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ARTICLE

MRI of bone metastases: the choice of the sequence

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Abstract

MRI is very sensitive to detect bone metastases. To improve specificity, a clever use of sequences, spin echo, gradient echo in or opposed phase, contrast medium and diffusion is needed.

Keywords: *Bone marrow; bone metastases; MRI.*

Introduction

MRI is the only imaging technique allowing the direct visualization of bone marrow and is the most sensitive[1]. If sensitivity is high, improving specificity needs a good understanding and an adequate choice of acquisition sequences. Technical improvements, with new coils and sequences, allow the study of the whole marrow in a reasonable time[2].

MR sequences

Fat and water distribution in bone marrow, indirect visualization of normal bone trabeculae, indirect evaluation of bone edema and cell density and the study of vascularization can be ingeniously combined to enable good detection and characterization of lesions.

Fat and water

Normal marrow contains both fat and water (yellow marrow 80% fat, but also 15% water, and red marrow 40% fat and 40% water). In infiltrative disorders, fat disappears in a diffuse, disseminated or solitary way. Sequences displaying differences between fat and water signal are thus useful.

T1-weighted (W) spin-echo (SE) sequences

Fat has a shorter signal than water and the highest signal. Thus, fatty marrow containing 80% fat exhibits a high signal and any focal lesion showing a lower signal is easy to detect. This explains why this sequence is very useful and usually the first used. Hematopoietic marrow, containing water but also fat, is hypointense to fat, but hyperintense to normal muscles. A marrow signal which is hypointense to the muscles and discs in the spine is abnormal.

Chemical shift imaging

The difference in resonance frequency between water and fat protons can be used. It has no consequence on the contrast on conventional SE sequences as the 180° pulse cancels the difference. Normally the read-out gradient is centered on the echo, which appears symetrically on the 90° pulse with respect to the 180° pulse. The signal is thus proportional to the sum of water and fat protons (in-phase image). By shifting the read-out window, it is possible to obtain images whose contrast is related to the difference between the quantities of water and fat protons (opposed-phase images)[3].

In gradient-echo sequences, the same phenomenon occurs, depending only on the echo time. If fat and water protons are in phase, their signals are added; if they

are opposed-phase, they are subtracted. If a pathology replaces normal marrow, fat can be obliterated, and no subtraction will occur. The difference from the signal produced by normal marrow, which always contains water and fat, will be emphasized on opposed-phase sequences[4].

Fat suppression techniques

A 180° inversion pulse is used initially for short tau inversion recovery (STIR) sequences[5]. The inversion time is chosen to cancel the signal of fat. This sequence can be obtained on any MR unit, but it is unfortunately time consuming and only a limited number of slices can be acquired. This can be overcome by using fast STIR sequences. The main drawback of the STIR sequence is that it cancels every signal identical to fat, for example blood in hematoma or contrast-enhanced tissue.

The difference between fat and water proton frequency is also used for fat presaturation. A saturation pulse with a narrow band at the exact fat frequency is used before the usual pulse. A very homogeneous magnetic field is required, and therefore this sequence is not efficient on every unit.

Bone trabeculae

Because of the lack of mobile protons, trabecular bone yields no detectable signal, but creates magnetic field heterogeneities. They have minimal impact on SE sequences, as their effect is cancelled by the 180° pulse. It may however be visible on gradient-echo sequences as field heterogeneity is not cancelled[6,7]. If the TE is long enough the signal can be decreased considerably because of the normal trabeculae. This is particularly visible in the vertebrae, pelvic bones, and the proximal ends of the long tubular bones. If bone trabeculae have been destroyed, the signal will be higher than in the preserved parts of the bone. We have an indirect technique for the diagnosis of a trabecular lysis.

Diffusion

Diffusion imaging, using echoplanar imaging, is well known in brain imaging. Its use is more difficult to apply outside the brain, as the signal needs to be stronger[8]. Single shot SE sequences are now available. When multiple walls (such as cell invasion) prevent diffusion, the signal is higher than in edema, where diffusion is easy.

Contrast medium

After injection of gadolinium chelates, changes in the signal of normal marrow are not visible on T1-W images. Measurements display no or a limited increase[9,10]. Various pathologies, in contrast, usually exhibit a strong signal increase. The absence of uptake practically rules out involvement of the marrow. Uptake is usually evaluated on T1-W SE sequences. A pre-injection sequence is mandatory, as the enhanced signal of the lesion may make it equal to the signal of fatty marrow, and thus render it inapparent. T1-W sequences with fat presaturation can also be used, so that uptake is more obvious.

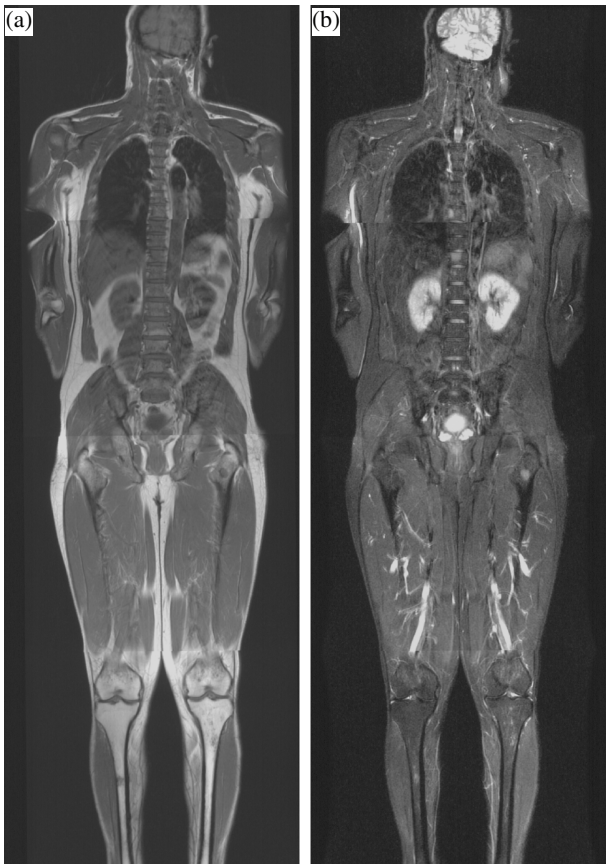

Figure 1 **Whole body MRI, on T1SE (a) and STIR (b) images.**

Imaging bone metastases

With new coils and sequences[2] the whole skeleton can be studied in 20 min, allowing the detection of more lesions than bone scan (Fig. 1).

T1-W SE sequences display fat and water (yellow and red marrow). As metastases usually have a low signal comparable to that of water on this sequence, they are easily discernable in yellow marrow (the elderly and some adult patients), and barely depicted in red marrow (children and young adults). As a high homogeneous fatty signal rules out metastases, this sequence may be sufficient (Fig. 2). If the problem is not solved, other sequences must be added. The usual choice is T2-W fat sat or fast STIR sequences. If the problem is not

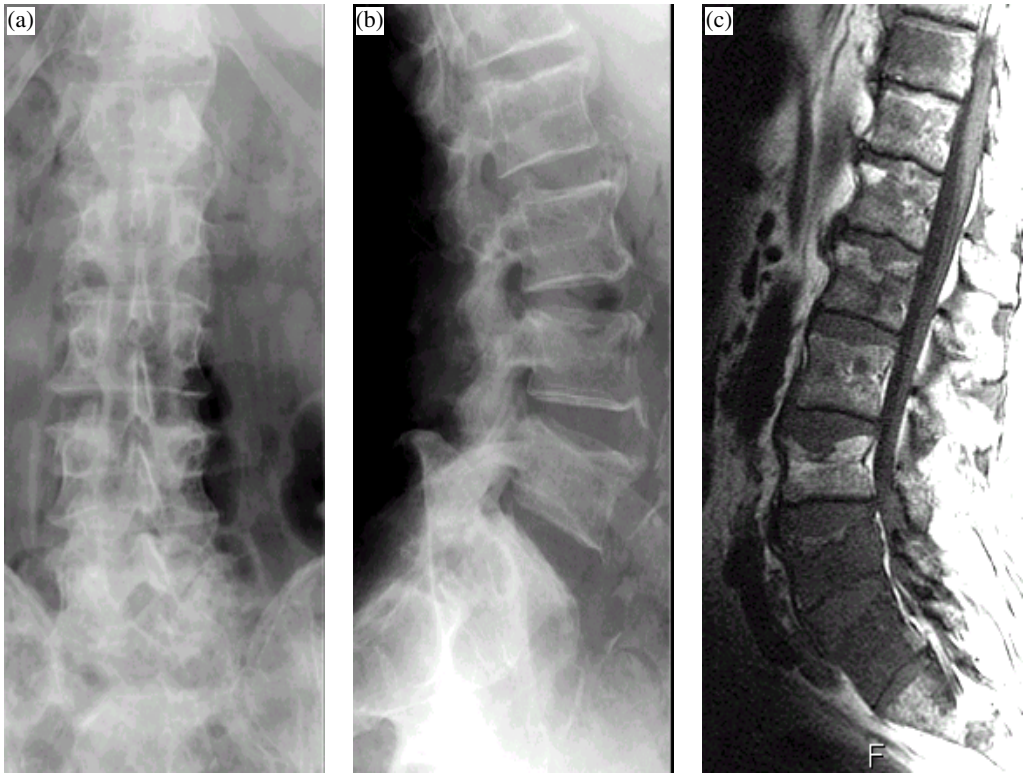

Figure 2 **Prostate cancer. Degenerative changes on plain films (a and b). Obvious metastases on sagital T1W spin-echo image. Metastases are obvious as low signal lesions, because of the normal high signal fat marrow.**

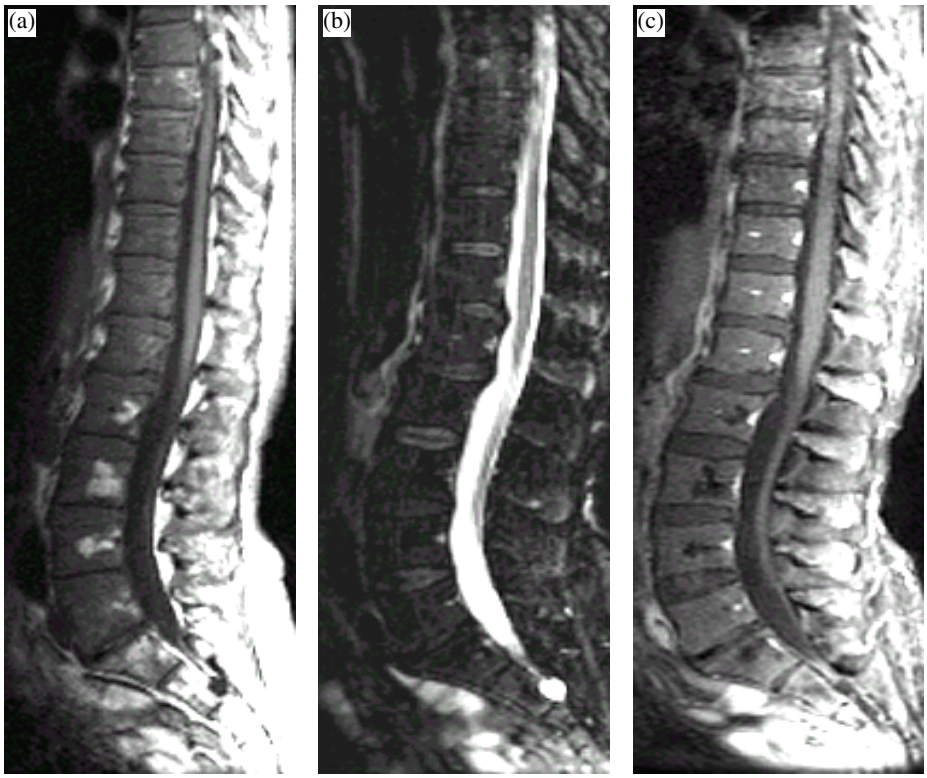

Figure 3 **Rectal cancer. Low signal of the lumbar marrow on T1WSE image (a). Low signal on FSET2 fat sat image (b). No uptake after injection (c): the low signal is due to an associated chronic anemia, with marrow regeneration. The lack of uptake rules out metastases.**

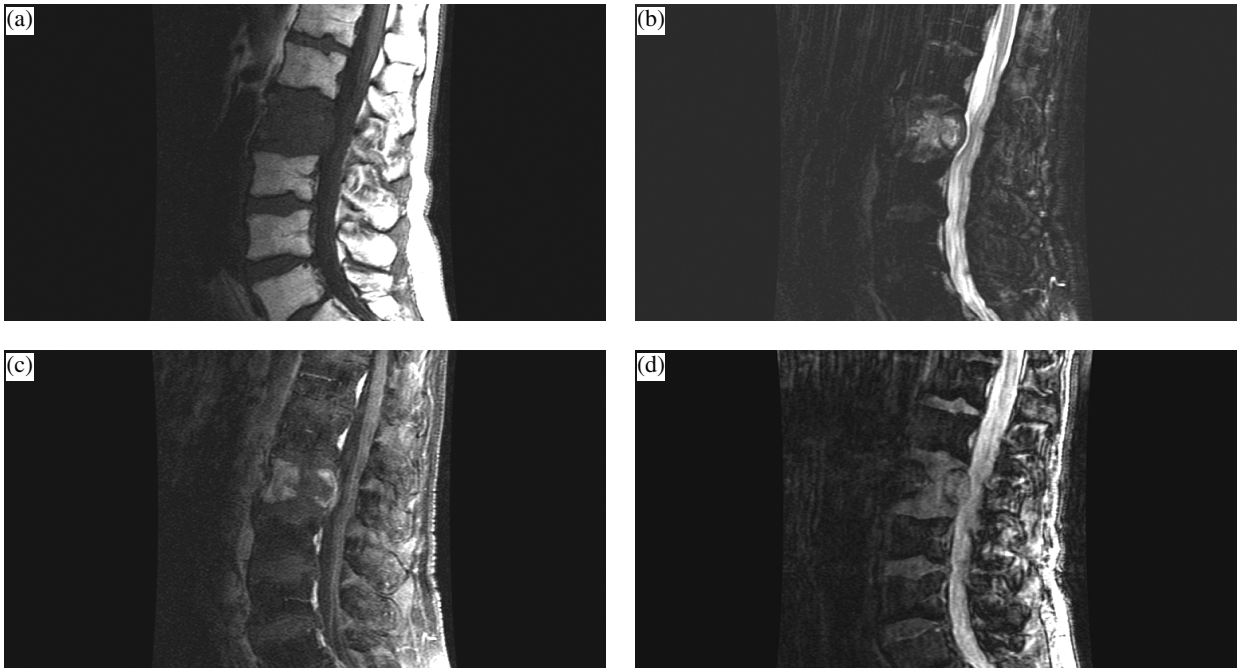

Figure 4 **Bladder cancer. Metastatic vertebral collapse of L3. T1SE (a), FSET2 fat sat (b), T1SE fat sat after injection (c), and GE in-phase sagital images. The high signal on GE in-phase image is due to the lack of artefact induced by bone trabeculae: the lesion is therefore metastatic.**

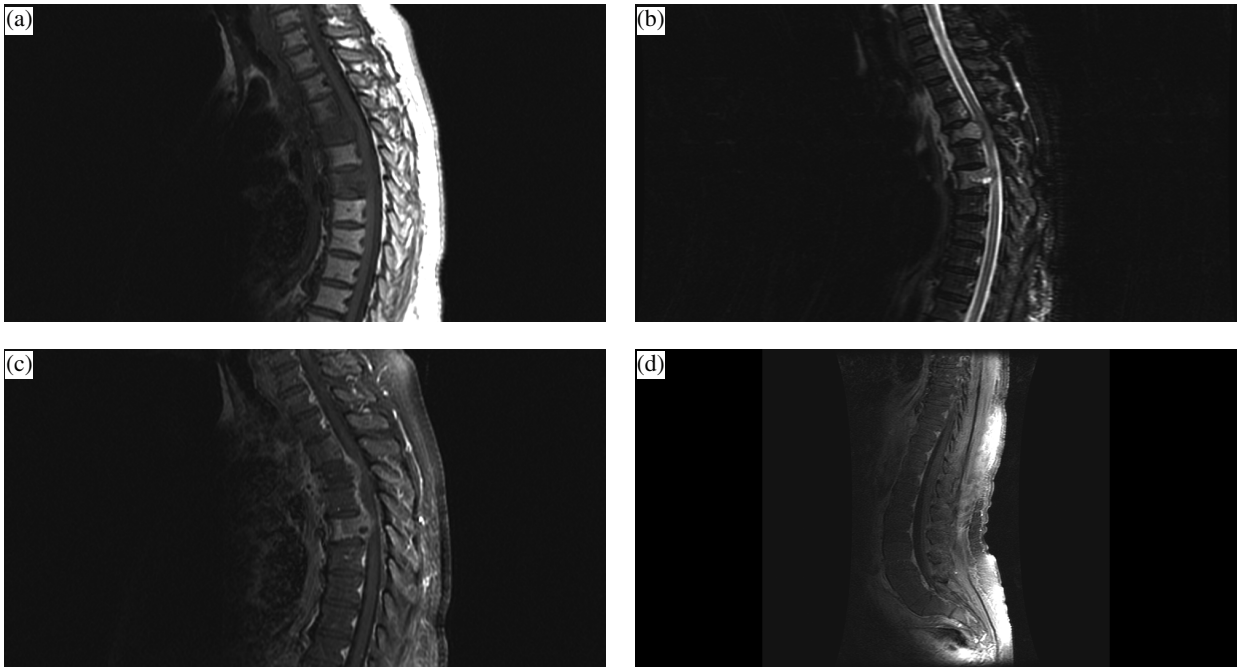

Figure 5 **T1SE (a), FSET2 fat sat (b), T1SE fat sat after injection (c) images of the thoracic spine: 2 levels of compression. The MR study of the rest of the spine is mandatory to rule out another level of compression before a surgical decompression (d: the normal lumbar spine on T1SE fat sat after injection).**

solved, contrast medium should be used on T1-W fat sat sequences (Fig. 3).

Sclerotic metastases usually behave like their lytic counterparts on MRI. When very marked, sclerosis rarely remains hypointense on all sequences.

Collapsed vertebral bodies

Collapsed vertebral bodies must be evaluated with care in osteoporotic patients. In old fractures bone marrow exhibits a normal fat signal, but in recent collapses the

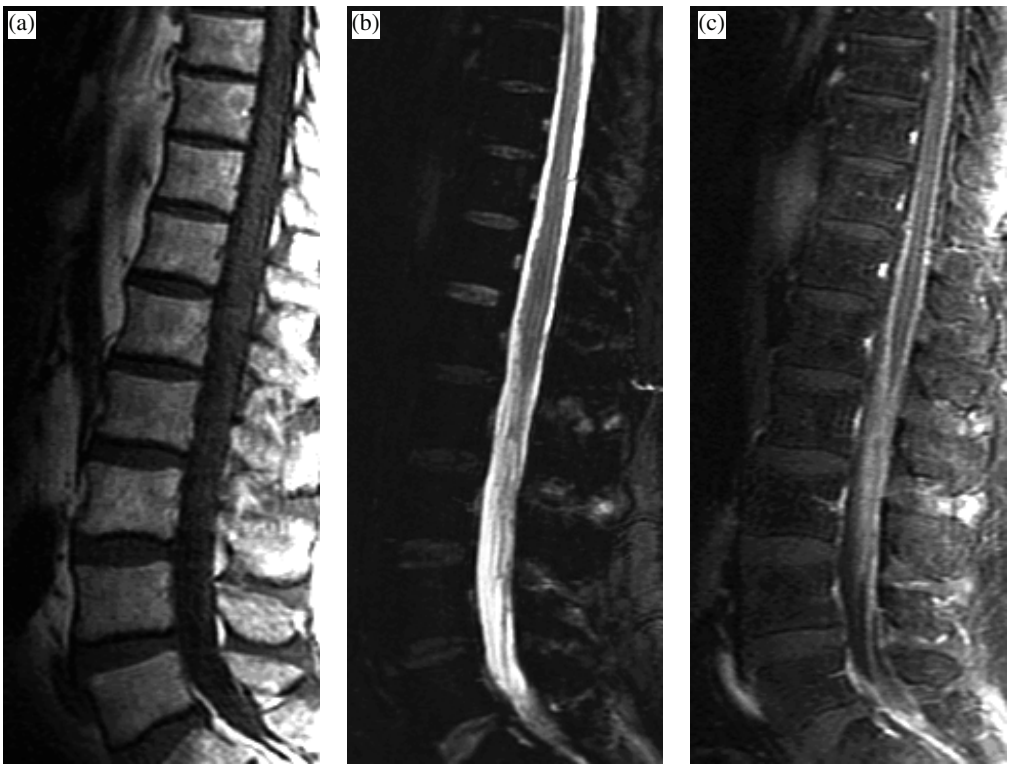

Figure 6 **Chest cancer. Clinical compression. Normal vertebral bodies on T1SE (a), and FSET2 fat sat images (b). The complete metastatic involvement of the lepto meningeal space becomes obvious only after injection of contrast medium (c).**

signal is decreased in both osteoporotic and metastatic lesions. Multiple fractures with normal signal from non-collapsed bodies, a partially preserved signal in the involved vertebral body, ill-defined borders between normal and involved marrow, vertebral body fragmentation and disc rupture are more suggestive of a benign lesion. Multiple involvement of non-collapsed vertebrae, involvement of the posterior arch, a convex posterior contour and sharp limitation suggest malignancy[11]. A high signal of the collapsed vertebral body on gradient-echo images, indicative of trabeculae destruction, is often seen in metastases, whereas a signal lower than that found in the non-collapsed vertebral bodies indicates more trabeculae, and therefore a benign collapse (Fig. 4)[12]. Diffusion images provide excellent distinction, the signal of metastases being higher, and the signal of osteoporotic collapses being lower than normal marrow. If in doubt, and if the treatment decision is contingent on the result, needle biopsy is an easy, fast, safe and reliable technique for the exact diagnosis. If a compression is detected and surgery is considered, the whole spine must be studied to rule out another compression level (Fig. 5). In case of clinical compression and no explanation on the plain sequences, contrast medium must be used to detect lepto-meningeal metastases (Fig. 6).

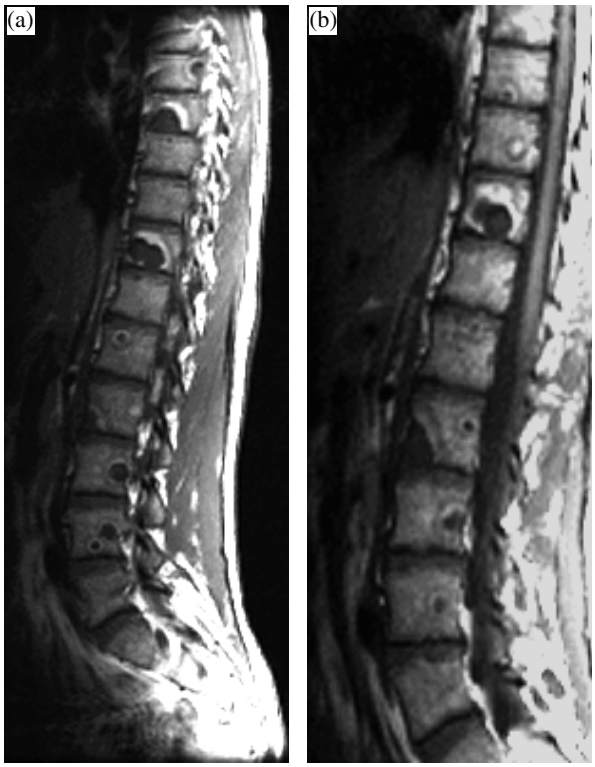

Figure 7 **Metastases studied after chemotherapy, on T1WSE images. The fatty halo at the periphery of the lesions indicates a partial regression of the lesions, and thus an effectiveness of treatment.**

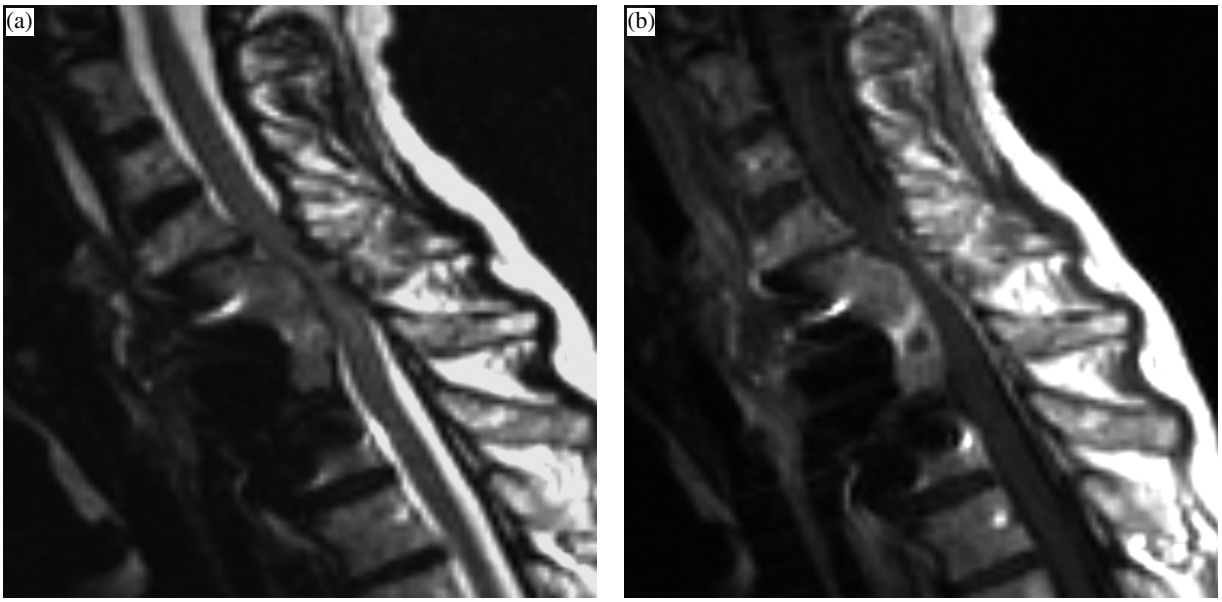

Figure 8 **Post surgical follow up of bone metastases. Despite the metal, a recurrence compressing the cord is visible on T2SE and TISE after injection images. Fat sat is avoided, as there would be too many artefacts.**

After treatment

MRI is particularly helpful after radiation therapy, as new lesions are easy to diagnose because of the high signal of the irradiated marrow on T1-W SE images. Although rare, lesions can exhibit a peripheral fat signal after chemotherapy, indicating the efficiency of treatment (Fig. 7). The signal of normal tissues undergoes very little change during chemotherapy[13]. When abnormalities persist after chemo- or radiation therapy, a low signal may be due to both residual active tumor or fibrosis. Neither gradient-echo sequences nor contrast medium injection permit a reliable differential diagnosis. The effectiveness of dynamic techniques has yet to be determined.

After surgery

After surgery and the placement of metal devices, follow-up with MRI is still possible, provided first that the metal is non-paramagnetic (for example titanium, which is increasingly used) and second that fixation is lateral (that is transpedicular for the vertebral bodies). In such cases it is often possible to obtain at least one good quality medial image, and SE T1-W sequences must be used, and not gradient-echo, which is more prone to artifacts (Fig. 8).

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