

# Diffusion-weighted MR imaging in differentiation between osteoporotic and neoplastic vertebral fractures

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Received: 15 February 2012 / Accepted: 19 February 2012 / Published online: 13 March 2012  
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## Abstract

**Purpose** To assess the usefulness of magnetic resonance imaging (MRI) with spin-echo echo-planar diffusion-weighted imaging (SE-EPI-DWI) in differentiation between vertebral osteoporotic fractures and pathological neoplastic fractures.

**Materials and methods** Thirty-three patients with both osteoporotic or neoplastic vertebral fractures diagnosed with X-ray or TC were studied with MRI exam, (1.5 T unit) with DWI sequences. DWI sequences were qualitatively analyzed. Apparent diffusion coefficient (ADC) values were also determined and compared to the definitive histologic diagnosis.

**Results** DWI of neoplastic lesions showed hyperintensity signal in 22 out of 23 cases. Mean ADC value of neoplastic fractures was  $1.241 \pm 0.4 \times 10^{-3} \text{ mm}^2/\text{s}$ ; mean ADC value of osteoporotic fractures was  $0.646 \pm 0.368 \times 10^{-3} \text{ mm}^2/\text{s}$ . Neoplastic fractures showed ADC values significantly higher than osteoporotic ones ( $p < 0.001$ ). DWI imaging and histology showed a significant correlation.

**Conclusion** DWI provides reliable information to support MRI diagnosis of neoplastic versus osteoporotic fractures. ADC value appears as a useful adjunctive parameter.

**Keywords** DWI · Vertebral fractures · MRI imaging · ADC values

## Introduction

Vertebral fractures may be detected on radiographs, computed tomography or radionuclide studies, but in today's clinical environment, the specific discrimination between benign and malignant vertebral compression fractures relies heavily on MR imaging features. Since most bony metastases are hematogenous in origin, the axial skeleton is the most common site of skeletal metastases initially due to abundant vascularization and red bone marrow [1]. However, osteoporotic compression fractures are also a common occurrence in the spine and can be confused with metastatic compression fracture in the acute phase. Since the prognosis and management differs in these two entities, accurate diagnosis is important.

The primary objective of this study was to evaluate the specificity and sensitivity of diffusion-weighted MR imaging (DWI) in the differentiation and characterization between benign and malignant vertebral compression fractures comparing the results of imaging to histology.

## Materials and methods

Between January 2010 and October 2010, we retrospectively reviewed 33 patients (10 males, 23 females; mean age  $60 \pm 11$  years) with vertebral fractures diagnosed with X-ray or TC. Patients with the history of vertebral compression fracture of more than 6 weeks, patients who were not MR compatible and those with sclerotic lesions were excluded from the study.

The 33 patients underwent biopsy and were divided into two groups: 23 patients (10 males; 13 females) with malignant tumoral fracture and 10 patients (3 males; 7 females) with non tumoral, osteoporotic fracture.

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The patients were imaged using the conventional T1 WI, T2 WI, short Tau Inversion Recovery and spin-echo echo-planar diffusion-weighted (SE-EPI-DWI) sequences [2] using a spinal phased array coil on a 1.5 Tesla super conducting MR System (Avanto, Siemens Medical Solution, Forchein, Germany), gradient strength 45 mT/m, slew rate 200 T/m/ms.

Lesions were studied at baseline with the following sequences: sagittal T1-SE (TR 500 ms, TE 13 ms, matrix 380, FOV 320, thickness 4 mm) sagittal STIR (TR 4,800 ms, TE 89 ms, NEX 2, matrix 380, FOV 320, thickness 4 mm), sagittal T2-TSE (TR 4,100 ms, TE 102 ms, matrix 380, FOV 320, thickness 4 mm) and single-shot (SS)-SE-EPI-DWI with a value  $b$  of 800 s/mm<sup>2</sup>.

Post-processing was performed on a dedicated workstation (Leonardo, Siemens Medical Solution, Forchein, Germany).

The images obtained were analyzed both qualitatively and quantitatively. For qualitative evaluation, the images were analyzed and categorized by two experienced radiologists (AZ, GP) independently and then in a consensus review.

The signal intensities of the fractured vertebra were visually compared with that of the presumed normal vertebra on all the sequences (T1 WI, T2 WI, STIR and DWI) and categorized as hypointense, isointense or hyperintense relative to the areas of presumed normal marrow.

Statistical evaluation of the qualitative analysis between the two groups was performed using the Mann–Whitney  $U$  test.

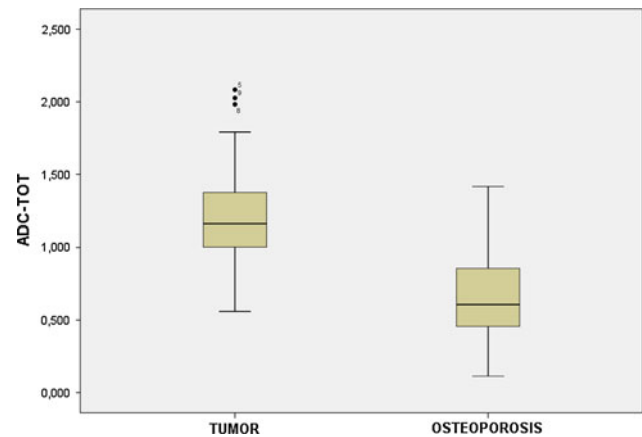
For the quantitative assessment, statistical analysis was obtained by mathematically calculating the apparent diffusion coefficient (ADC). ADC maps are automatically generated by the workstation based on three  $b$  values according to the formula  $ADC = \ln(S_0/S_1)/(b_1 - b_0)$ , where  $S_0$  and  $S_1$  are the signal intensity before and after application of diffusion gradients, and  $b_1$  and  $b_0$  are the different  $b$  values applied. The ADC is a numerical value calculated by manually placing a region of interest (ROI) over the solid portion of tumor. The size of the ROI used occupied at least three quarters of the area of abnormal or normal signal intensity but excluding the end-plates, cortical margins, disc spaces or adjacent normal or abnormal marrow.

Statistical analysis was performed with Microsoft Excel (Microsoft version 15) and MedCalc Statistical Software (version 8.1.0.0).

The histologic findings for each patient were compared with imaging findings.

## Results

Qualitative analysis of DWI MR imaging: the signal intensity of the osteoporotic vertebral fractures on the



**Fig. 1** Difference in ADC measurement between tumor fractures group and osteoporotic fractures group

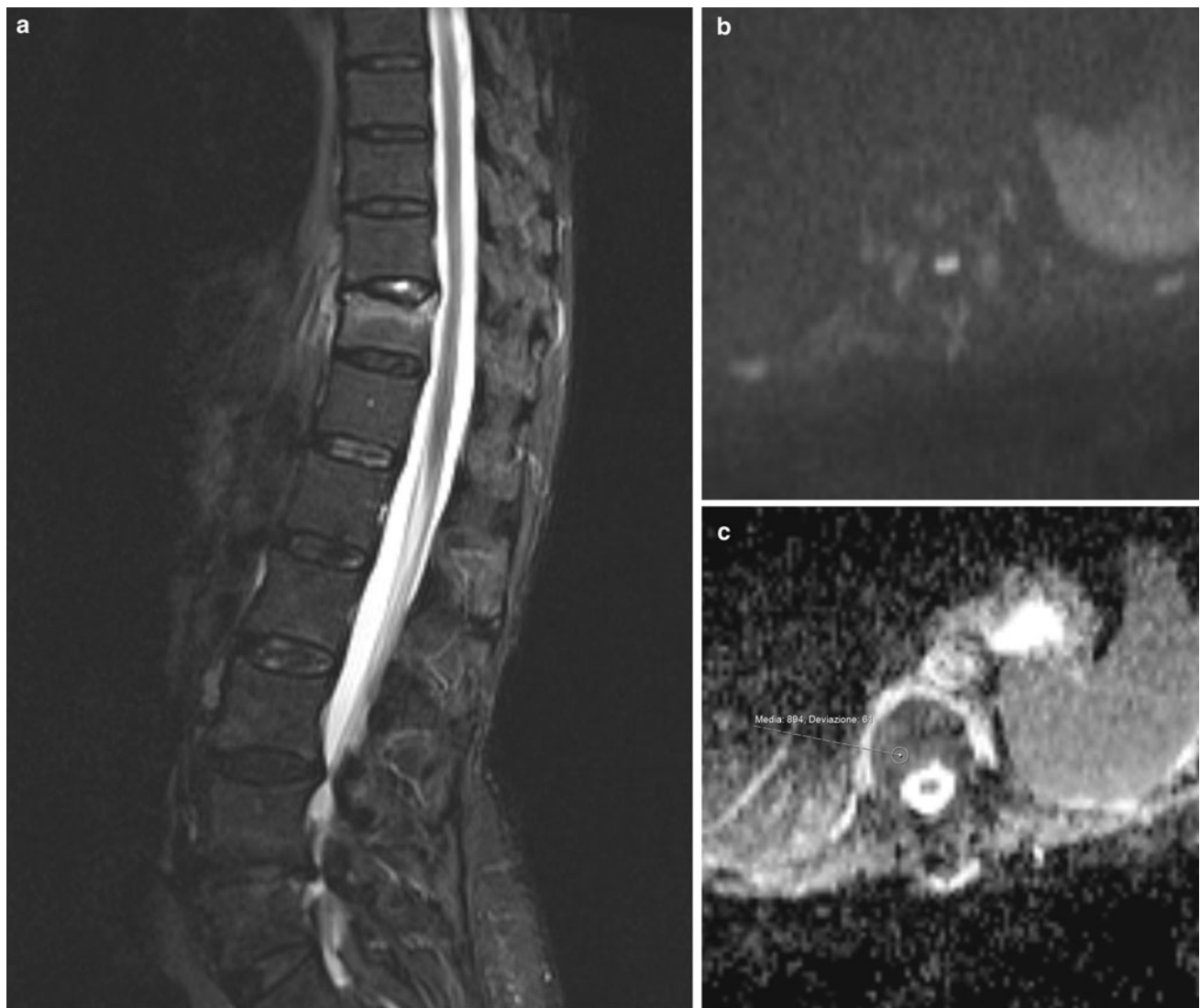
DWI was low in 90% (9/10) of lesions (Fig. 1), and isointense in 10% (1/10) of lesions. In the malignant group, the fractured vertebral bodies were hyperintense in 95.6% (22/23) of lesions (Fig. 2) and hypointense in 4% (1/23) of cases. In comparison with the histologic findings, the sensitivity and specificity of DWI was 95.6 and 90%, respectively. The positive predictive value of high signal on DWI for malignant fractures was 95.6% (22/23) (Table 1).

Quantitative analysis of DWI MR imaging: the mean ADC were calculated for each lesion. The mean ADC value for the malignant fractures was  $1.241 \times 10^{-3}$  mm<sup>2</sup>/s (range 0.56–2.1). For the osteoporotic fractures, the mean ADC value was  $0.646 \times 10^{-3}$  mm<sup>2</sup>/s (range 0.11–1.42). Normal bone mean ADC value was  $0.47 \times 10^{-3}$  mm<sup>2</sup>/s (range 0.02–0.84).

## Discussion

Benign vertebral lesions occur in approximately one-third of cancer patients [2] while metastatic vertebral lesions account for 39% of bony metastases in patients with primary neoplasm [3]. Differentiation between malignant and benign vertebral compression fracture is a common problem in management of the patients: establishing the correct diagnosis is of great importance in determining treatment, surgical approach, and prognosis [4, 5].

Although MR imaging using conventional T1 WI and T2 WI has proved helpful in differentiating between benign and malignant causes of vertebral collapse, confident diagnosis is not always possible. Morphologic signs such as the degree and pattern of bone marrow replacement, multiplicity of lesions, paravertebral soft-tissue masses, infiltration of posterior elements of the vertebrae [6, 7] and the presence of a fracture line in osteoporotic fractures (as a



**Fig. 2** **a** Sagittal STIR sequence of porotic fracture. Deformity of the endplate of T11, with edema of the vertebral body. **b** Axial DWI of T11, no hyperintensity of signal is noticed at b1000, indicating no evidence of neoplastic tissue. **c** ADC map at the same level

**Table 1** Differences between the tumor fractures group and the osteoporotic fracture group

	Tumor group ( <i>n</i> = 23)	Osteoporotic group ( <i>n</i> = 10)	<i>P</i> level
Age	56 ± 9	70 ± 9	0.256
Sex (male/female)	10/13	3/7	0.466
ADC altered signal	1.24122 ± 0.405	0.64660 ± 0.357	0.001
ADC normal bone	0.47091 ± 0.222	0.263 ± 0.204	0.021

Significant *p* < 0.05

linear hypointensity in the middle of the compressed vertebral body or adjacent to a compressed endplate) usually seen on T2 [8, 9] are common signs used for assessing the cause of the fracture. Despite the use of these features, there is still considerable overlap in the signal changes from acute to sub-acute fractures from malignant fractures as was also found in this study [10, 11].

Over the last decade, DWI MR imaging [12–14] of the vertebral body [15] has received considerable attention and has been successfully implemented for the differentiation of benign and malignant fracture edema (due to tumor infiltration) [16, 17].

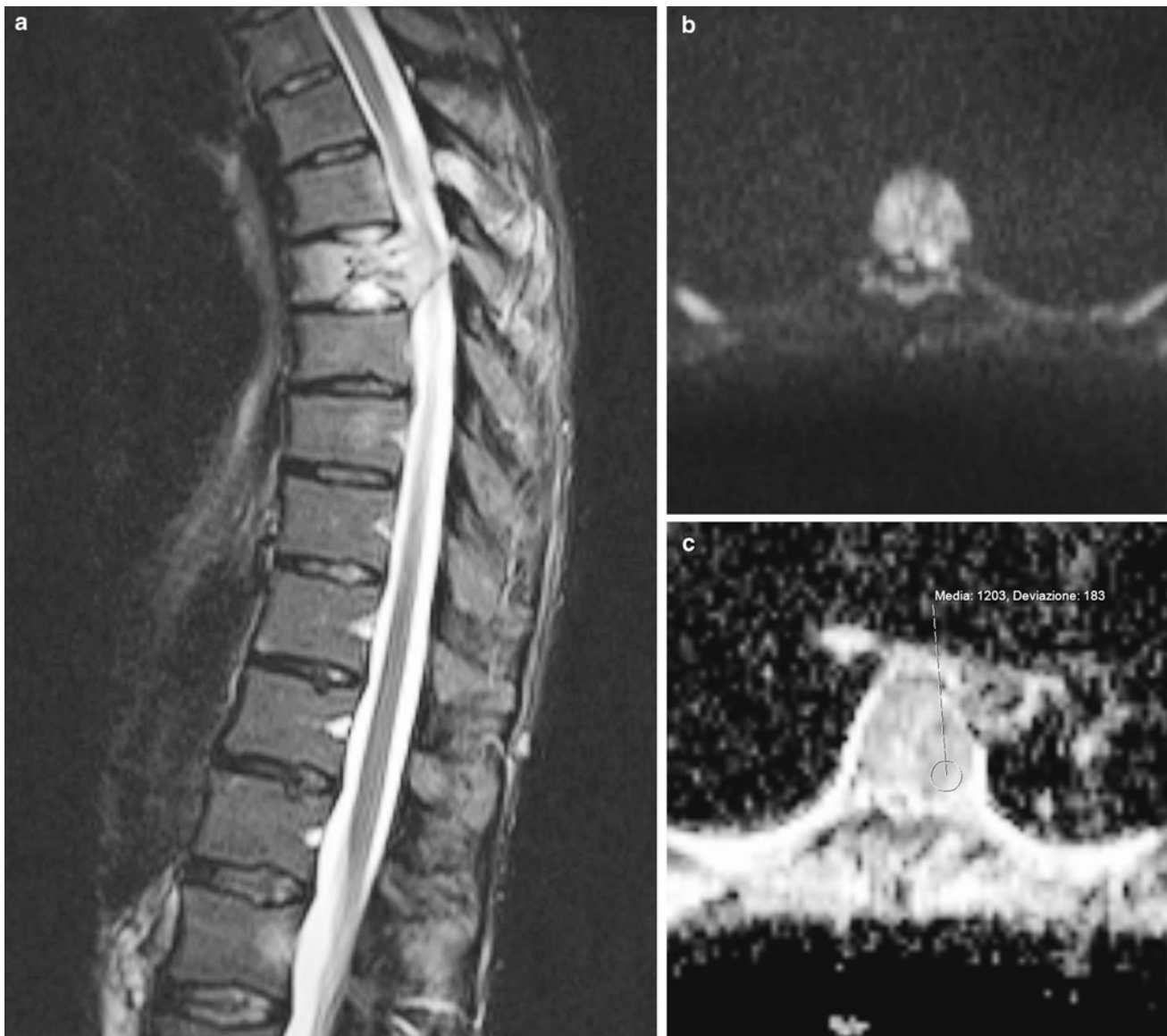
In DWI, the MRI signal intensity is sensitive to the self-diffusion, (the stochastic Brownian motion of water

molecules), which is influenced by the microscopic structure and organization of biological tissues. Technically this sensitivity is obtained by the insertion of a gradient pair [18] before image acquisition. Thus, diffusion-weighted images provide an additional contrast that is especially useful for the differentiation of normal and abnormal tissue.

This contrast can be assessed qualitatively by acquiring diffusion-weighted image data and localizing abnormal tissue as a region of decreased (increased) signal intensity caused by a higher (lower) diffusion than in normal tissue. However, this differentiation depends on the exact measurement setup, i.e., sequence choice, strength of diffusion weighting, etc. Alternatively, two or more images with

different diffusion weightings can be acquired and the ADC as a quantitative measure of diffusion can be determined from the signal attenuation at varying diffusion weightings. The strength of the diffusion weighting depends on the amplitude and duration of the diffusion gradient and is given in terms of the b-value ( $s/mm^2$ ).

The most successful application of DWI of the bone marrow is the differentiation of benign osteoporotic and malignant vertebral compression fractures, which has first been demonstrated by Baur et al. [19] in 1998. Benign osteoporotic fractures appear hypointense or isointense in DWI, while malignant fractures appear hyperintense. Several similar studies were performed [20–24] most of these being compatible with these results. However, two



**Fig. 3** **a** Sagittal STIR image of T6 fracture: notice the vertebral deformity and the high signal intensity indicating the presence of water within the vertebral body. **b, c** Axial DW imaging at the same

level (T6) showing high intensity signal at b1000, suggestive of neoplastic infiltration, and ADC map at the same level

studies showed that sclerotic metastases and treated metastases may also appear hypointense [22, 25]. In the case of sclerosis, this can be explained by the absence of water protons. This is why we excluded patient with sclerotic metastases.

Our findings are in accordance with the literature, showing high signal in 22 out of 23 neoplastic fractures and hypointensive signal in 9 out of 10 porotic fractures. Only 1 patient with porotic fracture showed isointensive signal (Fig. 3).

Several studies applied quantitative DWI to normal and pathological vertebral bone marrow (vBM) [20–22, 24].

Typical values of the ADC in normal bone marrow are in the range of  $0.2\text{--}0.5 \times 10^{-3} \text{ mm}^2/\text{s}$  [19]. Pathological bone marrow exhibits much higher diffusivities, ranging from about  $0.7$  to  $1.0 \times 10^{-3} \text{ mm}^2/\text{s}$  in metastases as well as malignant fractures, and from about  $1.0$  to  $2.0 \times 10^{-3} \text{ mm}^2/\text{s}$  in osteoporotic or traumatic fractures [26].

In our study, we found ADC values ranging from  $0.56$  to  $2.1 \times 10^{-3} \text{ mm}^2/\text{s}$  (mean 1,241) in malignant fracture. The higher ADC value was observed in one case of pathologic fracture on a non small cell lung cancer metastasis.

Although the measured ADC may be indicative for benign or malignant lesions, a considerable overlap has been described in several studies [19].

In our experience, according to the literature, we found very useful the qualitative evaluation of DWI images in differentiation between osteoporotic and malignant fractures.

ADC measures may be useful if associated to the qualitative analysis of the images.

**Conflict of interest** None.

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