Diffusion Measurements Free of Motion Artifacts Using Intermolecular Dipole-Dipole Interactions

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Synopsis

Acquisition of diffusion-weighted images using Stejskal-Tanner pulsed-gradient spin-echo methods in the presence of motion exhibit distortions. The distortions occur because the object moves relative to the magnetic gradient coils during the diffusion time. Diffusion-weighted images can also be acquired by using signals formed in the presence of a distant dipolar field (DDF) where the amount of diffusion-weighting depends on the dipolar correlation distance and the time allowed for signal formation. Here we demonstrate that measurements and images made using the DDF as a diffusion-weighting mechanism are insensitive to motion of the object.

Introduction

Diffusion processes have been demonstrated to reduce signals which form during the detection period of a CRAZED pulse sequence (1) while the DDF is present (2,3). Diffusion during this time reduces the DDF if the correlation distance, d_c, is on the order of the diffusion distance. The reduction of the DDF slows the "refocusing" of the magnetization and, therefore, the signal amplitude. Thus, the amount of diffusion-weighting depends on d_c and the time allowed for signal formation (TE in Fig. 1). A unique aspect of using the DDF as a diffusion-weighting mechanism is that, unlike the Stejskal-Tanner pulsed-gradient spin-echo (PGSE) method, the DDF originates in the sample and, therefore, if the sample moves, the DDF moves with it. Thus, images with diffusion-weighting due to DDFs should be free of the motion artifacts often associated with DWI acquired with standard PGSE methods.

Methods

The CRAZED-based pulse sequence shown in Fig. 1 was used with coherence order selection = -2. Diffusion-weighted data was acquired at 9.4T using this sequence and a conventional PGSE sequence with a Bruker/GE OmegaPSG.

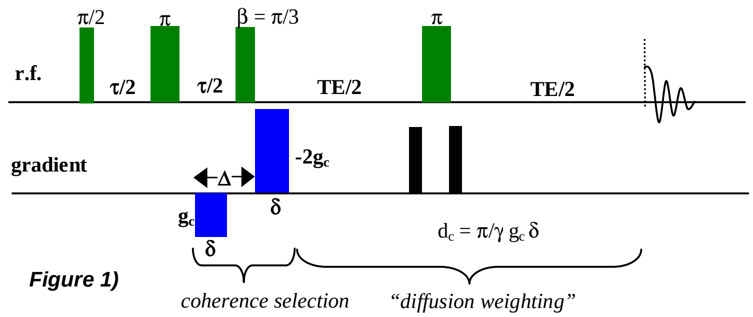

Figure 1)

Results

The hypothesis was tested by comparing motion-induced phase shifts and artifacts obtained using DDF diffusion weighting (DW-DDF) with conventional DW (DW-PGSE). DW-PGSE and DW-DDF parameters that yield approximately a 50% reduction in signal intensity relative to an unweighted signal were determined from calculations (3) and verified by measurements. The relative motion sensitivity of the two DW schemes were first compared by measuring the phase shift induced by constant-velocity translation parallel to the diffusion-weighted axis (Fig. 2). Next, images with and without diffusion-weighting were made of the same phantom moving in a pseudo-random fashion intended to simulate normal breathing (Fig. 3). Slight motion artifacts are seen in both unweighted images due to normal imaging gradients, but motion artifacts are greatly reduced in DW-DDF images compared to DW-PGSE images. Finally, DW-DDF images of the abdomen of a sedated mouse did not exhibit breathing related ghosts, unlike conventional DW-PGSE images (Fig 4).

Conclusions

Diffusion-weighting using the DDF is unique in that the refocusing "gradient" is carried within the sample and, thus, macroscopic motion of the sample does not cause a phase shift. Residual motion artifacts in DW-DDF might arise from conventional DW due to separation of the coherence-encode gradients. The delay between the coherence-encode gradients should be kept as short as possible.

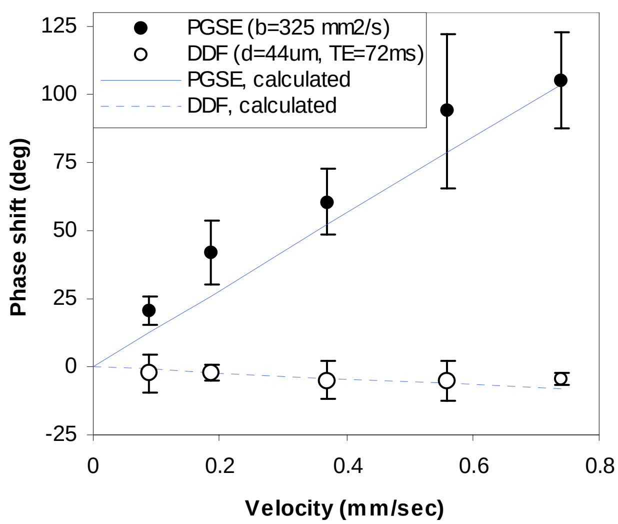

Fig. 2) A gelatin phantom was controlled by a step motor, which allowed linear motion of the phantom along the diffusion-weighted axis with constant velocities The slight negative slope in the DW-DDF data is due to the PGSE-type phase shift arising from the small delay Δ.

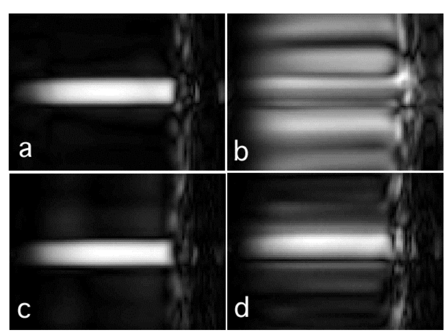

Fig. 3)
DW-PGSE images: (a) $b \sim 0$
(b) b = 325 s/mm^2
DW-DDF images: (c) d= 150 µm, TE =72 ms
(d) d =44 µm, TE=72 ms

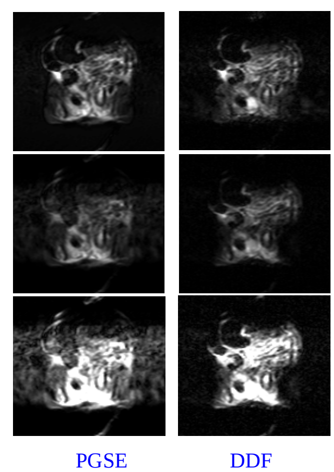

Fig. 4) C3H mouse abdomen
Top: no weighting
Middle: DW
Bottom: DW (intensity x3)

References: (1) W.S. Warren, *et al*. *Science* **262:**2005-2009 (1993); (2) P. Robyr, *et al*. *JMR* ser.A **121**:206-208 (1996); (3) I. Ardelean, *et al*. *JCP* **112**:5275-5280 (2000)