
MRI IN SPINAL BONE MARROW REPLACEMENT DISORDERS

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Abstract *Objectives.* The paper aims are: to present and illustrate the MRI aspects of the normal and pathological bone marrow involving the spine, focusing on MR techniques and interpretation in a precise clinico-biological context of each patient.
Material and methods. The cases included in this study were explored using a 1.5 MRI system in T1-weighted, T2 FSE, STIR, FSE T2 Fat Sat sequences, in sagittal and or coronal plane. Sections made in the axial plane in T2 wi, were centered at the level of the lesion(s). In case of primitive or secondary tumoral lesions we have performed T1-weighted SE sequences Fat Sat pre-/ and post-iv. injection of Gd-BOPTA in multiple planes. In particular cases, we have used T1-weighted sections with a TE in and /out of phase.
Imaging features. Normally, the bone marrow shows intermediate signal both on T1-/T2 -/, Stir- weighted images in comparison to paravertebral muscle. Pathological aspects include: diffuse and focal tumor infiltration (leukemia, lymphoma, multiple myeloma, metastasis), that must be differentiate from hyperplasia (reconversion) of the red marrow, bone marrow depletion, supportive tissue pathology (primary and secondary myelofibrosis, Gaucher disease).
Conclusions. MRI is the only imaging method that allows the analysis of the bone marrow. Knowledge of normal signal in different MRI sequences in correlation with the age and the clinico-biological context of the patient is essential for a correct interpretation and detection of different types of diseases involving bone marrow of the spine. In patients with a diffuse T1 hyposignal of the spinal bone marrow the differential diagnosis includes three main entities: conversion, myeloproliferative lesions and pathology of the support structures.

Key words: spinal bone marrow pathologies, tumoral lesions, MRI techniques and findings

Introduction

MRI is the only imaging technique that allows direct visualization of the bone marrow (1). MRI is the first and frequently the only evaluation

method to detect and characterize spinal bone marrow disease (SPMD). Technical improvements, with new coils and sequences, allow the evaluation of the whole marrow in a reasonable time (2).

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MR technique

For the evaluation of the spinal bone marrow (SBM) disease, the MRI protocol include obligatory T1-weighted spin-echo (SE) sequences, chemical shift imaging (in phase image/opposed-phase image), fat-suppression technique (STIR-sequences), diffusion (EPI), T1 SE after contrast medium (Gadolinium-Gd) injection. T1-weighted sequences with fat presaturation (FS) can be used-on this type of sequence in purpose to evaluate the uptake of the contrast material (Gd) compared to the non-enhanced T1 FS acquisition, that is more obvious than in classical T1 SE pre-/ and postcontrast sequences (2,3,6,11,49).

Anatomy of bone marrow

Bone marrow is divided into three parts: red marrow, yellow marrow and supporting structures (trabecular bone and reticulum). Active bone marrow is usually referred to the red marrow (4,5). Marrow content and its distribution changes with age and differs by sex (4-6). At birth the majority of marrow is red marrow (hematopoietically active) and it is uniformly found throughout the skeleton. In the adult red marrow is concentrated in the axial skeleton, but may be focal in other parts of the skeleton. Yellow marrow is generally hematopoietically inactive and is concentrated in the adult in the appendicular skeleton. In young children red marrow is approximately 40% water, 40% fat and 20% protein (3). At 70 years old that proportion is: 60% fat, 30% water and 10% protein (5, 42). Yellow marrow is 80% fat (3). Red marrow is composed of 60% hematopoietically active cells in the young (7,8), but only about 30% in the elderly (5-7).

Appearance of normal marrow in the spine on MRI

Red marrow has intermediate signal because it is compose by a mixture of water, fat and protein and has a slightly higher or equal signal compared to muscle on both T1w and T2w sequences (10). Red marrow has intermediate signal on T2 FS and STIR images (2). Yellow marrow show signal similar to fat on all pulse sequences (3, 9-11). Fat tissue has short T1 and T2 relaxation times and is hyperintense on T1w sequences and hypointense on true (conventional) T2-weighted sequences. On fast spin echo acquisitions (FSE) T2 weighted, the fat is not as hypointense that on the T2wSE (2,3). Water has a much longer relaxation time compared to fat and is

hypointense on T1w and hyperintense on T2w images (2). On T1w images in the adult, the signal of the vertebral body should be higher than adjacent intervertebral discs or muscle with few exceptions, that include calcified discs which have bright T1w signal and particularly islands of red marrow which can be confused with focal pathology such as tumor (12,13,15). T2w FSE sequence is substantially less reliable in assessing spinal marrow, particularly in diffuse disease, than T1w SE images (15). STIR uses an inversion pulse to cancel signal from fat (2,11). Most pathology will demonstrate relatively higher signal on T2w FS or STIR than red or yellow marrow (12-15). Others techniques have been utilized in purpose to differentiate normal from abnormal marrow: chemical shift imaging known as opposed phase imaging (16-18); diffusion (19); dynamic contrast enhancement and spectroscopy (20).

Bone marrow conversion

At the birth marrow signal is similar or even less than adjacent muscle and disc such that pathologic marrow may be very difficult to detect (8). Soon marrow undergoes a pattern of conversion to yellow marrow (5,7,46). This process begins first in the appendicular skeleton and proceeds in a centripetal manner (8). At the age of 25-30 years, normal marrow conversion is complete, except for the sternum, ribs, proximal aspects of the extremities, and the pelvis (46). Concerning the spine there is a variable mixture of red and yellow marrow, beyond infancy with progressive increase in fat content of red marrow and increased proportion of yellow marrow with aging (4,5,6,8).

Pathologic appearing of bone marrow

Diffuse disorders of the spinal marrow can be classified into: 1.reconversion or hyperplasia; 2. replacement disorders; 3.depletion disorders; 4.reticulum disorders or disorders of supporting structures (3,42,46).

Generally, diffuse pathologic processes in the spinal marrow have a non-specific appearance with reduced signal on T1w images and intermediate T2w signal (42-50). STIR images or post contrast images may or may not differentiate red marrow hyperplasia from pathologic cellular replacement (10,12,21, 46,48).

Bone marrow replacement disorders

Marrow replacement disorders are proliferation

of abnormal (frequently malignant) cells in the bone marrow (23-26). Three patterns of proliferation are recognized as: diffuse pattern where the normal bone marrow is completely replaced (leukemias); spotted pattern where tiny clusters of abnormal cells are present, and focal pattern where larger often round/oval lesions predominate. The focal pattern is the classical aspects of metastases from solid organ malignancies, myeloma, and lymphomas (29-37, 42). The normal marrow signal is usually completely replaced by abnormal signal, which appear hypointense on T1w images. In early stages of the disease, the MR may appear normal. Using MR to follow treatment is difficult in interpretation (29,35, 36,38,39).

Multiple myeloma (MM)

In MM the spinal MR evaluation may appear normal, diffusely abnormal, variegated (less than 5% of patients), multi-focally abnormal or as a solitary lesion- plasmocytoma (32-34,36). The forms may also be combined (Fig. 1). Up to 30% of focal MM lesions visible on T1w studies are not distinct on T2w, but are visible on T2w FS or STIR images (49,50). The diffuse pattern mimics other replacement disorders such as leukemia and even marrow reconversion (46). A diffuse pattern of marrow disease is associated with a higher stage and worse prognosis. Whole body MR has is use in staging and following this disorder (2,9,10, 32,46). Vertebral body fractures occur frequently in MM and retropulsion of bone and compression of neural elements are important and easy to assess by MR evaluation (46).

Lymphomas

Bone marrow involvement by malignant lymphoma is much more common in Non-Hodgkin (Fig. 2) disease than in Hodgkin disease and spreads to the marrow in 95% of the time hematogenously. Diffuse or mottled appearing infiltration is much more common than the multi-focal form (3,37,49,50). Signal intensity can vary with high T2 w FS areas and low signal areas on T1 w, aspects attributable to "dense" clusters with hypercellularity (46).

Bone metastasis

MRI is the most sensitive technique because it can detect an intramedullary lesion before any cortex destruction is detected on the bone scan (1,2,14). Metastases usually have a low signal

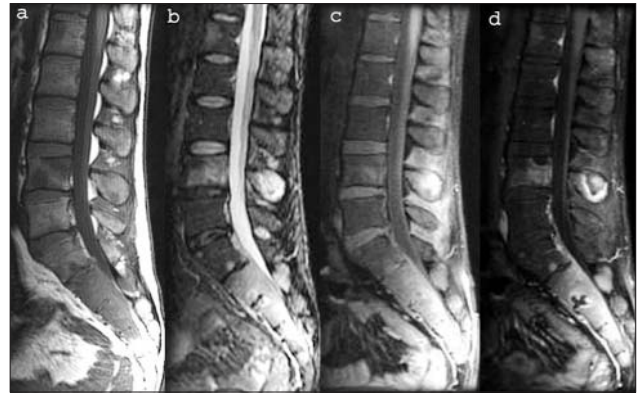


Figure 1 - Multiple myeloma. MRI evaluation :T1 SE (a), Stir (b), T1 SE FS without (c) and with Gd injection (d): multiple nodular and infiltrative tumoral lesions affecting the lumbar spine, sacrum and iliac bones with sacral nerves roots involvements.+



Figure 2 - Non-Hodgkin lymphoma. MRI evaluation: T1 SE (a), T2 FSE (b)-diffuse infiltration of SBM and extension in the epidural space (L5-S2) and presacral space

comparable to that of water on T1 SE sequence (Fig.4). Marked sclerotic metastasis remains hypointense on all sequences (14). Collapsed vertebral bodies must be evaluated with care in osteoporotic patients (2). In recent collapses the T1 w signal is decreased in both osteoporotic and metastatic lesion. Involvement of the posterior

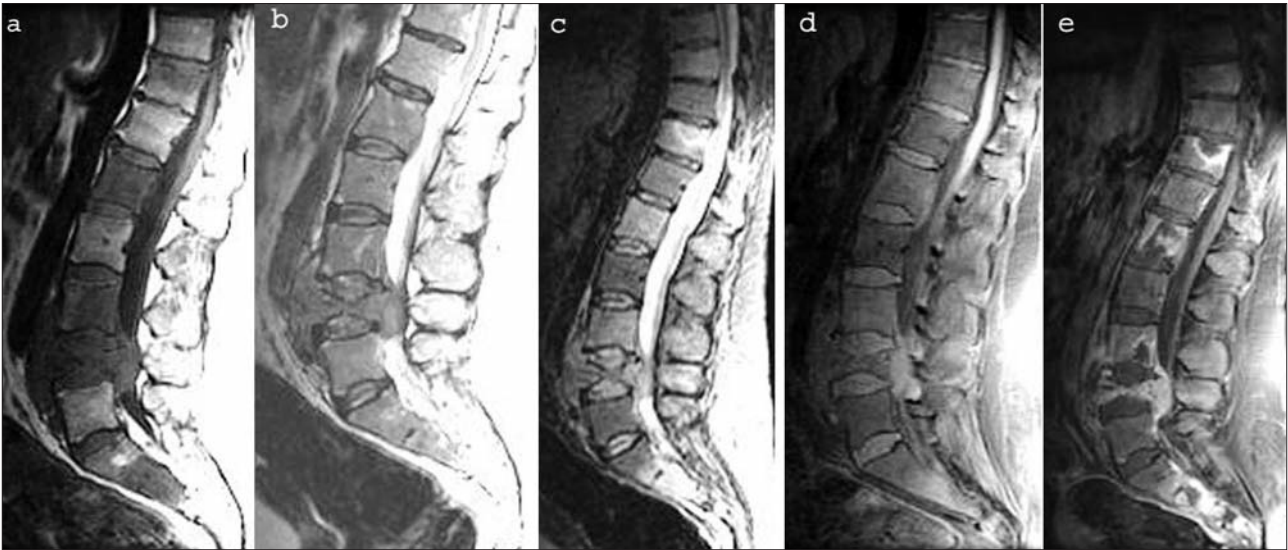


Figure 3 - Multiple vertebral metastasis. MRI evaluation T1 SE (a), T2 FSE (b), T2FS (c), T1SE FS without (d) and with GD (e): multiple nodular and infiltrative (L4) tumoral lesions in a female patient with antecedents of breast neoplasm

arch, a convex posterior contour (see Fig. 3), and sharp limitation suggest malignancy (1,3,9,10,14, 49,50). Diffusion images provide excellent distinction: the signal of metastasis is higher, and the one of osteoporotic collapses lower than normal marrow (19). If in doubt, needle biopsy is an easy, fast, and safe technique to make a precise diagnosis (2).

Leukemias

The infiltration of bone marrow by tumor is diffuse leading to a global decrease on T1w sequences (2).

After treatment

Follow-up of diffuse forms may be problematic in differentiating hypercellular reactive marrow, fibrosis and residual or recurrent active tumor (9,29,35,36). Myelofibrosis may develop after treatment (47). Chemotherapy and radiation therapy change the marrow in predictable ways and may affect its appearance on MR (38,39). Initially, edema and necrosis occur, followed by hypocellularity if a positive tumoral response is obtained. After two weeks, fatty replacement begins and may be visible on MR and classically occurs around the basivertebral veins. However some focal lesions in myeloma do not change significantly in appearance for up to 5 years (35). Reconversion can occur depending on the degree to which the therapy has obliterated the marrow. Bone marrow reconversion and the diffuse pattern of myeloma may be similar (36). Partially or

peripherally enhancing lesions are non-specific as post-treatment fibrosis will enhance (36-39,46,47). The appearance of marrow depletion disorders on MR can overlap with normal (1,12,15,18,48).

Conclusions

MRI is a very sensitive and good technique for evaluating spinal bone marrow. Knowledge of the signal on different MRI pulse sequences and pattern of marrow in the normal spine according to the age of the patient is essential in deciding what is pathologic and what is not. In a patient with diffusely low T1w marrow signal on MR, the differential diagnosis includes three principal entities: benign reconversion conditions, malignant myeloproliferative lesions and disorders of the supporting reticulum.

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