The aim of this study was to reinvestigate the usefulness of diffusion-weighted MR imaging for differentiating acute benign from neoplastic vertebral compression fractures.

Thirty-three patients with 42 lesions of acute vertebral compression fractures on conventional MR imaging were examined with diffusion-weighted MR imaging using a steady-state free precession (SSFP) sequence. In 42 lesions, 24 lesions were benign osteoporotic compression fractures; the remaining 18 lesions were pathologic fractures due to metastatic tumor infiltration. All lesions were confirmed by surgical histopathology, clinical or MRI follow-up. The signal characteristics of all lesions were investigated and scored by two independent radiologists blinded to clinical information.

On diffusion-weighted imaging, all lesions with acute benign fractures showed hypo- or isointense relative to normal vertebral body reflecting edema in the vertebral marrow. Most lesions with pathologic fractures showed hyperintense relative to normal vertebral body reflecting tumor infiltration in the vertebral marrow. Statistical analysis was performed using Student’s t test, showing that there were significant difference in signal-intensity scores on diffusion-weighted imaging in these two groups (P < 0.01).

Our results confirmed that diffusion-weighted MR imaging could be a useful and practicable tool on daily works in differentiating acute benign from pathologic compression fractures.

Key words: Magnetic resonance (MR), diffusion study; Fractures; MR; Spine

Acute vertebral compression is common. However, the distinction between benign and malignant causes of vertebral collapse is sometimes difficult. Although MR imaging has proved to be helpful in such instances, confident differentiation of a benign or malignant cause is not always possible on routine MR sequences because signal changes can be quite similar [1,2]. Diffusion-weighted MR imaging reflects the random motion of water protons on a molecular basis thus could provide information of tissue characterization [3]. Recently, initial results using diffusion-weighted imaging on vertebral compression fractures showed a reduced water mobility in pathologic fractures [4]. The known distinct underlying abnormalities of acute benign compression fractures with interstitial edema versus compact accumulation of tumor cells in pathologic compression fractures indicated that diffusion-weighted MR imaging maybe helpful in such cases. Although Baur et al. have first claimed that diffusion-weighted MR imaging of bone marrow provided excellent distinction between pathologic and benign vertebral compression fractures in 1998 [4], few articles were published and the case numbers were limited. In addition, some authors claimed that diffusion-weighted MR imaging offered no advantage over routine noncontrast MR imaging [5]. Furthermore, the signal changes on diffusion-weighted imaging were all measured by
computer-assisted tools in previous studies and were time-consuming. These raised the question whether diffusion-weighted MR imaging of the spine was really reliable and practicable on daily practice. Since the effect of diffusion-weighted MR imaging of spine is controversial, we designed this study to reinvestigate the usefulness and accuracy of diffusion-weighted MR imaging for differentiating acute benign from neoplastic vertebral compression fractures.

**MATERIALS AND METHODS**

In our study, a fracture was defined as acute when bone marrow signal changes were apparent on routine MRI examinations. On the basis of routine MRI examination with T1-weighted and short-tau inversion recovery (STIR) images, diffusion-weighted MR imaging of the spine was performed in 33 patients (17 men, 16 women; age range: 40-85 years; mean age: 71 years) referred to our institutions. In addition, 31 of these 33 patients also received gadolinium-enhanced fat-suppressed T1-weighted imaging. Overall, we analyzed 42 acute vertebral compressions in these 33 patients.

These 33 patients were divided into two groups according to the final diagnoses. Group 1 consisted of 24 benign compression fractures in 20 patients. Eighteen of them had a history of minor trauma and low back pain with durations from 2 days to 3 months. Two of them complained of low back pain for about 6 months without obvious trauma history. All of the 24 lesions showed obvious bone marrow edema on conventional T1-weighted and STIR images, indicating that the fractures were at acute stage. Confirmation of the diagnosis was achieved by follow-up MRI examinations after more than 3 months in 10 patients and by surgical intervention in 3 patients. In the remaining 7 patients, the clinical history initially ruled out malignancy as the cause of the fracture, and back pain resolved completely 3-6 months after the initial MRI examination. Group 2 consisted of 18 pathologic vertebral compression fractures in 13 patients. The underlying tumors included breast cancer (n = 3), prostate cancer (n = 4), bronchogenic carcinoma (n = 1), nasopharyngeal carcinoma (n = 1), neuroendocrine cancer (n = 1), cervical carcinoma (n = 1), adenocarcinoma of colon (n = 1), adenocarcinoma of penis (n = 1). The diagnosis of a pathologic fracture was confirmed by surgery in 6 patients and by follow-up MRI examinations after 6 months in 2 patients. In the remaining 5 patients, unequivocal imaging findings in the initial MRI examination and a history of primary tumor served as confirmation of the diagnosis. Infiltration of posterior elements, multifocal metastases in other vertebra were rated as unequivocal imaging findings of malignancy [6, 7].

MR imaging was performed with a 1.5T system (Magnetom Symphony, Siemens, Germany) with a

![Figure 1](https://via.placeholder.com/150)

**Figure 1.** Images in a 75-year-old woman with two acute osteoporotic compression fractures of T12 and L1 vertebral bodies. **a.** Low signal intensity (arrows) on the T1-weighted SE image and **b.** high signal intensity (arrows) on the STIR image are indicative of bone marrow edema. **c.** Diffusion-weighted MR image shows that the compressed vertebral bodies (arrows) are hypointense to normal vertebrae.
spine array surface coil. Sagittal T1-weighted spin-echo (SE) images (567/14 [TR/TE]) and short-tau inversion recovery (STIR) images (4000/73, TI = 130 ms) with a 4 mm slice thickness were acquired in all patients (matrix: 256 × 256 ~ 256 × 512; field of view (FOV): 300 × 300 mm ~ 350 × 350 mm). The diffusion-weighted MR imaging was performed using a steady-state free precession (SSFP) sequence with the following parameters: TR = 24, TE = 6.4, matrix = 256 × 256, FOV = 320 × 320 mm, slice thickness: 5 mm, number of slice: 3, number of acquisition: 3, acquisition time: 3.06 minutes. The diffusion sensitive gradient was 23 mT/m in the read-out (head-feet) direction with diffusion pulse length of 5.0 ms. The signal generation of the diffusion-weighted SSFP sequence is strongly dependent on tissue parameters, such as the T1 and T2 relaxation times and the sequence parameters. In principal, each voxel of the image has a different b value thus no global b value can be given, as Baur et al. claimed [7].

Images were analyzed and scored by two independent radiologists blinded to the diagnosis. The signal intensity of the collapsed vertebral body in each pulse sequence (T1W SE, STIR, and SSFP) was evaluated with a five-level score: +2: markedly hyperintense; +1: slightly hyperintense; 0: isointense; -1: slightly hypointense, -2: markedly hypointense relative to adjacent normal vertebral bodies. Statistical evaluation between the two groups of fractures was then performed with the Student’s t test. AP value less than 0.01 was considered statistically significant.

RESULTS

Vertebral fractures were found from the 8th thoracic to the 5th lumbar vertebral bodies in the osteoporotic group and from the 4th cervical to the 1st sacral vertebral bodies in the tumor group. On diffusion-weighted MR imaging, the signal intensities of the fractured osteoporotic vertebral bodies were hypointense in 23 lesions and isointense in 1 lesions evaluated by the first reader. The signal intensities were determined as hypointense in 20 lesions and isointense in 4 lesions by the second reader (Fig. 1).

In the tumor group, the fractured vertebral bodies were hyperintense in 17 lesions and isointense in 1 lesion by the first reader (Fig. 2). The signal intensities were determined as hyperintense in 16 lesions, isointense in 1 lesion, and hypointense in 1 lesion by the second reader (Table 1).

The quantitative analysis of the bone marrow signal intensity was achieved by using the five-level scoring system. On diffusion-weighted imaging, the scores of benign fractures were lower than those of pathologic fractures, which was statistically significant (P < 0.01) (Table 2). The bone marrow signal intensity scores had negative values on T1-weighted images and positive values on STIR images for both

Figure 2. Images in a 86-year-old woman with bony metastases from adenocarcinoma of colon and a pathologic compression fracture of L5. a. Sagittal T1-weighted SE image shows that the fractured vertebral body (arrow) is hypointense to adjacent normal vertebral bodies. b. Sagittal STIR image shows that the fractured vertebral body (arrow) is hyperintense to adjacent normal vertebral bodies. c. Diffusion-weighted image shows that the pathologic compression fracture (arrow) is hyperintense to adjacent normal vertebral bodies.
groups (group 1 and 2). The difference in these scores was not statistically significant (P > 0.01) (Table 3).

The sensitivity, specificity, and accuracy of diffusion-weighted MR imaging in diagnosing malignant vertebral collapse were listed in Table 4.

**DISCUSSION**

In our study, the conventional MRI sequences (T1-weighted SE and STIR) showed no significant differences of signal intensity between the acute benign and pathologic compression fractures. The acute compression fractures, whether benign or malignant, showed hypointense signal changes on T1-weighted images and hyperintense signal changes on STIR images (Fig 1, 2). No statistically significant differences in the signal intensity scores were found between the two groups, either (Table 3). We also performed contrast-enhanced fat-suppressed T1-weighted imaging in most of our patients. All of them (22 benign and 18 pathologic compression fractures in 31 patients) showed contrast enhancement in various degrees. Therefore, contrast-enhanced MR imaging seemed to yield little benefits in differentiating the causes of acute vertebral compression fractures.

Since both acute benign and pathologic compression fractures exhibited similar signal changes on routine MR images, accurate diagnosis was not always possible by routine MRI examinations [8, 9]. In our study, diffusion-weighted MR imaging showed promising results in solving this diagnostic dilemma. The diffusion-weighted SSFP sequence showed a high diagnostic accuracy for differentiating acute benign osteoporotic fractures from pathologic fractures. Hypointense signal was diagnostic for an acute benign fracture, whereas high signal intensity was suggestive of pathologic infiltration.

A possible explanation for our results is that in acute osteoporotic vertebral compression fractures, the increase of free water in bone marrow due to fracture edema leads to an increase in the water mobility. In contrast, in malignant fractures the reduction of the extracellular water volume due to densely packed tumorous tissue might lead to a lower mobility of water and, therefore, an increase in signal intensity on diffusion-weighted images [4].

In addition, Spuentrup et al. hypothesized that hypointense signal changes on T1-weighted images in tumor masses reflects mainly intracellular water, whereas hypointense signal changes on T1-weighted images in benign fracture edema reflects interstitial water. Water in vital tumor cells shows lower mobility as a result of cellular structures. In the presence of diffusion-sensitizing gradients, this finding should result in a higher signal intensity compared with more mobile extracellular water in benign fracture edema. Therefore diffusion-weighted imaging may be helpful in differentiating these two entities of bone marrow edema [10]. Because diffusion effects in biologic tissues are complex and the mechanism that allows differentiation of cellular edema with intracellular water in tumor infiltration and interstitial edema in benign fractures remains speculative, further studies are needed to investigate this issue.

In our study, diffusion-weighted MR imaging provided the good accuracy (97.61% by reader 1 and 95.24% by reader 2) in differentiating the benign and malignant causes of acute vertebral compression. Using high-signal intensity on diffusion-weighted images as diagnostic criteria of malignant compression

### Table 1. Signal intensity of vertebral compression fractures on diffusion-weighted MR imaging

<table>
<thead>
<tr>
<th>Hypointense</th>
<th>Isointense</th>
<th>Hyperintense</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reader 1</td>
<td>Group 1 (n = 24)</td>
<td>23 1 0</td>
</tr>
<tr>
<td>Reader 2</td>
<td>Group 2 (n = 18)</td>
<td>0 1 17</td>
</tr>
</tbody>
</table>

### Table 2. Signal intensity scores of vertebral compression fractures on T1-weighted SE, STIR, and diffusion-weighted imaging

<table>
<thead>
<tr>
<th>Group</th>
<th>T1-weighted Imaging</th>
<th>STIR Imaging</th>
<th>Diffusion-weighted imaging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 (Benign)</td>
<td>-1.96 ± 0.20</td>
<td>1.68 ± 0.48</td>
<td>-1.83 ± 0.48</td>
</tr>
<tr>
<td>Group 2 (Malignant)</td>
<td>-1.94 ± 0.24</td>
<td>1.62 ± 0.77</td>
<td>1.72 ± 0.57</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Student’s t test (P value)</th>
<th>Reader 1</th>
<th>Reader 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>

### Table 3. Signal intensity of vertebral compression fractures on diffusion-weighted MR imaging scored by two independent readers

| Reader 1 | Group 1 (n = 24) | 23 1 0 |
| Reader 2 | Group 2 (n = 18) | 0 1 17 |

Note: data are given as the mean ± standard deviation.

Note: data were given as the mean ± standard deviation. The results shown here were from the first reader. The results from the second reader also showed that no statistically significant differences in the signal intensity scores were found between the two groups (group 1 and group 2) at T1-weighted and STIR imaging (P > 0.01).
fracture, the specificity of 100% was promising. Although very few benign lesions may show iso-signal intensity rather than hypo-signal intensity on diffusion-weighted images, hyper-signal intensity never appeared in benign compression fractures in our study.

Two lesions in group 2 (malignant group) showed false-negative results (not hyperintense on diffusion-weighted images). One was in a 49-year-old patient with nasopharyngeal carcinoma status post radiation therapy two years ago. Hyperintense fatty replacement of the C1-T2 vertebral bone marrow on diffusion-weighted imaging was noted due to post-radiation changes; therefore precise assessment of the signal changes in the lesion site (pathologic compression fracture of T3) was difficult (Fig. 3). In this case, the new metastatic sites (T3-T7), not covered by the previous radiation therapy, showed obvious hyperintense signals on diffusion-weighted images. However, fatty changes of the bone marrow (C1-T2) showed even higher signal intensity on diffusion-weighted images. Therefore the interpretation of signal changes at the lesion site (T3) on diffusion-weighted images was misled. We kept this patient in our series although he had received radiation therapy because the lesion site analyzed was not covered by previous irradiation. Moreover, we would like to demonstrate the hyperintense fat-signal on diffusion-weighted images by showing this case, which was a quite common diagnostic pitfall while interpreting the diffusion-weighted images of spine.

The other example was a patient with prostate cancer and total collapse of T3 vertebral body. The vertebral collapse was too severe to evaluate the signal intensity on diffusion-weighted images. In fact, the posterior element of T3 vertebra in this patient still showed hyper-signal intensity on diffusion-weighted images; however, it was easily overlooked on the sagittal images (Fig. 4). If these diagnostic pitfalls of diffusion-weighted MR imaging could be avoided, we believe the sensitivity and accuracy of diffusion-weighted imaging for differentiating acute benign from malignant vertebral collapse will be even higher.

The two independent radiologists showed similar...
results in interpreting the signal intensities on diffusion-weighted images with high accuracy in diagnosis (Table 1, 2, 4). We found that it was reliable and reproducible to differentiate acute compression fractures by the signal characteristics on diffusion-weighted MR images. Moreover, the diffusion-weighted SSFP sequence used in our study with 3 sagittal slices of the spine only takes 3.06 minutes. It is appropriate to add this study to routine MRI examinations if an acute compression fracture is revealed by routine MR sequences.

In conclusion, our results showed that diffusion-weighted MR imaging appeared to be a promising method for differentiating between acute benign from malignant compression fractures, and could be easily applied on daily practice. Observation of signal characteristics on diffusion-weighted MR images allowed excellent distinction between these two disease entities. Further studies to fully explain the underlying mechanism and larger scale studies are needed.

ACKNOWLEDGEMENTS

The authors thank Yu-Hsiu Yeh and Yu-Shu Wu, two responsible MRI technologists in our department, for their great support.

REFERENCES

2. Rupp RE, Ebraheim NA, Coombs RJ. Magnetic reso-
nance imaging differentiation of compression spine fractures or vertebral lesions caused by osteoporosis or tumor. Spine 1995; 20: 2499-2504
7. Baur A, Huber A, Birgit EW, et al. Diagnostic value of increased diffusion weighting of a steady-state free pre-
cession sequence for differentiating acute benign osteo-
porotic fractures from pathologic vertebral compression fractures. AJNR 2001; 22: 366-372
9. Baker LL, Goodman SB, Perkash I, Lane B, Enzmann DR. Benign versus pathologic compression fractures of vertebral bodies: assessment with conventional spie-
以擴散加權磁振造影影像區分良性及病理急性脊椎壓迫性骨折：重新探討擴散加權影像之實用性

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這個研究的主要目的，是要重新評估擴散加權磁振造影影像，在鑑別良性和惡性的急性脊椎壓迫性骨折時之實用性。

經由傳統的磁振造影檢查，我們在33位病患身上發現了42處急性脊椎壓迫性骨折之病灶。我們利用steady-state free precession（SSFP）擴散加權磁振造影影像來檢視這些病灶。在這42個病灶中，有24個是良性的、因骨質疏鬆引起的壓迫性骨折；另外的18個是因惡性腫瘤轉移造成的病理型骨折。所有的病灶都經由手術取得的組織病理分析，或是後續的臨床及磁振造影追蹤，以得到確實的診斷。這些病灶在磁振造影影像上的訊號表現，由二位不知道其最終診斷的放射科醫師，分別加以評估並給予分數。

在擴散加權磁振造影影像上，所有的良性急性脊椎壓迫性骨折，較於鄰近的正常脊椎骨，呈現出低訊號或等訊號的變化。代表了病灶處的骨髓水腫現象。相反的，絕大多數的病理型骨折呈現出高訊號的變化，反應了骨髓被腫瘤細胞所浸潤佔據的狀況。我們並以Student's t test對這二組病灶的訊號強度分數進行了統計學分析，結果發現二組病灶在擴散加權磁振造影影像上的訊號強度有明顯的差異（P值小於0.01）。

我們的研究結果，證實了用擴散加權磁振造影影像來鑑別良性和惡性的急性脊椎壓迫性骨折，是一個非常有效且可實際運用於日常工作中的方法。

關鍵詞：擴散加權造影，骨折，磁振造影，脊椎