Intermolecular multiple-quantum coherence relaxation and its implication for MRI contrast

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Introduction

Warren et al have shown that the intermolecular zero-quantum coherence (iZQC) image reveals structural features which can not be seen in the conventional MR images (1-3). With optimized parameters for the best signal sensitivity, we have recently obtained similar results with intermolecular double-quantum coherence (iDQC) MRI (4). The intermolecular multiple-quantum coherence (iMQC) transverse relaxation rates \( T_{2,\text{n}} \) originated from the residual dipolar effect between distant spins may provide a new and intrinsic contrast mechanism which may eliminate the need for exogenous contrast agents. The purpose of this study was to investigate this new contrast mechanism.

Methods and Materials

A variation of the CRAZED sequence as shown in Fig. 1 was designed to accurately and selectively measure \( T_{2,\text{n}} \) by varying the relative amplitude \( n \) of the last pulsed field gradient (PFG). The first four PFGs were implemented to suppress radiation damping. To maintain the same condition for the dipolar correlation distance and diffusion attenuation, time interval \( \Delta \), gradient magnitude \( G \) and duration \( d \) were kept constant. The signal attenuation is only incorporated relaxation by varying the evolution time \( \tau \). \( T_{2,\text{n}} \) was directly and accurately extracted from such an array of spectra. \(^1\)H NMR spectra were carried out on a Varian INOVA 600 spectrometer with a 5 mm HCN triple-resonance probe. Sample: 20% D\(_2\)O in 80% H\(_2\)O. Other parameters as follows: a relaxation delay (RD) of 50 s; a \( \pi/2 \) RF pulse of width 9 \( \mu\)s; an evolution time \( \tau = 150 \) ms; a gradient pulse of duration \( \delta = 4 \) ms; a \( G_z = 10 \) Gauss/cm gradient amplitude. We also measure \( T_{2,\text{n}} \) for water and pork using a GE Omega 400 system by a spin echo iMQC sequence. Spin echo EPI iDQC images of a volunteer human brain were performed on a clinical 1.5 GE SIGNA scanner with the following parameters: TR/TE=3700/115, FOV=24mm, NEX=64, 10 mm slice thickness and 64×128 matrix.

Results and Discussion

Experimental results confirmed that the signal obtained by the new CRAZED sequence originates from iMQCs and not from a leakage of single quantum coherences. Quantitative determination of \( T_{2,\text{n}} \) requires an estimate of signal losses during the evolution and fitting to the theoretical curve to measured signal integrals. Notice that the signal attenuation during the evolution period depends on pitch length \( \pi/\delta G \delta \) and \( T_{2,\text{n}}^* \) which is a sum of the contributions of the iMQC \( T_{2,\text{n}} \) and the magnetic field inhomogeneity. The magnetic field inhomogeneity is almost eliminated with a refocusing \( \pi \) pulse at the middle of the evolution period for 400MHz experiment or small with good shimming for 600MHz. Without inhomogeneous broadening, iMQC decay is approximately exponential with decay time \( T_{2,\text{n}} = T_{2} / n \), since \( n \) spins participate in every iMQC. We list the \( T_{2,\text{n}} \) experimental values for water and pork in Table 1. A series of human brain iDQC images with the same TE and different evolution time \( \tau \) are shown in Fig.2.

<table>
<thead>
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<th>Sample</th>
<th>Machine</th>
<th>n=1</th>
<th>n=2</th>
<th>n=3</th>
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<td>600MHz</td>
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<td>189</td>
<td>125</td>
<td>97</td>
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<tr>
<td>Water*</td>
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<td>233</td>
<td>156</td>
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</tr>
<tr>
<td>pork</td>
<td>600MHz</td>
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<td>14.2</td>
<td>9.5</td>
<td>None</td>
</tr>
</tbody>
</table>

* different water samples were used on different machines

Fig. 2. Brain iDQC images with different evolution time on a 1.5 T scanner (a)12 ms, (b) 18 ms, and (c) 30ms.

Conclusions

Unlike conventional MRI, where image contrast is based on variations in spin density and/or relaxation times (often with injected contrast agents), contrast with iMQC images comes from \( T_{2,\text{n}} \) and pitch length \( \pi/\delta G \delta \). We demonstrate, for the first time, that iMQC \( T_{2,\text{n}} \) can be accurately measured using a variation of the CRAZED sequence. In contrast to the \( T_2 \), intermolecular \( T_{2,\text{n}} \) \((n>1)\) relaxes monoeXponentially during the evolution time with transverse relaxation rates \( T_2 / n \). The measurement of \( T_{2,\text{n}} \), especial in comparison with \( T_2 \), may provide a new contrast mechanism with the CRAZED sequence. This new contrast mechanism based on iMQC \( T_{2,\text{n}} \) may naturally provide a much more sensitive and distance-selected contrast for the detection of varying microstructure or pathologies in soft tissue.

References