A new approach to bright spot MRI: visualizing local dipolar fields with the CRAZED sequence

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Introduction

The most common strategy in molecular MRI is to label target structures with iron-based contrast agents. These appear as regions of low signal in conventional gradient echo images. Visualization of the target structure can be facilitated when positive image contrast is obtained from the contrast agent. Here we demonstrate how the CRAZED [1,2] sequence can be used to obtain images with bright contrast from local dipolar fields.

Theory

The CRAZED experiment detects signal from intermolecular double-quantum coherences (iDQCs) [1,2]. These are transformed into observable magnetization by the action of the distant dipolar field (B_{DDF}) which stems from the magnetization of the spins in the sample itself. Crucial for the CRAZED experiment is that a strong spatial modulation is imposed onto the magnetization. This is usually achieved by application of magnetic field gradients. If one-dimensional modulation is applied along the direction $\hat{s}$, which is at the magic angle (54.7°) with respect to B_0, B_{DDF} vanishes and no signal is detected in the CRAZED experiment [3], since:

$$\vec{B}_{DDF}(s) = \frac{1}{6}\mu_0\left(3(\hat{s}\cdot\hat{z})^2 - 1\right)\left[3M_z(s)\hat{z} - \vec{M}(s)\right] \qquad (1)$$

In the presence of an additional static, local dipolar field, as created by a small iron particle (SPIO) or an air bubble, the modulation of M_z is no longer one dimensional and Eq. (1) is not valid. In these circumstances, signal evolution can no longer simply be described using analytic expressions. Therefore we have performed computer simulations involving numerical solution of the Bloch equations modified to account for the effects of B_{DDF} and diffusion.

Experiments

Simulations were performed with the program MATLAB on conventional personal computers. For numerical solution of the Bloch equations the contribution from B_{DDF} and diffusion was calculated in k-space [4]. Simulations of a 2.3 mm slice of a water-filled tube with 2.2 mm diameter were performed for a 128*128*64 grid at B_0=17.6 T. A dipolar field corresponding to that created by an air bubble with 0.25 mm diameter located at the centre of the tube was used. A gradient imposed modulation length of 0.5 mm along the magic angle direction was simulated. All measurements were performed on a Bruker Avance 750 widebore spectrometer, equipped with a 200 mT/m gradient system and home-built rf-coils. A phantom sample consisting of agar gel containing air bubbles and 2 µm-sized iron-oxide particles in a 15 mm centrifuge tube was used. The CRAZED-imaging pulse sequence was implemented in Paravision. CRAZED images of a 64^2 matrix and 1 mm slice thickness were acquired in 3 minutes with TE/TR=50/3000ms. In further experiments, to suppress signal from single-quantum coherences (SQCs), a (x, -x) phase cycle was applied on the excitation pulse.

Results

Figure 1 shows the result of a simulation of a CRAZED experiment with gradient modulation along the magic angle in the presence of an additional dipole field. Close to the dipole, positive signal is observed over a lower background further away from the centre. Fig. 2 shows a conventional gradient echo image (a) of the phantom and the corresponding magic angle CRAZED image acquired without phase cycling (b). The dark contrast from the dipolar fields of two air bubbles (arrows) is turned into strong bright contrast in the CRAZED image, while background signal is strongly suppressed. Further simulations and experiments with phase cycling to suppress directly refocused SQCs both resulted in a reduction of signal intensity by more than a factor of ten. This shows that the dominant contribution to the signal comes from directly refocused SQCs.

Conclusion

The CRAZED experiment with gradient modulation along the magic angle can be used to create strong, positive contrast due to local dipolar fields, as are induced by SPIOs. Excellent background suppression can be achieved in relatively short scan times.

References

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Figure 1

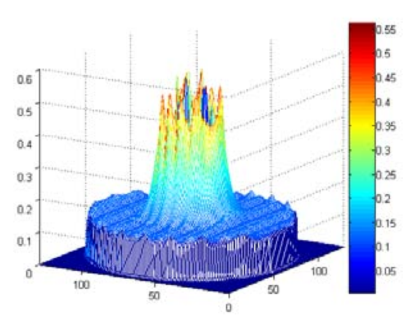

Figure 2