Contrast Enhancements in MRI and fMRI by Sensitivity-Improved Detection of Intermolecular Zero- and Double-Quantum Coherences

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Introduction

In liquids, intermolecular multiple-quantum coherences (iMQC) originate from the distant dipolar fields that are generally ignored in conventional framework of magnetic resonance [1-3]. It has been shown that MR images based on detection of iMQC (e.g., zero-quantum iZQC and double-quantum iDQC) give tumor enhancement in rat brains and novel contrast in human brain imaging (including functional activation) [4-6]. In this work, we propose a new pulse sequence to not only enhance the iZQC/iDQC signals but also make iDQC generate new contrast features. Numerical experiments are then used to demonstrate its applicability in MRI/fMRI to achieve enhanced contrast and sub-voxel resolution.

Methods & Results

For homonuclear dipole-coupled spin pairs, the ZQC and DQC evolve completely independently of each other. By invoking this property, the new pulse sequence shown in Fig. 1 can simultaneously acquire iZQC and both kinds of iDQC in one shot. The last two gradients make the different orders observable in the form of gradient echoes, which guarantee that the signals can be simply added to achieve sensitivity enhancement. For example, when the second RF pulse is 60°, the ratio of the echo intensities are: +iDQC:iZQC:-iDQC=0.7:0.9:1.3, where 1.0 is the normalized iZQC signal. As shown in the following, such sensitivity-improved iZQC/iDQC detection provide distance-selective contrast, reflecting local susceptibility variation and distribution.

Example I: iZQC/iDQC MRI tumor detection. Contrast with iZQC images comes from variations in the susceptibility over a distance dictated by gradient strength. This contrast is useful in the detection of small tumors, in that susceptibility correlates with oxygen concentration. Figure 1 shows simulated (a) iZQC and (b) +iDQC brain images (top: x-magnetization, bottom: y-magnetization) with a "tumor region" having the same magnetization density and relaxation times as surrounding tissue, but slightly different resonance frequency (+15 Hz) reflecting a different oxygenation level. Note that the "tumor" edges produce dramatically altered signal. The origin of the iDQC contrast, however, arises from partial coherence transfer and mismatched evolution of DQC before and after the refocusing 180x pulse[6]. Consequently, the iDQC signal detected by this sequence depends on the resonance frequency difference of the spin pairs, in a way similar to iZQC. These overall simulated results agree with our previous in-vivo observations [4-6].

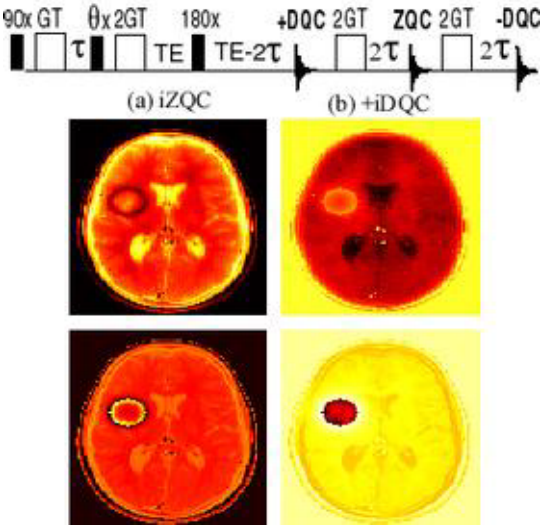

Fig. 1. Simulated brain tumor detection by iZQC and iDQC MRI.

Example II:Sub-voxel resolution in fMRI. The boxed prefrontal cortext region in (a) is simulated with the known value of magnetization density and relaxation times, plus a random distribution (b) of small arteries (40mm wide, z-oriented) with different oxygenation, while (c) and (d) show the x- and y-magnetization of the iZQC fMRI signals for this distribution (64x64 pixel images; arteries are 1/4 pixel wide), acquired by the same sequence. The iDQC fMRI images (not shown) exhibit similar yet different contrast features. The regions with resonance frequency variation have dramatically altered signal intensity and phase, reflecting details of local structure.

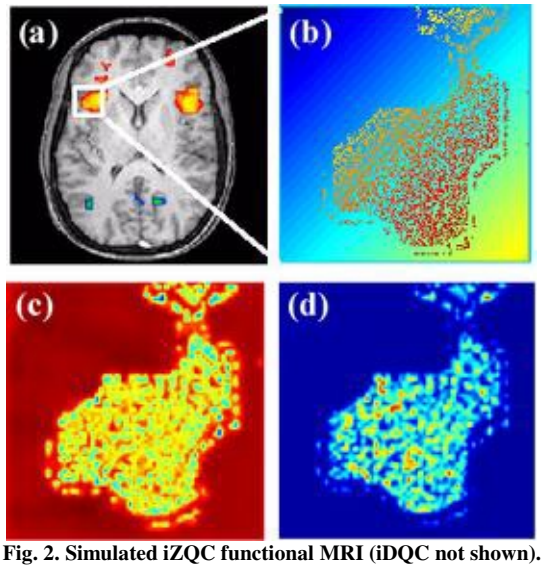

Fig. 2. Simulated iZQC functional MRI (iDQC not shown).

Discussion & Conclusion

Example I shows that contrast in iZQC/iDQC images due to susceptibility variations can be nearly 50~100% of the signal, and the lower overall intensity can be more than compensated by the larger fractional differences. Even richer contrast can be obtained by coadding both iDQC and iZQC images. The precise size and structure of sub-voxel features dramatically alters the iZQC/iDQC images, as demonstrated in Example II. The capability of extracting sub-voxel information, which cannot be obtained by conventional methods, may help accelerate the theoretical understanding of fMRI, permit exploration of smaller activation features, and improve soft tissue characterization in MRI, particularly if it correlates with physiologically important functions. In this regards, quantitative numerical simulations are valuable in providing reliable predictions to the experimental outcome, physiological model to relate the observed activation, and effective guidelines in pulse sequence optimization.

Acknowledgement

This work was supported by the NIH (GM35253), Army Breast Cancer Research Program, and the McKnight Endowment Fund for Neuroscience.

References

1. W. S. Warren et al., Science 262, 2005 (1993).
2. W. Richter et al., Science 267, 654 (1995).
3. S. Vathyam et al., Science 272, 92 (1996).
4. 1. W. S. Warren et al., Science 281, 247 (1998).
5. R. R. Rizi et al., Mag. Res. Med. 43, 627 (2000)
6. W. Richter et al., Mag. Res. Imaging 18, 489 (2000)