Technical Innovation

Use of MR Exponential Diffusion-Weighted Images to Eradicate T2 "Shine-Through" Effect

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Diffusion-weighted MR imaging has been shown to be a valuable tool in the characterization of brain lesions [1, 2]. In particular, diffusion-weighted imaging is useful in discriminating acute cerebral infarction, which appears hyperintense on diffusion-weighted images, from other lesions [3]. This hyperintense appearance is a result of the reduced apparent diffusion coefficient (ADC) that is associated with restricted microscopic diffusion of water. On the basis of the signal intensity seen on diffusion-weighted images, acute infarcts can be distinguished from subacute and chronic infarcts as well as from other lesions that simulate infarcts.

Signal intensity on diffusion-weighted images is influenced by two factors: water diffusibility and the intrinsic T2 properties of the tissue being examined [3]. Sensitivity to the latter factor is associated with the heavily T2-weighted features introduced by the long TR and TE required in this pulse sequence. Therefore, the hyperintense appearance of infarcts on diffusion-weighted images after the first few hours results from a combination of factors. The relative contributions of abnormal diffusion and the intrinsic T2 properties are difficult to determine on diffusion-weighted images alone. In addition, infarcts can occasionally continue to appear hyperintense on diffusion-weighted images in the late acute and subacute stages (i.e., when the increase in signal intensity due to restricted water diffusion is expected to begin to decrease) because of progressive T2 prolongation. The resultant hyperintense signal on diffusion-weighted images, which is attributable to the intrinsic T2 signal characteristics of infarcted tissue, has been termed the T2 "shine-through" effect.

One method by which the T2 shine-through effect can be eradicated is by generating an ADC map that reflects only the diffusional properties of water and not the characteristics of the T2 signal [3]. This technique, which is analogous to generating a map of T2 relaxation times as opposed to a T2-weighted image, has drawbacks because it requires generation and interpretation of a set of ADC maps with the diffusion-weighted images. Another drawback is that these maps have different contrast characteristics from those of diffusion-weighted images to which radiologists have become accustomed. We report the use of a single set of MR images that shows abnormal signal intensity because of restricted diffusion while negating the contribution of T2 signal intensity to diffusion-weighted images. These images, which we call the exponential images, retain the hyperintense signal characteristics of infarcts as seen on diffusion-weighted images to which radiologists have grown accustomed (Fig. 1). Whereas on an ADC map, an acute infarct is seen as a hypointense region against an intermediate-signal-intensity background with relatively poor lesion conspicuity, on exponential images, an acute infarct is seen as a hyperintense lesion against a background of intermediate-signal-intensity normal brain tissue with high lesion conspicuity (Fig. 1). We tested the ability of exponential images to accurately reflect the degree of decrease in ADC values in the setting of cerebral infarction and compared this ability with that of diffusion-weighted images.

Materials and Methods

To assess the usefulness of an exponential image, we retrospectively examined a series of 21 patients who had undergone diffusion-weighted imaging on a Signa 1.5-T system (General Electric Medical Systems, Milwaukee, WI). All patients included in the study had an infarct age that could be accurately determined on clinical grounds. Diffusion-weighted imaging (TR/TE, 12,000/101) was performed in three orthogonal directions using a maximum B value of 1000 sec/mm^2. A baseline image with a B value of 0 sec/mm^2 was also obtained. In all patients, a CSF-suppression pulse was used to null the signal from CSF [4]. Sixteen of the 21 patients had acute infarcts (i.e., 6 hr–3 days in duration), and five patients had subacute infarcts (i.e., 4 days–1 month in duration). We studied the ability of exponential images to eliminate the T2 shine-through effect by assessing whether exponential images more accurately reflected changes in ADC values than did trace diffusion-weighted images. In each patient, we measured the percentage

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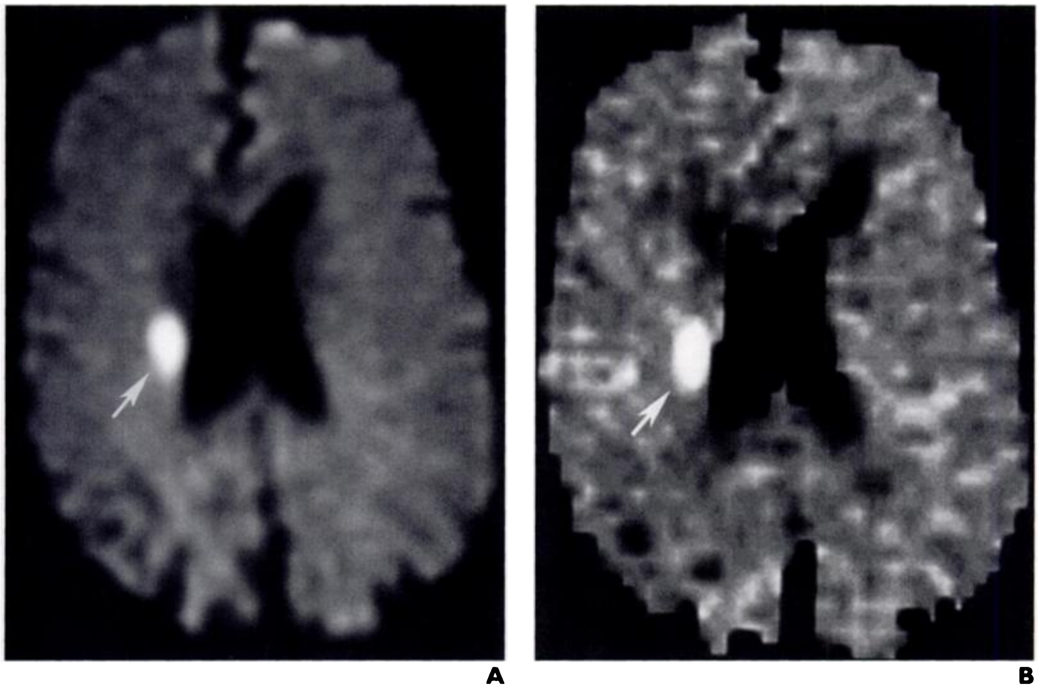


Fig. 1.—64-year-old man with 1-day history of left hemiparesis.

A, Trace diffusion-weighted MR image (B = 1000 sec/mm^2) using CSF-suppression pulse shows region of hyperintense signal (*arrow*) representing restricted diffusion within acute cerebral infarct. Lesion was only mildly hyperintense on T2-weighted MR images (not shown).

B, Exponential diffusion-weighted image reflecting only diffusional properties shows restricted diffusion within infarct having hyperintense signal (*arrow*) with contrast characteristics similar to those seen in **A**. On an apparent diffusion coefficient map that was generated from diffusion-weighted images (not shown), infarct was markedly hypointense, which is characteristic of acute infarcts.

of change in signal intensity of infarcts (compared with that of normal tissue in the contralateral cerebral hemisphere) shown on diffusion-weighted images and on exponential images. Thereafter, we measured ADC change in infarcts compared with ADC change in normal brain tissue in the contralateral hemisphere. Finally, we correlated both the change in signal intensity on diffusion-weighted images and the change in signal intensity on exponential images with the decrease in the ADC using Spearman rank correlations.

Results

In all patients, relative changes in signal intensity of infarct (compared with those of normal tissue) were substantially higher on diffusion-weighted images than on exponential images. In 18 of the 21 patients, the degree of change in signal intensity of infarcts on exponential images more closely reflected the ADC decrease than did diffusion-weighted images. In two patients, exponential images and diffusion-weighted images were equivalent, and in one patient, the diffusion-weighted image more closely reflected the ADC decrease than did the exponential image. The change in signal intensity on the exponential images was highly correlated with the decrease in ADC values ($r = .865$, $p < .00005$). The change in signal intensity on the diffusion-weighted images correlated less closely with the decrease in ADC values ($r = .469$, $p = .03$).

Discussion

The exponential image can be generated on a workstation through simple image algebra and is derived by dividing the maximal B value diffusion-weighted image by the B_0 image (i.e., by the diffusion-weighted image obtained before application of the diffusion gradient). In mathematical terms, the exponential image represents the negative exponential of the ADC and can be considered a calculated or synthetic diffusion-weighted image without T2 shine-through effects. The resultant image has contrast characteristics similar to those of a diffusion-weighted image: Regions of restricted diffusion (and decreased ADC), such as hyperacute and acute infarcts, appear hyperintense, and CSF appears hypointense relative to normal brain tissue, which has intermediate signal intensity. As ADC values return to normal, subacute infarcts appear relatively isointense to normal brain tissue. Chronic infarcts appear hypointense to brain tissue on the exponential image as the ADC of infarcted tissue increases relative to that of normal brain tissue.

Because mere reversal of the gray scale of ADC maps combined with reversal of the standard gray scale would also show acute infarcts as having hyperintense signal, this technique might be expected to provide similar information on exponential images. However, the lesion-to-background contrast seen on an ADC map with reversal of the gray scale would be lower than that seen on an exponential image. This statement is true because the ADC map is based on the logarithm of the ratio B_{max}/B_0 (i.e., ADC = –logarithm B_{max}/B_0), whereas the exponential image is based solely on the ratio B_{1000}/B_0. The logarithm factor in the ADC calculation serves to attenuate some of the contrast differences, with resultant diminished lesion-to-background contrast, on ADC maps with reversal of the gray scale compared with that of exponential images.

Exponential images provide a more accurate depiction of diffusion effects within cerebral infarcts than trace diffusion-weighted images by removing the contribution from T2 signal intensity of the tissue being examined (Fig. 2). Although, in general, the removal of the T2 signal-intensity contribution moderately lowered signal intensity of infarcts on exponential images compared with that of infarcts on diffusion-weighted images, lesion conspicuity was sufficient in all cases to allow identification of infarcts. Furthermore, because only a single set of images is needed, exponential images are easier to use than a combination of trace diffusion-weighted images and ADC maps. In addition, because the contrast characteristics of exponential images are similar to those of diffusion-weighted images, the imaging findings are similar to those to which radiologists have grown accustomed. Finally, exponential images can be used to more precisely determine the presence of restricted water diffusion, which should help to increase the accuracy of estimating the age of cerebral infarcts.

Fig. 2.—Subacute left hemisphere infarct in 70-year-old woman with 10-day history of right arm weakness. All images are from same slice level.

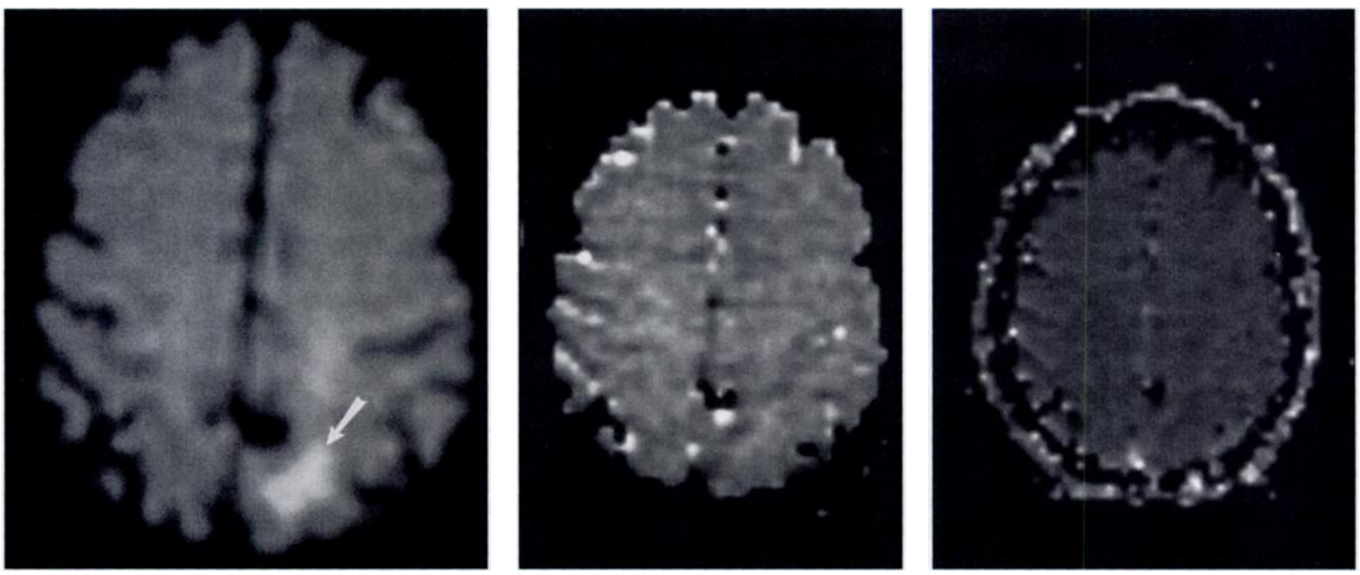
A, Trace diffusion-weighted image without application of diffusion gradients (B = 0 sec/mm^2), using CSF signal suppression pulse (i.e., essentially T2-weighted image with CSF suppression) shows region of hyperintense signal (*arrow*) within left parietal lobe, consistent with infarction.

B, Trace diffusion-weighted image (B = 1000 sec/mm^2) using CSF-suppression pulse shows region (*arrow*) to be hyperintense, as seen on **A**. Relative contributions of signal due to restricted diffusion and to T2 prolongation (T2 "shine-through" effect) cannot be determined.

C, Exponential diffusion-weighted image in which only diffusional properties are reflected and T2 effects are eradicated shows normal signal in left parietal lobe. Finding indicates that diffusion characteristics within this region are essentially identical to those of rest of brain. Therefore, hyperintense signal seen in **A** and **B** is caused by T2 shine-through effect rather than by restricted diffusion.

D, Apparent diffusion coefficient (ADC) map generated from **A** and **B** shows normal signal within left parietal lobe, confirming findings seen on **C** and indicating that **C** contains data inherent in combination of B and ADC map.

A



B **C** **D**

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