SNR Potential of Intermolecular Double-Quantum Coherence Imaging at High Magnetic Fields

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Introduction
Recently, there has been much interest in MR imaging based on contrast arising from the intermolecular double-quantum coherence (iDQC). Since the iDQC signal is much lower than the single-quantum (SQC) signal normally used for imaging, it is necessary to carefully optimize imaging parameters in order to acquire useful data. Theoretical simulations predict that the ratio of iDQC signal relative to SQC signal is related directly to magnetic field strength, and is expected to increase with the field strength. In this study, SQC and iDQC signals in water phantoms are compared using human imaging systems with field strengths of 1.5, 4.0, and 7.0 Tesla.

Methods
The pulse sequence used for acquisition of iDQC images is based on the CRAZED sequence originally described by Richter, et al. (1), with optimizations developed by Zhong, et al. (2). SQC signal was acquired using a standard spin-echo sequence. In all cases, the readout was by means of single-shot EPI. The volume of interest for this study was explicitly designed to cover only a few cubic centimeters, so B1 inhomogeneity, which becomes more severe at high fields, was negligible.

1.5 T images were acquired using a standard GE quadrature head coil, 4.0 T images were acquired using a custom TEM head coil, and 7.0 T images were acquired with an actively detuned two-coil quadrature transmit/receive surface coil setup. TR/TE were optimized individually for each scan: TR values were 5 sec at 1.5 T and 12 sec at 4.0/7.0 T; TE for iDQC ranged from 100-200 ms. TE for SQC was set to the minimum, as was the iDQC parameter $\tau$.

Results
SQC and iDQC images of the water phantom at the two highest field strengths (4.0 T and 7.0 T) are presented in Figure 1. iDQC images vary with the orientation of the encoding gradient from the Z-axis (parallel to B0), to the X-axis (perpendicular to B0), to the magic angle. The window level for the three iDQC images at each field strength is identical for comparison purposes. The window levels for the SQC images, however, are separately optimized for display purposes.

Comparisons of SQC and iDQC signal intensities are presented in Figure 2 for each of the three field strengths. Again, iDQC signal acquired using the three previously described encoding gradient orientations are presented as verification of the purity of the iDQC signal.

Discussion
Based on theoretical calculations, true iDQC signal is expected to be dependent on the orientation of the encoding/selection gradients. When these gradients are applied along the B0 axis (Z-axis), the iDQC signal is at the maximum. When they are applied perpendicular to the B0 axis, the signal is expected to decrease by 50%. Finally, the iDQC signal is expected to vanish completely when encoding gradients are applied along the 'magic angle' to B0. From Figure 2, it is clear that the iDQC signal acquired at each field strength follows this theory within experimental errors, and is therefore considered to be uncontaminated by SQC leakage.

From Figure 2, it can be seen that the iDQC signal relative to SQC signal does in fact increase with increasing field strength. At 1.5 T, this fraction is 6.1%; at 4.0 T, it is 7.8%; at 7.0 T, it is 12.2%. This is in agreement with the theoretical predictions of Zhong, et al., though the highly sensitive dependence of iDQC imaging on sequence suggests that these results could possibly be improved upon with further optimization of the imaging parameters.

The implications of these findings are quite encouraging in the context of the future potential of iDQC imaging. The main limitation of iDQC imaging has always been extremely low SNR, leading to poor-quality images or excessively long imaging times to accommodate repeated signal averaging. At high fields such as 7 Tesla, however, iDQC SNR is quite sufficient for standard imaging techniques. Assuming a linear relationship between SQC SNR and field strength, and using the 12.2% iDQC/SQC signal ratio observed in this study, one can achieve a rough equivalence in SNR between iDQC imaging at 7.0 T and SQC imaging at 0.85 T. High-field imaging systems at 7.0 T and beyond clearly appear to be platforms for future applications of iDQC contrast in MR imaging.

References

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