

## Highlights

- The pathoetiology of vertebral marrow signal alteration are legion and includes the broad categories of trauma (fracture, contusion), stress reaction, neoplasia, inflammation (infectious and non-infectious), developmental variants and degeneration.
- Bone marrow edema (BME) signal alteration in the vertebral marrow has a variety of histopathology underpinnings and as such may be more appropriately considered as “bone marrow edema like” (BMEL) or “bone marrow lesion” (BML)
- Bone marrow edema like signal represents a non-specific feature that should be put in clinical context and with other associated morphological findings in order to ascribe a specific diagnosis
- Advanced quantitative MR techniques such as chemical shift imaging (CSI), diffusion weighted imaging (DWI) and magnetic resonance spectroscopy (MRS) can help differentiate benign from malignant etiologies of marrow edema like signal although none of these techniques are totally discriminatory

## Introduction

Bone marrow systematic diagnostic approach is proposed with categorization of various etiologies of BMLs. Use of typical imaging features on conventional MR imaging techniques in combination with other problem solving techniques, such as chemical shift imaging and diffusion weighted imaging (DWI) can be used to achieve the diagnosis or limit the differential.

## Technical elements

Routine sequences include T1-WI for specificity and fluid sensitive sequences (e.g. STIR, T2-fat sat) for sensitivity. Chemical shift imaging is employed a gradient-echo MR imaging with TEs selected with fat and water in phase and out of phase and is available on virtually all of the current MR imaging install base. MR spectroscopy is technically challenging and performs better at higher field strengths where there is greater spectral resolution.

## Degenerative

The two primary functions of the intervertebral disc are weight-bearing and accommodation of flexion, extension, lateral bending, rotation, and intersegmental mobility. The vertebral endplate is the point of transfer of these stresses between the disc and the vertebrae. The lumbar intervertebral disc undergoes a complex process of progressive age-related degeneration. Since the disc is relatively avascular, part of this degeneration is related to decreased nutrition leading to impaired cellular function and eventual cell death. Commonly observed on MR imaging, signal intensity changes in the vertebral body bone marrow adjacent to the endplate of degenerative discs, or “Modic” changes, take three main forms. Type I is associated with increased vascularity within the subchondral bone marrow, with about 4% prevalence. Type II is due to fatty replacement of the marrow, thought to be a result of marrow ischemia with about 16% prevalence. Type III is thought to be due to subchondral sclerosis. Overall, reported prevalence of Modic changes has been noted to range from 20% to 48%. Both Modic and Lawrence found that the prevalence of degenerative disc disease increased with aging. Disc desiccation and disc space narrowing are both markers for degenerative disc disease of the lumbar spine.

Degenerative lumbar disease has been conjectured to be the result of chronic loading. Reactive endplate changes usually parallel both sides of the endplate. But at every spinal level, the compressive strain at the superior vertebral rim tends to be higher than that at the inferior vertebral rim. Additionally, Hilton and Ball noted that rim lesions are more frequent in the upper rim. In a prospective longitudinal trial by Elfering et al., most severe progressive degenerative disc disease occurred at the L4-L5 and L5-S1 vertebral levels. Likewise, more than 95% of lumbar intervertebral disc herniations occur at L4-L5 or L5-S1. de Roos et al. found endplate changes to be located mostly posterior and adjacent to the disc. Modic et al. found that these changes usually extended from anterior to posterior of the endplate. Hilton and Ball noted that vertebral rim lesions are more common anteriorly, although they believed them to be traumatic in origin. With degeneration, permeability gradually decreases and calcification begins to occur centrally in the endplate. Resulting central hyperemia, followed by marrow replacement, is possibly responsible for our finding of the frequency of Modic changes centrally.

Recently an infectious (*Propionibacterium acnes*) has been asserted as the pathoetiology of BME endplate signal alteration in patients with intervertebral disc herniation and Modic type I endplate signal alteration.

### *Neoplasia*

Differentiating benign from malignant vertebral marrow processes has been an important and sought after goal of imaging. MR imaging is a sensitive method for assessing bone marrow but is lacking in specificity. Several specific MRI features using signal intensity characteristics, morphological characteristics, quantitative techniques, and findings at other levels can be useful for distinguishing benign from malignant vertebral compression fractures (VCFs). The majority of the published articles use qualitative MRI findings. However, quantitative MRI techniques are appealing because they can reduce observer variability by using an explicit decision threshold. The ability to detect residual microscopic fat with opposed-phase (chemical shift) imaging shows a high discrimination capability for separating benign from malignant bone marrow processes in non-VCF contexts and is easy to use on the currently installed base of magnets, usually taking less than 2 minutes of image acquisition time with gradient echo pulse sequences. Diffusion (as measured by ADC) is a field strength and pulse sequence independent physical parameter that can theoretically be compared across magnets, patients, and institutions without normalization, making this an appealing MRI feature. Certain biophysical and technical factors explain the variable DWI results in the literature. Interpretations of ADC are typically based on water-specific models. Lipid signal (in addition to diffusion) contributes to the quantitative measurement of ADC and results from investigations using non-fat-suppressed (or non-water-selective) pulse sequences may not reflect accurate representations of these water-specific models. Nevertheless, absolute diffusion imaging should be used and is best accomplished with EPI. Of the technical considerations, higher b values ( $>500 \text{ s/mm}^2$ ) allow slow diffusion to be seen. ADC values are being evaluated in a number of other malignancies with promising results and the cutoff values reported are often between 1 and  $1.5 \text{ mm}^2/\text{s}$ .

### *Trauma*

Vertebral marrow edema is observed in the setting of trauma in association with a fracture line representing extracellular fluid or hemorrhage or with a bone contusion representing microtrabecular fracture in addition to edema/hemorrhage. Resolution of marrow edema reflects healing.

*Inflammatory*Infection

MR imaging is the procedure of choice for evaluating infections in the spine. Advantages of MR imaging include the capability of multiplanar imaging, direct evaluation of the bone marrow, and simultaneous visualization of the neural structures. Numerous descriptions of MR findings in various infections, including discitis and epidural abscess, are available in the literature. Several studies show the sensitivity and specificity exceed those of radiography and scintigraphy. Numerous MR imaging findings have been described to be indicative of spinal infection, including decreased disc height, intradiscal T1 hypointensity, intradiscal T2 hyperintensity, disc enhancement, effacement of the nuclear cleft, and erosion of the vertebral endplates on T1-weighted MR images. The use of paramagnetic gadolinium-based contrast material to enhance the tissues of the spine increases the confidence in the diagnosis of disc infections and osteomyelitis and also identifies active infections from those that responded to antibiotic treatment. This allows the patient at risk for discitis or other spinal infections to be expeditiously evaluated and treated appropriately. In addition to the appearance of various infectious processes, the normal postoperative changes around the spine have been described. Conditions such as degenerative disc disease (erosive intervertebral osteochondrosis), inflammatory spondyloarthropathy, hemodialysis associated spondyloarthropathy, and neuropathic arthropathy may also lead to signal-intensity alterations that may be mistaken for infection.

Rheumatic

Spondylitis, or spondyloarthritis (SpA) is a group of inflammatory diseases impacting the spine and other joints, can be detected by MR imaging. Early stages of ankylosing spondylitis (the prototype for SpA) are also missed by traditional radiography but they can be detected by MR imaging. MR imaging is also more sensitive than computed tomography for detection of the disease. Short tau inversion recovery is useful for detecting disease activity, and T1-weighted MRI is useful for detecting structural lesions in the spine. Monitoring of patients with ankylosing spondylitis using MRI is also valuable for prognosis of disease progression. Inflammatory spinal lesions detected by MRI are predictive of syndesmophyte development in the future. The Assessment of SpondyloArthritis International Society (ASAS) includes detection of sacroiliitis by MRI as a classification criteria for axial SpA. These guidelines define active sacroiliitis as the presence of at least two inflammatory lesions, such as osteitis, on a single MR imaging slice or two consecutive MRI slices if only a single lesion is observed. MR imaging may also be used to monitor response to anti-inflammatory therapy for SpA. Whole-body MR imaging is another feasible option for detection of SpA and compares well to conventional MR imaging.

*Conclusion*

Vertebral marrow abnormalities and specifically bone marrow edema can be due to a legion of etiologies from several categories of disease: degenerative, infectious, inflammatory, traumatic, and neoplastic. Advanced MR quantitative imaging techniques and morphologic features can assist in discriminating these various causes.

Table: Normal and abnormal bone marrow (SI = signal intensity)

MR Technique	MR Sequence(s)	Normal Marrow (including hematopoietic)	Abnormal/Pathologic Marrow
<b>Conventional</b>	T1-WI SE	SI > Muscle/Disc	SI = or < Muscle/Disc
	PD-WI/T2-WI (non fat-suppressed)	Minimally increased SI < Fat	SI approaching or similar to Fat
	<u>Fluid Sensitive Sequences</u> STIR Fat sat T2-WI	Minimal increased SI.  Less commonly, focal islands of red marrow	Increased SI approaching vessels/fluid  Focal Lesions  Extra-osseous soft tissue component
	Contrast Enhanced T1-WI	<35% Enhancement	>35% Enhancement
<b>Problem Solving Techniques</b>	CSI (chemical shift imaging)	>20% SI loss on out of phase imaging	< 20% SI loss / Increased SI on out of phase imaging
	DWI (diffusion weighted imaging)  ADC (Apparent Diffusion Coefficient)	No diffusion restriction  ADC value greater than $1.5 \times 10^{-3}$ mm <sup>2</sup> /s or less (with b value 500 s/mm <sup>2</sup> )	Diffusion restriction  ADC value less than $1.5 \times 10^{-3}$ mm <sup>2</sup> /s or less (with b value 500 s/mm <sup>2</sup> )
	MRS (proton)	No Choline peak	Choline peak present

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