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Commentary

Diffusion-Weighted MR Imaging: A Useful Adjunct to Clinical Diagnosis or a Scientific Curiosity?

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It has been appreciated from the earliest development of MR imaging that MR images are exquisitely sensitive to motion. This sensitivity remains the major limitation in the application of MR to the body. However, it also has been appreciated that motion is not simply a problematic source of artifact. Motion sensitivity can be used to advantage in sequences designed to highlight the flow sensitivity in blood, making possible MR angiography. Provided flow and pulsatile motion can be controlled satisfactorily, motions as small as those arising from perfusion and diffusion can be used to enhance contrast in specially sensitized MR imaging sequences.

The pioneering work of Le Bihan et al. [1] in 1986 showed that MR pulse sequences can be sensitized to perfusion and diffusion. This sensitization showed specificity for certain neurologic disorders. The diffusion sensitivity of such images was based on straightforward physical principles, which had been elucidated two and three decades earlier [2, 3]. The MR acquisition records two interleaved images: (1) a standard spin-echo image and (2) an identical image with additional balanced diffusion-gradient pulses that have no effect on static spins but result in a loss of phase coherence for randomly diffusing spins. Subtraction of the second diffusion-sensitive image from the first reference image results in a much noisier image in which the contrast is proportional to the diffusion coefficient at least for pure static liquids. In a patient, a large number of additional factors contribute to this different image. The contrast is therefore referred to as an apparent diffusion coefficient (ADC). If the diffusion-encoding gradients are comparatively weak, the contrast in the ADC image will depend on susceptibility, perfusion, and restricted diffusion [4], but as the strength of the diffusion-encoding gradients becomes greater, the contrast becomes dependent primarily on diffusion [5].

By 1988, ADC imaging had attracted the attention of a number of groups. More than a dozen papers at the Society of Magnetic Resonance in Medicine meeting in San Francisco in 1988 reported preliminary results of the appearance of a variety of pathologic conditions on ADC images.

Despite the interest and enthusiasm, it was clear that ADC imaging still had a number of technologic problems: (1) Persistent eddy currents arising from large pulse gradients can contribute to signal intensity in nondiffusing tissue. This problem has been resolved to a large degree with the advent of self-shielded gradients with markedly diminished eddy current properties (Le Bihan et al., paper presented at the annual meeting of the Society of Magnetic Resonance Imaging, Los Angeles, 1989). (2) Motion seriously degrades ADC images. The sensitivity of ADC imaging to the small motion associated with diffusion makes the technique highly sensitive to any displacement motion of the tissue. Restriction of motion has required restraint of the head by means of sophisticated packing techniques and even sedation. Multiple averages and gradient-moment-nulling techniques also reduce the effect of patient motion and flow. Nonetheless, use of ADC imaging is restricted to the head, and even there residual motion of the

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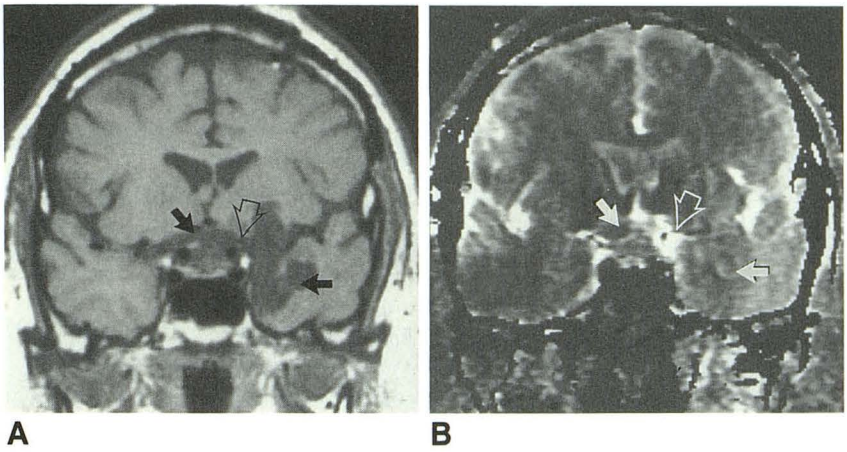

Fig. 1.—*A* and *B*, On T1-weighted MR image (*A*), regions of suspected tumor (*solid arrows*) cannot be distinguished from cisternal CSF (*open arrow*). On apparent diffusion coefficient (ADC) image (*B*), ADC of tumor is equivalent to that of parenchyma brain (*solid arrows*), indicating solid nature of mass. (Reprinted with permission from Tsuruda et al. [6].)

orbits can seriously degrade ADC images. More recently, apparent diffusion sensitization has been combined with echo-planar imaging to diminish some of the impact of tissue motion. (3) Even when gross tissue motion is controlled, small-amplitude pulsatile motion makes significant contributions to the ADC. Cardiac gating is required to diminish this effect in ADC imaging, although it is unlikely to eliminate pulsation completely as a source of some of the contrast.

Thus, reliable ADC imaging requires careful control of other confounding sources of motion that could contribute apparent contrast. The appropriate management of all motion other than diffusion is essential for reliable ADC contrast. Although many helpful techniques have been worked out, reliable ADC contrast cannot be achieved in every study.

What kind of medically useful information can be obtained from ADC images? Does it provide a useful adjunct for differential diagnosis? Or is ADC imaging simply another example of MR technical wizardry? Will it remain simply a scientific curiosity?

This issue of *AJNR* presents an example [6] of clinical problems for which ADC imaging provides additional useful information. Tsuruda et al. have shown that ADC imaging can help differentiate between extradural cysts and epidermoid tumors, which can appear identical on T2-weighted sequences. The epidermoid tumors, which are generally more solid than arachnoid cysts, lead to less ADC contrast than is seen in CSF (Fig. 1). Bulk flow of nonencapsulated CSF yields an even greater ADC and allows ready distinction of arachnoid cysts from the surrounding CSF. This appears to be a better method for differentiating arachnoid cysts than the one that uses the flow sensitivity of gradient-echo sequences [7].

The article by Moseley et al. [8] in the May/June 1990 issue of *AJNR* reports that regions of brain ischemia show a twofold decrease in ADC 1 hr after the loss of vascular supply, whereas T2 contrast changes require 5 hr to develop. The cause of the decrease in ADC is not yet fully understood. It is unlikely to be due to changes in intracellular edema at this early time and simply may arise from reduced pulsatility in the ischemic region. Alternatively, it could arise from a decrease in temperature in the infarcted region with an associated decrease in the diffusion coefficient. Whatever the mechanism of action may be, it appears to be a reproducible and reliable correlate of ischemia.

ADC imaging also can be used to distinguish necrotic regions within tumors from viable tumor cells. The necrotic region with degraded cell walls shows a higher ADC than the viable tumor tissue does. Enhanced apparent diffusion contrast correlates with extracellular gadolinium contrast en-

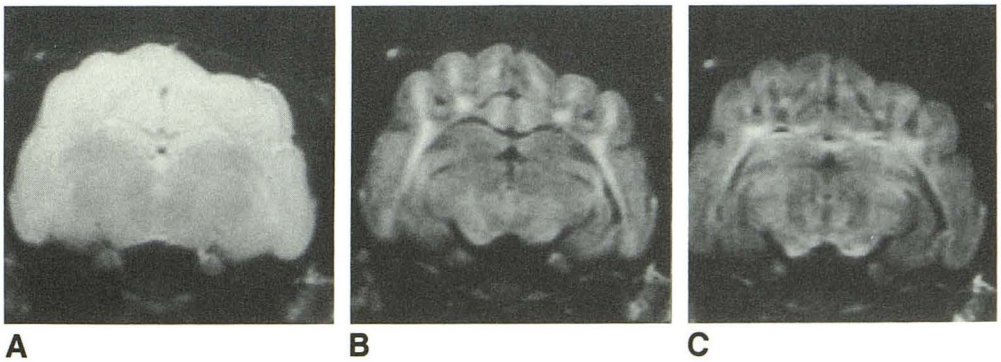

Fig. 2.—*A–C*, T2-weighted (*A*) and diffusion-weighted (*B* and *C*) coronal MR images of cat brain. Direction of diffusion-sensitizing gradient is left to right in *B* and top to bottom in *C*. When white-matter tracts are oriented parallel to direction of diffusion gradient, fast directional diffusion of water is indicated by regions of hypointensity. (Reprinted with permission from Moseley et al. [7].)

hancement in the necrotic regions (Moseley ME, personal communication).

Thus, several areas of clinical diagnosis already are benefiting from ADC imaging. As the technique becomes more widely established, undoubtedly additional problems in differential diagnosis will benefit from the unique information provided by this new form of MR contrast.

Beyond immediate diagnostic applications, ADC imaging is providing fundamental insights into the nature of relaxation processes in MR imaging. Recent work by Moseley et al. (personal communication) shows that the ADC has a marked directional dependence in white matter, which is probably a reflection of the restricted diffusion of water within the layers of the myelin sheath (Fig. 2). Similar restricted diffusion has been detected in MR spectroscopy of phosphorus metabolites in muscle [9]. These kinds of measurement, which are unlikely to be of immediate diagnostic use, provide deeper insight into the mechanistic processes that give rise to relaxation contrast in MR imaging. As these processes are understood more completely, it is likely that much more specific imaging acquisition sequences with unique contrast characteristics can be developed to exploit such contrast mechanisms.

Diffusion-weighted MR imaging is here to stay. It already has demonstrated its ability to provide differential diagnostic information. It also is beginning to give us new information that enhances our understanding of the mechanisms of tissue relaxation themselves, satisfying our scientific curiosity *and* promising further contributions to reliable clinical diagnoses.

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