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Vertebral Bone Marrow Signal Abnormalities on Magnetic Resonance Imaging : From Benign to Malignant

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ABSTRACT

Magnetic resonance imaging (MRI) is the gold standard examination for evaluating the spinal cord and spinal nerve structures [1]. Whether discovered incidentally or as part of a specific workup, vertebral body signal abnormalities represent a frequent diagnostic challenge. Their correct interpretation is crucial for distinguishing normal variants and benign lesions from malignant pathologies. This article aims to provide a narrative and didactic review of the different types of vertebral signal abnormalities on MRI, classifying them based on their presentation and emphasizing key semiological features, differential diagnoses, and potential pitfalls. A synthetic analysis of recent scientific literature was conducted using the PubMed and Google Scholar databases. Signal abnormalities can be classified into several categories: age-related, degenerative, inflammatory, tumoral, vascular, and traumatic. T1-weighted, T2-weighted, STIR, post-contrast T1, and diffusion-weighted (DWI) sequences are the cornerstones of characterization [2, 3]. The combination of features (hypo-/hyperintense on T1, enhancement pattern, diffusion restriction) guides the diagnosis. A systematic approach integrating morphological appearance, signal characteristics, and clinical-biological context is essential. MRI, with its array of sequences, allows for strong diagnostic guidance and management planning in the majority of cases.

KEYWORDS :

Spinal MRI, Vertebral signal abnormality, Bone marrow, Metastases, Differential diagnoses, Bone imaging, MRI semiology.

MAIN ARTICLE

INTRODUCTION:

Magnetic resonance imaging (MRI) has revolutionized the exploration of the spine due to its excellent soft tissue and bone marrow contrast resolution [1]. While its primary indication is often the study of neural structures, the analysis of vertebral bodies is an essential component. The discovery of a vertebral signal abnormality, whether symptomatic or fortuitous (incidentaloma), is a common occurrence in daily radiological practice [4]. Bone marrow parenchyma is a dynamic tissue whose composition evolves with age and health status, resulting in physiological signal heterogeneity [5]. When faced with an abnormality, the main questions are: is it a normal variant or a lesion? Benign or malignant? Answering these questions requires rigorous semiological analysis. The objective of this review is to categorize the main abnormalities, describe their cardinal MRI features, and propose a rational diagnostic approach.

BASIC SEMIOLOGY: NORMAL SIGNAL AND KEY SEQUENCES:

Normal bone marrow in young subjects is rich in hematopoietic cells. With age, a progressive fatty conversion occurs, influenced by multiple factors [5, 6].

T1-weighted Sequence: Key sequence. A lesion hypointense on T1 compared to the intervertebral discs is highly suspicious [7].

T2-weighted / STIR Sequence: STIR is highly sensitive for detecting marrow edema, which appears markedly hyperintense [2].

T1 Fat Sat Sequence after gadolinium injection: Allows assessment of inflammatory or tumoral activity [8].

Diffusion-weighted Imaging (DWI): DWI sequences with ADC calculation have become crucial for differentiating cellular malignant processes (diffusion restriction) from benign lesions [3, 9].

CLASSIFICATION AND CHARACTERISTICS OF SIGNAL ABNORMALITIES:

1. Age-Related and Degenerative Abnormalities:

Age-related fatty conversion: Normal and symmetrical phenomenon. T1 hyperintensity, STIR hypointensity [5, 6].

Modic changes: Degenerative changes of the vertebral endplates.

Type I (edematous): T1 hypointense, T2/STIR hyperintense.

Type II (fatty): T1 hyperintense.

Type III (sclerotic): T1 and T2 hypointense [10].

2. Benign Tumoral and Proliferative Lesions:

Vertebral hemangioma: Common. Typical appearance: T1 and T2 hyperintense, "honeycomb" or "corduroy" appearance, intense enhancement [11].

Aneurysmal bone cyst: Expansile lesion with characteristic fluid-fluid levels on T2 [12].

3. Malignant Pathologies:

Metastases: Multiple lesions, T1 hypointense, STIR hyperintense, often intensely enhancing. Typical diffusion restriction (DWI hyperintensity, low ADC) [3, 7, 9].

Multiple myeloma: Can present as focal, diffuse, or micronodular. Diffusion restriction is often very pronounced [13].

4. Inflammatory and Infectious Pathologies:

Infectious spondylodiscitis: Contiguous involvement of two vertebrae and the disc. T1 hypointensity and T2/STIR hyperintensity of the endplates, disc hyperintensity, intense enhancement [14].

Spondyloarthropathies: Inflammatory bone edema at the vertebral corners and sacroiliac joints [15].

5. Vascular and Traumatic Abnormalities:

Vertebral infarction: "H"-shaped or bifid lesion involving the central vertebral body. T2/STIR hyperintensity, peripheral enhancement in the subacute phase [16].

Benign osteoporotic fracture: Diffuse edema of the vertebral body. Key differentiating sign on DWI: High ADC (no restriction), unlike a pathological fracture due to metastasis [3, 9, 17].

Summary Table: MRI Characteristics of Major Vertebral Signal Abnormalities

Entity	T1 Signal	T2/STIR Signal	Enhancement	DWI / ADC	Remarks
Fatty Marrow	Hyperintense	Hypo (STIR)	None	High ADC	Symmetrical, no edema
Modic I	Hypointense	Hyperintense	Yes	Variable	Adjacent to degenerative disc
Hemangioma	Hyperintense	Hyperintense	Yes (intense)	High ADC	Characteristic striated/honeycomb appearance
Metastasis	Hypointense	Hyperintense	Yes (often intense)	Restriction (Low ADC)	Multiple, frequent pedicle involvement
Spondylodiscitis	Hypo (endplates)	Hyper (endplates+disc)	Yes (pronounced)	Possible restriction	Involvement of 2 vertebrae + disc
Benign Fracture	Hypointense	Hyperintense	Linear (fracture)	High ADC	Fracture line, osteoporotic context
Malignant Fracture	Hypointense	Hyperintense	Nodular/mass-like	Low ADC	Tissue mass in canal, known primary

ANALYSIS STRATEGY AND DIAGNOSTIC PITFALLS

A systematic approach is recommended, integrating the number of lesions, signal on different sequences, and clinical context [2, 7].

Main Pitfalls:

Focal fatty conversion can mimic a hemangioma.

An acute edematous osteoporotic fracture can simulate a malignant lesion; DWI and contrast injection are then essential [9, 17].

DWI artifacts in the thoracic region can falsely suggest restriction [3].

CONCLUSION AND PERSPECTIVES

MRI is a powerful tool for characterizing vertebral signal abnormalities. The combination of morphological and functional sequences, integrated with the clinical context, allows for a precise diagnosis in the majority of cases [2, 7]. Diffusion-weighted imaging has become an indispensable complement [3, 9].

Future developments, including whole-body MRI and radiomics, will enable more precise mapping of bone marrow and even finer detection of infiltrative abnormalities.

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