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Diffusion-weighted MR Imaging Offers No Advantage over Routine Noncontrast MR Imaging in the Detection of Vertebral Metastases

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BACKGROUND AND PURPOSE: **Diffusion-weighted MR imaging of the spine has been used to differentiate benign from pathologic vertebral body compression fractures. We sought to determine the utility of diffusion-weighted MR imaging in the detection of vertebral metastases and to compare it with conventional noncontrast T1- and T2-weighted MR imaging.**

METHODS: **Fifteen patients with metastases to the spine were studied using conventional MR imaging and diffusion-weighted imaging. Blinded review of all images was undertaken, and patients were categorized according to whether they had focal or multiple lesions. The signal intensity of the lesions was compared on T1-, T2- (fast spin-echo), and diffusion-weighted images.**

RESULTS: **In five patients with focal disease, metastases were hypointense on T1-weighted images; hypointense (n = 2), isointense (n = 1), or hyperintense (n = 2) on T2-weighted images; and hypointense (n = 3) or hyperintense (n = 2) on diffusion-weighted images with respect to presumed normal bone marrow. In 10 patients with disease in multiple sites, all lesions were hypointense on T1-weighted images; hypointense (n = 2), isointense (n = 4), hyperintense (n = 2), or mixed (n = 2) on T2-weighted images; and hypointense (n = 5), hyperintense (n = 3), or mixed (n = 2) on diffusion-weighted images with respect to presumed normal bone marrow.**

CONCLUSION: **As used in this study, diffusion-weighted MR imaging of the spine showed no advantage in the detection and characterization of vertebral metastases as compared with noncontrast T1-weighted imaging, but was considered superior to T2-weighted imaging.**

Metastases to the vertebrae are found in 5% to 10% of all patients with cancer, particularly those with primary tumors in the breast, prostate, uterus, or lung, or in those with multiple myeloma or lymphoma (1). Most of these metastases are located in the thoracic spine, and, although the most common clinical presentation is pain, neurologic symptoms occur when there is either a fracture or tumor extension in the epidural space with compression of neural elements, or both.

Normal adult bone marrow is relatively hyperintense on T1-weighted MR images, owing to the presence of fatty marrow (2). Conversely, tumors tend to be hypointense on noncontrast T1-weighted images, reflecting replacement of fatty bone marrow, increased water content, and hypercellularity (3). Diffusion-weighted MR imaging has been used to evaluate vertebral compression fractures and shows that pathologic compression fractures are of high signal intensity, whereas benign compression vertebral fractures are relatively hypointense (4).

We sought to determine the utility of diffusion-weighted MR imaging in the detection of vertebral body metastases and compared the findings on diffusion-weighted images with those on conventional noncontrast T1- and T2-weighted images.

Methods

Fifteen consecutive patients with metastases to the spine were studied using conventional and diffusion-weighted MR imaging. The study group consisted of five men and 10 women, ranging in age from 33 to 72 years. Five patients had local disease and 10 had multiple lesions. The primary tumors were as follows: breast (n = 5), unknown primary (n = 3), lung (n = 2), prostate (n = 2), multiple myeloma (n = 1), diffuse lymphoma (n = 1), and Ewing sarcoma (n = 1). All patients had either documented metastases to other organs or metastases to the spine documented by radionuclide bone scanning; thus, the disease in the spine was assumed to represent metastases in all 15 patients. Two patients had a history of prior focal radiation therapy to the spine and presented with pre-

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Signal intensity of vertebral metastases

	Signal Intensity/ Sequence	Hypo-intense	Hyper-in-tense	Isoin-tense	Mixed Signal Intensity
Focal metastasis (n = 5)	T1-weighted	5	0	0	0
	T2-weighted	2	2	1	0
	Diffusion-weighted	3	2	0	0
Multiple level metastases (n = 10)	T1-weighted	10	0	0	0
	T2-weighted	2	2	4	2
	Diffusion-weighted	5	3	0	2

sumed metastases involving the previously treated region. All patients presented with pain; neurologic symptoms were not present.

All images were acquired using receive-only phase-array coils on 1.5-T echo planar-capable MR units. The conventional sequences included sagittal T1-weighted (500/15/1 [TR/TE/excitations]) images with 4-mm-thick sections; sagittal fast spin-echo T2-weighted (3500/90/1) images with 4-mm-thick sections; axial gradient-echo T2-weighted (650/20/2; flip angle, 30°) images with 4-mm-thick sections; and axial T1-weighted (600/15/2) images with 4-mm-thick sections. Sagittal diffusion-weighted images (22/1.0/10) were obtained with 4-mm-thick sections for a yield of 12 sections in 6 minutes 21 seconds. The b value was 165 s/mm^2 and was chosen because it has been reported to result in adequate signal-to-noise ratio within clinically acceptable imaging time periods (4). The diffusion gradient was applied only in the readout (frequency) direction, owing to equipment restrictions. The diffusion gradient strength was 24 mT/m, and its duration was 2 milliseconds. This sequence was based on reversed fast imaging with steady-state precession (4). The entire spine was imaged in all patients by using a field of view that varied from 250 to 370 mm, depending on the number of segments into which the examination was divided.

All images were reviewed by two neuroradiologists who were blinded to the patients' clinical histories (although bias may have occurred as a result of their initial review of the T1-weighted images). The patients were categorized according to those in whom the abnormalities were focal (only one vertebra found to be abnormal) and those in whom the abnormalities were multiple (more than one involved vertebra). In those with multiple-level disease, the segments involved were recorded. In all patients, the signal intensity of the abnormal vertebra(e) was visually compared with that of normal vertebrae or with residual normal vertebrae. In the absence of completely normal vertebra(e), the abnormal signal intensity was compared with that of residual vertebral foci of relatively high T1 signal intensity, which were assumed to represent normal residual fatty bone marrow. Thus, we categorized the signal intensity of the abnormal vertebrae on T1-weighted images as hypointense relative to the presumed normal marrow. The signal of the abnormal vertebrae on T2-weighted images was categorized as either hypointense, isointense, or hyperintense relative to the areas of presumed normal marrow. On the diffusion-weighted images, the areas of abnormal signal intensity were categorized as hypointense, isointense, or hyperintense with respect to the presumed normal marrow. This categorization was used for patients with focal and multiple disease. No postcontrast fat-suppression techniques were used. We then compared the results of all three sequences to establish which one provided the most useful information regarding visualization of the metastatic disease. We reviewed all medical records to establish the presence of metastatic disease elsewhere, pertinent therapy (such as prior radiation), other imaging studies documenting metastases, and primary sites.

Results

Focal Disease

In five patients with focal disease, the lumbar spine was involved in three and the thoracic spine in two. On precontrast T1-weighted images, all le-

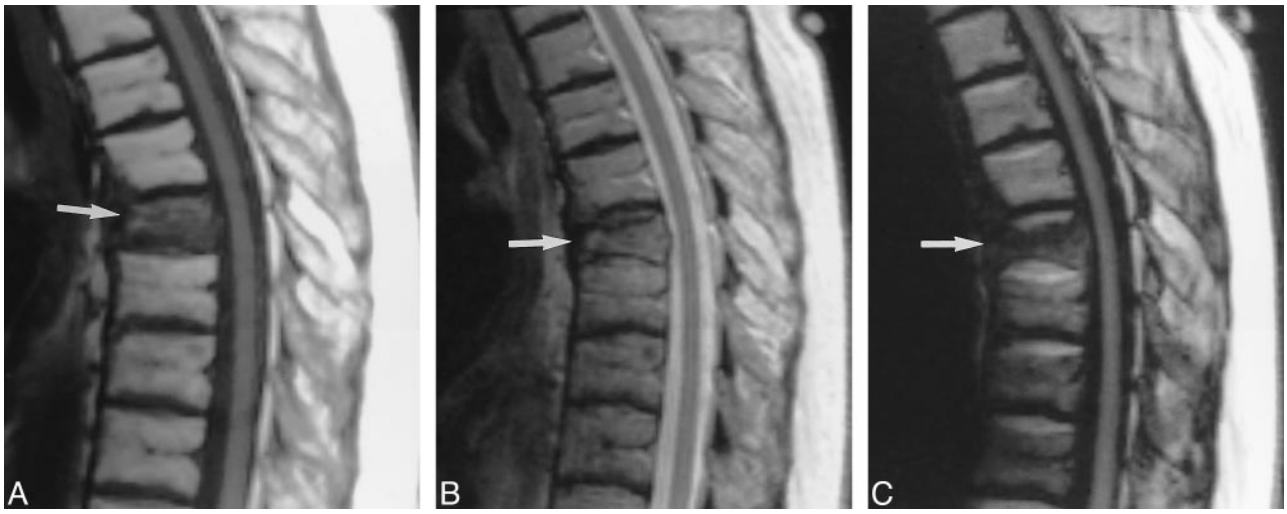

FIG 1. Involvement of a single vertebra.

A, Midsagittal T1-weighted image in a patient 6 months after spine radiation for breast metastases who presented with new pain and a positive radionuclide bone scan. This image shows hypointensity and partial wedge deformity of T7 (*arrow*). Note that vertebrae above and below the lesion are hyperintense as a result of prior radiation therapy.

B, Corresponding T2-weighted image shows lesion (*arrow*) to be minimally hypointense with respect to presumed normal bone marrow above and below.

C, Corresponding diffusion-weighted image shows that T7 (*arrow*) is hypointense relative to other vertebrae. Although the abnormality is perhaps seen better on diffusion-weighted image than on the T2-weighted image, the diffusion-weighted image is not superior to the T1-weighted image.

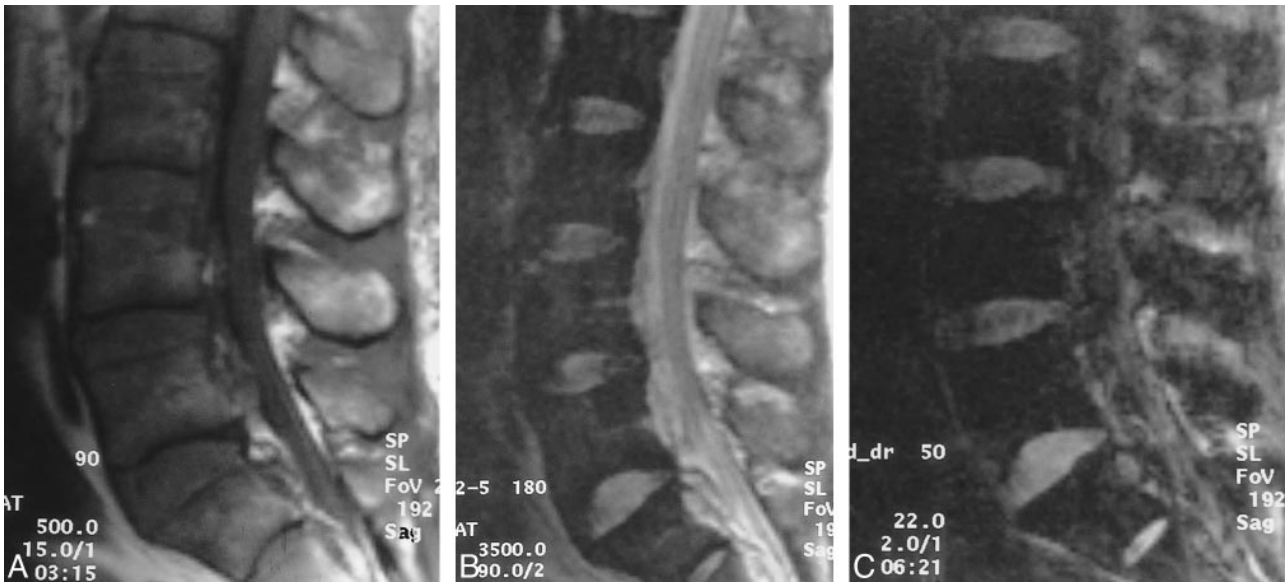

FIG 2. Patient with diffuse bone metastases from prostate cancer, with hypointensity on all sequences.
A, Midsagittal T1-weighted image shows diffuse and mostly hypointense signal intensity in lower lumbar and sacral vertebrae.
B, Corresponding T2-weighted image shows that the vertebrae are diffusely hypointense.
C, Corresponding diffusion-weighted image shows that the vertebrae involved by metastases are hypointense. This hypointensity on all sequences could be related to sclerosis seen on radiographs of this region. The abnormality is more difficult to perceive on diffusion-weighted image than on T1-weighted image.

sions were hypointense with respect to presumed normal bone marrow (Table). On T2-weighted images, the lesions were hypointense (n = 2), isointense (n = 1), or hyperintense (n = 2) with respect to presumed normal bone marrow. On diffusion-weighted images, the abnormal vertebrae were hypointense (n = 3) or hyperintense (n = 2) relative to presumed normal marrow (Fig 1). Two patients in this group had undergone prior radiation therapy of the spine. Although vertebrae adjacent to the level of focal disease showed postradiation T1 hyperintensity, the signal characteristics of the vertebrae involved by tumor were not influenced by the prior radiation (both were hypointense on T1- and diffusion-weighted sequences). Two patients had compression fractures at the site of involvement and, on diffusion-weighted images, the involved vertebrae were of low and high signal intensity, one each.

Multiple Disease

In three patients, the cervical, thoracic, and lumbar regions were diffusely and simultaneously affected. In two patients, metastases involved the cervicothoracic and thoracolumbar regions, respectively. In the other five patients, only the lumbar spine was involved, but the disease was present in more than one vertebra. In all cases, T1-weighted images showed the lesions to be hypointense with respect to presumed normal bone marrow (Table). On T2-weighted images, the lesions were hypointense (n = 2), isointense (n = 4), hyperintense (n = 2), and mixed (hypo- and hyperintense) (n = 2). On diffusion-weighted images, the diffuse metastases were either hypointense (n = 5) (Fig 2) or hyperintense (n = 3) (Fig 3) relative to presumed normal bone marrow. In two patients with hypointense metastases on diffusion-weighted images, the primary tumor was in the prostate, and diffuse bone sclerosis, seen on radiographs of the same regions, could have accounted for the hypointensity not only on diffusion-weighted images but also on T1- and T2-weighted sequences. In two patients, despite the fact that the vertebrae were of abnormal homogeneous low signal intensity on T1-weighted images, the T2- and diffusion-weighted sequences showed the vertebrae to contain mixed areas of low and high signal intensity (although mostly hyperintense) (Fig 4). It was only in these two patients that, although some regions of abnormalities were more obvious on diffusion-weighted images than on T1-weighted images, the full extent of the disease was judged to be depicted better on the T1-weighted images. There were no isointense metastases on diffusion-weighted images. No patient had compression fractures that resulted in greater than a 50% loss of height, but depression of multiple endplates was present in two patients. The vertebrae with depressed endplates showed no specific signal abnormalities on any of the imaging sequences.

Comparison between T1-, T2-, and Diffusion-weighted Sequences

In all patients, the affected vertebrae were hypointense on T1-weighted images with respect to presumed normal marrow. T2-weighted images were not considered more useful because of the

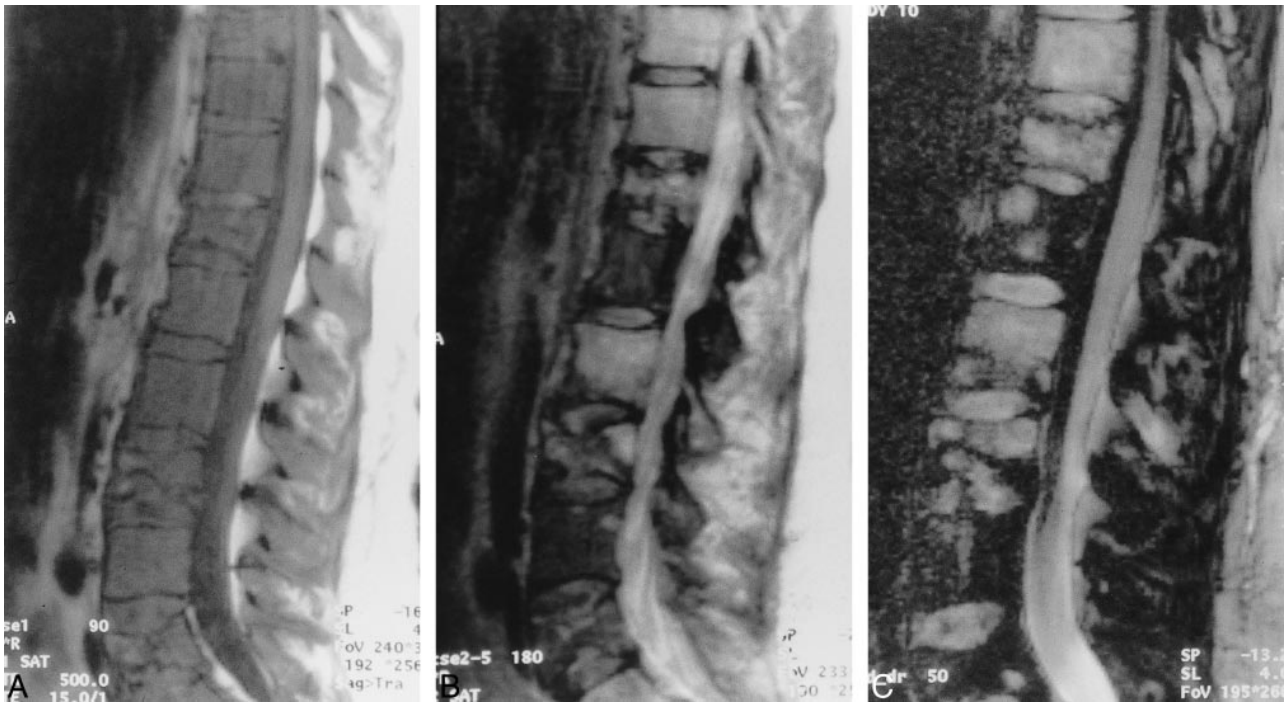

FIG 3. Patient with diffuse involvement from an unknown primary tumor, with hyperintensity on diffusion-weighted images.

A, Sagittal T1-weighted image shows diffuse hypointense metastatic involvement. There are compression fractures involving T12, T9, L5, and L3.

B, Corresponding T2-weighted image shows diffuse hyperintensity without focal lesions throughout all vertebrae visualized.

C, Corresponding diffusion-weighted image shows that the diffuse lesions are mostly hyperintense with minimal patchy appearance. The lesions are better seen on the T1-weighted image than on the T2- and diffusion-weighted sequences.

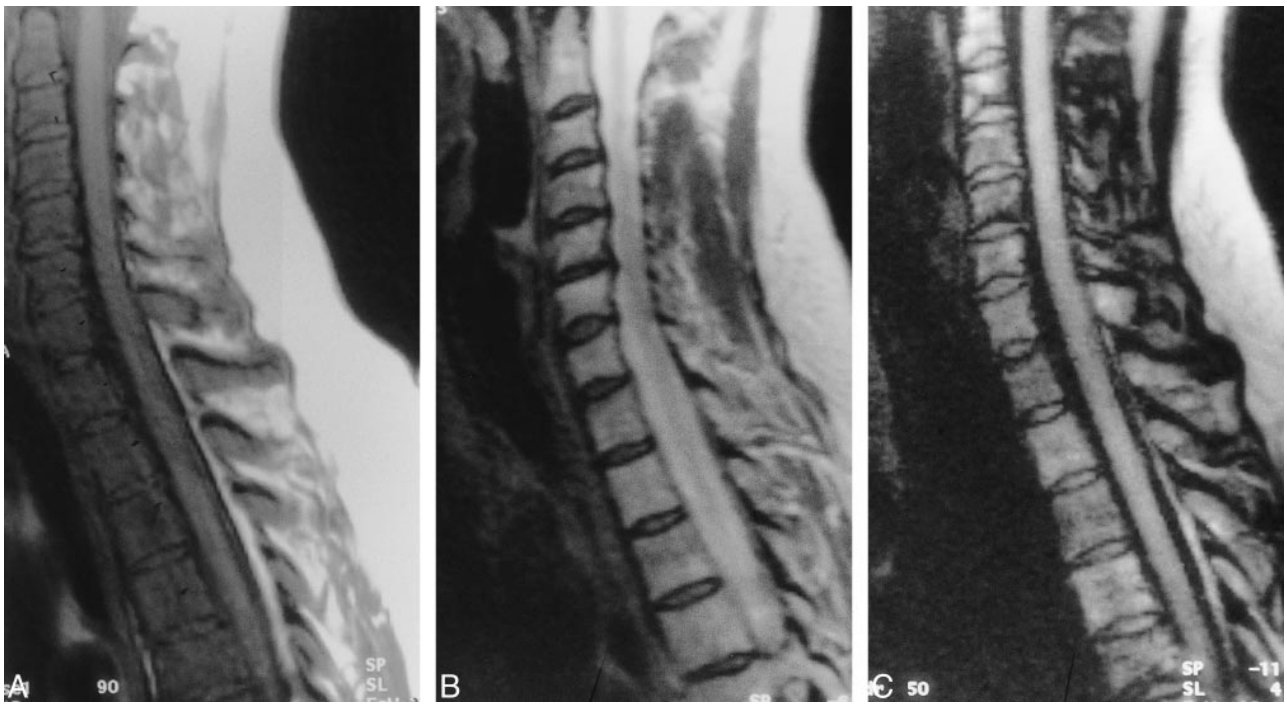

FIG 4. Patient with diffuse involvement from lung cancer, with patchy hyperintensity on diffusion-weighted images.

A, Sagittal T1-weighted image shows diffuse hypointensity throughout all visualized vertebral bodies.

B, Corresponding T2-weighted image shows patchy areas of hyperintensity mixed with hypointense regions.

C, Corresponding diffusion-weighted image shows patchy signal intensity throughout the vertebrae. The areas of increased signal intensity correspond to those seen on the T2-weighted image and, although more obvious on the diffusion-weighted image, the diffuse nature of disease is better seen on the T1-weighted image. The areas of hyperintensity on diffusion-weighted images are probably at least partially accounted for by shine-through artifact from the T2-weighted abnormalities. The inhomogeneous appearance of the CSF is due to the inherent sensitivity to macroscopic fluid motion of the type of diffusion-weighted imaging used in this study.

variability of the appearance of the metastases. On T2-weighted images, metastases were hypointense (25%), isointense (35%), or hyperintense (40%). On diffusion-weighted images, metastases were hypointense in eight patients (53%), hyperintense in five (34%), and patchy (but mostly hyperintense) in two (14%). All metastases that were bright on diffusion-weighted images were also bright on T2-weighted images. Diffusion-weighted images did not show any lesions that were not present on T1- or T2-weighted images, although in two instances the patchy appearance of the lesions on diffusion-weighted images made them easier to see than on the T1-weighted images (Fig 4). Nevertheless, the full extent of disease in these two patients was judged to be better seen on the T1-weighted images. Vertebrae that were compressed or that harbored depressed endplates showed no specific signal intensity abnormalities.

Discussion

MR imaging is an excellent method for assessing the bone marrow (3, 5). With age, active (red) marrow converts into fatty (yellow) marrow. In adults, the relatively high signal intensity of normal fatty bone marrow on T1-weighted images creates a natural contrast that helps to identify metastases and other abnormalities, such as hematopoietic reconversion, which are hypointense. It is known that MR imaging is as sensitive or perhaps even more sensitive than radionuclide bone scanning in the detection of bone marrow abnormalities and that it may serve to guide biopsy of areas of abnormal signal intensity (3). Replacement of the bone marrow always appears hypointense relative to normal marrow on T1-weighted images (3–5). This hypointensity is nonspecific. Replacement of the vertebral bone marrow may be so extensive that initially a study may be perceived as normal (6). Because of this, it has been suggested that the normal vertebral bone marrow is always hyperintense relative to normal intervertebral disks on T1-weighted images (6).

Several MR imaging techniques have been used to study spinal metastases. Contrast administration allows for identification of intramedullary spinal cord abnormalities and extradural lesions (particularly in the epidural space) that may result in compression of the spinal cord and alter proposed treatment (7). However, on conventional T1-weighted sequences, the administration of contrast material may cause metastases to enhance and become isointense with normal bone marrow, thereby obscuring them. Thus, if contrast material is administered, some authors recommend the use of sequences that suppress the signal intensity of normal fatty bone marrow, allowing for clear identification of the enhancing metastatic foci (8).

The diffusion-weighted technique has been used in brain imaging, but in the spine it has been used only to differentiate pathologic compression fractures from those caused by osteoporosis (4). On diffusion-weighted images, a pathologic vertebral compression fracture has been reported to be hyperintense with respect to normal bone marrow and a benign vertebral compression fracture to be either hypointense or isointense with respect to normal bone marrow (4). On the basis of that observation, we sought to determine whether diffusion-weighted imaging has any utility and benefit in the identification of metastatic disease to the spine as compared with other, conventional MR imaging sequences.

We chose to image our patients using a b value of 165 s/mm^2 because it results in optimal signal-to-noise ratio within a clinically acceptable time frame (4). This is important because, in many patients with metastases to the spine, the entire spine needs to be imaged, leading to a lengthy examination. Although this b value is relatively low, it has been shown that increasing it up to 650 s/mm^2 results in no additional diffusion-related information but leads to a decrease in signal. We routinely use contrast-enhanced imaging to look for epidural and intramedullary spinal cord lesions, but these sequences are not included in the analysis presented here. At our institution, fat-suppression sequences are not routinely used in an attempt to null the signal intensity of normal fatty bone marrow to make enhanced tumor more conspicuous. We reserve the use of fat-suppression imaging only for cases in which the conventional MR sequences do not fully address clinical concerns.

We found that the noncontrast T1-weighted images were most helpful in identifying vertebral metastases. All tumors were hypointense on this sequence. Compared with the T1-weighted studies, diffusion-weighted images were considered the second most useful sequence. On diffusion-weighted images, the metastases were hypointense with respect to presumed normal bone marrow in eight patients (53%), hyperintense in five (34%), and patchy (but nearly all hyperintense) in two (14%). On diffusion-weighted images, no lesion was isointense with normal bone marrow. However, because T1-weighted images are easy to acquire with all MR units and are obtained in relatively short periods of time (approximately 4 minutes 30 seconds in this study versus 6 minutes 30 seconds for diffusion-weighted images), we still consider them superior to diffusion-weighted sequences. T2-weighted images were considered less useful than T1- and diffusion-weighted studies. On T2-weighted images, the appearance of vertebral metastatic deposits was variable. On T2-weighted images, metastases were hypointense, isointense, or hyperintense. This is in contradiction with other studies, in which T2-weighted images were found to be superior to T1-weighted images in the evaluation of tumor involving the spinal bone marrow (8). T2-weighted images may be helpful in the evaluation of extraosseous tumor extension. The presence of vertebral

fractures did not appear to influence the signal abnormalities in the vertebrae of our patients.

The low signal intensity of metastases on diffusion-weighted images probably reflects a combination of factors. We believe that despite tumor-related hypercellularity within a vertebra(e), the extracellular space probably remains normal (or near normal) and the water it contains is relatively free to have brownian (random) motion, leading to spin dephasing and loss of signal on diffusion-weighted images. In two of our patients, the vertebral hypointensity seen on all sequences was probably related to bone sclerosis associated with prostatic metastases, as seen on radiographs corresponding to those regions. In cases in which lesions are hyperintense on diffusion-weighted images, the opposite also may be true. That is, increased tumor cell packing may lead to a smaller and more restricted extracellular space, resulting in increased signal from restricted water protons. This decreased amount of free water as well as its restricted mobility due to hypercellularity may result in increased signal intensity on diffusion-weighted images. It has been observed that spinal tumor in the presence of vertebral body compression fractures is of high signal intensity on diffusion-weighted images, possibly by virtue of tumor packing and restriction of brownian motion in the extracellular spaces (4). The fact that the five lesions that showed hyperintensity on diffusion-weighted images were also hyperintense on T2-weighted images implies that some degree of shine-through phenomenon was present and contributed to the findings on diffusion-weighted images. Because we did not obtain diffusion-weighted images with a lower b value or calculated apparent diffusion coefficient maps, it is not possible to quantify the contribution of tissues with long relaxation times on T2-weighted images to the findings on diffusion-weighted images. Therefore, it is not possible to determine the degree of true diffusion abnormality contributing to the findings on diffusion-weighted images. However, we propose that shine-through from the T2-weighted images may be an important factor contributing to the hyperintensity of vertebral metastases on diffusion-weighted images. Trace diffusion-weighted imaging, which we were not able to perform because of technical limitations, should decrease the T2 shine-through. In our cases, it was not of critical importance to ascertain whether a compression fracture was pathologic or benign, as all patients were known to have diffuse metastatic disease. The appearance of the lesions in two patients with a history of radiation therapy to that area was no different from that in the untreated patients.

Conclusion

We found that low-strength diffusion-weighted images showed vertebral metastases in all patients but that conventional noncontrast T1-weighted images were of superior quality. On T1-weighted images, all tumors were hypointense with respect to normal bone marrow, whereas on diffusion-weighted images they were hypointense, hyperintense, or patchy. All hyperintense lesions on diffusion-weighted images were also hyperintense on T2-weighted images, and shine-through from tissues with long relaxation times may have contributed to their appearance on diffusion-weighted images.

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