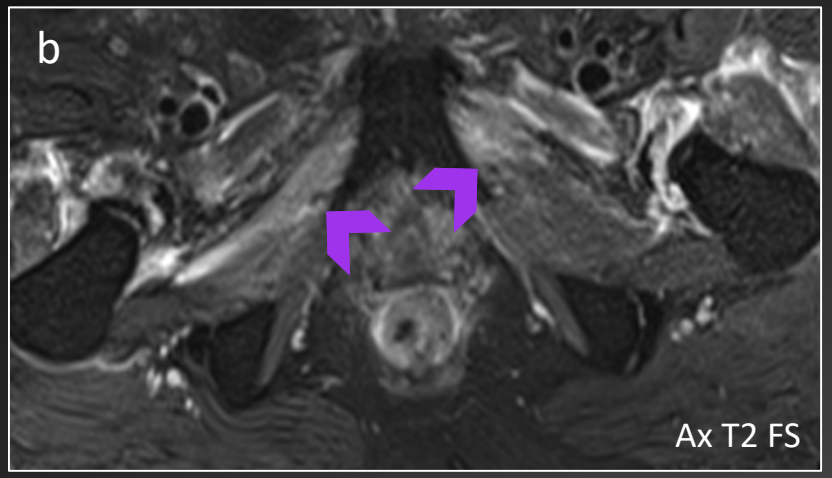
MRI Protocol and Search Pattern

Fluid Sensitive Sequences (T2 FS / STIR / SPAIR): Key Facts

Well suited for assessment of:

- Nerve caliber and signal intensity
- Perineural and fascicular edema
- Muscular edema; isolated to muscles downstream to the injured nerve



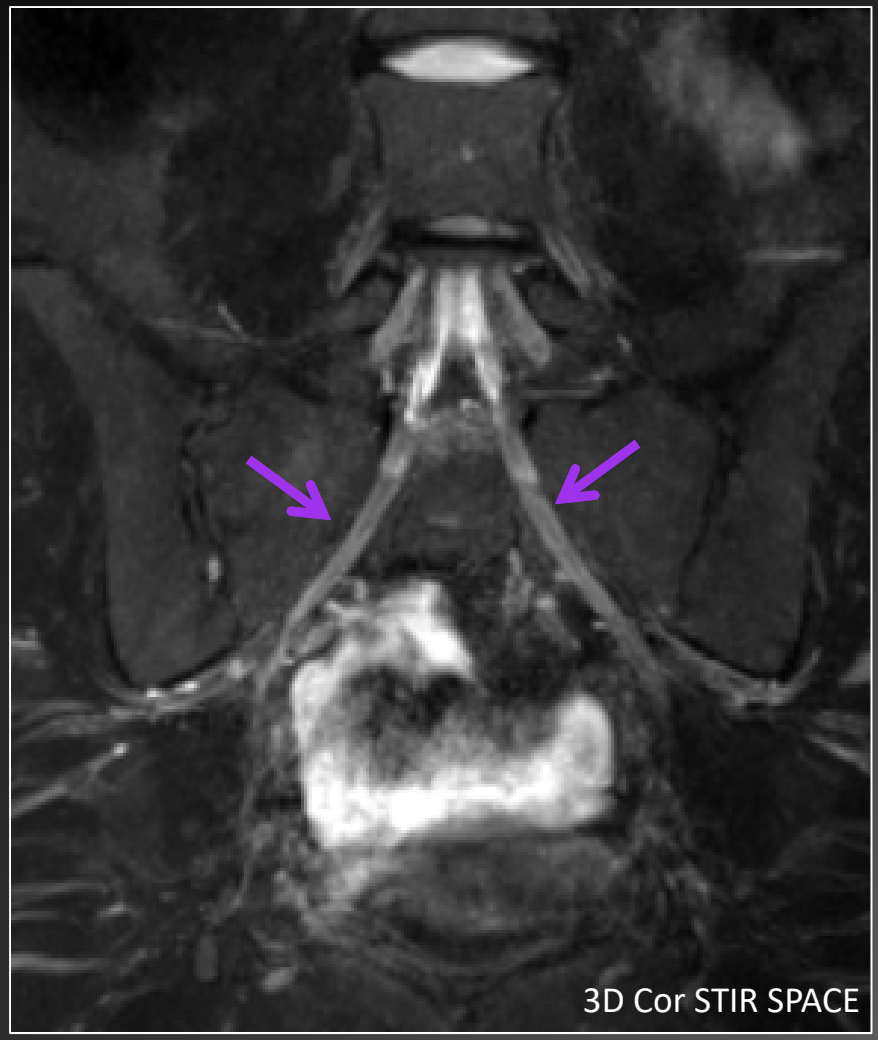


(a) Image from a normal lumbosacral plexus MRI demonstrates symmetric caliber of the exiting sacral nerves. The nerves are smooth in contour and mildly STIR hyperintense (arrows). The muscles are symmetric in signal intensity without edema (asterisks). (b) Images from a patient with diffuse muscle weakness in the setting of polyneuropathy related to chemotherapy demonstrate marked bilateral muscular edema (chevrons), in this setting compatible with denervation edema changes

MRI Protocol and Search Pattern

Fluid Sensitive Sequences: 2D or 3D Coronal STIR SPACE MIPs

- High signal-to-noise ratio (SNR)
- Thin slices permit high resolution multiplanar reconstructions (MPRs)
- Excellent fine detail assessment of normal nerve size, normal fascicular architecture, and subtle contour abnormalities



MRI of a normal lumbosacral plexus demonstrates symmetric caliber and signal intensity of the exiting nerve roots.

MRI Protocol and Search Pattern

Post Contrast : Key Facts

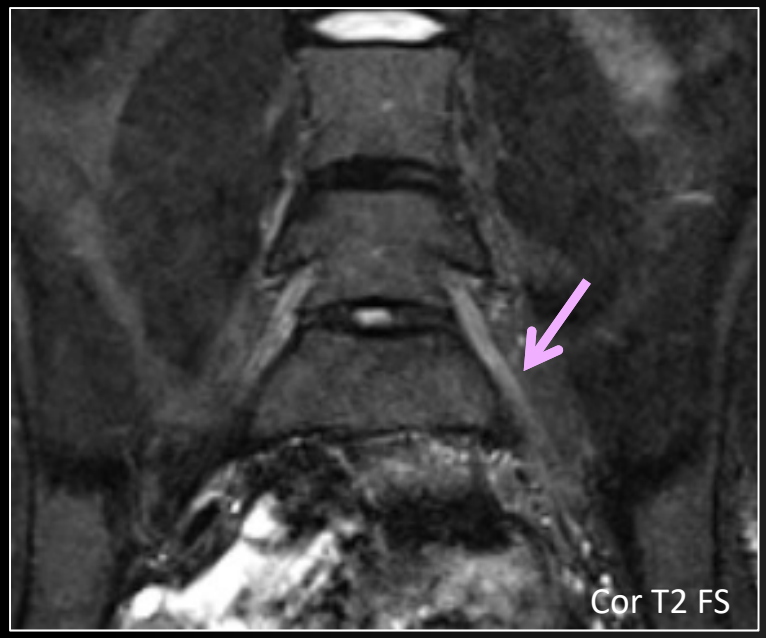
Well suited for assessment of:

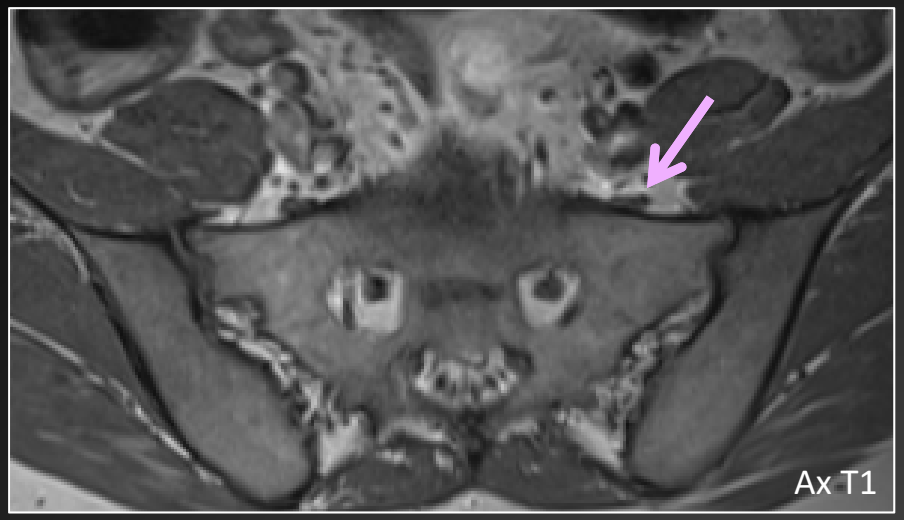
- Infection
- Acute Inflammation
- Tumor

MRI demonstrates long segment avid post - contrast enhancement of the sciatic nerve along its visible course in this case of amyloidosis

Case courtesy of Dr. Avneesh Chaabra

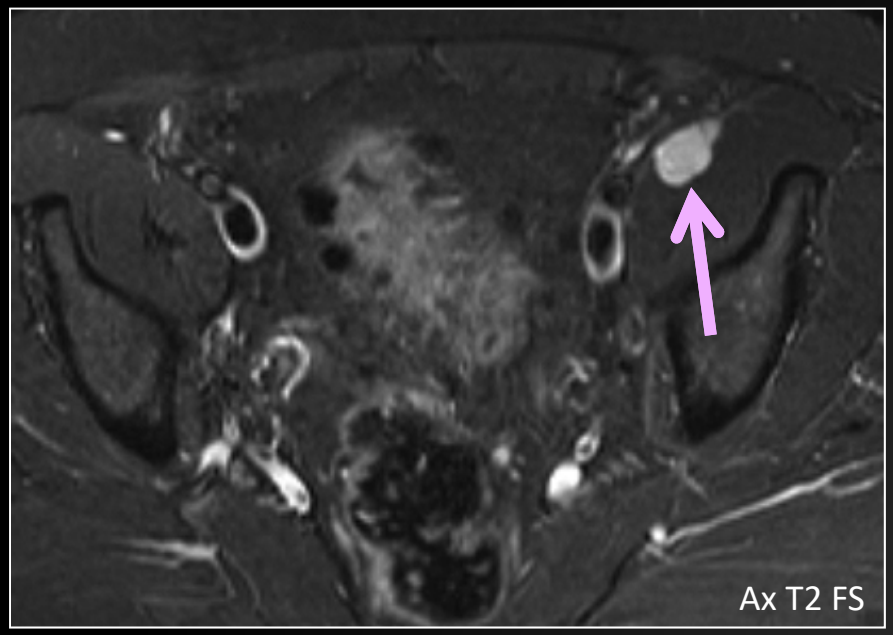
MR Evaluation of Peripheral Nerves: Normal

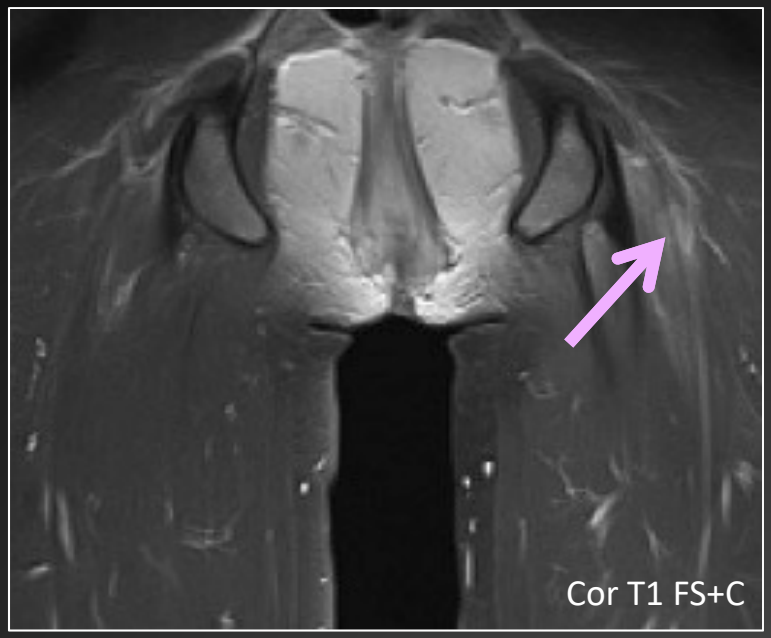




- Normal nerves:
  - Intermediate in signal on T1 weighted images, and intermediate to slightly hyperintense in signal on T2 weighted images
  - Smooth fascicular pattern
  - Similar in size to adjacent arteries along their proximal segments, with smooth caliber tapering of their distal segments
  - Preserved perineural fat
  - Little to no enhancement, given the existence of an intact blood-nerve-barrier

MR Evaluation of Peripheral Nerves: Abnormal





- Abnormal nerves:
  - Increased hyperintense signal on fluid sensitive sequences
  - Disrupted fascicular pattern with loss of normal nerve architecture
  - Focally or diffusely enlarged nerve caliber, larger than the adjacent coursing arteries
  - Effaced perineural fat
  - + Post contrast enhancement (in the setting of tumor, infection and acute inflammation) secondary to breakdown of the blood-nerve-barrier

Lumbosacral Plexus Pathology

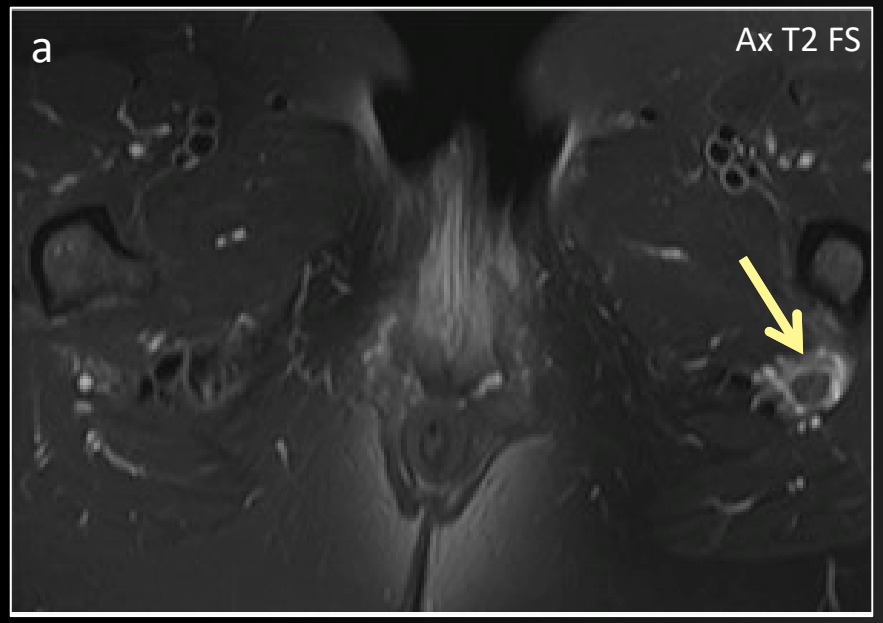
DDx and Case Based Imaging Review

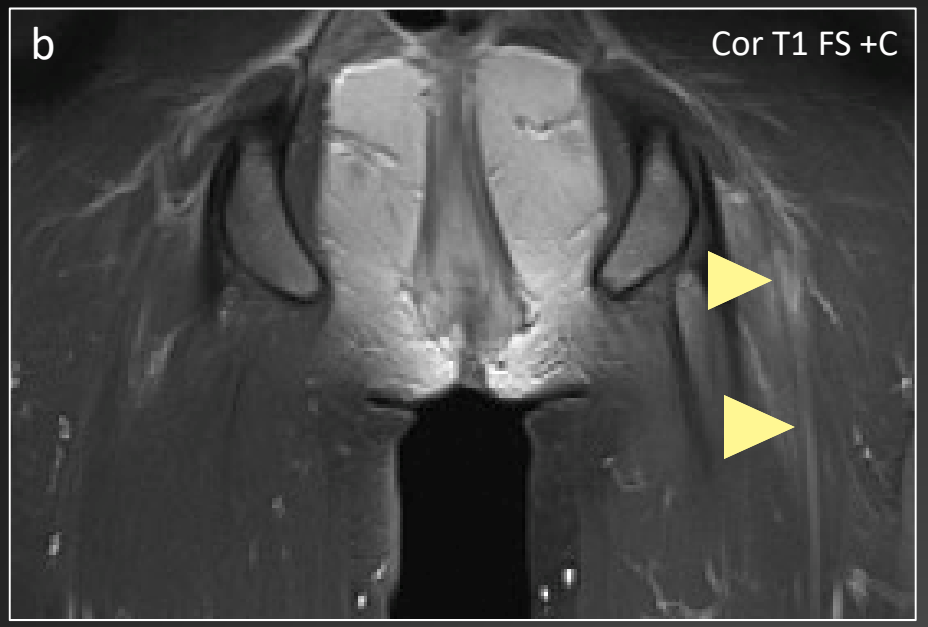
- Intrinsic Neuropathy
  - Acute
  - Acute on Chronic
  - Chronic*
- Diffuse Neuropathy
  - Diabetes Mellitus*
  - Amyloidosis
- Trauma
  - Neurapraxia
  - Axonal Injury
  - Nerve Transection*
- Tumor/Tumor-Like Lesions
  - Neurofibromatosis
  - Perineurioma
  - Lymphoma
  - Lymphangiomatosis
  - Inflammatory Pseudotumor*
  - Charcot Marie Tooth*
  - Endometriosis*
- Inflammatory
  - CIDP
  - Multifocal Motor Neuropathy *
  - Radiation Plexopathy
  - Arachnoiditis

*Case examples of these pathologic entities are not included in this educational exhibit

Neuropathy: Acute, Compressive Type

- 36-year-old woman who awoke after being in prolonged lithotomy position during a partial colectomy with new onset left lower extremity pain, weakness, and numbness

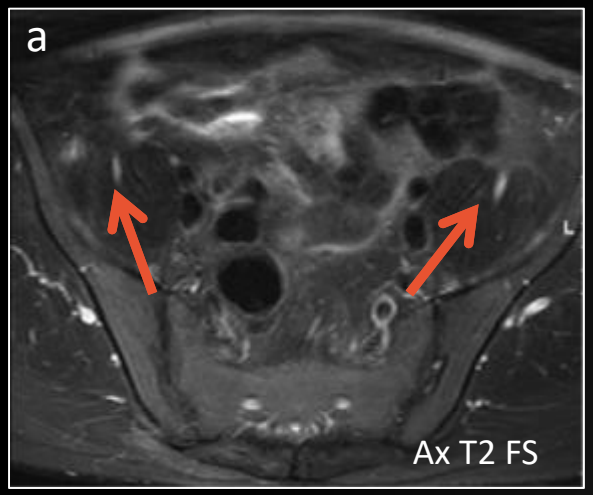




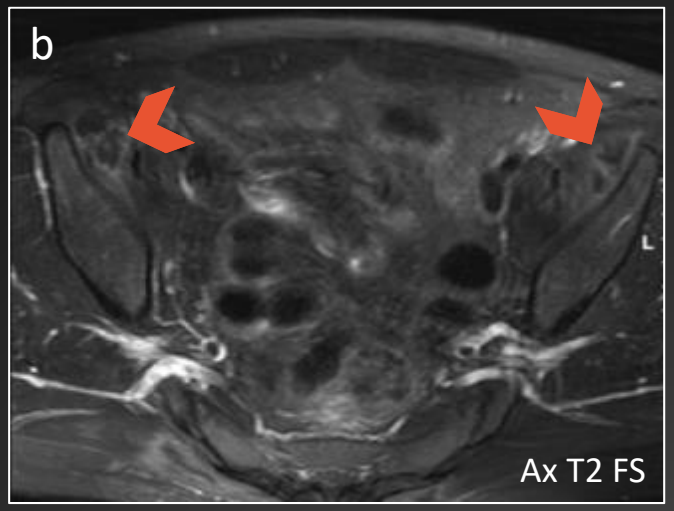
(a) Fat-suppressed MR images demonstrate focal enlargement and increased T2 signal intensity of the left sciatic nerve (arrow) with peri-neural edema. (b) Post-contrast images demonstrate confluent enhancement of the left sciatic nerve (arrowheads). Note the lack of concurrent intramuscular denervation edema. This case is compatible with acute rather than chronic neuropathy

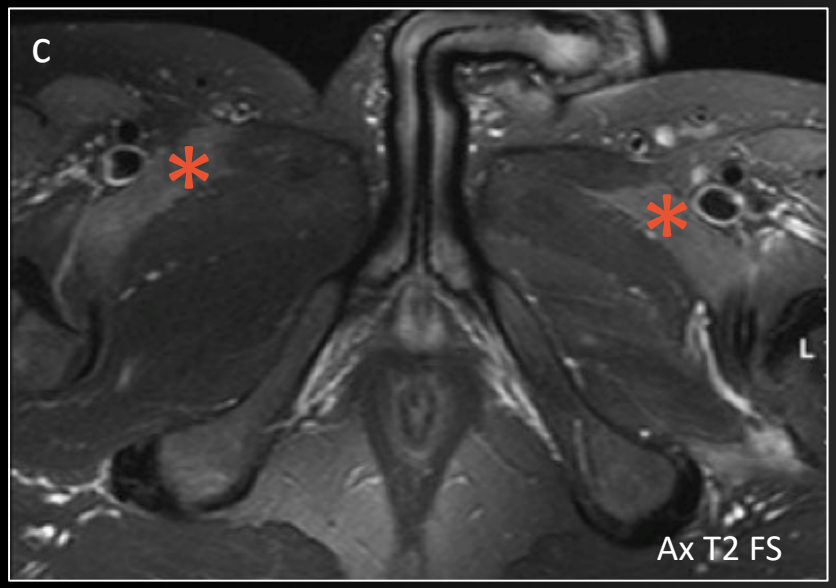
Neuropathy: Acute, Compressive Type

- 37-year-old man “found down” for unknown length of time, admitted with rhabdomyolysis and clinical weakness with thigh flexion



(a) The bilateral femoral nerves are clearly seen coursing along the psoas muscles with increased signal and symmetric enlargement (arrows)



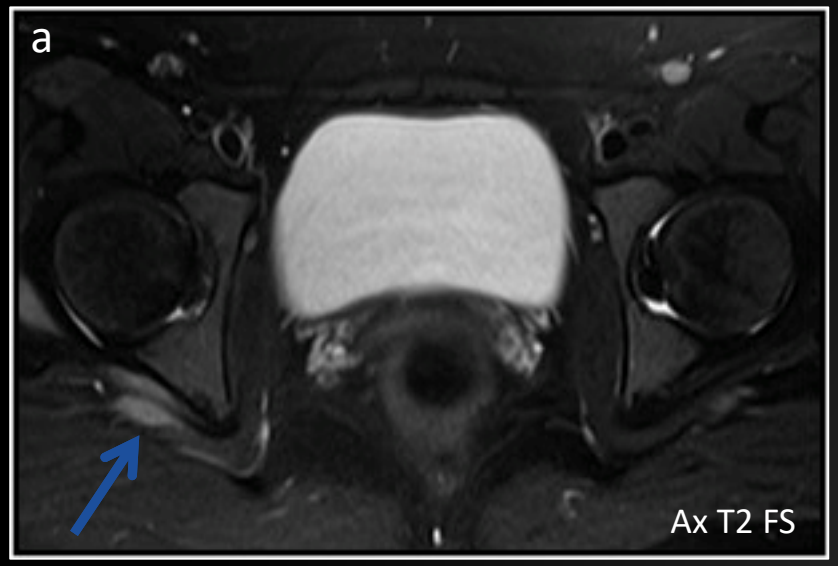


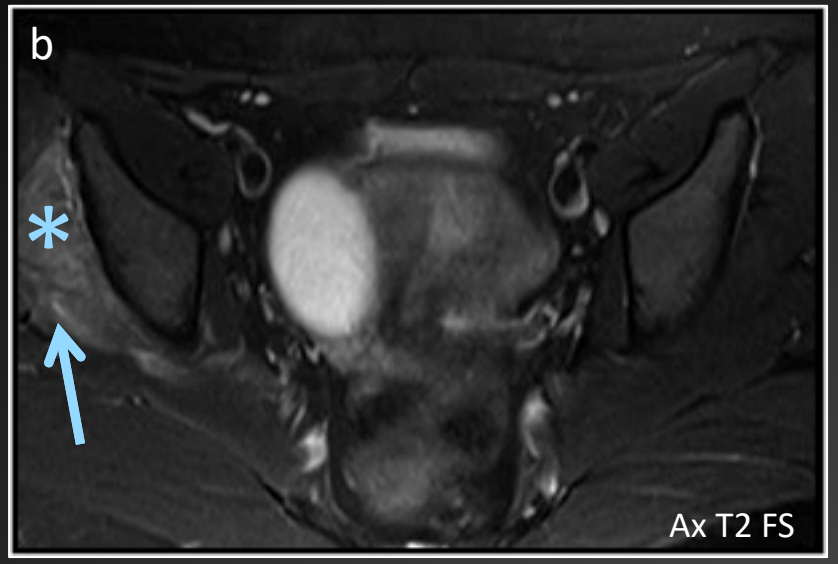
(b) Edema in the iliopsoas muscles surrounds areas of myonecrosis (chevrons)
(c) In the lower pelvis, there is early denervation edema in the bilateral adductor muscles (asterisks)

- Onset of denervation muscular edema can be seen as early as 15 days following the initial nerve injury and can last up to 1-year

Neuropathy: Acute on Chronic

- 26-year-old woman with myasthenia gravis presents with worsening right buttock pain and weakness





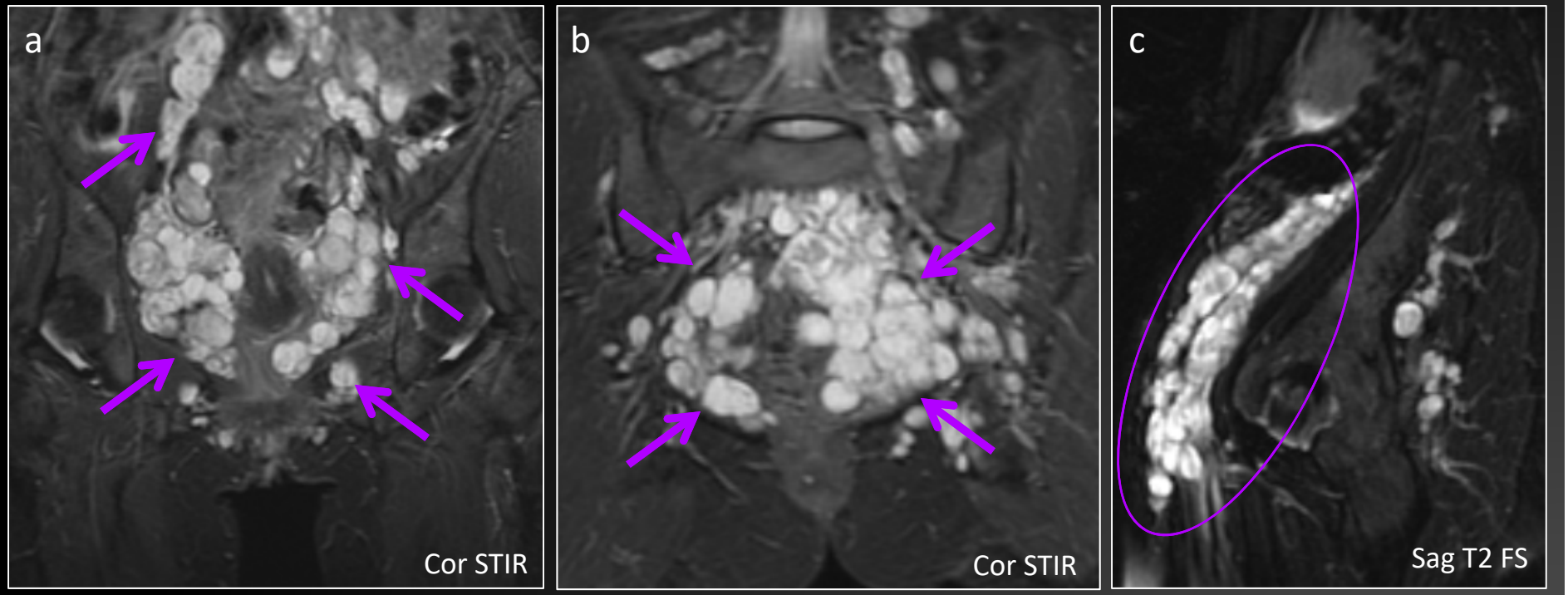
(a) The right sciatic nerve is asymmetrically enlarged and mildly hyperintense (blue arrow). (b) The right superior gluteal nerve is also enlarged (light blue arrows). The right gluteus medius muscle (asterisk) is edematous, as is the gluteus minimus (not shown) consistent with denervation change

- SPAIR sequences are most sensitive for muscle denervation, followed by STIR and then fat suppressed T2 weighted sequences

The gluteus minimus and medius muscles are innervated by the superior gluteal nerve (nerve roots L4-S1)

Tumor: Neurofibromatosis Type 1

- 50-year-old woman with a history of NF1 presents with worsening bilateral leg weakness

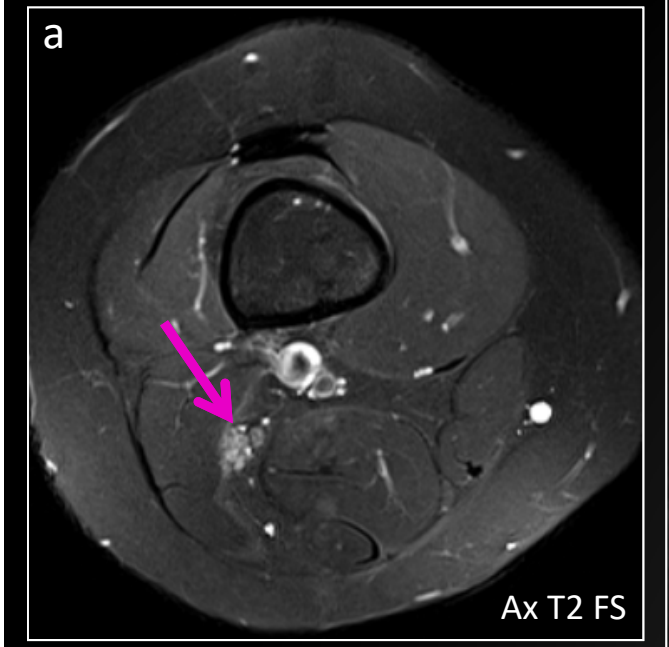


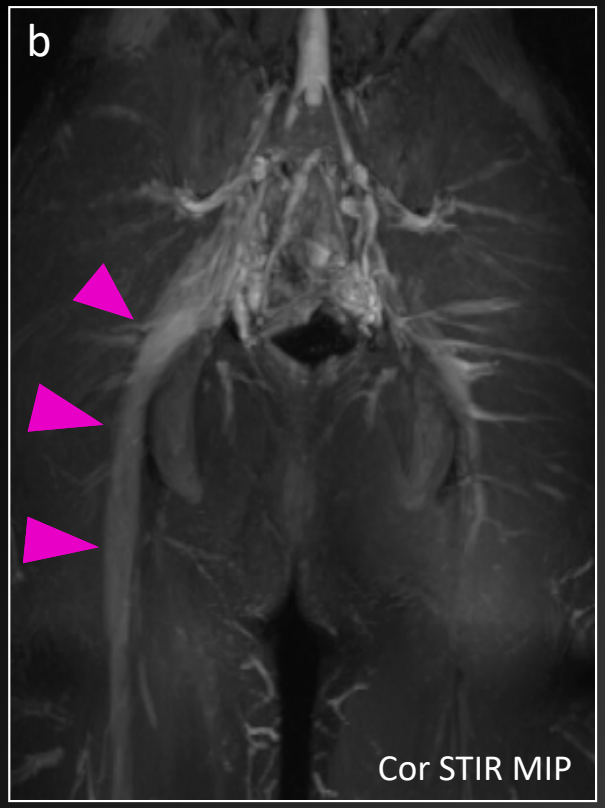
(a-c) MR images demonstrate diffuse, nodular/beaded, masslike enlargement of the coursing nerves of the lumbosacral plexus consistent with plexiform neurofibromas (arrows and circle) in the setting of NF-1

- Plexiform neurofibroma formation is pathognomonic for NF1; 5-10% of large plexiform neurofibromas undergo malignant transformation --> MPNST
- 50% have associated MSK abnormalities including long bone dysplasia, bowing deformities, vertebral body scalloping in the setting of dural ectasia and neurofibromas

Tumor: Intraneural Perineurioma

- 35-year-old woman presenting with lower extremity weakness





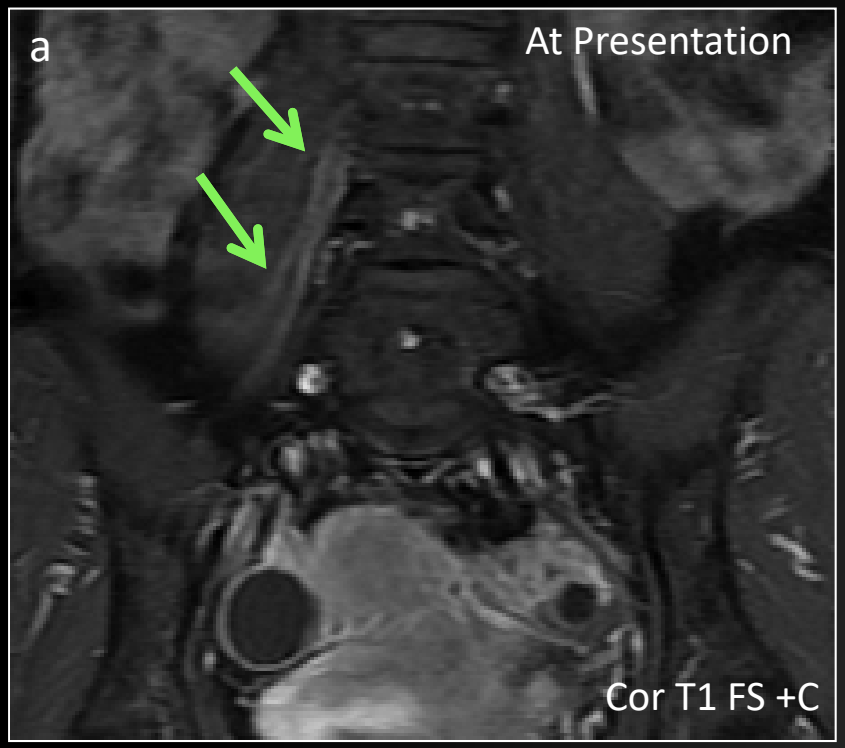
(a) The distal right sciatic nerve is enlarged and hyperintense with fascicular edema (arrow). (b) Coronal MIP image demonstrates fusiform enlargement of the entire visualized sciatic nerve (arrowheads). Post contrast images (not shown) reveal homogenous enhancement of the nerve

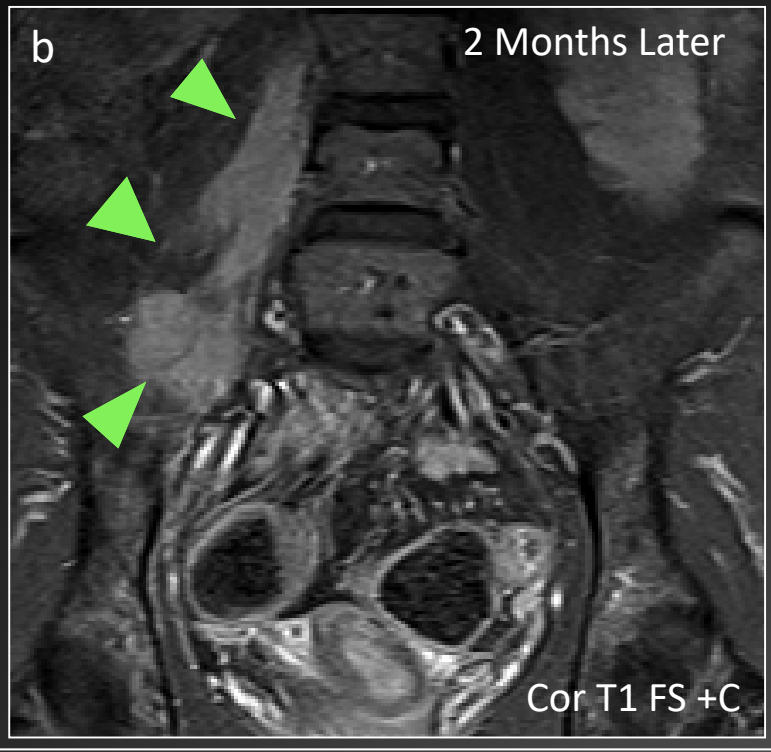
**Case courtesy of Avneesh Chhabra, MD*

- A benign neoplastic condition in which perineural connective tissue cells proliferate into whorls of tissue confined by the endoneurium
- Typically >10 cm in length, and most commonly involves a large nerve trunk (e.g. sciatic).
- Treatment usually involves supportive care, although resection and nerve grafting has been performed.
- DDx: Acute neuritis, nerve sheath tumor

Tumor: Lymphoma

- 45-year-old woman with a history of Non-Hodgkin lymphoma presenting with progressive right lower extremity pain and weakness



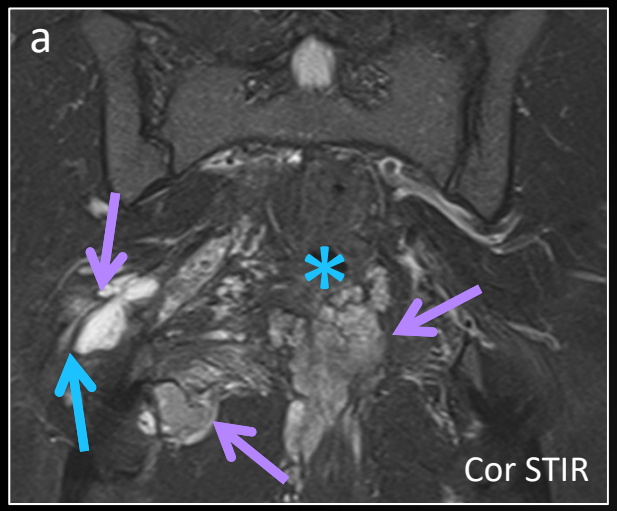


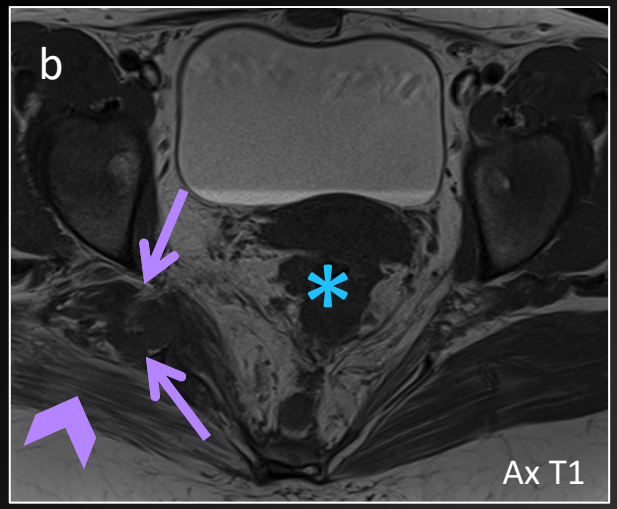
(a) Post contrast coronal MRI demonstrates diffuse enlargement and enhancement of the coursing lumbar nerves with loss of the normal fascicular architecture (arrows). (b) Imaging two months later demonstrates marked disease progression with solid enhancing infiltrative masses along the nerves (arrowheads)

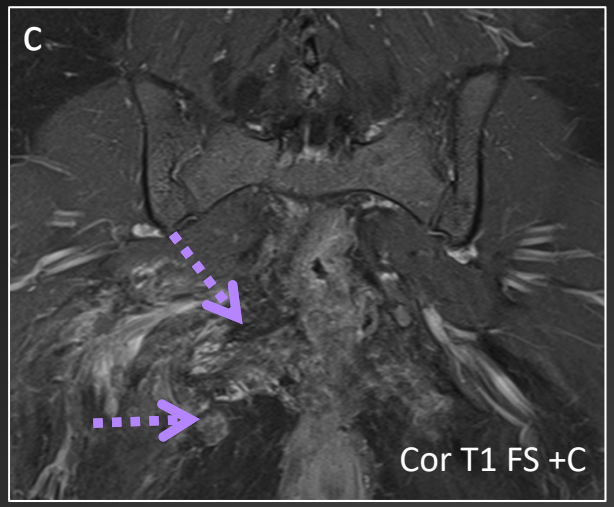
- Neoplastic involvement of the LS plexus is most commonly due to extrinsic spread from primary malignancy and metastatic lymphadenopathy. Direct tumor involvement of the nerves is less likely but can be seen with lymphoma, breast, prostate, and cervical cancer
- Perineural spread of tumor and tumor infiltration typically show nodular, mass like solid enhancement vs. thickened, varied enhancement with radiation induced fibrosis

Tumor: Lymphangiomatosis

- 24-year-old woman with a history of previously resected pelvic lymphangiomas presenting with right leg weakness, paresthesias, and urinary retention





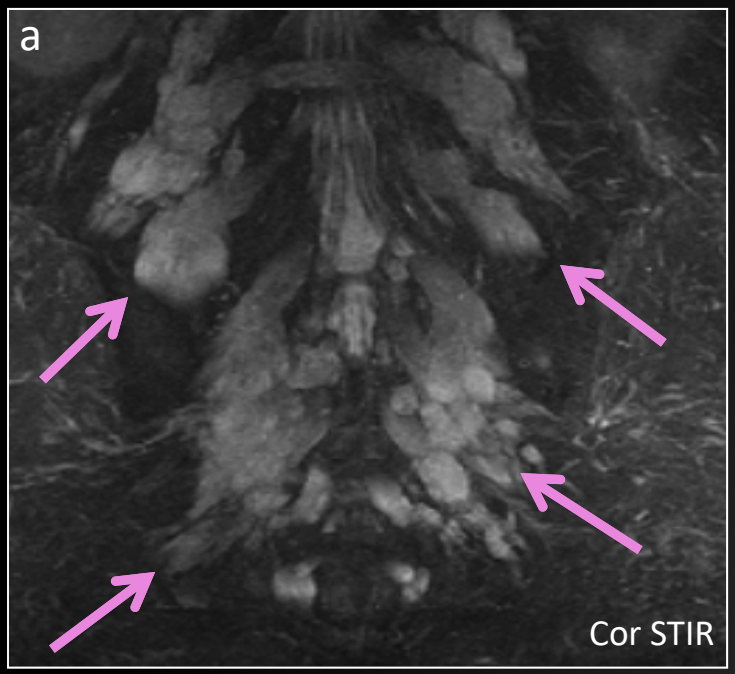


(a,b) MRI shows numerous T2 hyperintense, T1 hypointense serpiginous cystic masses (purple arrows) in the right sciatic notch, presacral space, right sacral neural foramina, and about the rectum (asterisk). The masses are interspersed amongst the right lumbosacral nerves (blue arrows) which are increased in signal. There is marked asymmetric atrophy of the gluteal muscles (chevron). (c) The masses mildly enhance (dashed arrows). These findings were compatible with plexus and pelvic organ involvement by systemic lymphangiomatosis

- Lymphangiomatosis is characterized by lymphangiomas involving multiple body systems such as soft tissues, bones, solid organs, and as in this case, nerves
- Involvement of the plexus is uncommon, however can be considered in the setting of multiple serpiginous cystic masses involving multiple body systems
- DDx: Charcot Marie Tooth, NF1, CIDP

Inflammatory: Chronic Inflammatory Demyelinating Polyneuropathy (CIDP)

- 26-year-old woman with two months of progressive back pain

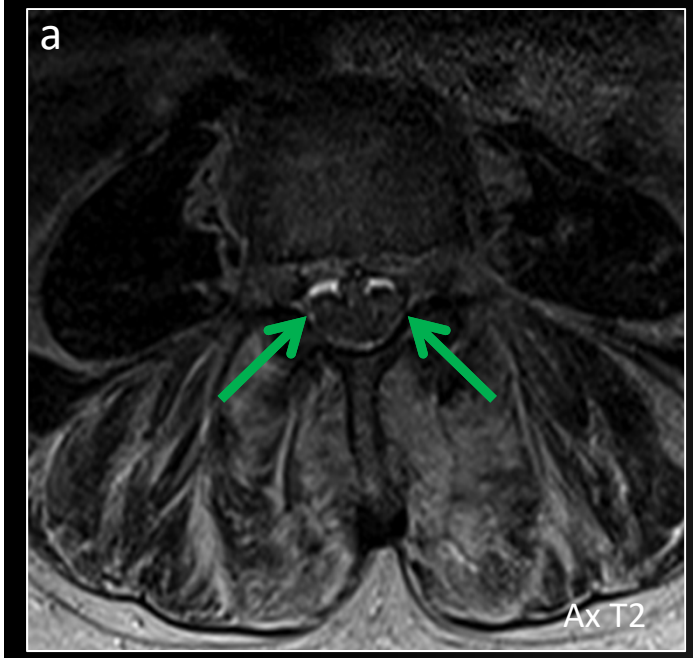


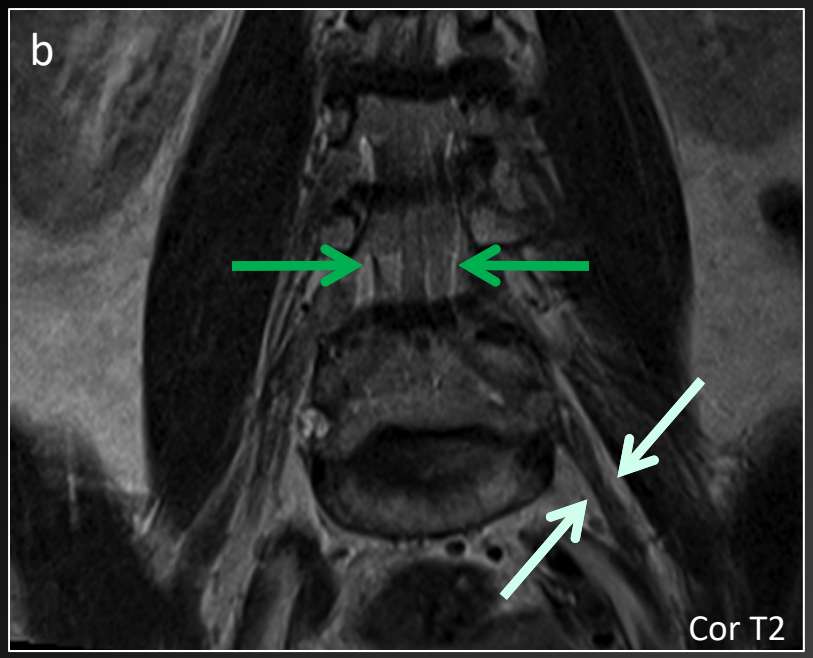
(a) There is marked bilateral, symmetric nodular enlargement of the coursing nerves in a classic "onion bulb" pattern (arrows). The nerves are hyperintense on T2/STIR weighted sequences. Post-contrast images (not shown) demonstrate avid nerve enhancement

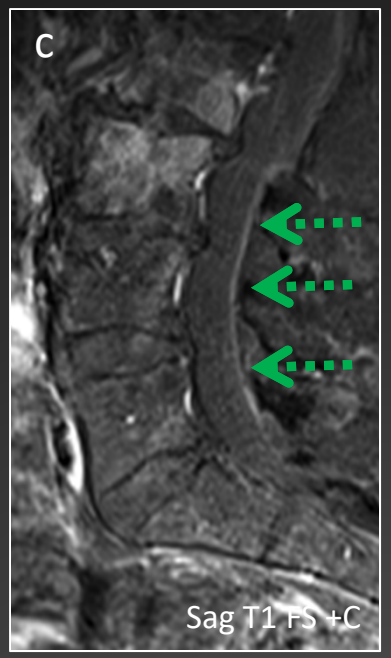
- Rare acquired immune-mediated inflammatory disorder involving peripheral nerves
- Patients present with progressive radicular pain, with progressive proximal and distal muscle weakness, sensory deficits, and areflexia
- Considered a chronic form of Guillain-Barré Syndrome, with clinical symptoms lasting longer than 2 months
- DDx: Charcot-Marie-Tooth and Neurofibromatosis Type I

Inflammatory: Arachnoiditis

- 81-year-old woman with a remote history of L1-L2 posterior decompression, presenting with back pain and leg weakness





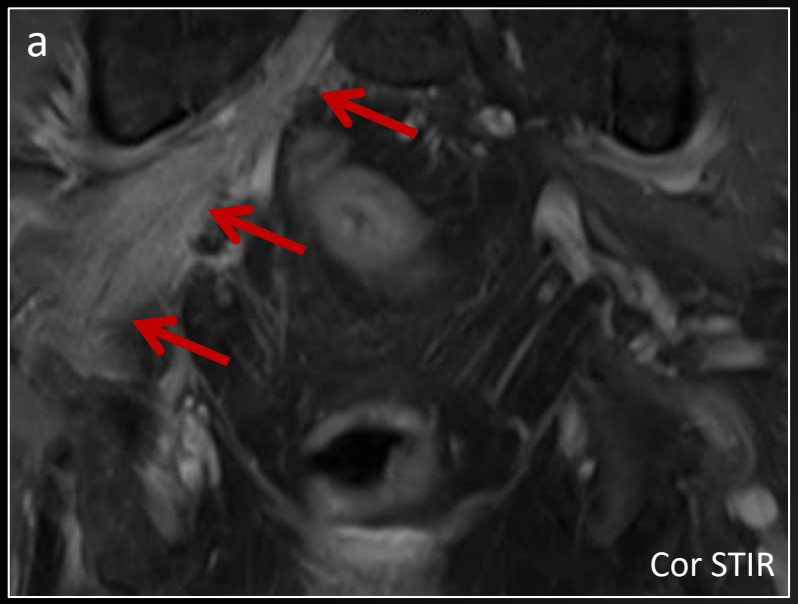


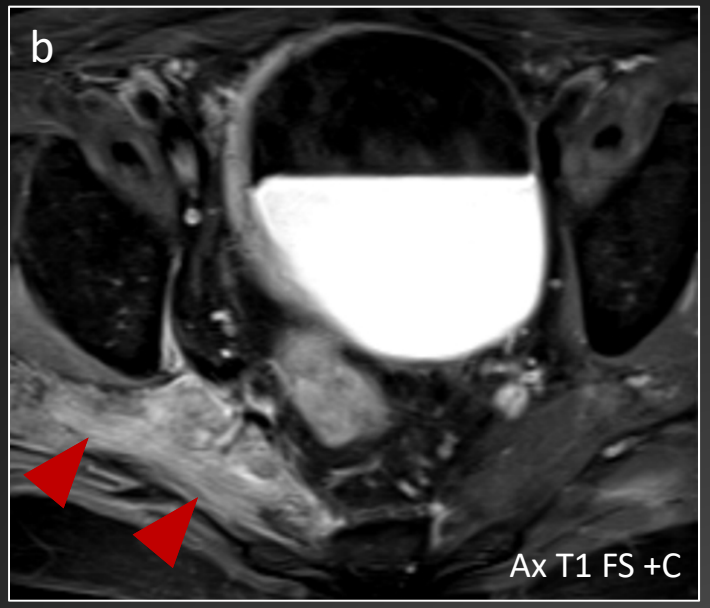
(a) There is marked thickening and clumping of the nerves of the cauda equina (green arrows). (b) More distal extra-foraminal segments resume normal caliber (light green arrows). (c) Post contrast images demonstrate thin, peripheral enhancement of the nerve roots (dashed green arrows)

- Arachnoiditis is an abnormality limited to the nerve roots within the dural sac
- It can result from multiple inflammatory and infectious etiologies in addition to sequela of spinal surgery, hemorrhage, iatrogenic steroid administration, contrast dye and chronic pressure from disc herniation and severe spinal canal stenosis

Inflammatory: Radiation Induced Plexopathy

- 59-year-old man with a history of prostate cancer with right pelvic nodal metastases treated with pelvic radiation presenting with right leg pain and weakness



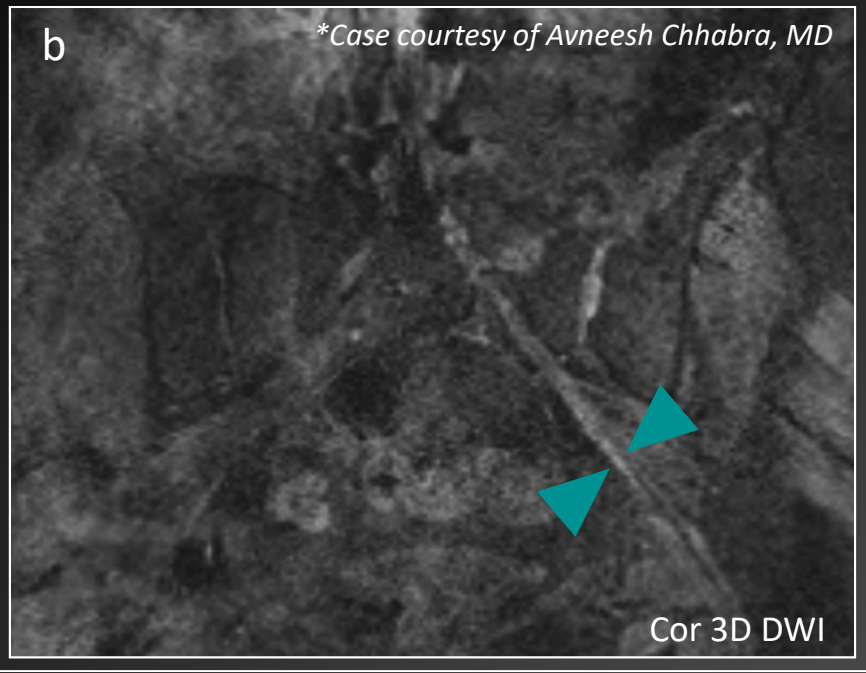


(a) MRI demonstrates diffuse asymmetric enlargement of the coursing lumbosacral plexus with enhancement (arrows) in a known radiation field. (b). There is enhancing edema (arrowheads) of the right piriformis muscle, compatible with post radiation denervation changes

- Patient history is crucial when evaluating plexopathy in the setting of prior radiation treatment
- Symptom onset is typically within weeks to years following treatment
- Radiation plexopathy is dose dependent and is typically seen in doses > 60 Gy

Trauma: Nerve Stretch Injury

- Patient with a history of mildly displaced left sacral insufficiency fracture presenting with left leg pain and weakness

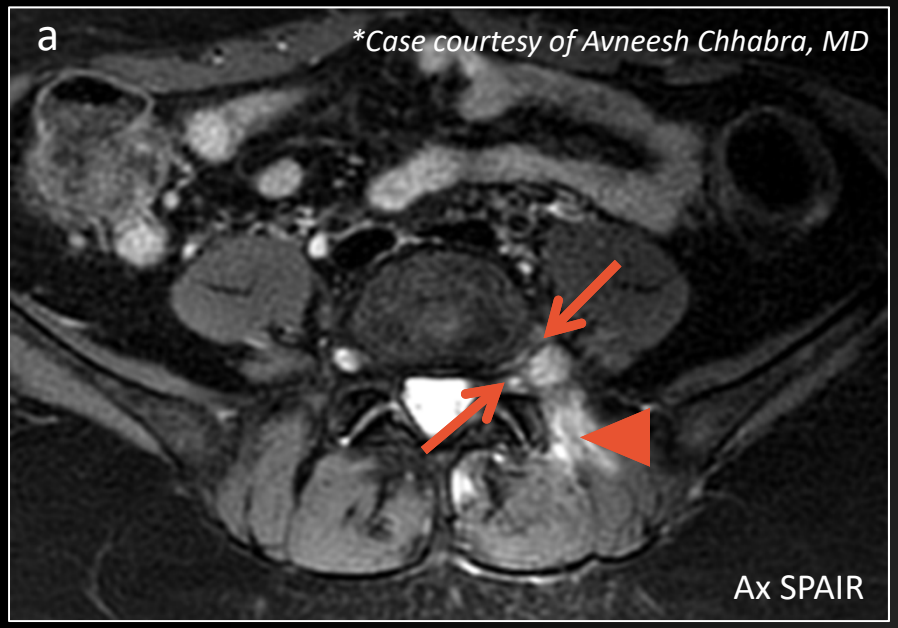


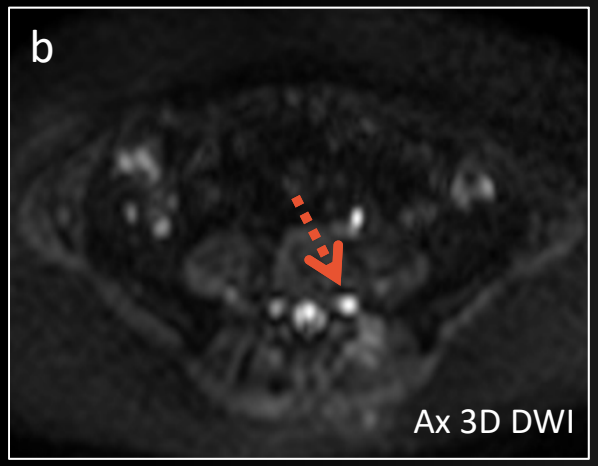
(a) The S1 nerve root is asymmetrically increased in signal with focal kinking but normal caliber (arrows) as it traverses the fractured sacrum (chevron). No corresponding muscle edema is present, compatible with low-grade injury. (b) Subtle increased signal of the extra foraminal sacral nerve on DWI images (arrowheads).

- Low grade nerve stretch injuries, also known as neurapraxia, present as temporary loss of both motor and sensory function
- Traumatic nerve injuries are most commonly due to stretching or laceration, particularly in the setting of sacral fractures or spinal surgery

Trauma: Axonal Injury

- Patient with dense weakness and numbness in the L5 territory. Symptom onset occurred immediately following a L5-S1 discectomy performed several months previous





(a) The left L5 nerve root upon exiting the neural foramen is significantly enlarged with enlarged individual fascicles (arrows). There is denervation edema of the adjacent erector spinae musculature (arrowhead). (b) There is significantly increased signal of the left L5 nerve on DWI images (dashed arrow)

Sunderland Classification of Nerve Injuries* (at right)

*Chhabra *Indian J Radiol Imaging* 2014

Class	Description	MRI Findings	Recovery Potential
I	Nerve stretch injury (neurapraxia)	Nerve is T2 hyperintense but normal in caliber.	Full
II	Axonal injury (axonotmesis) with intact endoneurium	Enlarged, hyperintense nerve. Fascicular pattern preserved.	Full
III	Axonal injury (axonotmesis) with disrupted endoneurium	Enlarged, hypertintense nerve with enlarged or effaced fascicles. + Denervation changes.	Slow, Partial
IV	Endoneurium and perineurium disrupted; epineurium intact. (neuroma-in-continuity)	Focally enlarged nerve with disrupted fascicles. + Denervation changes.	Poor
V	Complete nerve transection (neurotmesis)	Complete nerve discontinuity. Over time neuroma can develop. +Denervation changes.	None

Take Home Points

- The diagnostic evaluation of patients with pain, weakness, paresthesias and other neurologic symptoms referable to the low back and pelvis is complex and should be patient-specific

- Lumbosacral plexus MRI provides excellent anatomic detail and contrast resolution, allowing detailed localization of lesions and characterization of the myriad of associated pathologic entities

- A robust understanding of nerve anatomy, downstream innervation patterns in combination with a systematic sequence-based approach to MRI interpretation is key to the identification and characterization of pathology involving the lumbosacral plexus

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