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Diffusion-weighted Imaging of Acute Vertebral Compressions: Specific Diagnosis of Benign Versus Malignant Pathologic Fractures

In this issue of the *AJNR*, Bauer et al (page 366) publish their second major article showing the high accuracy of MR diffusion-weighted scanning in discriminating acute benign from malignant pathologic vertebral compression fractures. The differentiation between benign and malignant compression fractures of the spine is a common neuroimaging task with important clinical impact. A large percentage of osseous lesions in patients with metastatic malignancies occur in the spine, and it is a critical site for pathologic fractures. Benign osteoporotic and traumatic compression fractures are also extremely common, especially in elderly patients, patients with chronic metabolic and nutritional deficiencies, and patients with traumatic injuries to the spinal axis. It is important to remember that even in patients with a prior history of malignancy, benign vertebral fractures occur frequently.

Vertebral fractures may be detected on radiographs, CT scans, or radionuclide bone scans, but in today's clinical environment, the specific discrimination between benign and malignant vertebral compression fractures relies heavily on MR imaging features. Previous studies have described several MR features of varying utility, including: 1) the marrow-space signal intensity on various sequences, 2) the location and extent of the signal abnormalities in the compressed vertebral body, 3) involvement of the pedicles and neural arch structures, 4) the presence of epidural or paravertebral soft-tissue masses, 5) the contour of the dorsal cortex of the involved vertebral body, 6) the presence of other spinal metastases, 7) the presence of associated disk herniations, and 8) the contrast enhancement patterns (1–4). Applying these criteria, studies have established an accuracy for MR imaging in the 79–94% range, depending on the methods used and the patients selected (1–3). With adequate scan quality, application of some of the above observations, and a clinical history, I believe that a diagnosis of ''probable'' or ''definite'' benign- or malignant-appearing fracture is made in routine clinical interpretations well over 90% of the time (in terms of a five-point scale for a receiver operating characteristic analysis). The occurrence of ''unknown'' or ''on the fence'' vertebral fractures in routine clinical work is, in my experience, probably a few percent. But appearance is not everything; I am sure all of us have seen benign-appearing fractures that were subsequently determined to be malignant, as well as malignant-appearing fractures that were proven benign by biopsy or follow-up scanning.

I believe there are four patient selection issues that weigh critically on the literature's stated accuracy of conventional MR imaging in this application: 1) the relative number of patients with chronic osteoporotic compression deformities and remote traumatic compression fractures, which are readily diagnosed by the fatty marrow-space signal intensity on unenhanced T1-weighted images, 2) the number of patients with multiple, typical-appearing spinal metastases, for which the pathologic nature of the fracture is readily apparent, 3) the number of acute benign fractures, which may be difficult to ascertain on the basis of MR imaging features alone, but clinical history can usually aid in the diagnosis, and 4) the number of patients with multiple myeloma, for which it is well known that vertebral compressions often appear benign despite diffuse marrow-space disease (5). Of the MR imaging features listed above, one of special note with respect to this editorial matter is that untreated metastatic spinal lesions most frequently have hyperintense signal on T2-weighted scans, occurring 85–100% of the time (1–4). Exceptions to this include sclerotic metastases, such as from prostate carcinoma, and metastatic lesions in patients that have undergone various treatments resulting in lesion or marrow fibrosis and sclerosis. Of course, acute benign compression fractures are associated with local marrow edema, and they also regularly show hyperintense signal on T2-weighted scans. Therefore, signal intensity on T2-weighted scans has not been proven to be a highly reliable discriminator between acute benign and pathologic vertebral compression fractures.

Bauer et al published their first major article on this subject in *Radiology* in 1998 (6). They described a steady-state free precession (SSFP) MR diffusion technique that showed malignant pathologic fractures to be high in signal intensity compared to normal bone marrow, and benign osteoporotic and traumatic fractures to be low in signal intensity. Using a quantitative parameter termed the bone marrow contrast ratio, Bauer et al showed 100% accuracy in discriminating the 22 benign and 17 pathologic compression fractures included in their study, on the basis of lesion signal intensity on diffusion-weighted scans alone. T1-weighted spin-echo (SE) and T2-weighted short-inversion-time inversion recovery (STIR) scans detected all fractures, but there was no discriminatory power based on signal intensity or bone marrow contrast ratio. All fractures, benign and malignant, were low in signal on T1-weighted scans, and high in signal on T2-weighted STIR scans. I must admit to being quite intrigued at the time by this application of diffusion scanning.

In the May 2000 issue of the *AJNR*, Castillo et al (7) published the second major article on diffu-

sion-weighted scanning of vertebral compression fractures, with quite different results. They demonstrated no advantage of diffusion-weighted scanning in the detection or characterization of vertebral metastases. They used a virtually identical SSFP diffusion scanning technique as Bauer et al (6), but had a different selection of tumors, with only four of 15 metastases being hyperintense on T2-weighted scans. Castillo et al found only 34% of metastases to be hyperintense on diffusion scans; 53% of the metastatic compression fractures were hypointense on the diffusion scans, and the rest had patchy or inhomogeneous signal changes (7). They also noted that all the metastatic lesions that were hyperintense on diffusion scans were also hyperintense on T2-weighted scans, and they suggested that T2 shine-through may be playing a prominent role in the appearance of the metastatic lesions.

The current article by Bauer et al was probably submitted about the same time that the Castillo et al article was published. The article by Castillo et al is not included among the references in Bauer et al's current article, and the critical contradictory issues raised in Castillo et al's article are unfortunately not discussed. Bauer et al refined their method by addressing the signal patterns of benign and malignant compression fractures on SSFP scans with several increasing levels of diffusion weighting. Again, they describe signal intensities and quantify data using the bone marrow contrast ratio, and demonstrate an accuracy of 100% in discriminating benign from malignant vertebral compression fractures. What is the explanation for these contradictions?

I believe we are dealing with patient selection bias in small preliminary studies, and a diffusion method that has some limitations. Neither of these issues is particularly unusual, nor necessarily a mortal blow to pioneering research. Bauer et al used the SSFP diffusion technique because it worked, with reasonable scan times. There has been considerable difficulty producing adequate quality diffusion-weighted echo-planar MR images (EPI) of the spine, and SE diffusion techniques take too long and have substantial gross motion artifacts. In Bauer et al's technique, the SSFP scans are heavily T2 weighted, with diffusion weighting applied only in the readout axis (craniocaudal dimension). Greater diffusion weighting is imparted by increasing the diffusion pulse length, which fortunately does not have a major impact on the T2 weighting of this SSFP technique, because other sequence parameters are fixed. The scans are single slice, with scan times of 1–3.5 minutes, depending on the number of acquisitions used (10–40 acquisitions). The ''base'' images are evaluated, and clearly these images are going to be highly influenced by T2 shine-through effects. Bauer et al's two studies have really shown the same basic results. Patients with hyperintense metastatic lesions on T2-weighted scans have hyperintense metastatic lesions on their T2-weighted SSFP diffusion scans, and the hyperintense signal associated with acute benign compression fractures seems to be more suppressible by increased diffusion weighting. Refining their technique by incorporating images with progressively increased diffusion weighting clearly begs the adoption of a quantitative evaluation method such as apparent diffusion coefficient mapping, which should help discriminate T2 shine-through from actual diffusional variations between tissues. Unfortunately, the steady-state nature of the sequence makes the mathematical description of the diffusion method complex, dependent on all the factors influencing the evolution of the steady-state signal in various tissues.

In conclusion, the study of Bauer et al in this issue renews the faith that there probably is potential for diffusion-weighted imaging of selected pathologic vertebral compression fractures. Nonetheless, an understanding of patient selection and technical issues certainly indicates that additional work is needed before embracing this application. I believe that furthering the science in this field will eventually require dropping the SSFP method in favor of the more conventional Stejskal-Tanner–type diffusion methods, which will facilitate quantitative diffusion analyses. Our frequently performed cervical-thoracic-lumbar survey examinations for metastatic disease would clearly be prolonged by performing the SSFP diffusion method with several levels of diffusion weighting, which would also compel the use of single or multishot EPI methods. Finally, whether the diffusion scans provide unique information that significantly impacts the accuracy of diagnostic interpretations has yet to be shown.

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