Stimulated echo induced misestimate on diffusion tensor indices and its remedies

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Introduction

The presence of eddy current is known to result in b-value-dependent spatial displacements in diffusion imaging techniques including diffusion tensor imaging (DTI) (1). Without proper corrections, derivation of DTI parameters such as the apparent diffusion coefficient (ADC) or fractional anisotropy (FA) is prone to errors resulting from image mis-registration. The dual spin-echo method with twice-refocused gradient (2,3), when appropriately trimmed, provides DTI images immune to eddy-current effects. It was found out, however, that the estimated values of ADC and FA were inconsistent with those measured from conventional single spin-echo DTI. In this work, we report the origin of this artifact and its remedies.

Theories

The dual spin-echo technique is shown schematically along with the twice-refocused gradient in Figure 1. With a series of three RF pulses, stimulated echo forms at half TE2 following the third RF pulse. When TE1 is set equal to or close to twice of TE2, the stimulated echo forms at about the same time as the second spin echo, if the flip angles of the three RF pulses deviates from 90-180-180. As a result, the signal intensity for the second spin echo is anticipated to increase. Such phenomena occur only for the b = 0 images. With diffusion-weighted gradients turned on, the stimulated echo which undergoes diffusion weighting only before the first 180 RF pulse and after the second 180 RF pulse becomes dephased, rendering no effects from the stimulated echo. Hence, the computation of ADC is anticipated to be over-estimated. Such an over-estimation is especially prominent for low ADC, leading further to an overall under-estimation of FA values.

Materials and Methods

Imaging experiments were performed on a 1.5T system (Siemens Vision+, Erlangen, Germany) using 6-direction DTI with b-value equal to 1000 s/mm^2. Slice thickness was 5 mm with in-plane resolution of 1.7x1.7 mm^2. A dual spin-echo EPI sequence with twice-refocused diffusion-weighted gradient was implemented, with TE1 = 2*TE2 = 100 msec. The crusher gradients, with alternating polarity, along the slice direction were added before and after the two 180 pulses in the b0 image to intentionally dephase the stimulated echo. Another version without crusher pairs was also implemented to examine the effects of stimulated echo. Notice that the b-value induced by crusher gradients was less than 0.5 sec/mm^2 and could be neglected. The flip angles of the three RF pulses were automatically calibrated (i.e., not intentionally mis-adjusted) using commercial packages from the manufacturer to reflect situations encountered in routine practice. Nine healthy subjects volunteered participation in the imaging experiments. Analysis of the images yielded ADC and FA values in the genu and splenium of the corpus callosum, bilateral corona radiata, internal capsule, and the superior frontal lobe. The ADC and FA values obtained from imaging with crusher pairs were expressed as compared with corresponding values from those without crushers in Fig.2.

Results

Figure 2 shows the percentage changes in ADC and FA values resulting from the presence of stimulated echo. As seen in the plots, the stimulated echo could lead to an over-estimation of ADC as high as 96% and an under-estimation of FA up to 35%. The derived FA maps displayed at equal window level (Fig.3) showed differences that were visually prominent.

Discussion

Although the dual spin-echo DTI with twice-refocused gradient has been shown effective in elimination of eddy-current-induced spatial displacement, in appropriate settings may lead to simulated-echo interference resulting in ADC over-estimation and FA under-estimation, as shown in this work. The use of crusher gradients with alternating polarity to dephase the stimulated echo could remove the artifactual influence. Other remedies include a lengthening of the time interval between the two 180 pulses, such that the commencement of the stimulated echo can be separated from the second spin-echo when TE1 > 2*TE2. Placing the pre-phasing gradient in between the two 180 pulses provides another option to spatially encode the second spin-echo without combining the stimulated echo effects. For routine practice using dual spin-echo DTI, a comparison of measurement values of ADC and FA with literature reports is recommended to avoid erroneous results.

References

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2. Reese TG, et al. MRM 2003;49:177-182.
3. Alexander AL, et al. MRM 1997;38:1016-1021.

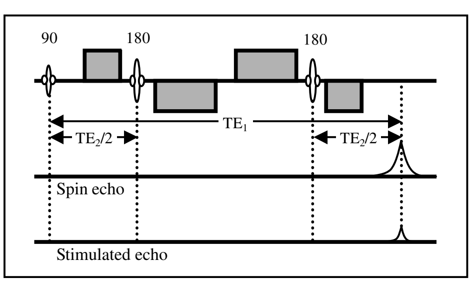
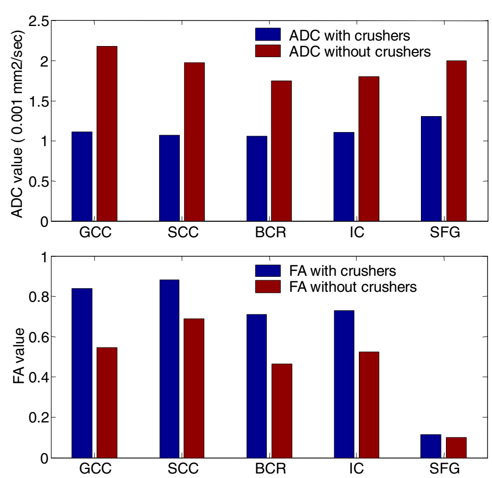


Fig.1 showed the pulse sequence of twice refocused spin-echo with diffusion weighted gradient. When TE1 was chosen twice of TE2, the spin-echo and stimulated echo would be refocused at the same time



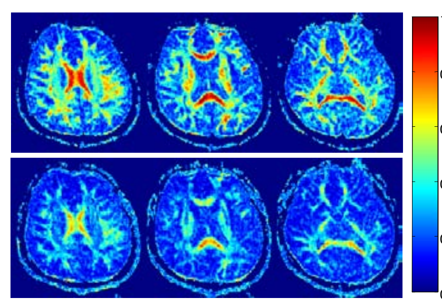


Fig.3 (Above) The upper row demonstrated the FA maps with crusher gradients applied, and the lower was those without crushers. Images in each column were at the same slice selection.

Fig.2 (Left) In the upper chart, ADCs of the genu and splenium of corpus callosum, bilateral corona radiata, internal capsule, and superior frontal gyrus were shown from left to right. FA values of the same ROIs were plotted in the lower.