Removing Ambiguity Caused by T2 Shine-through using Weighted Diffusion Subtraction (WDS)

Koichi OSHIO1*, Shigeo OKUDA1, and Hiroshi SHINMOTO2

1Department of Diagnostic Radiology, Keio University School of Medicine
35 Shinanomachi, Shinjuku-ku, Tokyo 160–8582, Japan
2Department of Radiology, National Defense Medical College
(Received January 8, 2015; Accepted March 25, 2015; published online June 23, 2015)

We propose a novel image processing technique that combines images routinely acquired with low and high b values to create a single image that contains clinically useful information without the ambiguity of T2 shine-through. The contrast of resulting images is similar to that of a T2 image, but the signals of pixels with low apparent diffusion coefficient (ADC) values are inverted. The proposed technique takes the threshold ADC value as the one adjustable parameter.

Keywords: computed DWI, diffusion, T2 shine-through

Introduction

In a clinical setting, diffusion-weighted images are usually acquired with two b values, for example, b = 0 and b = 1000 (s/mm²). Although pathological tissue with low apparent diffusion coefficient (ADC) values appears as pixels with high intensity in images obtained with high b values, the inverse is not necessarily true. Tissues with long T2 and normal ADC values sometimes appear as bright spots in images obtained with high b values, a phenomenon termed T2 shine-through, and their correct differentiation from tissues with actual low ADC values is sometimes difficult. The use of higher b values or of computed diffusion-weighted imaging can reduce this problem1,2 but cannot completely remove the fundamental ambiguity.

We propose a novel image processing technique that uses images routinely acquired with low and high b values to create a single image that contains clinically useful information without the ambiguity of T2 shine-through.

Method

We generated a new image from a pair of diffusion-weighted images obtained with low and high b values, using a pixel-by-pixel calculation:

\[ S(x, y) = S_0(x, y) \exp(-\Delta b D_{\text{thres}}) - S_1(x, y) \]
\[ = S_0(x, y) \exp(-\Delta b D_{\text{thres}}) - S_0(x, y) \exp(-\Delta b \text{ADC}(x, y)) \]

where \( S \) is the signal intensity of the new image, \( S_0 \) is that of the image obtained with the low b value, and \( S_1 \) is that of the image acquired with the high b value. \( D_{\text{thres}} \) is the threshold value of the diffusion coefficient at which the sign of the signal of the new image is inverted, and \( \Delta b \) is the difference between the b values of the two diffusion-weighted images.

Because the exponential term with \( D_{\text{thres}} \) is just a constant, this calculation is a simple linear combination of the two diffusion weighted images, and the method is tentatively called weighted diffusion subtraction (WDS). The contrast of the new image is similar to that of the T2-weighted image (\( S_0 \)) but with the signs of the pixels with small ADC values inverted. Thus, the new image demonstrates clearly whether the ADC value is smaller than certain values (e.g., 1.0 mm²/s), regardless of the intensity in the image obtained with b = 0.

Results and Discussion

Figure 1 shows examples of the resulting images. For each case, 3 images are shown, one obtained with a low b value, one acquired with a high
In this study, we used $b = 0$ as a low $b$ value and $b = 1000$ to 2000 as the high $b$ value, depending on the case. Pathological tissues often have long $T_2$ and low ADC values. In diffusion-weighted images, this type of tissue can be seen as areas of high intensity in both low and high $b$-value images. However, certain types of tissues with long $T_2$ and ADC values greater than 1.0 may result in high intensity regions in images obtained with both low and high $b$ values, a pattern so-called $T_2$ shine-through. Low ADC and $T_2$ shine-through are sometimes difficult to distinguish because the difference exists only in the amount of signal decay between the images obtained with low and high $b$ values. This ambiguity is ultimately resolved by creating a quantitative ADC map, but ADC maps are inconvenient for visual diagnosis because of their relatively low tissue contrast and diminished depiction of anatomical structures.

In WDS images, the sign of the signal of the pixel changes depending on whether the ADC of the location is smaller than the threshold value. We used $1.0$ as the threshold value of $1.0 \text{mm}^2/\text{s}$. Although more rigorous study is needed to determine an optimum value, the value of 1.0 seems fairly reasonable as seen in the example images. The rationale for selecting the value of 1.0 is based on the theory the ADC values less than 1.0 in the pathological tissues are result of restricted diffusion in small cells.5

![Fig. 1. Proposed weighted diffusion subtraction (WDS) images of prostate (top row), breast (middle row), and endometrial (bottom row) cancers. Each row, left to right, image obtained with a low $b$ value ($b = 0$), with a high $b$ value ($b = 1000, 1500, \text{or} \ 2000$), and with WDS. In the WDS images, the hypointense lesions indicate the area with apparent diffusion coefficient (ADC) value less than $1.0 \text{mm}^2/\text{s}$. Note that these areas can be seen without ambiguity, and anatomical information is retained.](image-url)
Although images obtained with high b values may provide more information regarding diffusion, much anatomical information is lost, so they are not suitable for diagnosis without images obtained with \( b = 0 \). In other words, both images and the process of mentally registering them are necessary for the complete picture. In the proposed method, inclusion of both anatomical (\( T_2 \)) and diffusion information in a single image greatly facilitates interpretation.

Because WDS is a subtraction technique, misregistration between 2 image sets is a significant limitation. In the diffusion imaging techniques, the main reason for this misregistration is motion and image distortion due to eddy current caused by the motion-probing gradient (MPG). In our initial experience, we noticed no distortion from the eddy current, but respiratory motion in the upper abdominal area caused artifacts at the tissue edges.

**Conclusion**

A novel method to combine low b and high b images was proposed. Both \( T_2 \) and ADC information can be obtained unambiguously in the single image, created by simple weighted subtraction.

**References**

1. Blackledge MD, Leach MO, Collins DJ, Koh DM. Computed diffusion-weighted MR imaging may improve tumor detection. Radiology 2011; 261:573–581.
2. Maas MC, Fütterer JJ, Scheenen TW. Quantitative evaluation of computed high b value diffusion-weighted magnetic resonance imaging of the prostate. Invest Radiol 2013; 48:770–786.
3. Oshio K, Shinmoto H, Mulkern RV. Interpretation of diffusion MR imaging data using a gamma distribution model. Magn Reson Med Sci 2014; 13:191–195.