American Academy of Osteopathy®

Osteopathic Neuromusculoskeletal Medicine in the 21st Century

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MRI of the Lumbar Spine

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Full Definition of MAGNETIC RESONANCE IMAGING

: a noninvasive diagnostic technique that produces computerized images of internal body tissues and is based on nuclear magnetic resonance of atoms within the body induced by the application of radio waves —abbreviation *MRI*

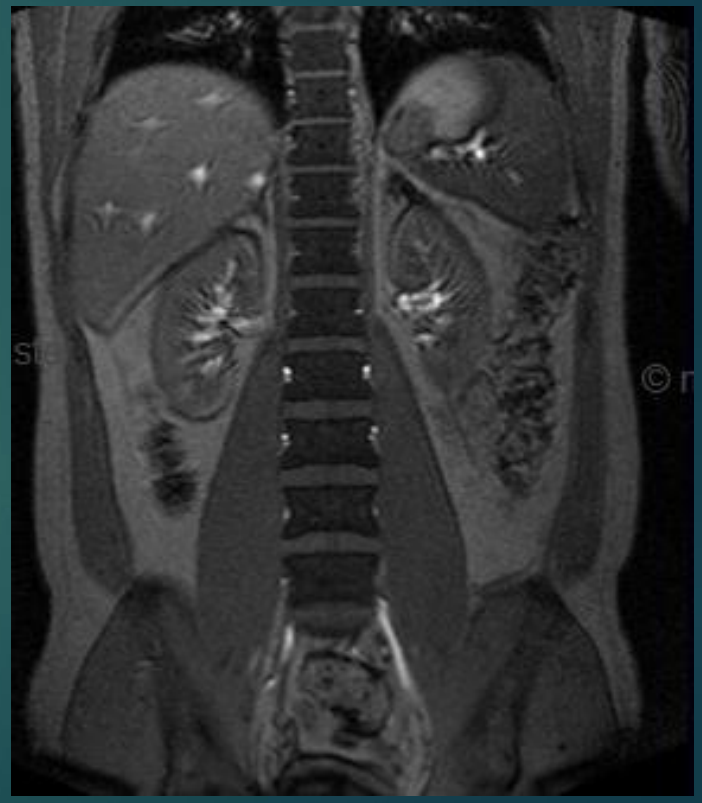
* Definition from Merriam Webster dictionary

MRI sequences (truncated list)

- **T1**
  - gadolinium enhanced
  - fat suppressed
- **T2**
  - fat suppressed
  - fluid attenuated
  - susceptibility sensitive
- **proton density**
  - fat suppressed
- **diffusion weighted**
- **flow sensitive**
  - MR angiography
  - MR venography
  - CSF flow studies
- **miscellaneous**
  - MR cholangiopancreatography (MRCP)
  - MR spectroscopy
  - MR perfusion
  - functional MRI
  - Tractography
  - DTI
  - MR Elastography
  - MR prostate

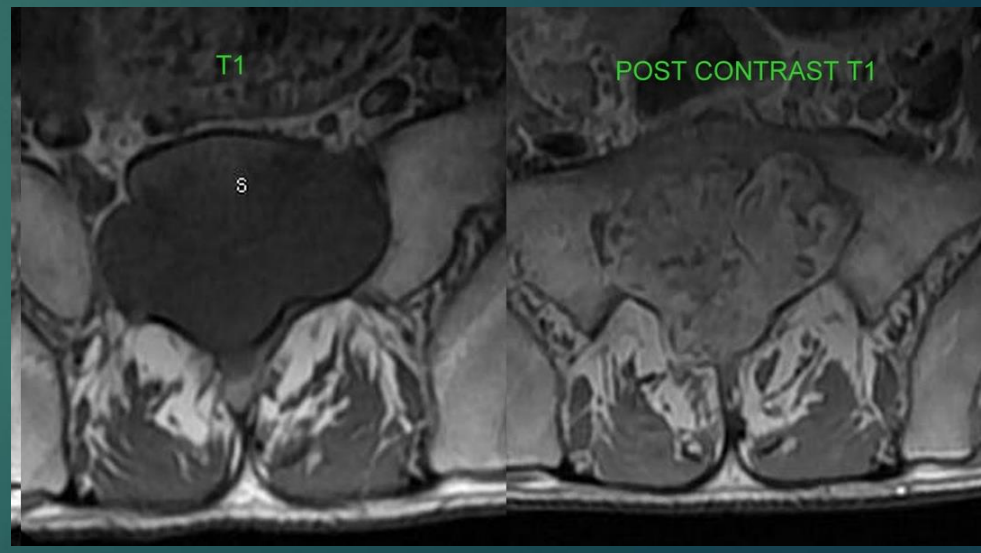
MRI basics – Quick hits

- T1
  - **<u>T1-weighted images are generally considered to show the best anatomy</u>**
    - **Although they are not that sensitive to pathology**
  - They have the best signal-to-noise per-unit time of scanning
  - On T1-weighted images:
    - Tissues with short T1 times (like subcutaneous fat or fatty bone marrow) appear bright
    - Tissues with long T1 times (like fluid, cotical bone) appear dark
    - If "fat saturation" is used, fat will appear dark on a T1-weighted image.



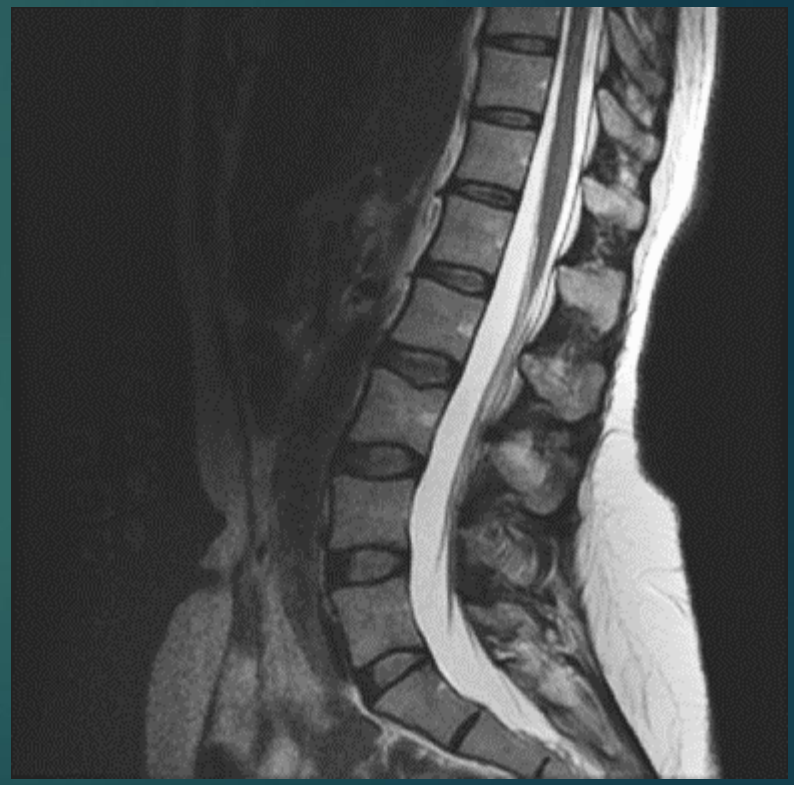
MRI basics – Quick hits

- T1 – Post contrast
  - Often post contrast T1 sequences are also fat suppressed to make this easier to appreciate enhancement
  - Enhancement = accumulation of contrast (mostly due to leaky blood vessels)
    - Tumors
    - Areas of inflammation
    - Infection



MRI basics – Quick hits

- T2
  - **<u>T2-weighted images are the most sensitive to pathology</u>**
  - Tissues with short T2s appear dark
    - tendons, ligaments, menisci, periosteum, cortical bone
  - Tissues with long T2s are bright
    - Since fluid has a long T2, joint effusions and muscle or bone marrow edema appear bright
    - However, fat appears bright. In order to see subtle bone marrow edema, fatty bone marrow must be suppressed
      - Another way to suppress fat is to use a technique called short T1 inversion recovery (STIR)



MRI basics – Quick hits

- Identifying T1 vs T2
  - Easiest way to determine which pulse sequence was used is to look at the cerebrospinal fluid
    - If the CSF is bright (high signal), it must be a **T2-weighted** image
    - If the CSF is dark (low signal), it is a **T1-weighted** image

MRI basics – T1 vs T2

- T1:
  - Black (low intensity)
    - Fluid (e.g. urine, CSF)
  - Gray (intermediate intensity)
    - Muscle
    - Gray matter
  - White (High intensity)
    - Fat
    - White matter
- T2
  - Black (low intensity)
    - White matter
    - [Fat; if fat saturated image]
  - Gray (intermediate intensity)
    - Muscle
    - Gray matter
  - White (High intensity)
    - Fluid (e.g. urine, CSF)
    - [Fat; if NOT fat saturated image]

MRI basics – CT vs MRI

- MR and CT are both competitive and complimentary

- CT
  - Performs better in cases of trauma and emergent situations
  - Better bone detail
  - Higher sensitivity for acute hemorrhage
  - CT scanning is fast

- MR
  - Functions best as an elective outpatient procedure
  - Proper screening of patients, equipment, and personnel for ferromagnetic materials, pacemakers, etc. is mandatory
  - Imaging also requires more time

LUMBAR SPINE

Clinical Indications

- With its high contrast and spatial resolution and lack of ionizing radiation, MRI is considered by many to be the best imaging technique for the investigation of LBP
- Limitations
  - Among patients without red flags (clinical signs and symptoms indicating serious underlying conditions), early imaging (vs conservative treatment without imaging) **does not** improve patient outcomes
  - MRI is expensive
  - High prevalence (64%) of abnormal findings among individuals without LBP
    - This high prevalence makes it difficult, or possibly even perilous, to attribute a patient's symptoms to certain imaging findings
  - Approximately 70% of acute LBP patients can attribute their pain to spinal muscle strain or sprain

Clinical Indications

- Indications for when to get an MRI scan include:
  - After 4 to 6 weeks of leg pain, if the pain is severe enough to warrant surgery
  - After 3 to 6 months of low back pain, if the pain is severe enough to warrant surgery
  - If the back pain is accompanied by constitutional symptoms (such as loss of appetite, weight loss, fever, chills, shakes, or severe pain when at rest) that may indicate that the pain is due to a tumor or an infection
  - For patients who may have lumbar spinal stenosis and are considering an epidural injection to alleviate painful symptoms
  - For patients who have not done well after having back surgery, specifically if their pain symptoms do not get better after 4 to 6 weeks.
  - ...or other "red flags" symptoms

Table 1. Red Flags: Indications of a more complicated status include back pain/radiculopathy in the following settings (adapted from [7]).

Red Flag	Potential Underlying Condition as Cause of LBP
• History of cancer • Unexplained weight loss • Immunosuppression • Urinary infection • Intravenous drug use • Prolonged use of corticosteroids • Back pain not improved with conservative management	• Cancer or infection
• History of significant trauma • Minor fall or heavy lift in a potentially osteoporotic or elderly individual • Prolonged use of steroids	• Spinal fracture
• Acute onset of urinary retention or overflow incontinence • Loss of anal sphincter tone or fecal incontinence • Saddle anesthesia • Global or progressive motor weakness in the lower limbs	• Cauda equina syndrome or severe neurologic compromise

Contrast – with or without

SPINE INDICATIONS	RECOMMENDED STUDY	COMMENTS
Herniated Disc Cervical or Thoracic	MRI Contrast - No	MRI superior to CT
Lumbar Herniated disc	MRI Contrast – No If post surgery then W/WO	Contrast helps distinguish between scar & disc post surgery. MRI superior to CT
Stenosis	MRI Contrast - No	CT can be adequate in lumbar spine if MRI contraindicated MRI superior to CT
Discitis/Osteo/CA	MRI Contrast - W/WO	MRI preferred to R/O Discitis/Osteo/CA. CT may be done post \discogram – with contrast from fluoro. MRI superior to CT
Metastasis, Epidural Tumor	MRI Contrast – W/WO	MRI also superior to myelography & CT.
Compression Fracture, Trauma	MRI Contrast – No	MRI allows evaluation of bone marrow.
Brachial Plexus – Mass, Lesion.	MRI Chest. Contrast - WO/W.	

If ordering a test with IV contrast: Creatinine or GFR is required for patients 70 years or older, with kidney disease, one kidney, diabetic, hx of multiple myeloma or chemotherapy in the last 30 days. Lab results must be within the last 30 days. Hemodialysis patients may receive contrast, but only if the patient signs an informed consent and is scheduled for hemodialysis within 2 hours of the injection of contrast and again at 24 hours.

Clinical Contra-Indications

- Contraindications for undergoing an MRI scan for spine-related pain in the back, neck or leg include:
  - Patients who have a heart pacemaker may not have an MRI scan
  - Patients who have a metallic foreign body (metal sliver) in their eye, or who have an aneurysm clip in their brain, cannot have an MRI scan since the magnetic field may dislodge the metal
  - Patients with severe claustrophobia may not be able to tolerate an MRI scan, although more open scanners are now available, and medical sedation is available to make the test easier to tolerate
  - Patients who have had metallic devices placed in their back (such as pedicle screws or anterior interbody cages) can have an MRI scan, but the resolution of the scan is often severely hampered by the metal device and the spine is not well imaged.
  - (Contrast reactions)

Roudsari and Jarvik

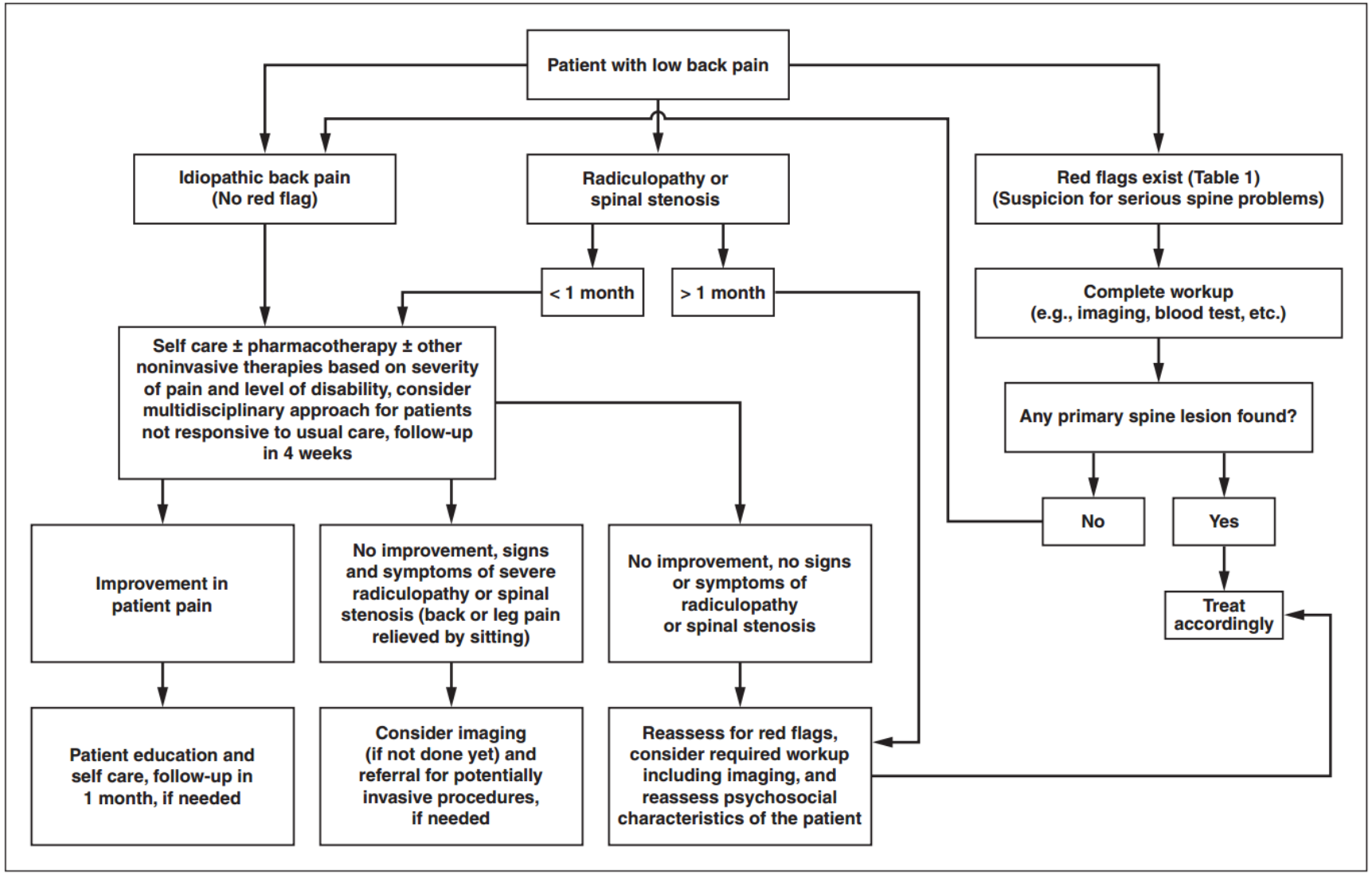


Fig. 2—Flowchart shows clinical practice guideline for management of low back pain [7].

Gadolinium Contrast Reactions

- Adverse Reactions
  - Frequency of all acute adverse events ranges from 0.07% to 2.4%
  - Mild (vast majority)
    - coldness at the injection site, nausea with or without vomiting, headache, warmth or pain at the injection site, paresthesias, dizziness, and itching
  - Severe/allergic reactions
    - 0.004% to 0.7%
    - Rash, hives, or urticaria are the most frequent of this group
    - Bronchospasm
    - Severe, life-threatening anaphylactoid or nonallergic anaphylactic reactions
    - Nephrogenic systemic fibrosis (NSF)
      - rare but serious systemic disease is characterized by fibrosis of the skin and other tissues throughout the body
      - Exact etiology of NSF is unclear
      - Most reported cases have been documented in patients with severe acute or chronic renal failure,
        - Glomerular filtration rate (GFR) < 30.
  - Extravasation of IV contrast

Gadolinium Contrast Reactions

- Risk Factors
  - 8 times higher risk in patients with a previous reaction to gadolinium-based contrast media
  - Persons with asthma and various other allergies are also at greater risk
  - If concern for contrast reaction, recommend standard premedication prep with steroid and antihistamine.

Standard L-Spine Sequences

- T1-weighted
  - Axial
  - Sagittal
- T2-weighted
  - Axial
  - Sagittal
- STIR or T2 fat sat
  - Sagittal

L-spine search pattern

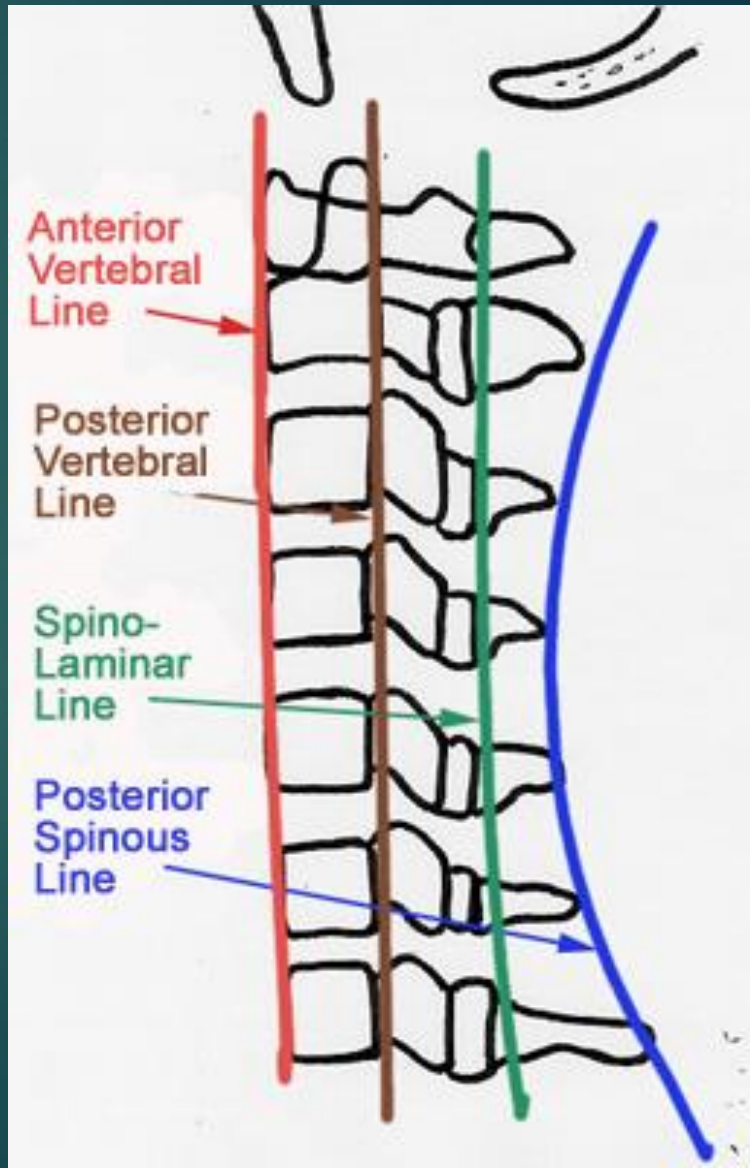
- A
- B
- C
- D
- E

L-spine search pattern

- Alignment
- Bone
- Cord/Canal
- Discs
- Everything else

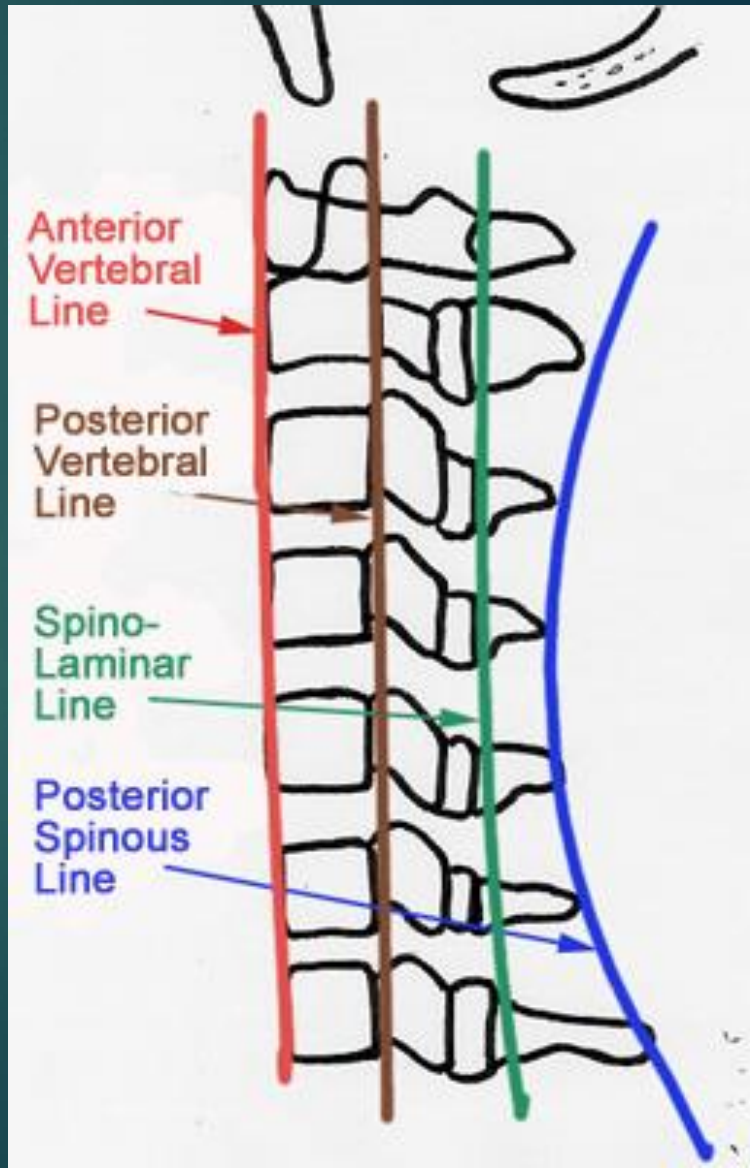
L-spine search pattern

- Alignment
  - anterior vertebral bodies
  - posterior vertebral bodies
  - facets
  - posterior spinal canal line
  - spinous processes



L-spine search pattern

- Alignment
  - Spondylolisthesis
    - Etiology
      - Trauma
      - Degenerative
      - Congenital



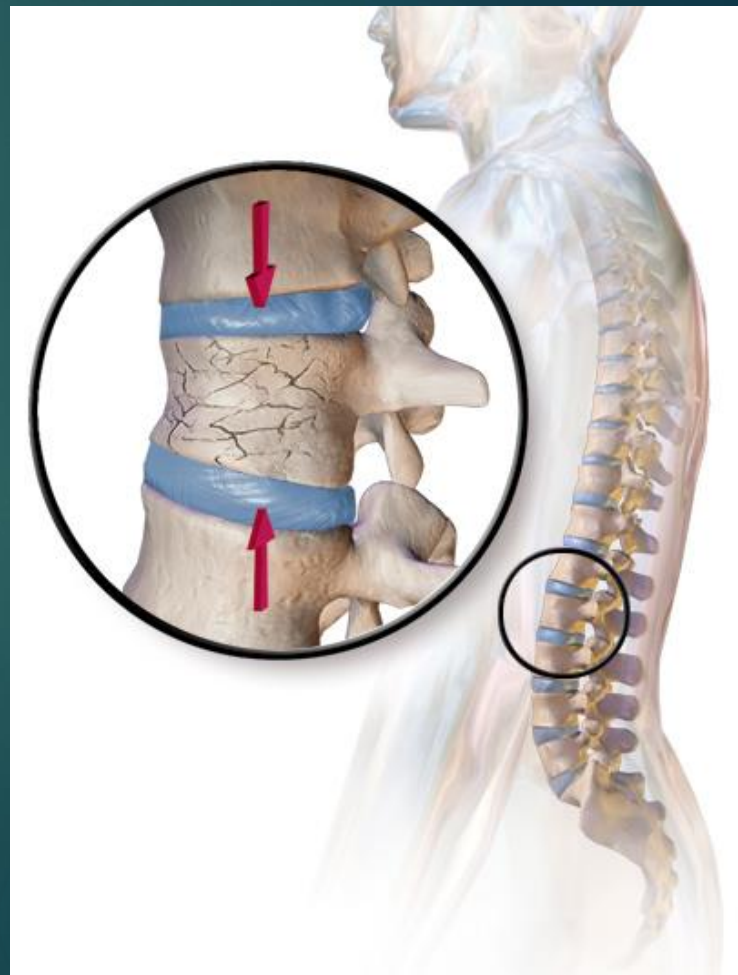
Spondylolisthesis

Mild (T1)

Mod/Severe (T2)

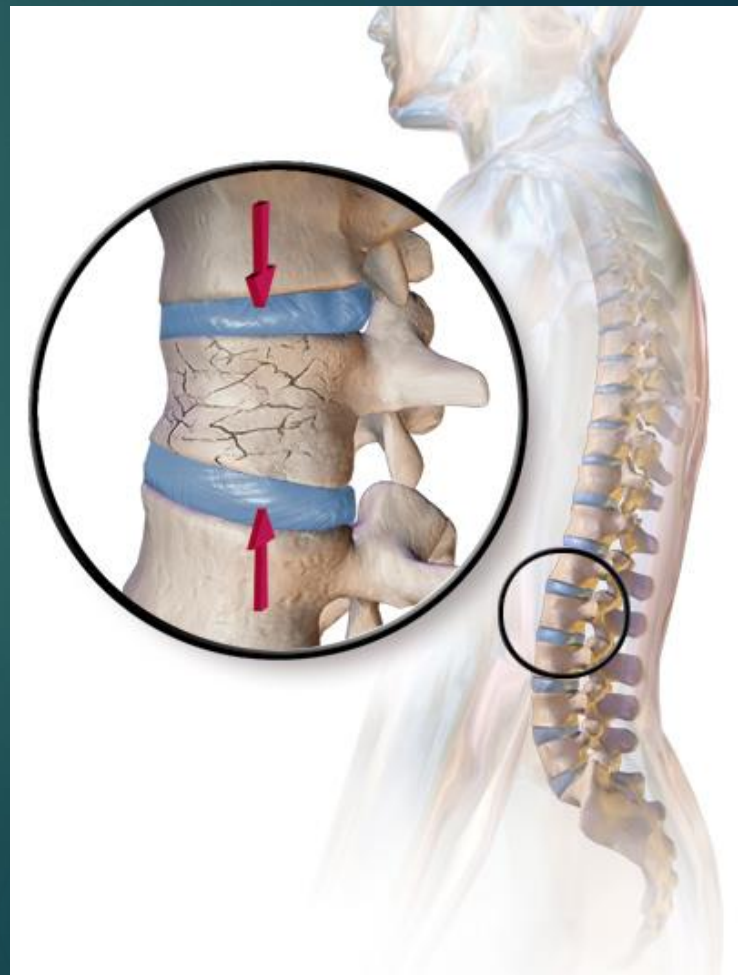
L-spine search pattern

- Bone
  - Fractures
    - Vertebral body compression
  - Blastic / lytic lesions



L-spine search pattern

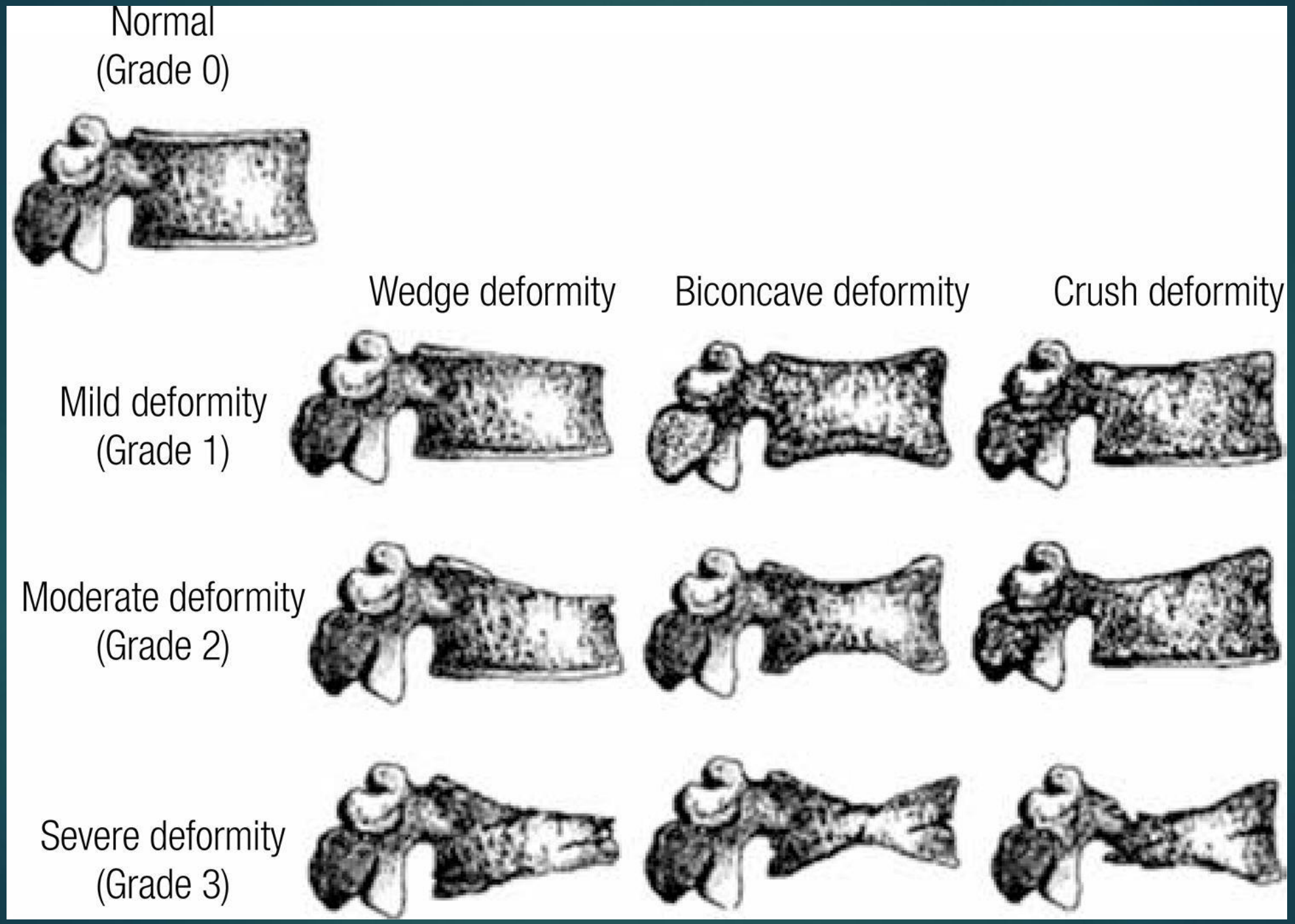
- Bone / Bone Marrow
  - Fractures
    - Vertebral body compression
      - Grading
        - mild: 20-25%
        - moderate: 25-40%
        - severe: >40%
  - Blastic / lytic lesions



Thoracolumbar Injury Classification and Severity (TLICS) Scale

Category	Points
Injury morphology	
Compression	1 (another point added [total of 2] if burst component present)
Translation/rotation	3
Distraction	4
Posterior ligamentous complex (PLC) integrity	
Intact	0
Suspected/indeterminate	2
Disrupted	3
Neurological status	
Intact	0
Nerve root injury	2
Spinal cord, conus medullaris	3 if incomplete, 2 if complete
Cauda equina	3

Score	Interpretation
≤3	Nonoperative treatment
4	Nonoperative or operative
≥5	Operative treatment

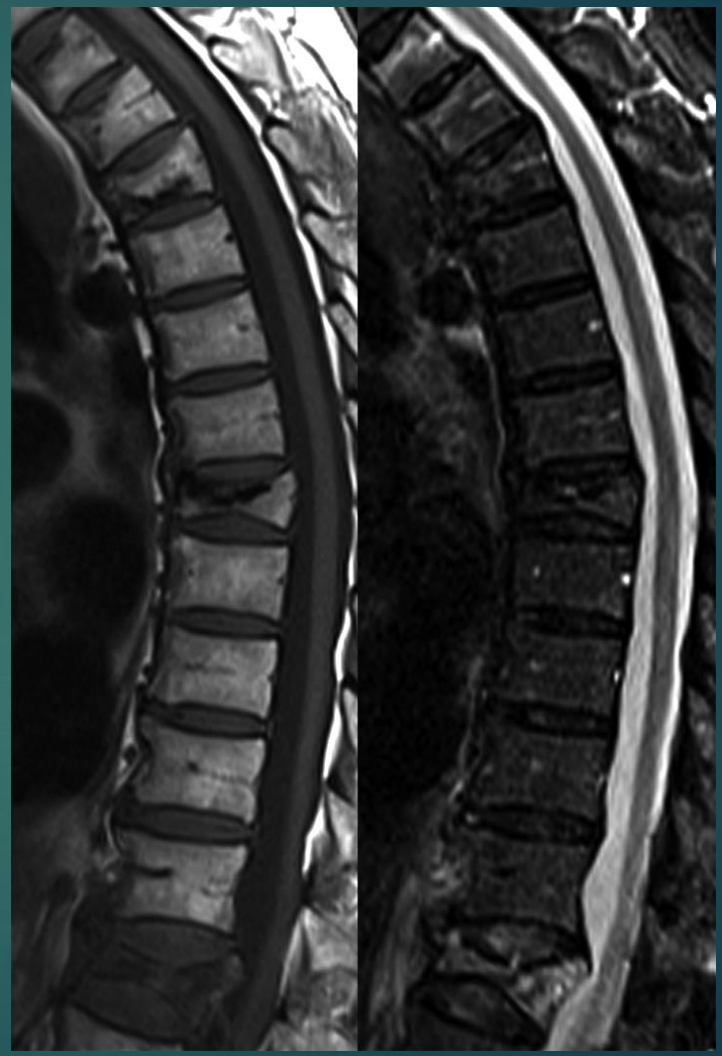

Normal
(Grade 0)
Wedge deformity
Biconcave deformity
Crush deformity
Mild deformity
(Grade 1)
Moderate deformity
(Grade 2)
Severe deformity
(Grade 3)

Compression Fractures

Mild/Mod

(T1) (T2)

Severe



(T1) (STIR)

Acute

This MRI side view shows that the bone marrow indicated by the arrow has a whiter appearance indicating the bone fracture, with the signal change due to edema and swelling associated with the fracture process.

Chronic

Sagittal T1 W (a), T2 W (b) and STIR (c) MR images of spine show moderate/grade 2 fracture in D12 (arrow) without any edema suggestive of chronic fracture

Normal Bone marrow

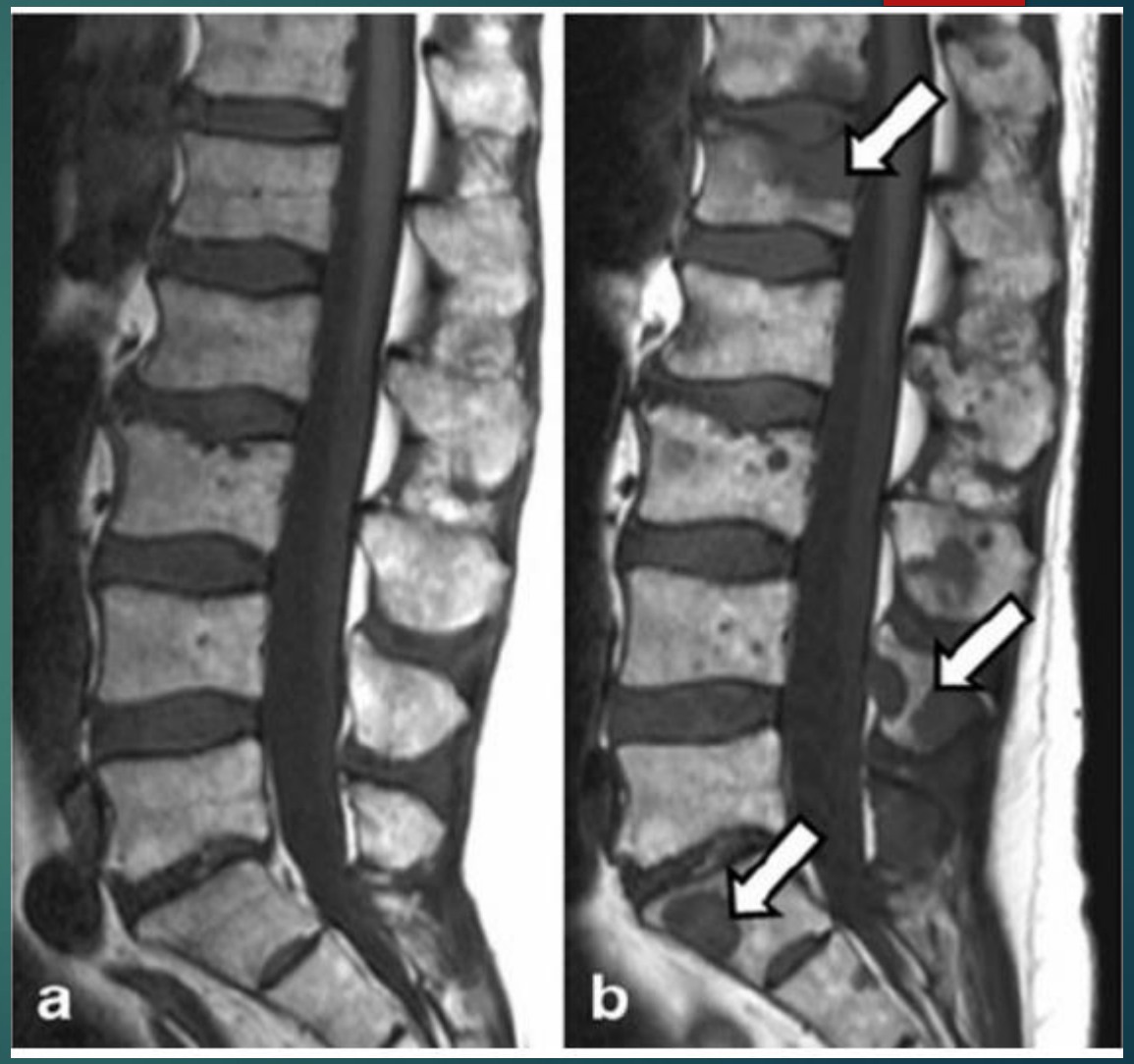
28-year-old man with vague back pain. Sagittal T1-weighted spin-echo image shows normal marrow signal intensity of lumbar vertebral bodies, which are slightly hyperintense relative to adjacent intervertebral disks. White arrowheads depict normal fat signal intensity in region of basivertebral plexus.

64-year-old woman with chronic low back pain. Central hyperintense signal (arrows) is seen within vague hypointense lesions within L2 and L3 vertebral bodies on this sagittal T1-weighted image, consistent with bull's eye sign of normal hematopoietic marrow. Overall heterogeneous appearance of marrow is due to osteoporosis.

Metastatic disease

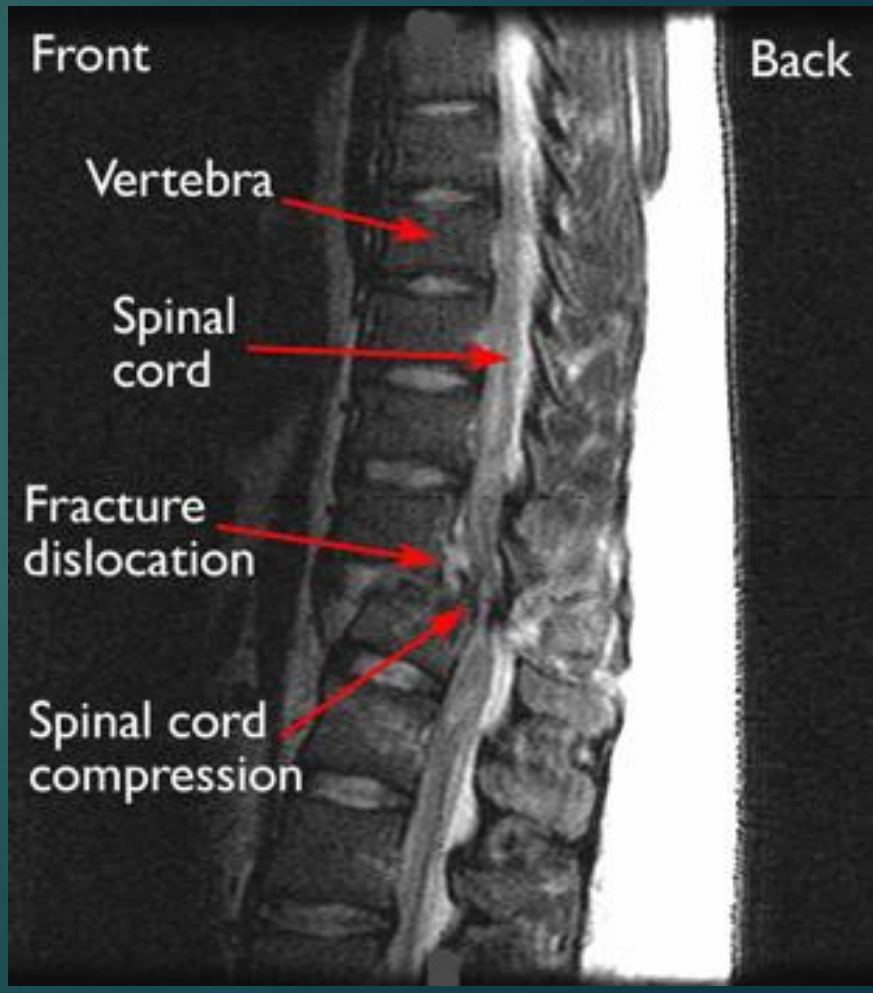
Progressive metastatic disease to bone at MRI.

a. Baseline sagittal T1-weighted MR image of the lumbar spine with a typical normal bone marrow pattern (homogeneous high signal intensity).
b. Three- month follow-up MR image shows appearance of multiple low signal areas corresponding to metastases (arrows).

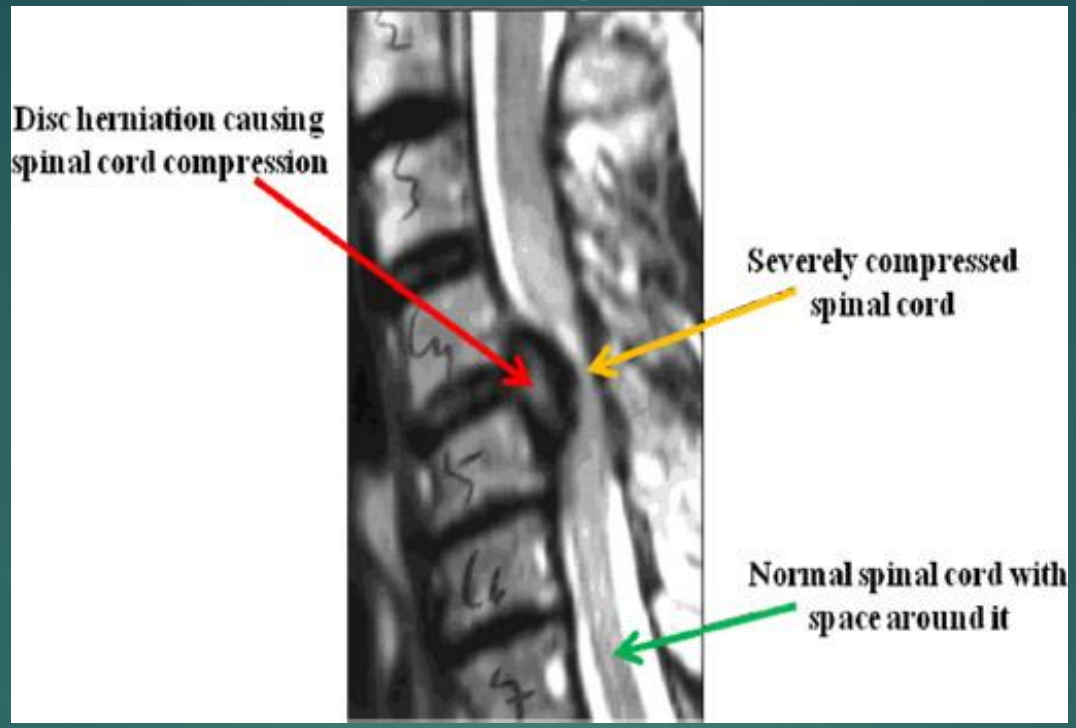


L-spine search pattern

- Cord/Canal
  - Cord normally terminates at L1-2
  - Cord compression
  - Canal hematoma
  - Tumors



Cord compression



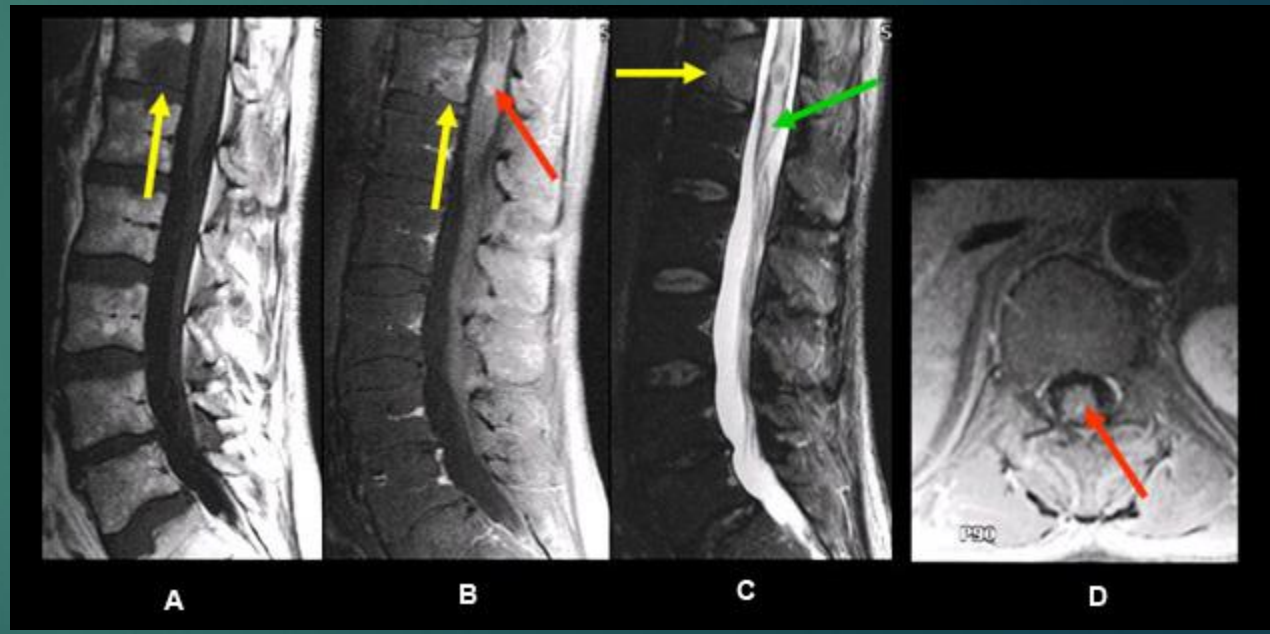
- The spinal cord may be compressed by bone, hematoma, abscesses, tumors, or a ruptured or herniated disk.
- Symptoms can include back pain, abnormal sensations, muscle weakness, or impaired bladder and bowel control.
- Diagnosis based on symptoms and the results of a physical examination and/or magnetic resonance imaging.

…look for cord edema/expansion

- **Cord compression is an emergency**

70 year old male with vertebral body metastasis and intramedullary metastasis from renal cell carcinoma

A.Pre-contrast sagittal T1wtd. MRI of the lumbar spine
    A. bony metastasis (yellow arrow) is seen involving the T12 vertebral body
B.Post-contrast (C+) sagittal T1wtd. MRI
    A. yellow arrow points to the bony metastasis that enhances with contrast
    B. red arrow points to intramedullay location of metastasis within the distal thoracic cord and showing contrast enhancement
C.Sagittal T2 wtd. MRI
    A. green arrow points to edema within the thoracic cord
D.Post-contrast (C+) axial T1wtd. MRI
    A. red arrow points to intramedullary metastasis



Cauda Equina Syndrome

- Definition:
  - Serious neurologic condition in which damage to the cauda equina causes loss of function of the lumbar plexus of the spinal canal below the termination (conus medullaris) of the spinal cord.
- Symptoms:
  - Low back pain, sciatica, leg weakness, saddle hypoesthesia/anesthesia, urinary incontinence or retention, and incontinence of bowel
- Incidence:
  - Cauda equina syndrome is rare with prevalence estimated at approximately 1 in 65,000 (range 33,000 to 100,000)
  - Estimated to occur in ~1% (range 0.1-2%) of herniated lumbar discs

Cauda Equina Syndrome

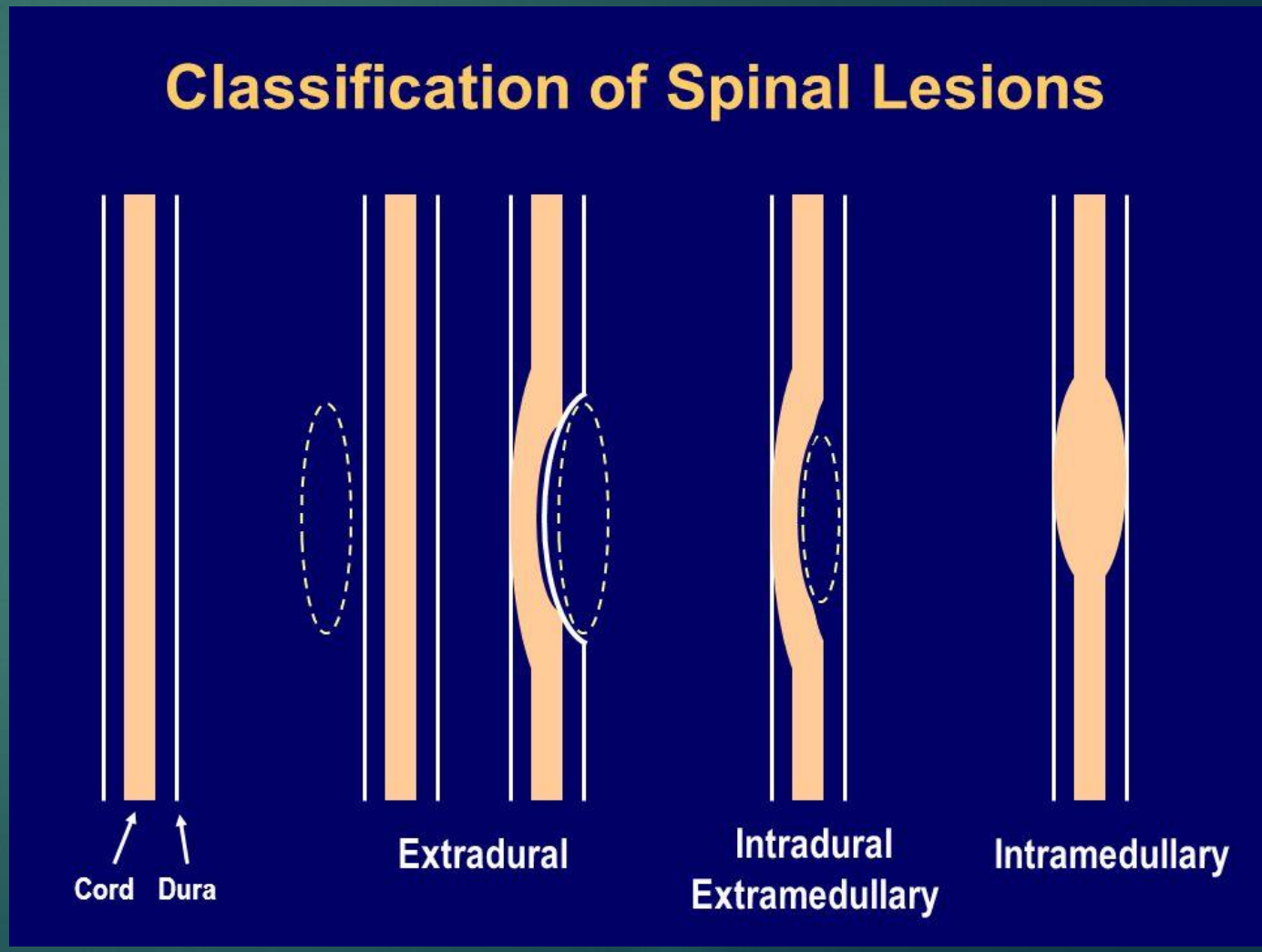
- Partial list of causes of compression:
  - Bone
    - If the vertebrae are fractured, dislocated, or grow abnormally, they may compress the spinal cord.
  - Connective tissue
    - Connective tissue that lines the spinal canal often enlarges and hardens as people age. This change narrows the spinal canal and compresses the spinal cord.
  - Hematoma
    - The most common cause of a spinal hematoma is an injury, but many other conditions can cause hematomas. They include abnormal connections between blood vessels (arteriovenous malformations), tumors, bleeding disorders, and use of anticoagulants or thrombolytic drugs
  - Tumors
    - Cancer that has metastasized to the spine or the epidural space. Rarely, a tumor within the spinal cord causes compression.
  - Abscess
    - May accumulate outside the spinal cord and compress it.
  - Ruptured or herniated disk
    - Most common cause
    - A herniated disk can compress spinal nerve roots or the spinal cord itself

Cauda Equina Syndrome

- Imaging:
  - Plain radiograph
    - limited value; may demonstrate gross degenerative or traumatic bony disease
  - CT myelogram
    - useful in patients in whom MRI is contraindicated or not available
    - Shows partial or complete blockage of contrast
    - May demonstrate an "hourglass" shape to the contrast-filled thecal sac in complete blockage
  - MRI
    - imaging modality of choice
    - sagittal and axial T1 and T2 sequences are usually sufficient
    - post-contrast and STIR sequences may be required if infective causes are suspected
  - Treatment and prognosis
    - Cauda equina syndrome is considered a diagnostic and surgical emergency although there is some debate about timing of surgery (and depends on acute vs. chronic) but surgical decompression within 24 hours seem to have the best outcomes

Spinal Cord/Canal Tumors

- Extradural
- Intradural / Extramedullary
- IntraMedullary



Spinal Cord/Canal Tumors

- Extradural
  - Outside the thecal sac

Spinal Cord/Canal Tumors

- Intradural / Extramedullary
  - Within thecal sac
    - But outside the cord

Spinal Cord/Canal Tumors

- IntraMedullary
  - Within the cord

Spinal Cord/Canal Tumors

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    - limited value; may demonstrate gross degenerative or traumatic bony disease
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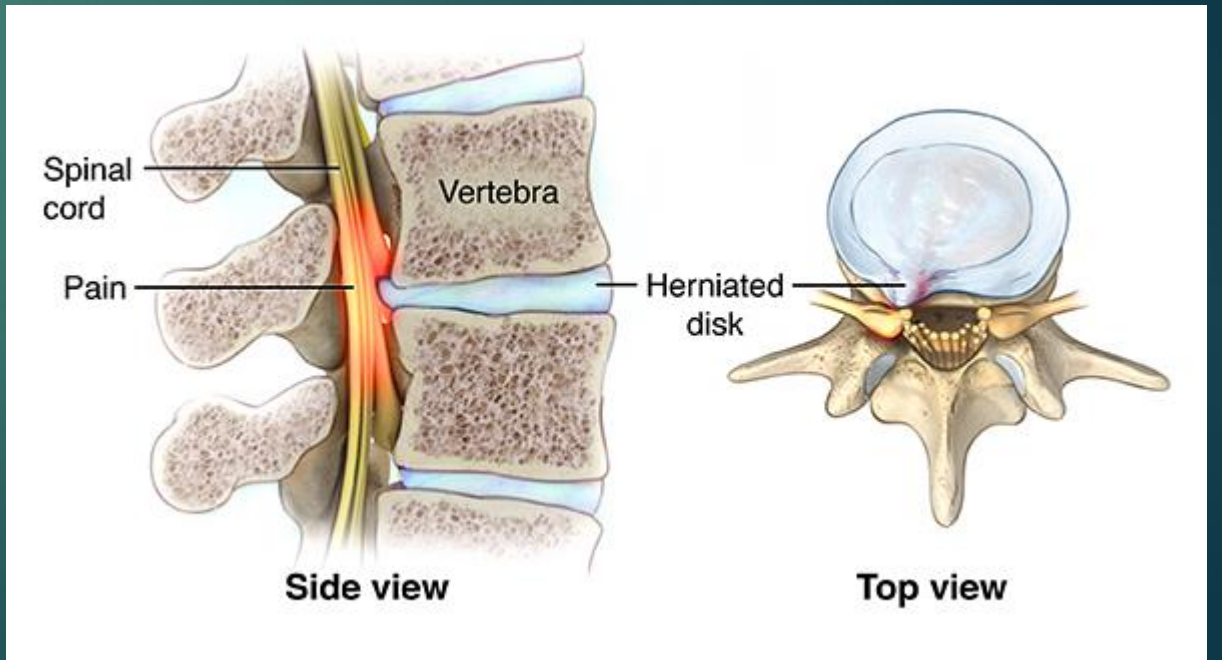
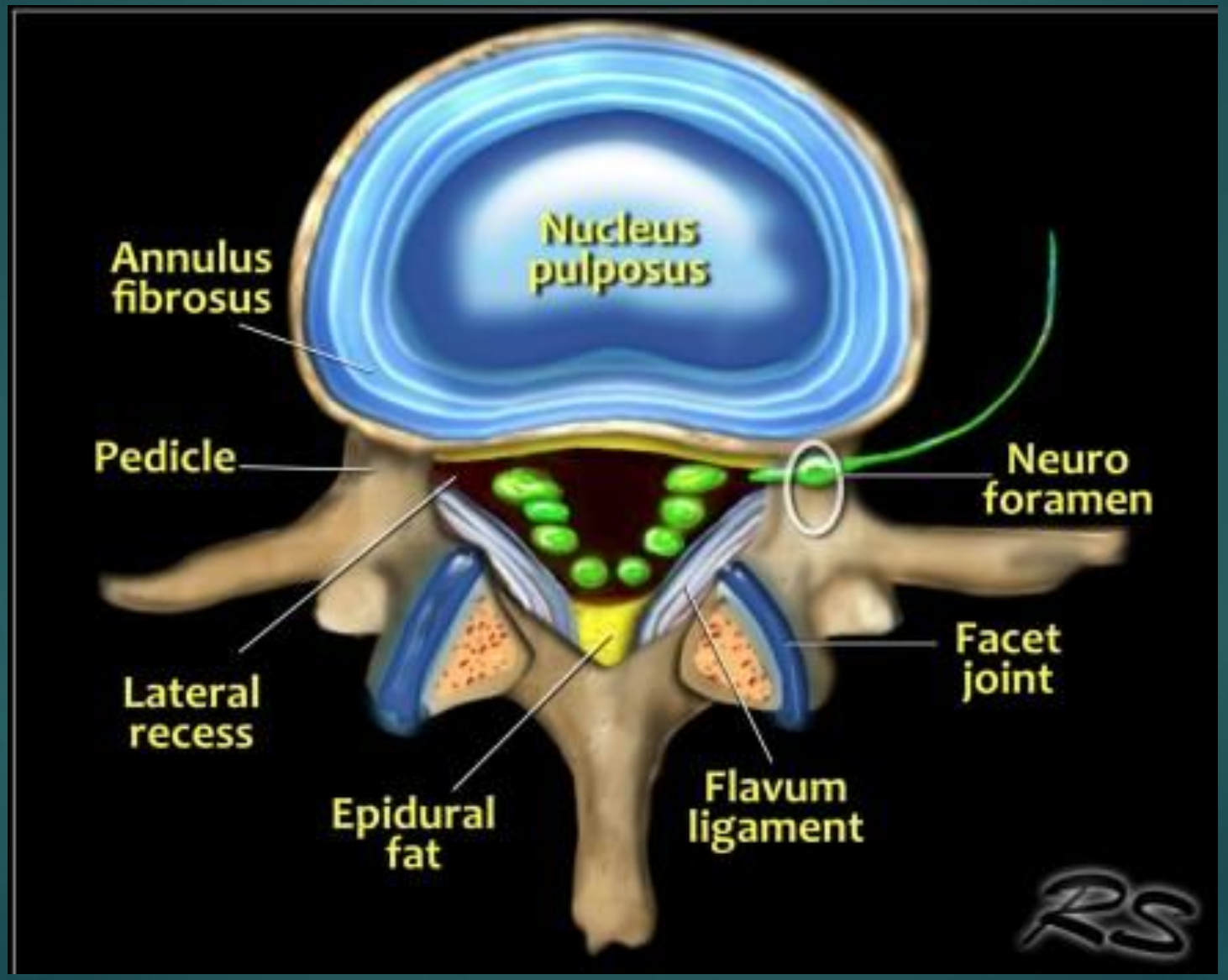
L-spine search pattern

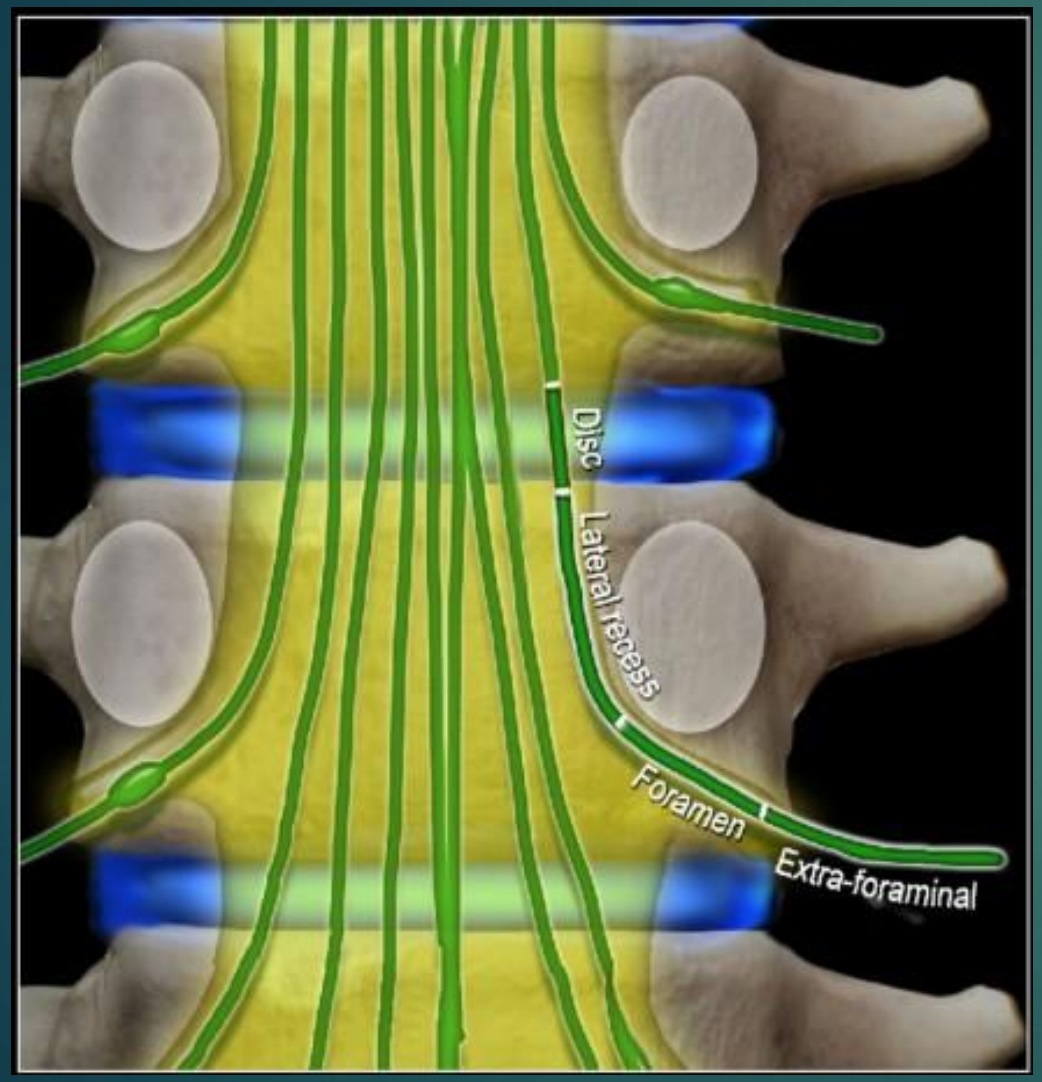
- Discs
  - Height loss
  - Bulge/protrusion
  - Discitis



Anatomy


Annulus fibrosus
Nucleus pulposus
Pedicle
Neuro foramen
Lateral recess
Facet joint
Epidural fat
Flavum ligament
RS

Anatomy

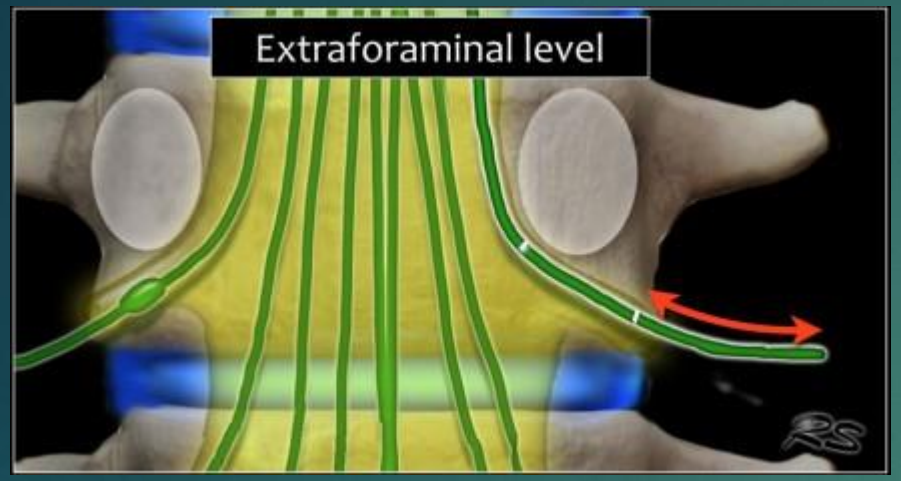


Four levels of nerve compression

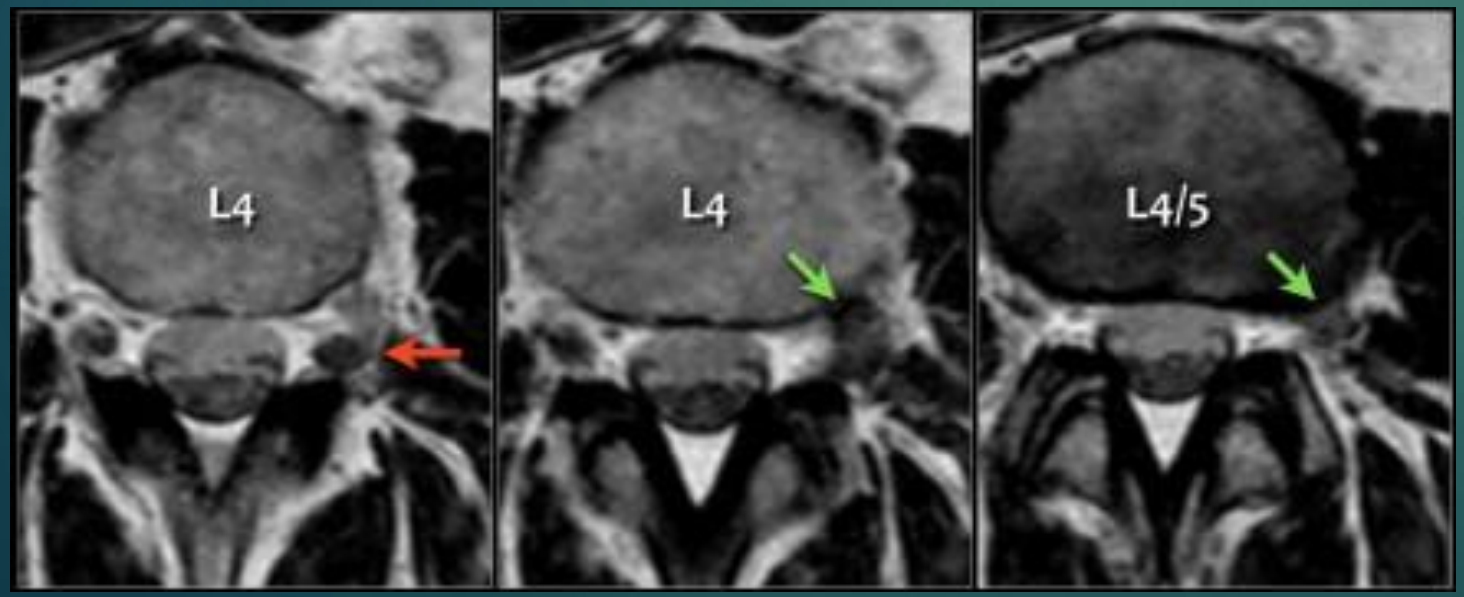
In patients with symptoms of nerve root compression, there are four levels that need to be studied:

- Disc level
  - This is the most common area where nerves are compressed.
  - Mostly by herniated discs and less frequently due to spinal stenosis.
- Level of lateral recess
  - This is the area below the disc where the nerve runs more laterally towards the foramen.
  - Narrowing of the lateral recess is caused by facet arthrosis, usually in combination with hypertrophy of the flavum ligament and bulging of the disc.
- Foramen
  - This is the area between two pedicles, where the nerve leaves the spinal canal.
  - Narrowing of the foramen is seen in facet arthrosis, spondylolisthesis and foraminal disc herniation - usually a migrated disc from a lower level.
- Extra-foraminal
  - This is the area lateral to the foramen.
  - Nerve compression in this area is uncommon, but is sometimes caused by a laterally herniated disc.

Anatomy



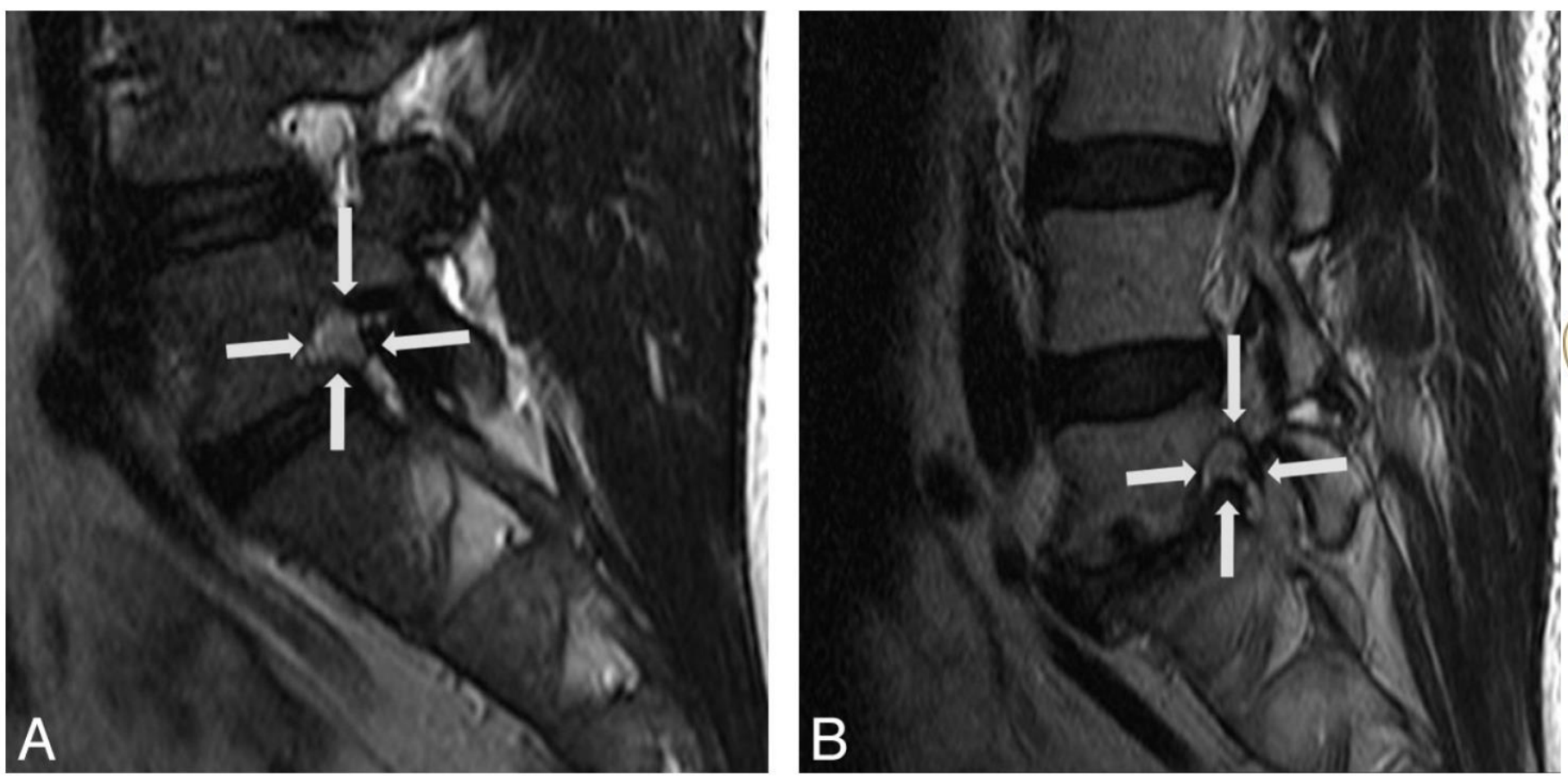
Extraforaminal nerve compression is seen in about 5% of cases. Almost always it is a lateral disc herniation from a lower level that compresses the extraforaminal part of the nerve.

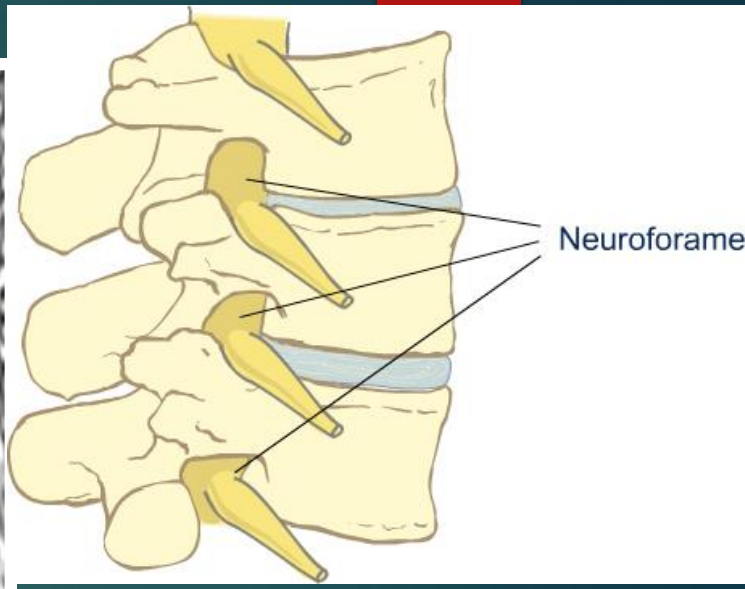


Here an example of a lateral disc herniation that produces compression of the superiorly exiting nerve root and ganglion.

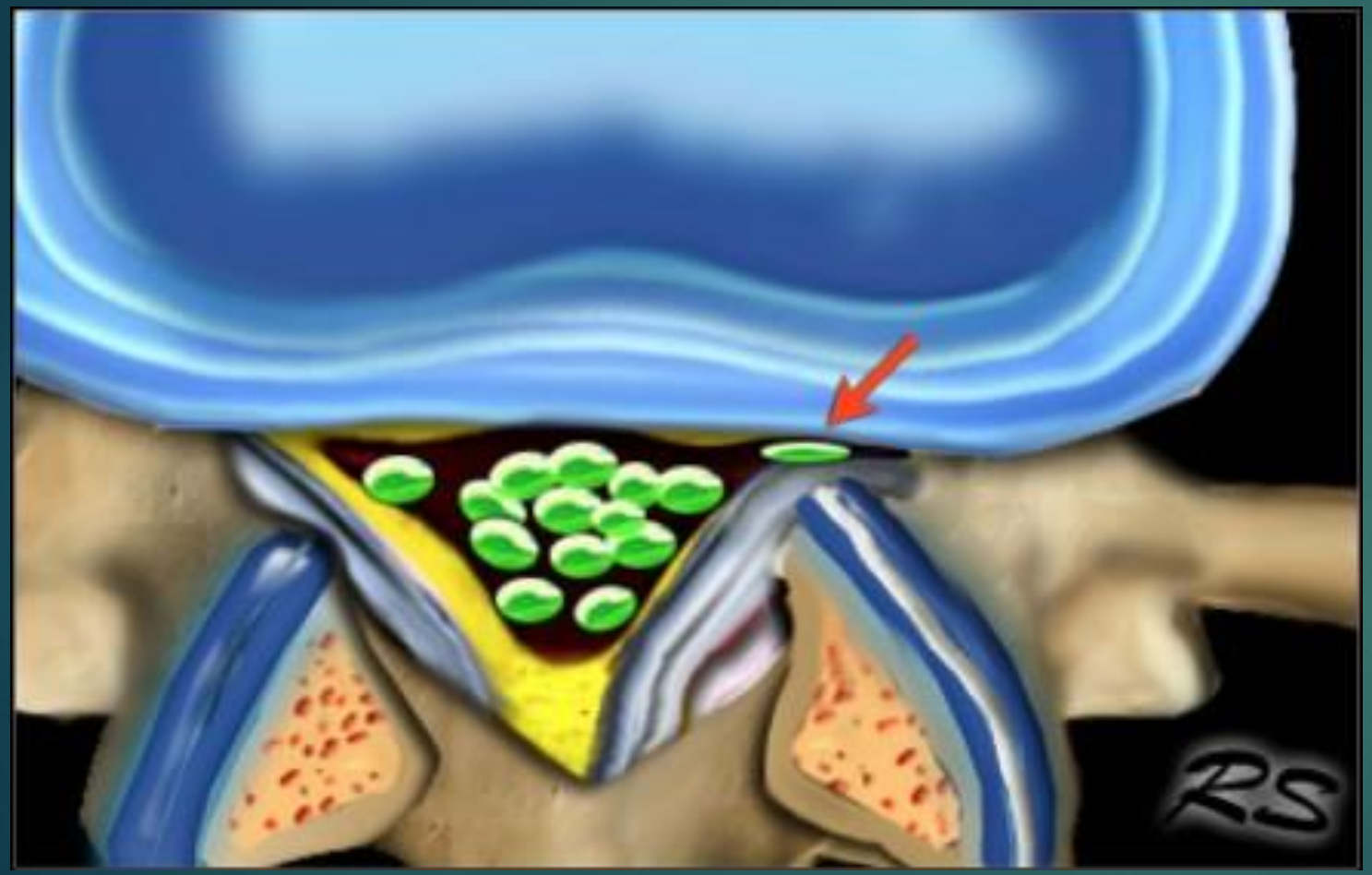
Notice the L4 nerve (red arrow), which is being displaced posteriorly by a lateral disc herniation at the L4-5 level (green arrow).

Anatomy – Neuroforamen



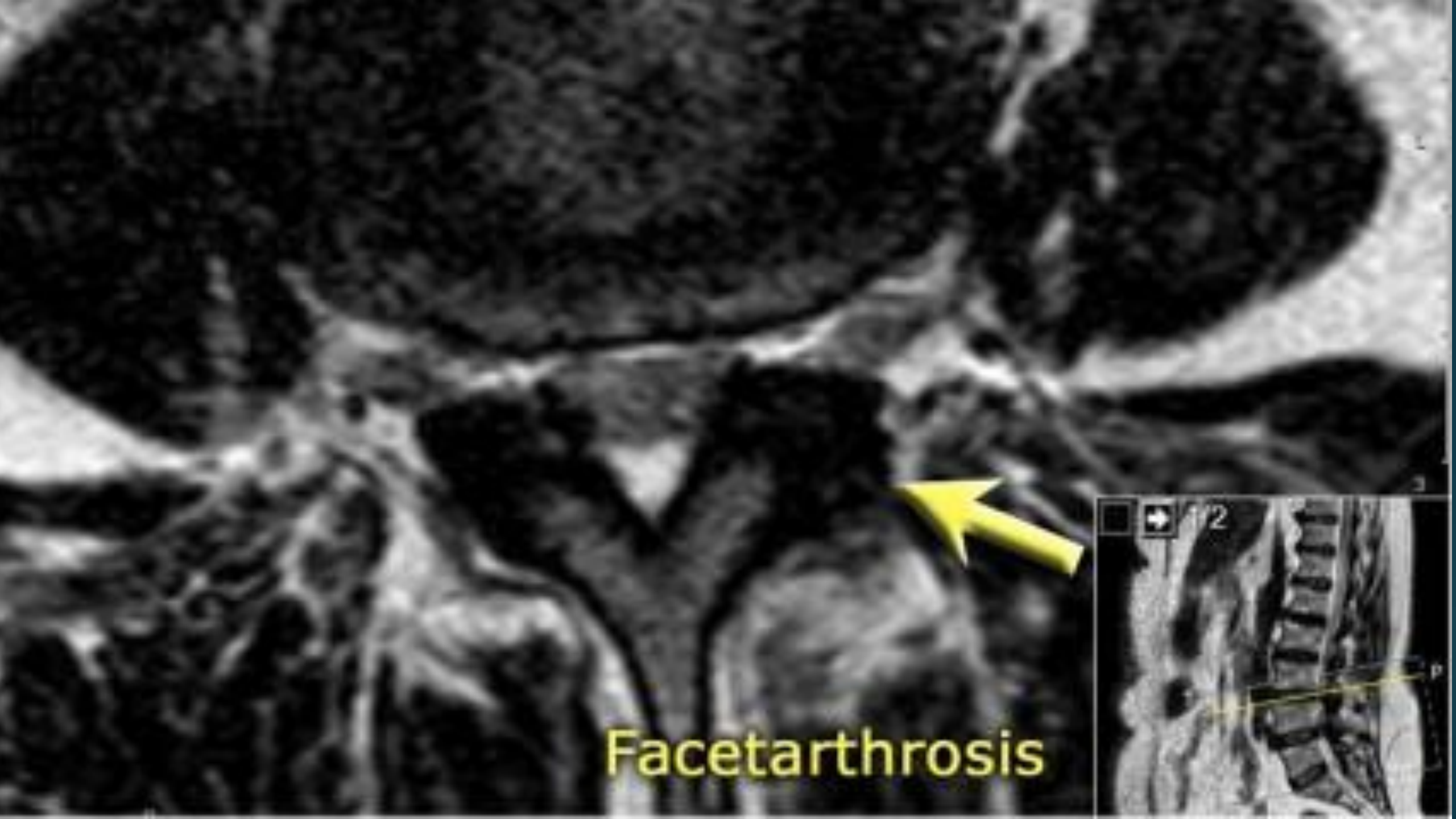


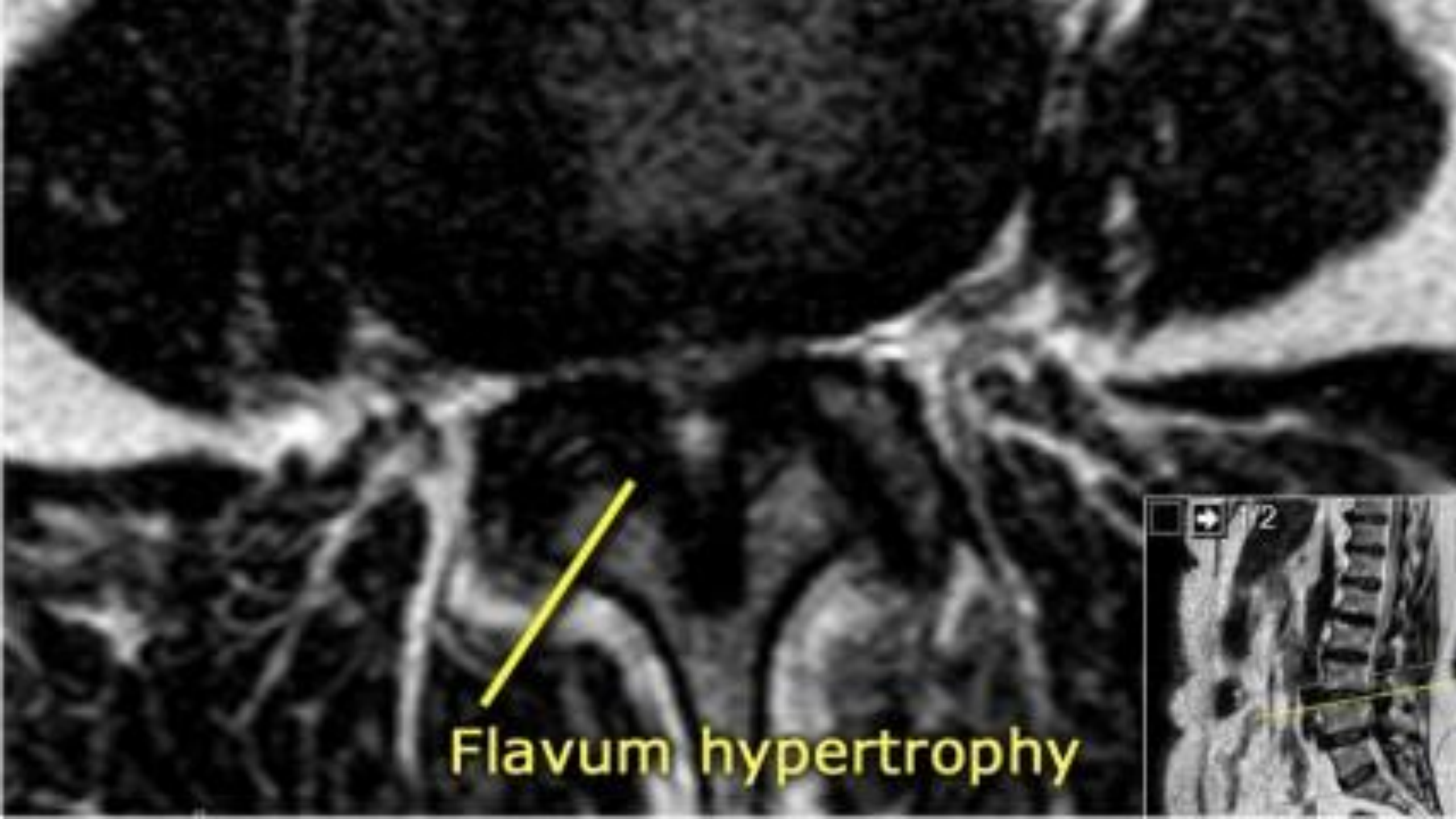
Anatomy – Lateral Recess

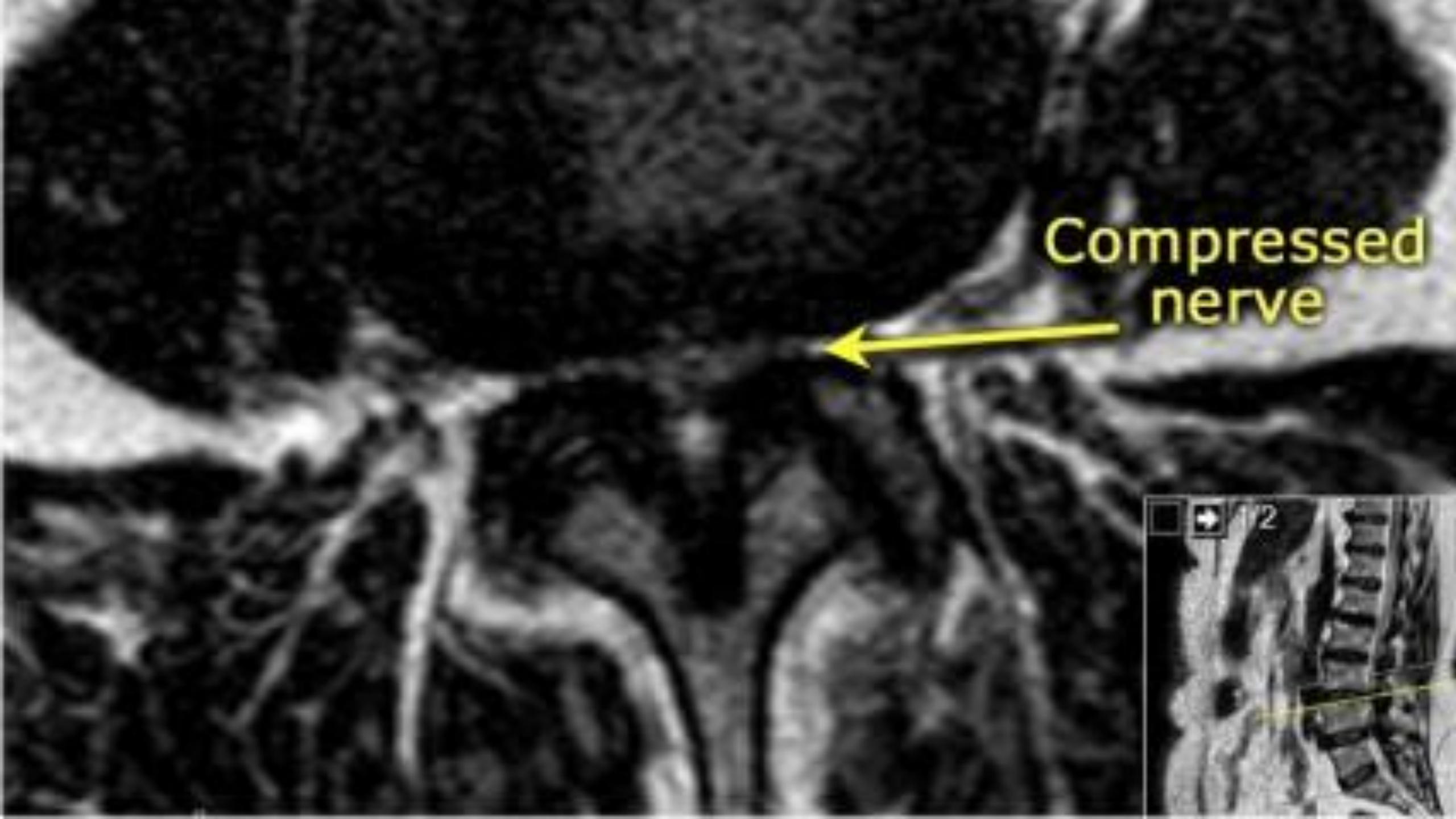


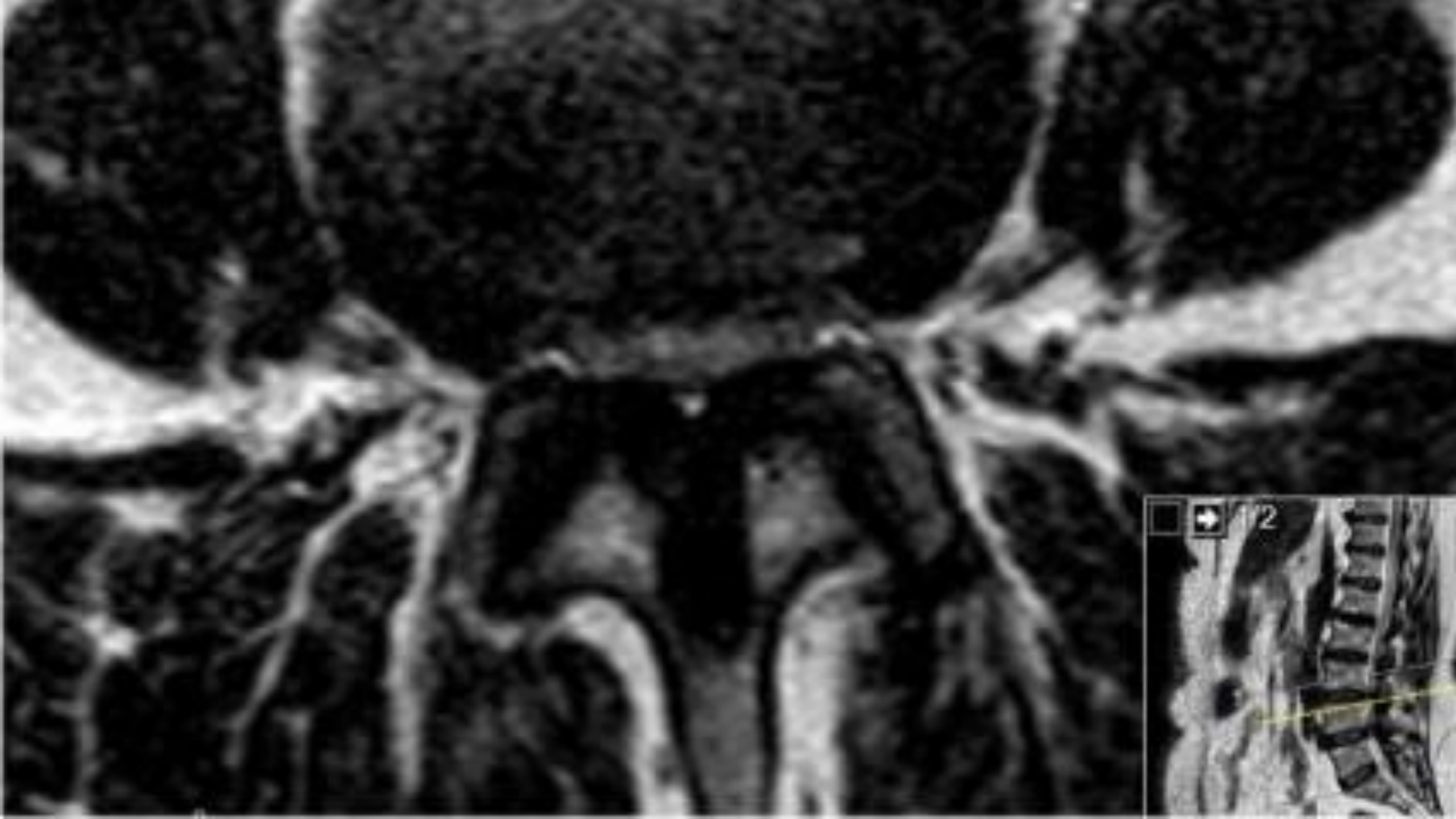
Stenosis of the lateral recess is a common problem especially in older patients.

The stability of the vertebral column decreases, which results in instability. This results in hypertrophy of the facet joints and arthrosis, bulging of the disc and more stress on the flavum ligament resulting in hypertrophy.
All these mechanisms lead to stenosis of the lateral recess (figure).
In advances cases of arthrosis a synovial cyst may form, which contributes to the narrowing.

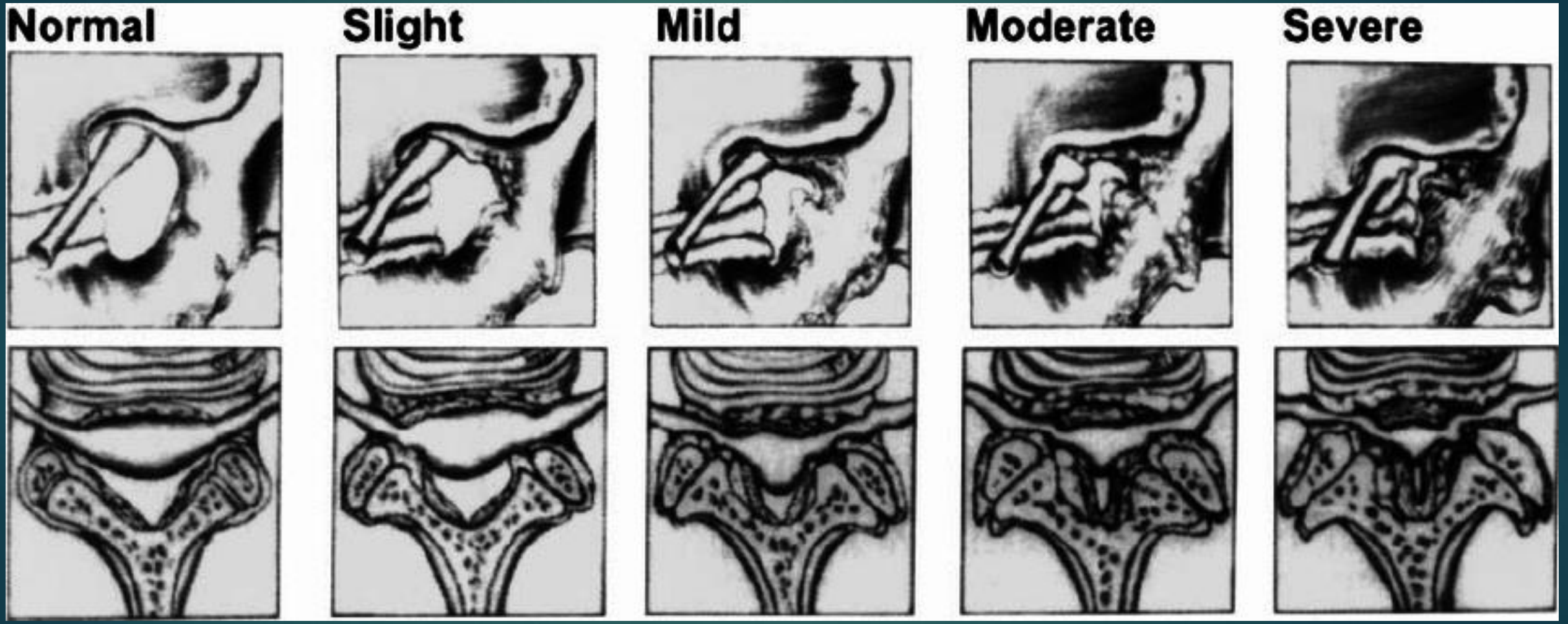

Facetarthrosis

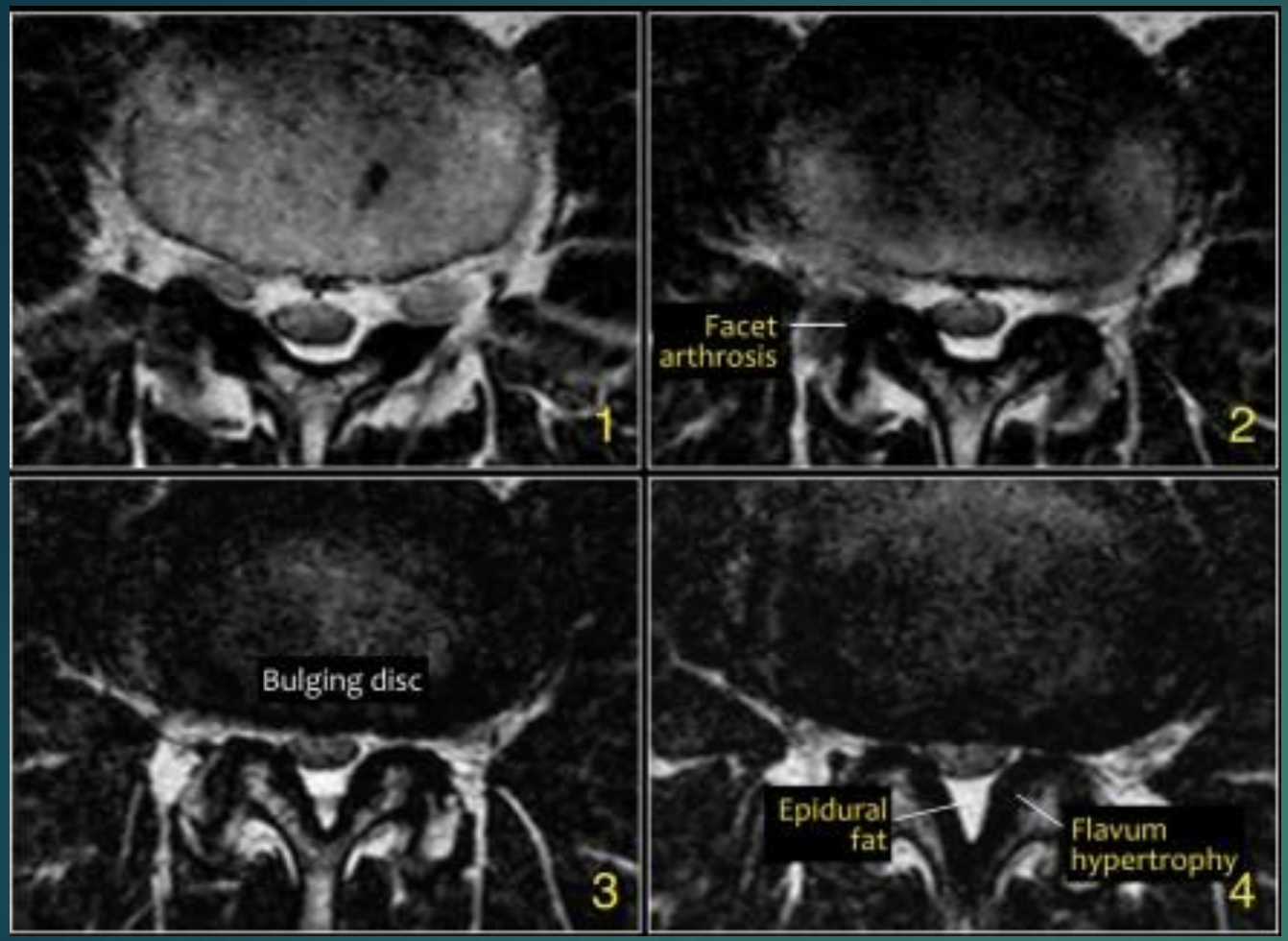

Flavum hypertrophy
T2

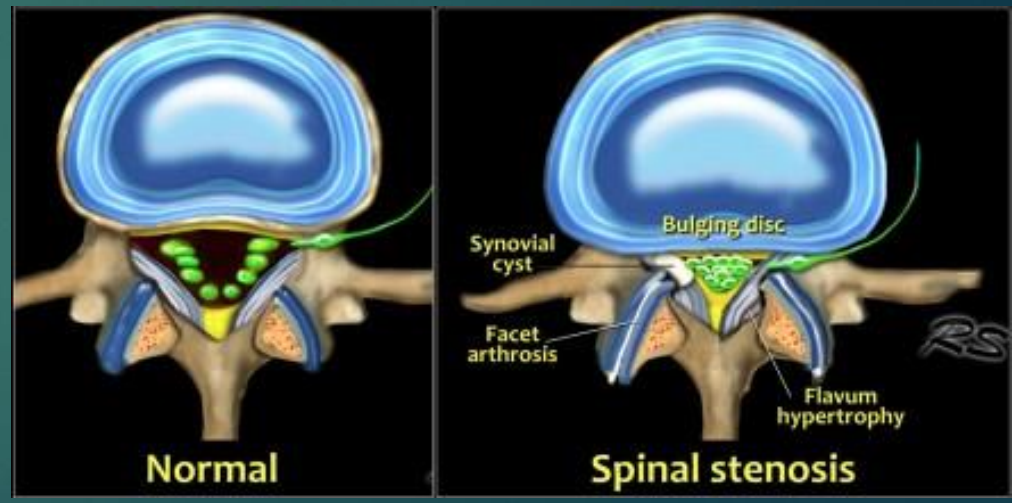

Compressed
nerve


T2

Grading Spinal Canal Stenosis



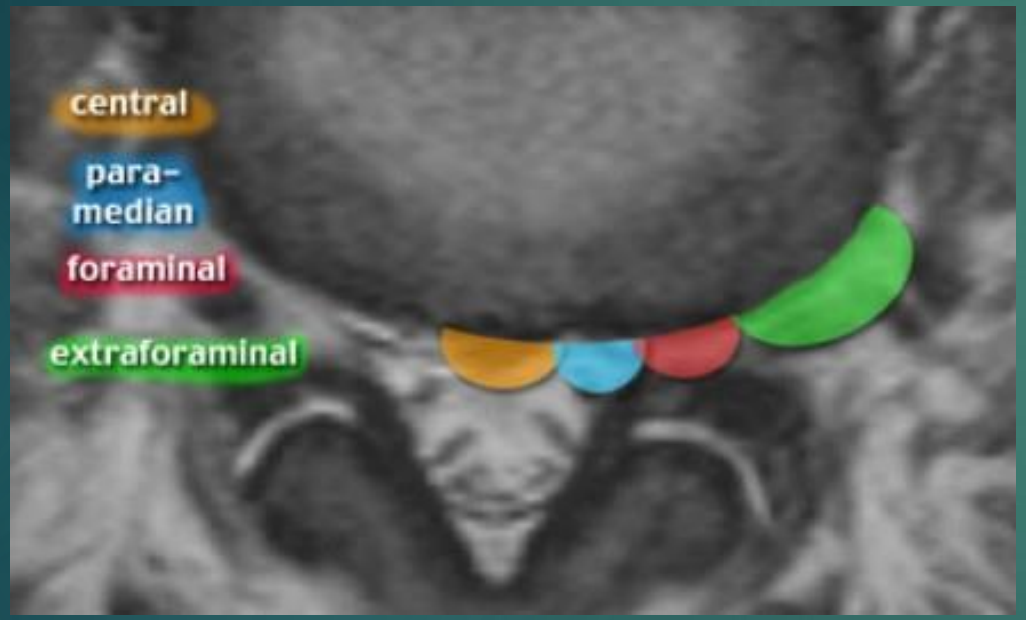




On the axial T2W-images you can see, that there is no CSF visible surrounding the nerve roots.
This means that there is a severe spinal stenosis.
The epidural fat compresses the nerves from posteriorly.


Normal Disc
Degenerative Disc
Bulging Disc
Herniated Disc
Thinning Disc
Disc Degeneration with
Osteophyte Formation

Herniated disc: Location

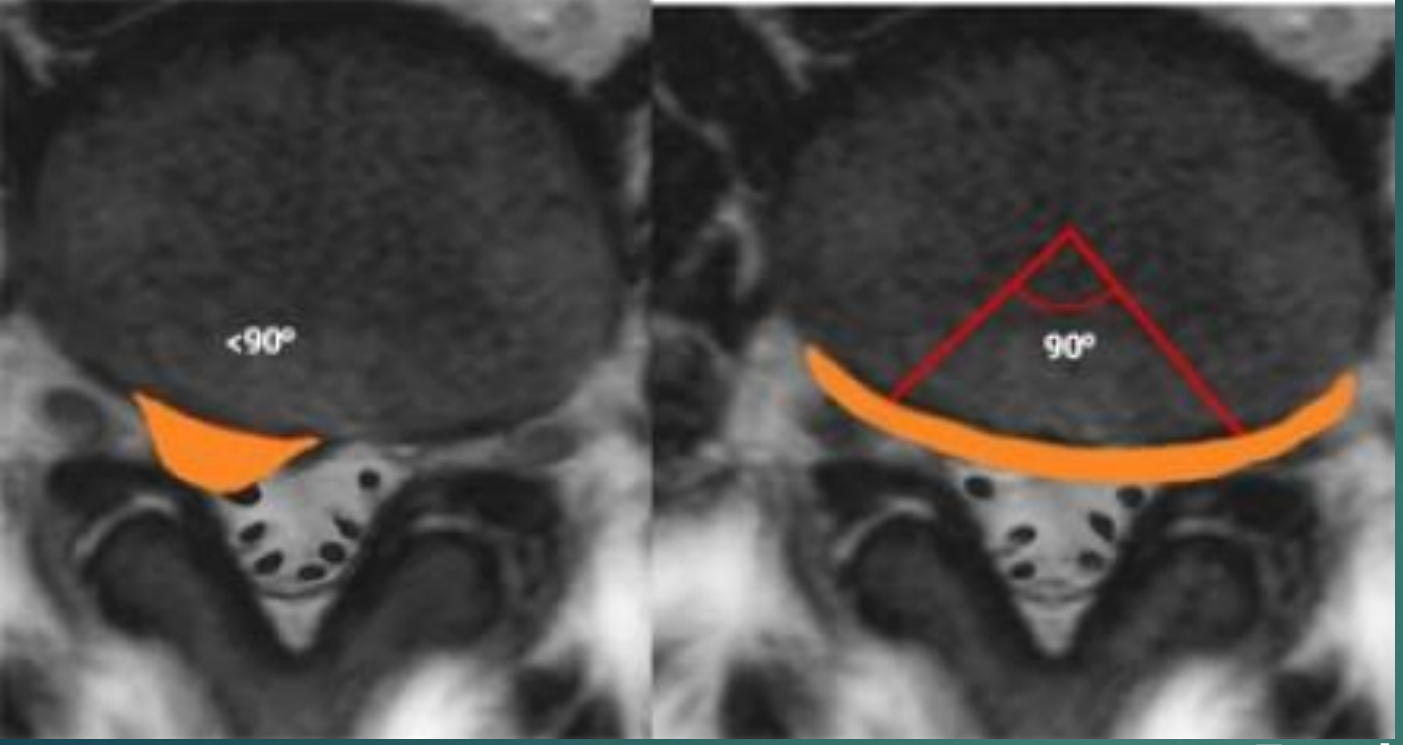


Central or medial (orange). Since the PLL (posterior longitudinal ligament) is at its thickest in this region, the disc usually herniates slightly to the left or right of this central zone.

Paramedian or paracentral or lateral recess (blue). Because the PLL is not as thick in this region, this is the number one region for disc herniations to occur in.

Foraminal or subarticular (red). It is rare for a disc to herniate into the intervertebral foramen. Only 5% to 10% of all disc herniation occur here or farther out.
When herniations do occur in this zone, they are often very troublesome for the patient.
This is because a super-delicate neural structure called the 'Dorsal Root Ganglion' (DRG) lives in this zone resulting in severe pain, sciatica and nerve cell damage.

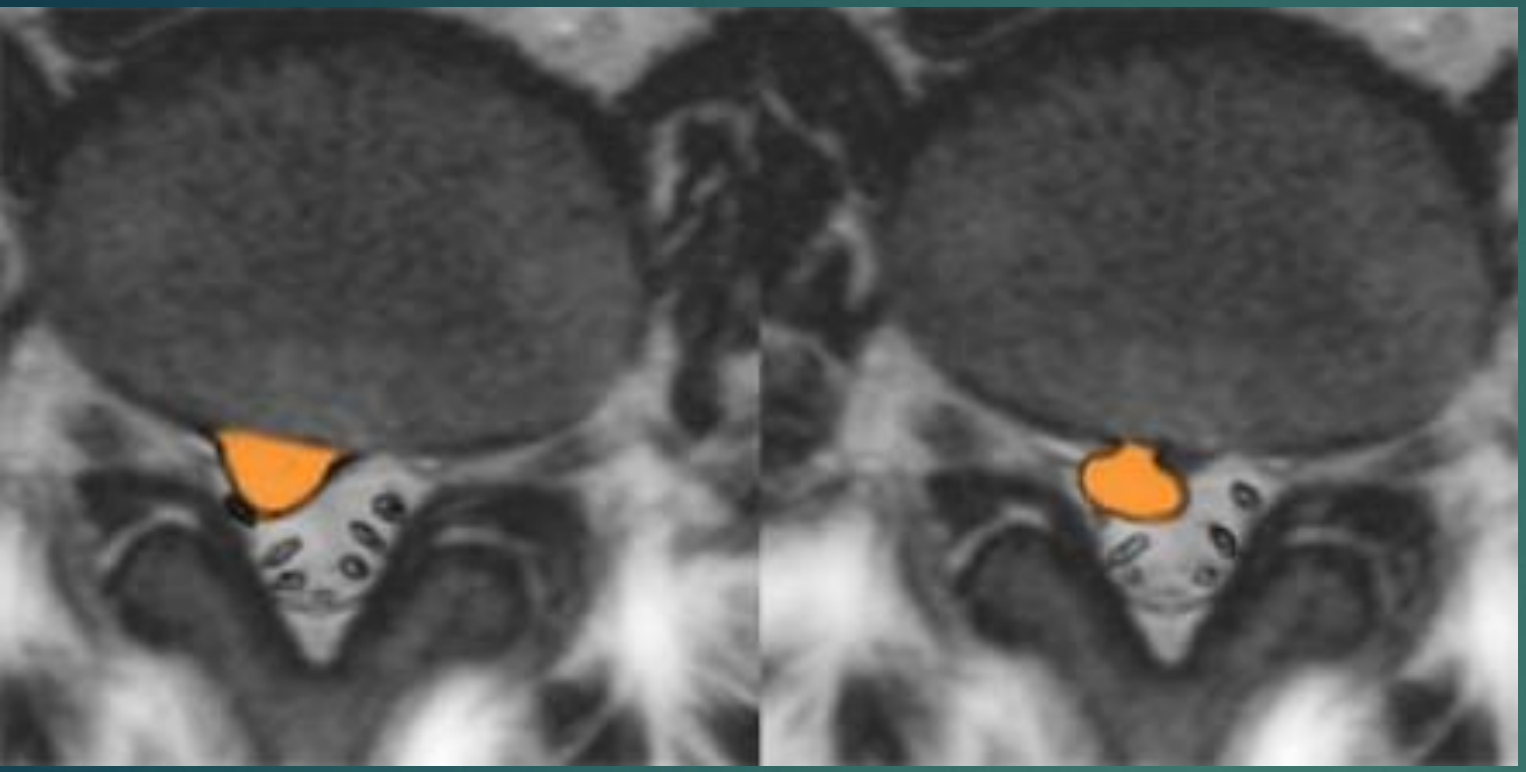
Extraforaminal or lateral (green).
Disc herniations in this region are uncommon.



Focal herniation is a herniated disc less than 90º of the disc circumference.

Broadbased herniation is a herniated disc in between 90º-180º of the disc circumference.

Bulging Disc is the presence of disc tissue 'circumferentially' (180º-360º) beyond the edges of the ring apophyses and is not considered a form of herniation.
The nucleus pulposus is covered by the intact annulus fibrosus.



Protrusion indicates that the distance between the edges of the disc herniation is less than the distance between the edges of the base.

Extrusion is present when the distance between the edges of the disc material is greater than the distance at the base

Migration indicates displacement of disc material away from the site of extrusion, regardless of whether sequestrated or not.

Sequestration is used to indicate that the displaced disc material has lost completely any continuity with the parent disc

Degenerative Disc Disease

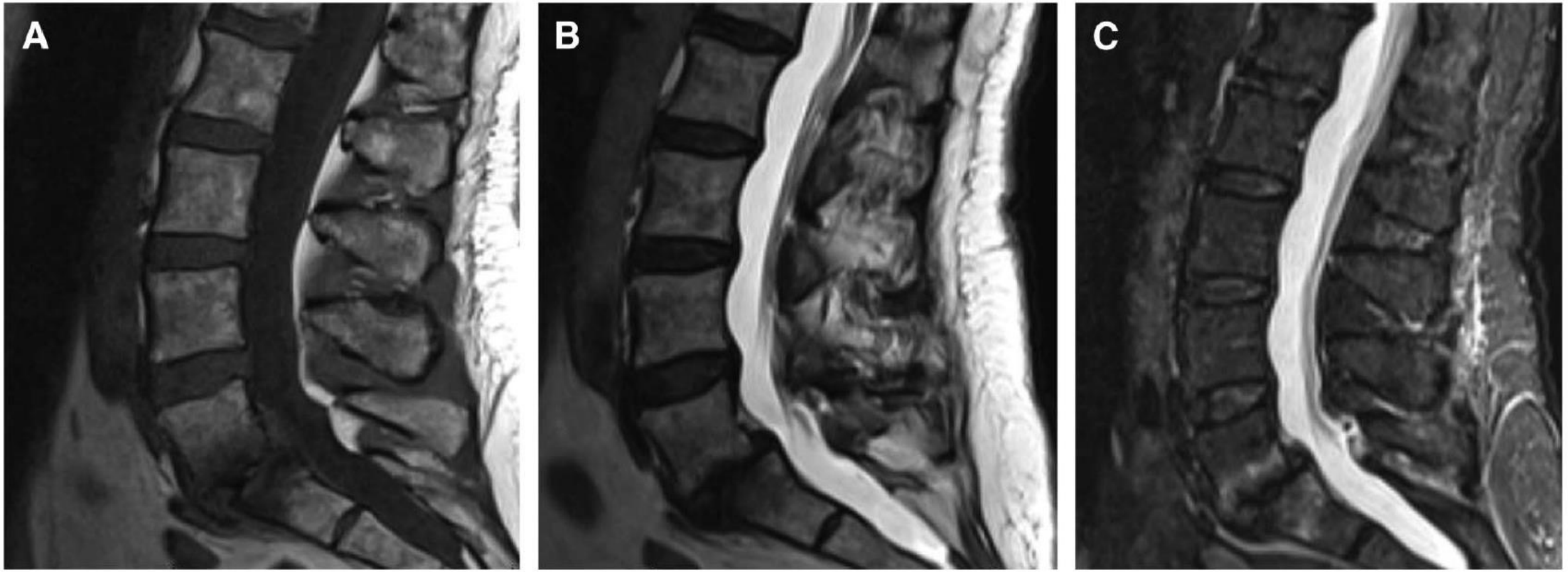


FIGURE 3. *Sagittal (A) T1-weighted, (B) T2-weighted, and (C) STIR images of the lumbar spine exhibit type 1 fibrovascular endplates changes at L5-S1 with hypointense T1, heterogeneously hyperintense T2, and hyperintense STIR signal intensities.*

Discitis / Osteomyelitis

- Symptoms of spondylodiscitis are non-specific
  - Back or neck pain is very common
    - But up to 15% of patients may be pain-free
  - Fever is less commonly experienced and occurs in only about half of patients
- *Staphylococcus aureus* is the predominant pathogen, accounting for about half of non-tuberculous cases
- Predisposing factors
  - Diabetes mellitus is the most commonly identified risk factor
  - Advanced age, injecting drug use, immunosuppression, malignancy, renal failure, rheumatological disease, liver cirrhosis and previous spinal surgery

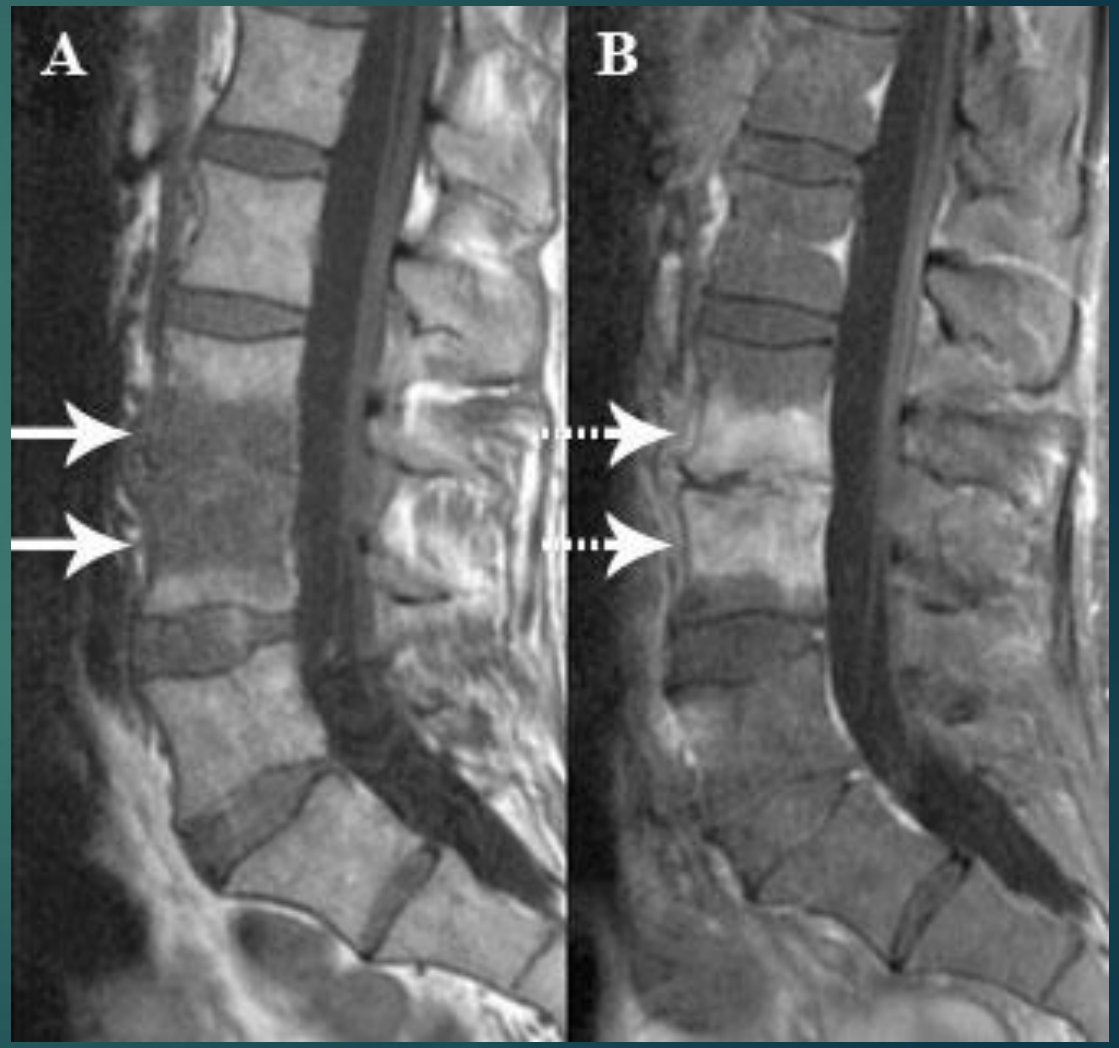
Discitis / Osteomyelitis: work-up

- Complete neurologic examination
- Laboratory evaluation
  - CBC, ESR, BMP, UA/UC, blood cultures.
- Stat imaging of the spine
  - Ideally within 2 hours if abnormal neurological findings
    - or within 6 hours if normal neurological findings
  - MRI with and without contrast of the complete spine is the ideal imaging study
    - Omit contrast if contrast would delay imaging
  - If MRI is not possible (e.g., because of body habitus, implanted device, etc.)
    - Then a stat CT myelogram should be performed
  - If CT myelogram not possible
    - then CT with contrast of the complete spine should be performed
- Biopsy
  - If there is evidence of VO on imaging and negative blood culture, then urgent/emergent biopsy by neuroradiology using imaging guidance within 24 hours

Discitis / Osteomyelitis

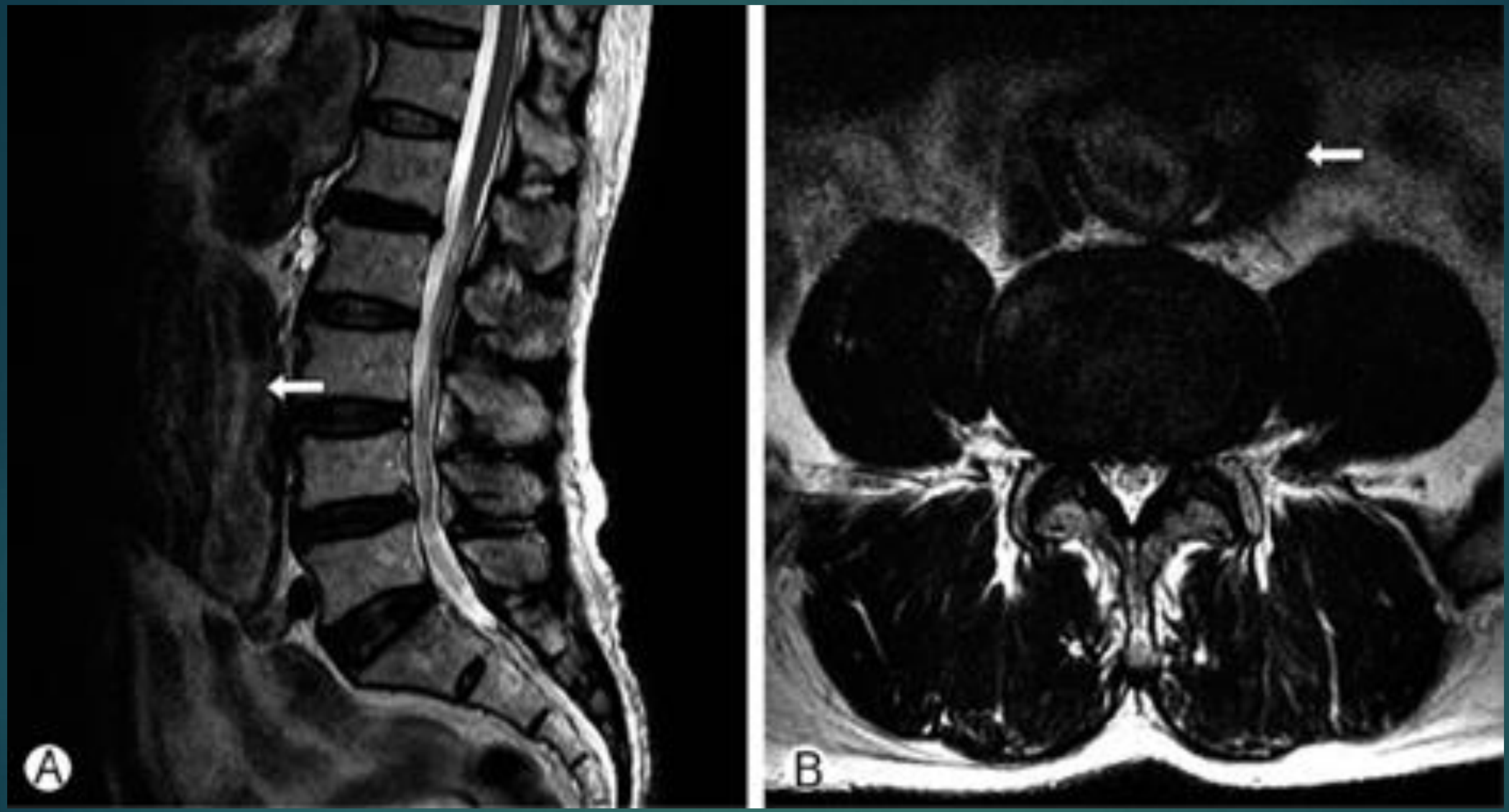
MRI of lumbar spine discitis/osteomyelitis.

A. Sagittal T1-weighted images of the lumbar spine in the same patient as figure 1 demonstrate T1-hypointense signal (solid arrows) centered around the L3-4 interspace.
B. B. Post gadolinium sagittal fat-suppressed T1-weighted images shows marrow (dashed arrows) and disc enhancement with endplate erosions.



L-spine search pattern

- Everything else
  - Soft tissues
  - Intra-abdominal structures (aorta, kidneys, liver, adrenals, etc)



Don’t miss the incidental Abdominal Aortic Aneurysm!!

REVIEW: L-spine search pattern

- Alignment
- Bone
- Cord/Canal
- Discs
- Everything else

REVIEW: L-spine search pattern

- Alignment - anterior and posterior portion of vertebral bodies, facets, posterior spinal canal line, spinous processes
- Bone - fractures, vertebral body compression, blastic/lytic lesions
- Cord/Canal - cord compression, canal hematoma, terminates at L1-2
- Discs - height loss, bulge/protrusion
- Everything else - soft tissues, thyroid, aorta, pneumothorax, kidneys, liver, adrenals, etc

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