Systematic Interpretation of Lumbar MRI

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1. Image Orientation

1. ***Sagittal Images*** – Lengthwise view, Anterior to Posterior
   Sequences Right ➔ Center ➔ Left, or Left ➔ Center ➔ Right (no consistency)
2. ***Axial Images*** – Cross section of spine
   Patient's feet are towards you so left side of patients is always on the right of the image.
   Films arranged superior to inferior or inferior to superior.
   Most will be continuous slices. Some will be focal slices only through discs.
3. ***Coronal*** – Lengthwise views, Right to Left orientation (Uncommon)

II. MRI Image Type

Identify image type quickly by looking at CSF and Spinal Cord.

T1 ➔ CSF Dark – Cord Gray
T2 ➔ CSF Bright – Cord Dark
Fat Suppressed T2 ➔ Same as T2 plus Vertebrae dark
Intermediate T2 ➔ CSF Light Gray – Cord Light Gray
Gadolinium T1 ➔ CSF Dark – Cord Gray – Labeled or marker C+

Table 1. Relative signal intensities of body tissues on different image types

T1	*Bright:* gray: dark: variable:	*adipose tissue* cartilage, tumor, abscesses, hyaline cartilage, CSF, muscle, bone, tendon, ligament, fibrocartilage, gas hemorrhage
T2	*Bright:* gray: dark: variable:	*water, abscesses, occasionally non-neoplastic tumor* hyaline cartilage, muscle, cartilage, tumor bone, tendons, ligaments, fibrocartilage, water, gas, occasionally neoplastic tumor
Intermediate T2	*Very dark:*	*ligaments, cartilage*
Gadolinium-Enhanced T1	*Bright:*	*Areas of increased vascularity (vascular malformations, inflammation, tumors, scar tissue)*

MRI EXAMINATION QUICK REFERENCE SHEET

STEP (1) Verify patient identification, date of scan

STEP (2) Sort Films T1 & T2 Sagittal, T1 and T2 Axial, others

STEP (3) <u>T1 sagittals</u> (spinal fluid is dark and fat is bright)
Determine left-right orientation. May not be labeled. On left, aorta gives off branches at ~L1; On right, renal artery runs posterior to Inferior Vena Cava. Aorta has anterior branching arteries.
Working from outside to inside, caudal to rostral observe:
Neural foramina and nerve roots: Observe for compression
Intervertebral discs: width, protrusions/ herniations
Spinal column: alignment (spondylolisthesis), vertebral body shape (compression fractures, Schmorls' nodes), posterior bony elements (spondylolysis), degenerative end plate changes (changes in fat content), hemangiomas.
Retroperitoneal space: adenopathy, masses, great vessel aneurysm, etc

STEP (4) <u>T2 sagittals</u> (spinal fluid is bright)
Working from caudal to rostral observe:
Dural sac—cord and rootlets: width, compression, irregularities
Intervertebral discs: width, protrusions/ herniations, hydration, high intensity zones
Spinal column: alignment (spondylolisthesis), vertebral body shape (compression fractures, Schmorls' nodes), posterior bony elements (spondylolysis), degenerative end plate changes (changes in fat content), hemangiomas.
Posterior bony elements: facet joints effusions, etc.

STEP (5) <u>Intermediate +/or Fat Saturated T2 Sagittals</u>

STEP (6) <u>T1 Axials</u> (CSF appears gray and fat appears bright) Proceed sacral to rostral
Orientation – neural foramina lie at level of discs.
Content of the spinal canal and neural foramina: Trace course of nerve roots through neural foramina
Intervertebral discs— continuity, bulges, etc.
Bone – Vertebral bodies; spondylolisthesis, posterior bony elements (spondylolysis, breakage)
Ligamentam flavum: thickened appearance, impingement
Retroperitoneal space: adenopathy, masses, muscle, etc.

STEP (7) <u>T2 Axials</u> (spinal fluid appears bright) Work from sacrum to rostral
Content of the spinal canal and neural foramina: Trace course of nerve roots through neural foramina
Intervertebral discs— continuity, bulges, etc.
Bone – Vertebral bodies; spondylolisthesis, posterior bony elements (spondylolysis, breakage)
Ligamentam flavum: thickened appearance, impingement
Retroperitoneal space: adenopathy, masses, muscle, etc.

STEP (8) <u>Gadolinium Enhanced T1 images</u> (Marked C+ or with sticker)
Evaluate level of prior surgery for enhancement
May reveal enhancement around inflammation, neoplasms, fractures

STEP (9) Assessment and Plan
Assessment: Summarize your findings. Compare with radiologist report.
Plan: Patient care plan.

Systematic Analysis of Lumbar MRI

Step 1. Identify subject's <u>NAME</u> and <u>DATE</u> of MRI

Step 2. Sort films.

Sagittal T1
Sagittal T2
Other Sagittal Intermediate T2, Fat suppressed T2, Gadolinium enhanced T1
Axial T1
Axial T2
Other Axial – Gadolinium enhanced T1

Step 3. T1 Sagittal Analysis

Determine right-left orientation. Sagittal images are presented as slices beginning on one side of the spine and move sequentially through the mid-spine to the other side. Knowing which side is right or left is therefore essential. This is often labeled as the slice locator printed on each image (e.g. "R 12.5", "R10.0", "R7.5"…"L7.5", "L10.0", "L12.5") or through numbered labeling based on a scout axial or coronal image. If labeling is not evident, simply recall that the aorta lies on the left and the inferior vena cava (IVC) runs on the right side of the anterior vertebral body. The aorta is recognizable by its greater width and also by the superior mesenteric and celiac arteries branching anteriorly at about the T12/L1 levels. The IVC can be recognized by the right renal artery that slips between it and the vertebral column near the L1 level

Neural foramina and nerve roots: A normal foramen should appear bright and peanut-shaped due to the fat within it, and the nerve root as a gray round spot within the fat at the superior aspect of the foramen. Deformity of the neuroforamen is evident when the fat is displaced. This is often caused by disc material extending beyond it normal boundary or alteration of the surrounding bone structures. You may need to scan two or three adjacent slices to ensure that the foramen is indeed patent throughout its width. Start with the L5 – S1 neural foramina, then move to the more rostral neuroforamina (L4-L5, L3-4, L2-3, L1-2). Once you have completed this on one side, repeat this on the opposite side of the spine.

Intervertebral discs, spinal canal, dural sac:

Intervertebral discs – Look in turn for the following:

Disc width – reduction in disc width can provide a clue about degeneration

Disc protrusions/ herniations – Posterior extension of disc material (intermediate signal) beyond its normal margin can often be visualized if it displaces the epidural fat (bright) in the spinal canal or neuroforamina. As disc material and CSF can appear similar, detection of central disc herniations can be difficult.

Spinal column:

Vertebral body alignment– Inspection of mid sagittal cuts will demonstrate misalignment from spondylolisthesis if present. In cases of lumbar scoliosis, the spinal canal comes in and out of view on different slices at the upper, mid and lower lumbar spine.

Vertebral body shape - Wedge-shaped vertebral bodies may indicate compression fractures. Schmorls' nodes, common benign findings, appear as round defects in the vertebral endplates and represent invagination of the intervertebral disc through the endplates.

Posterior bony elements – If spondylolisthesis is present, evaluate the pars interarticularis of the superior vertebrae at that level for possible spondylolysis. First identify where the pedicles leave the vertebral body. Now follow this bone to the superior and inferior facets. Spondylolysis is identified as a break in the bridge of bone (pars interarticularis) between the superior and inferior facets, and appears as a malalignment and dark line or gap of the pars.

Degenerative end plate changes- Frequently, the vertebral end plates adjacent to degenerated discs show changes in signal intensity. Decrease in fat content is indicated by hypointensity (as part of benign sclerotic changes) and increase in fat by hyperintensity.

Hemangiomas- These slow growing, benign lesions are common findings. They appear as bright, roundish areas with the vertebral bodies.

Retroperitoneal space – Look for any irregularities in the structures found here such as adenopathy, masses, great vessel aneurysm, etc.

STEP 4 T2 sagittals (spinal fluid is bright)

Dural sac– With T2 sagittal images, we utilize the brightness of CSF to highlight abnormalities that affect the intradural nerve roots or spinal cord. Trace the course of the dural sac longitudinally, looking for changes in width or compression by extradural structures. Look at the posterior wall of the intervertebral discs for displacement of the dural sac by protruding or herniated disc material. Also observe the effects of the bony structures and ligamentum flavum of the dural sac. If the nerve rootlets can be visualized, observe the relationship of any extradural structural abnormalities on their course. When you get to the images that best visualize the central spinal canal, evaluate for distal spinal cord. This generally occurs around the level of L1. Look at the cord for any increased signal intensity (clues to cysts, syrinxes, areas of demyelination, tumors, etc).

Intervertebral discs

Disc degeneration reduces hydration of the nucleus pulposus and thus decreases intensity or brightness of the disc signal. Look in order at each intervertebral disc for its hydration status.

Disc protrusions/herniations –fluid in the dural sac provides good "contrast" for evaluating these findings. Dark disc material may bulge, protrude or herniate posteriorly, and thereby displace the bright CSF filled dural sac.

High Intensity Zones (HIZ)—these areas of increased signal intensity are thought to indicate tears, scarring, or vascularization of the annulus. These are most common in the posterior walls of discs.

Spinal Column

As above, study vertebral body alignment, vertebral body shape, and the posterior elements.

Hemangiomas – while these are always bright on T1, they are may be either bright or isointense on T2 images.

Posterior bony elements – Evaluate the pars interarticularis as above. Degenerative facet joints may have joint effusions. These appear as bright lines in sequences that cross the joints.

Step 5 – Intermediate T2 Sagittal (CSF and cord appear gray and blend together)

Intervertebral discs

Disruption of the posterior wall of the annulus will appear as a defect in the thin, dark line that delineates this structure.

Step 6 - T1 Axial Images (CSF appears gray and fat appears bright)

Identifying Vertebral Level - We recommend that one start with the most caudal images. These are usually of the easily recognizable sacrum. Examine from the sacrum through the L5-S1 disc level the structures indicated below. Next proceed to L4-5, L3-4, etc. to complete your analysis.

Content of the spinal canal and neural foramina – Because of the excellent contrast between bright epidural fat and the dark nerve roots, T1 axial images are the perfect studies for following the course of the lumbar nerve roots. With this in mind, identify the right and left S1 nerve roots, and dural sac within the sacrum. Follow the S1 roots as they track medially in sequential images until they merge with the dural sac. Note where the epidural fat extends bilaterally into the L5-S1 neuroforamina. This usually marks the L5-S1 disc level. Look for extension of disc material into the spinal canal or neuroforamina that displaces fat or contacts either the dural sac or nerve roots. After following the course of the S1 nerve roots, identify the L5 nerve roots in the lateral aspect of the L5-S1 neuroforamina. Track their courses medially through the neuroforamina and into the spinal canal until they merge with the dural sac, noting any abnormalities. Repeat this process for the L-4 and proximal roots.

Intervertebral discs – The intervertebral disc is imaged at the inferior level of the neuroforamina. The circumferential margin of the disc must be inspected for evidence of extension beyond normal boundaries. Do this both within the spinal canal and lateral to the neuroforamina.

***Bone*:**

Vertebral bodies – examine for integrity. Also, note any changes in intensity, which should be correlated with the sagittal images.

Spondylolisthesis— In cases of anterior spondylolisthesis, the posterior wall of the superior vertebral body is displaced anteriorly as compared to the inferior vertebrae or sacrum. This elongates the anterior-posterior dimension of the spinal canal and can appear as a double image.

Posterior bony elements —Spondylolysis manifests itself as a defect in the posterior bony ring. Examine this region for continuity of bone on images that include the pedicles, the pars interarticularis, and laminae. Inspect the facet joints for thickening or deformity, findings that suggest degeneration.

Ligamentum flavum – examine for a thickened appearance. These may narrow the spinal canal.

Retroperitoneal space — Paraspinal and psoas muscles are nicely seen in these images. Note any asymmetries of the muscles. The aorta is also well imaged in cross section, as are the kidneys in upper lumbar images.

Step 7 - T2 Axial Images (spinal fluid appears bright) Just as you did with the T1 images, use the neural foramina to identify disc level. Starting at the sacrum proceed rostrally one level at a time, examining the following structures:

Content of the spinal canal and neural foramina

Dural sac — using the bright CSF as contrast, examine the outline of the dural sac itself for displacement by disc protrusions, disc herniations, bony hypertrophy, ligamentum flavum hypertrophy or masses. Next, examine the contents of the dural sac for compression or displacement of nerve rootlets or the spinal cord. Also look for evidence of abnormalities of the nerve rootlets or spinal cord.

Intervertebral discs –Inspect the margins of discs for extension beyond normal boundaries. These are the best images for identifying disc herniations within the spinal canal. Look for areas of brightness in the outer annulus (HIZ - High Intensity Zones)

Bone: Examine the vertebral bodies, and posterior bony elements as in step (3). Note the facet joints often have a bright signal along the joint line. Effusions within the facet joints will appear as a widening of that line.

Ligamentum flavum – examine for a thickened appearance, this can impinge upon the dural sac.

Retroperitoneal space — adenopathy, masses, muscle, etc.

STEP 8 – Gadolinium Enhanced Images Review these as you did the T1 images, paying specific attention to any areas where prior surgery has been performed. Compare these areas between the two images and note where any brightening of abnormal (scar) tissue that occurs with gadolinium. If brightening is not noted, recurrent disk herniations can be suspected.

STEP 9 - Assessment and Plan

Finally, step back and have a last, look at the scans. Now is the time to correlate information from sagittal and axial images, and to summarize your observations.

Reading the radiologist's report at the very end can provide invaluable confirmatory feedback; but sometimes the rewards of systematic MRI examination lie in finding something previously overlooked.

Abnormality	MRI Findings	Clinical Significance
Disc		
Bulges, protrusions, herniations	Extension of disc material beyond normal disc boundaries, sometimes impinging upon neural structures. Contrast enhancement may be seen around disc bulge (Komori et al., 1998)	Often asymptomatic, but may lead to radicular symptoms. Bulges, but not herniations, increase in frequency with age (Videman, 1995). Anterior bulges are asymptomatic.
Degeneration	Dehydration associated with decreased T2 intensity. Degenerated discs lose volume, height, and peripheral annulus bulges circumferentially, with ridging due to bony reaction. With more marked degeneration, vacuum phenomenon may occur, (focal, decreased T1 and T2 intensity in pockets of gas). Increased disc intensity on T2; perhaps contrast enhancement (neovascularity) from disc disruptions from vertebral end plate fractures or acute Schmorl's nodes.	Often asymptomatic; may be associated with generalized but not focal back pain (Luoma, 2000).
"High Intensity Zones" (HIZ)	High intensity regions in disc annulus (posteriorly/ posterolaterally). Contrast enhancement can be seen with the associated extradural inflammation (Saifuddin et al., 1999)	Considered to be tears or inflammation in the annulus. High positive predictive value for painful disc on stress discography (Aprill & Bogduk, 1992). But often poor clinical correlation with symptoms (Kaiser, 1999; Saiffudin, et al. Feb 1998; Schellhas et al, 1996; Smith et al., 1998).
Vertebral body		
Schmorl's nodes (Vertical prolapses of disc into adjacent body endplates)	Endplate concavities; occasional marked invagination of nucleus pulposis into vertebral body. [1]	May also present as acute foci associated with back pain – should follow up for infection, metastases.
Hemangioma (mixtures of thin walled sinusoidal vessels and a fatty stroma)	Pathognomonic: bright on T1 *and* T2 sequences (but sometimes not too visible on T2's). Enhance with contrast in proportion to vascularity.	Generally benign; seen in 10% asymptomatics. But hemangiomas with no obvious fatty stroma may mimic metastases and myeloma. CT scan may resolve issue.

[1] Acute Schmorl's nodes: reactive changes in adjacent bone, with decreased T1 intensity, increased T2 intensity, and contrast enhancement. With time: fatty replacement and /or sclerosis similar to Modic changes. site of herniation may have focal T2 hyperintensity and contrast enhancement. Older lesions: sharply defined margins.

Vertebral body endplate changes adjacent to degenerative discs	Degenerative disc pathology may incite end plate changes known as Modic Changes changes. (Modic et al, 1988)[2] Increase or decrease in fat on T1's at endplates; sometimes increased vascularity on T2's. Reactive bone changes (ridging and focal spurring) due to disc bulging, intraosseous herniations of discs, fractures of vertebral bodies or ring apophyses.	Often asymptomatic, seen in one-fifth or more of symptomatic patients referred for MRIs. (Braithwaite et al., 1998; Modic et al., 1988)
Facet Joints		
Arthropathy	Hypertrophy, spurring, joint space narrowing, osteophytes, sclerosis. May cause stenosis of lateral recess in spinal canal. Often found in association with: degenerative disc disease (Fujiwara 1999), scoliosis, bone hypertrophy, subluxations, effusions, synovial cysts, ganglia, ligamenta flava thickening, fusions, anterolisthesis.	Can contribute to back pain by: (1) nerve root compression, (2) direct irritation of local pain fibers in facet joint. Degenerative arthritis is most common cause. Facet asymmetry may predispose to clinical symptoms. (Dai & Jia, 1996).
Dural sac		
Dural arteriovenous fistula	Cord edema (marked by increased T2 intensity and swelling), as well as prominent tortuous veins on the cord surface that may enhance diffusely.	An arteriovenous communication resulting in pressure on spinal cord veins. Uncommon but important to treat to prevent neurologic deficits. May be associated with myelopathy and/or radiculopathy.
Neoplasms	Contrast enhancement should be used in evaluating possible intradural neoplasm.	Differential diagnosis includes schwanoma, meningioma, ependymoma, hematogenous metastases, and "drop metastases" from epidermoid/ dermoid malignancy.
Arachnoiditis	Clumping" of nerve roots; adherence to dural sac edge ("empty sac" appearance); subarachnoid space loculations	Previous inflammatory disease, injection of diagnostic or therapeutic agents, or prior surgery may result in adhesion. Fitt and Stevens, 1995

[2] In a study by Modic et al (1988) of 474 consecutive patients referred for MRI lumbar spine imaging, 4% had Type 1 changes (inflammatory-like reaction with decreased TI and increased T2 intensity), 16% had Type 2 changes (fatty replacement of marrow in vertebral body). Focal increased intensity on TI and fast spin echo T2 scans (but low T2 intensity on fat suppressed scans). Type 3 involves a sclerotic pattern (decreased TI and T2 intensity; tiny end plate erosions).

Posterior Bony Ring		
Spondylolysis	Defect in posterior bony ring. Early findings may include hypointensity in pars on T1 coronals (Yamane, 1993)	Spondylolysis/listhesis are often a cause of back pain in adolescents engaged in spinal extension activities (e.g. gymnastics)
Spondylolisthesis	Superior vertebral body is displaced anteriorly or posteriorly as a result of spondylolysis or incompetence of facet joints from degeneration. Can distort the spinal canal and produce stenosis. When advanced, can also result in distortion and stenosis of neural foramina.	Can produce back pain. When stenosis develops, can produce radiculopathies.
Infection	Disc space/ vertebral osteomyelitis: increases T2 intensity and contrast enhancement (Grane et al, 1998). Vertebral end plate often is eroded. Intradiscal abscess: focal fluid collection (focus of non-enhancement in otherwise bright disc on T2) Established infection: Often soft tissue swelling in epidural space, neural foramina, paraspinal tissues.	Progressive and relentless back pain usually the presenting symptom. Fever only occasionally present.
Atraumatic fractures		
Insufficiency fractures	Typically affect vertebral bodies, causing loss of anterior height. Occasional mild retropulsion of part of body. Acute fractures can have < 1 cm soft tissue swelling. Vertebral body intensity relates to acuteness.	May present as acute back pain
Pathologic fractures	Often associated with bone destruction – especially posterior vertebra (where metastases are more common) – and well-defined soft tissue masses. Acute reactive changes may confuse matters.	May be associated with tumor
Fatigue fractures	Typically involve posterior element, especially pars, lamina, pedicle	

Transitional vertebra	Abnormal number (4 or 6) of lumbar vertebrae. Various hybrid configurations of lumbar and sacral vertebrae possible	Important for localization for invasive procedures. (Driscoll et al, 1996)
Stenosis	Narrowing of the lateral recesses, central spinal canal, or neural foramina	May cause neurogenic claudication: radicular pain, sensory disturbances, motor deficits developed while standing or walking. Usually due to degenerative disc and facets; but also from spondylolisthesis, facet joint synovial cysts, Paget's disease.
Scar	Marked by hyperintensity and gadolinium enhancement .	Distinguishing between scar and recurrent disc herniation is important for establishing plan of care. (Bundschuh et al, 1988; Ross et al, 1990)

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