Nonischemic causes of hyperintense signals on diffusion-weighted magnetic resonance images: a pictorial essay

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Diffusion-weighted magnetic resonance imaging (MRI) allows for tissue characterization on the basis of microscopic intravoxel incoherent (diffusional) motion of water. Diffusion-weighted MRI is performed by applying a pair of pulsed magnetic field gradients in association with a 90°–180° spin-echo pulse; this results in varying degrees of signal loss according to the rate of diffusion (i.e., random motion) of water molecules within tissue. The rate of signal loss depends on a number of factors, including some that are operator dependent (e.g., strength and duration of gradient pulses) and some that are tissue specific (e.g., microscopic structure of the tissue).

The hyperintense appearance of acute cerebral infarction on diffusion-weighted magnetic resonance images has been well outlined in numerous reports. In this pictorial essay, increased signal intensity on diffusion-weighted images due to causes other than acute cerebral ischemia are reviewed.

Hyperintense signal due to normal anisotropic diffusion

In the normal brain, water does not diffuse uniformly in all directions, but is restricted by the presence of highly ordered white-matter pathways. Diffusion is relatively unimpeded along such pathways, but is relatively restricted perpendicular to the path of a white-matter tract; this phenomenon is termed anisotropy. In clinical practice, anisotropy becomes an important consideration when diffusion-weighted MRI is performed using a diffusion gradient in a single direction and the rate of tissue water diffusion (measured as the apparent diffusion coefficient [ADC]) is sampled in only 1 direction. Even normal diffusional motion along white-matter pathways that are perpendicular to the applied diffusion gradient will appear to be restricted (i.e., have a decreased ADC) and can simulate restricted diffusion due to other causes (e.g., infarction) (see Fig. 1). This problem is alleviated by sampling the ADC in many directions, usually 3, and a summed image that gives the average diffusional motion for all sampled directions (termed a trace-weighted image) can be produced that is relatively free of anisotropy effects (Fig. 1). It is also possible to compute the ADC in each voxel and display these values as a map; ADC maps display signal intensity solely on the basis of relative differences in tissue diffusion and allow quantitative measurements of the ADC. Such maps are useful for measuring the degree of diffusion abnormality in lesions, which can be helpful in characterizing lesions and obtaining a rough estimate of infarction age.

Increased signal intensity due to T₂-prolongation effects

Unlike the signal intensities displayed on ADC maps, the appearance of
tissues on diffusion-weighted images is dependent not only on signal properties associated with the random motion of water molecules but also on T₂-relaxation properties. Approximately 7–10 days after infarction occurs, ADC values return to normal levels again, even though the infarct is hyperintense on T₂-weighted images. At this point and for some weeks thereafter, infarcts can appear bright on diffusion-weighted images, despite normal ADC values, because of T₂-prolongation effects.¹ This phenomenon has been termed

FIG. 1: Diffusion-weighted magnetic resonance images in a 63-year-old woman with a 1-day history of right hemiparesis showing 2 causes of hyperintense signal (acute cerebral infarction and anisotropy effects).
A: T₂-weighted image shows 2 foci of hyperintense signal (arrowheads) within the posterior limb of the left internal capsule, consistent with infarction.
B: Axial trace-weighted diffusion-weighted image, which represents a composite of diffusion gradients applied in 3 directions (and is therefore relatively free of anisotropy effects), shows a region of hyperintense signal consistent with acute infarction.
C: Axial diffusion-weighted image obtained with diffusion gradient applied solely in the superior–inferior direction shows regions of hyperintense signal (arrows) that are not seen on trace-weighted image in B and represent anisotropy effects due to the diffusion gradient being applied perpendicular to the course of white matter tracts.
D: Axial diffusion-weighted image obtained with diffusion gradient applied solely in the right–left direction shows regions of hyperintense signal (arrows) that are not seen on the trace-weighted image in B or on the single-direction diffusion gradient image in C. The regions of hyperintense signal represent anisotropy effects.
E: Axial diffusion-weighted image obtained with diffusion gradient applied solely in the anterior–posterior direction shows regions of hyperintense signal (arrows) that are not seen in B, C, or D and are due to anisotropy effects.
F: Axial apparent diffusion coefficient (ADC) map reveals areas of decreased signal (arrows) corresponding to the regions of hyperintense signal seen in B, confirming acute infarction.
the $T_2$ shine-through effect (Fig. 2). If this effect is not considered when evaluating an infarct that is bright on diffusion-weighted images, a subacute or chronic infarct can be mistakenly determined to be acute. ADC maps have no contribution from $T_2$ effects and are useful to differentiate areas of truly restricted diffusion from $T_2$ shine-through (Fig. 2).

**Hyperintense appearance due to nonischemic lesions**

**CNS infections**

Cerebral abscesses in diffusion-weighted imaging studies have been reported to have a hyperintense appearance relative to normal tissue, reflecting restricted diffusion and confirmed by lower ADC values on ADC maps. Restricted water diffusion, which has been postulated to be caused by the viscous nature of pus, has been seen within large abscesses (Fig. 3). However, in our experience hyperintense signal also seen on diffusion-weighted images of small abscesses is likely due to $T_2$ prolongation, or shine-through, rather than restricted diffusion because ADC values are not decreased.

Diffusion-weighted MRI of herpesvirus type 1 encephalitis has also shown hyperintense lesions (Fig. 4) in association with decreased ADC values. Restricted microscopic water diffusion noted in patients with encephalitis has been attributed to cytotoxic edema secondary to cell death.

**FIG. 2:** Magnetic resonance images in a 72-year-old man with a 10-day history of ataxia showing hyperintense signal due to $T_2$-prolongation effects (so-called $T_2$ shine-through) associated with subacute infarct rather than restricted diffusion associated with acute infarction.

A: Axial $T_2$-weighted image shows region of hyperintense signal (arrow) in the left cerebellar hemisphere, consistent with infarction.

B: Axial trace-weighted diffusion-weighted image shows region of hyperintense signal in left cerebellar hemisphere (arrow). Relative contributions of restricted diffusion (seen in acute infarction) and $T_2$-prolongation effects are not evident.

C: Axial ADC map shows region of hyperintense signal seen in B (arrow) appears normal. Normal ADC values within this region indicate that the lesion seen in B is subacute (rather than acute) and that the hyperintense signal represents $T_2$ shine-through effect.
Seizure foci

Although infrequently seen on diffusion-weighted imaging, epileptogenic foci in patients with complex partial status epilepticus are a non-ischemic cause of hyperintense signal. The hyperintense appearance of epileptic regions correlates with low ADC values and indicates the presence of cytotoxic edema (Fig. 5). The hyperintensity is thought to be due to changes in the proportion of water in extracellular...
and intracellular compartments, possibly reflecting failure of the sodium–potassium adenosine triphosphatase pump caused by energy depletion. As such, diffusion-weighted imaging abnormalities due to continuous seizures are potentially reversible, but if prolonged, continuous seizures can cause irreversible changes, as seen on follow-up T₂-weighted images.

Trauma

Cranial trauma produces lesions that are hyperintense on diffusion-weighted imaging, a result of cytotoxic edema (Fig. 6). Such lesions exhibit decreased ADC values on ADC maps and could potentially be mistaken for cerebral infarction. In the absence of a clinical history, the distribution of lesions is a primary means...
of distinguishing these entities. Traumatic injury typically occurs at a few specific locations: at the grey–white matter junction and corpus callosum (diffuse axonal injury), cerebral cortex (contusion) and basal ganglia and thalamus (deep grey matter injury).

Neoplasms

Most reports of diffusion-weighted imaging of cerebral neoplasms have indicated better water diffusion through neoplasms than through normal brain tissue. However, neoplasms can occasionally have a hyperintense appearance on diffusion-weighted MRI (Fig. 7). Although, in some cases, this may be due to dense small-cell packing and restricted extracellular diffusion, the hyperintense appearance of tumours on diffusion-weighted images is likely most often due to T2 shine-through effects (Fig. 7).

SUMMARY

A number of entities other than acute cerebral infarction can produce bright signal intensity on diffusion-weighted magnetic resonance images, and an understanding of the range of possible diagnoses for these hyperintense lesions is important for radiologists who must interpret these images.

REFERENCES