Multi-shot Diffusion-Weighted Split-Echo PROPELLER MRI of the Abdomen

J. Deng1, R. A. Omary1,2, and A. C. Larson1

1Departments of Radiology and Biomedical Engineering, Northwestern University, Chicago, IL, United States, 2Robert H. Lurie Comprehensive Cancer Center, Chicago, IL, United States

Introduction

Diffusion-weighted MRI (DWI) provides a non-invasive method for in vivo evaluation of tissue water mobility. Most DWI studies employ single-shot DW-EPI techniques which can suffer severe artifacts and image distortion in abdominal imaging applications. Multi-shot TSE-based DW-PROPELLER [1] may overcome these limitations. DW-PROPELLER for brain [2] and abdominal [3] imaging has demonstrated improved image quality and the potential for high resolution DWI. Despite of these improvements, multi-shot DW TSE acquisition in the abdomen is particularly challenging due to artifacts resulting from violation of Carr-Purcell-Meiboom-Gill (CPMG) conditions. Incoherent signal phase due to motion during DW preparation can lead to destructive interference between spin echo and stimulated echo signals and consequent rapid signal loss. The SPLICE (split-echo acquisition of fast spin echo signals) technique may avoid this problem by separating the two signal components [4,5]. The purpose of our study was to investigate the feasibility of combining SPLICE and DW-PROPELLER techniques (DW-SP-PROPELLER) for abdominal DWI. In phantom and normal volunteer studies we demonstrate that DW-SP-PROPELLER can mitigate the non-CPMG artifacts sometimes present when using conventional DW-PROPELLER.

Methods

**PROPELLER** These techniques use a multi-shot TSE acquisition strategy with each segment of data acquired as a single rectilinear blade along a propeller-shaped k-space trajectory (Fig. 1). The concentric k-space region of each blade permits phase correction before segment combination and image reconstruction. Our implemented pulse sequence was based upon the BLADE sequence (Siemens implementation of PROPELLER TSE).

**SPLICE** Two families of echoes (E1 and E2) with destructive interaction can be separated with the first spin echo refocused asymmetrically with regard to symmetric TSE convention. The SPLICE technique uses an unbalanced readout gradient to acquire the two signal components separately by extending the original readout gradient. For our DW-SP-PROPELLER sequence (Fig. 1) two separate PROPELLER k-space datasets were phase corrected and reconstructed. The two magnitude images were summed for final image reconstruction.

**MRI** All imaging experiments were performed using a 1.5 T clinical scanner (Magnetom Sonata, Siemens Medical Solutions). DW-PROPELLER and DW-SP-PROPELLER images were acquired in phantom models and three normal volunteers. For phantom studies two cylindrical vials (distilled water and ethanol) were imaged using a single-channel head coil. We compared both relative SNR and ADC accuracy for both sequences. Volunteer studies were performed at a single axial abdominal slice position using a flexible anterior 6-channel phased-array abdominal coil and a posterior spinal array coil. Common imaging parameters for DW-PROPELLER and DW-SP-PROPELLER sequence (Fig. 1) two separate PROPELLER k-space datasets were phase corrected and reconstructed. The two magnitude images were summed for final image reconstruction.

**Diffusion-Weighted MRI** DW-PROPELLER and DW-SP-PROPELLER images were acquired in phantom models and three normal volunteers. DW images and reconstructed ADC maps of Water (W) and Ethanol (E) phantom using DW-PROPELLER (upper) and DW-SP-PROPELLER (lower). Notice non-CPMG artifacts (arrows) in DW-PROPELLER images not present in DW-SP-PROPELLER images.

**Results**

As shown in Table 1, for each phantom specimen, SNR for DW-SP-PROPELLER decreased by approximately $\sqrt{2}$ as expected compared to DW-PROPELLER at $b=0$ s/mm$^2$, while SNR for DW-SP-PROPELLER increased compared to DW-PROPELLER at $b=500$ s/mm$^2$, mostly likely due to the suppression of non-CPMG artifacts on DW-SP-PROPELLER. Mean ADC values measured by DW-SP-PROPELLER were more consistent with literature values ($\text{ADC}_{\text{water}} = 2.5 \times 10^{-3}$ mm$^2$/s and $\text{ADC}_{\text{ethanol}} = 1.0 \times 10^{-3}$ mm$^2$/s). DW-SP-PROPELLER images and ADC maps were more homogenous (i.e. lower SD of ADC) than those of DW-PROPELLER (Fig. 2). DW images and reconstructed ADC maps acquired using DW-PROPELLER and DW-SP-PROPELLER sequences are shown for a representative normal volunteer in Fig. 3. The unstable breathing pattern of human subjects can lead to severe artifacts obscuring abdominal organs. These signal-drop banding artifacts due to non-CPMG conditions were well mitigated by using DW-SP-PROPELLER.

**Conclusion**

The SPLICE technique was highly effective for overcoming non-CPMG artifacts for abdominal DW-PROPELLER MRI. DW-SP-PROPELLER offers the potential for robust high-resolution DWI particularly beneficial for abdominal oncologic imaging applications.

**Table 1.**

<table>
<thead>
<tr>
<th></th>
<th>Water</th>
<th>Ethanol</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNR DW $b=0$ s/mm$^2$</td>
<td>183</td>
<td>26</td>
</tr>
<tr>
<td>SNR DW $b=500$ s/mm$^2$</td>
<td>128</td>
<td>20</td>
</tr>
<tr>
<td>Mean ± SD ADC ($\times 10^{-3}$ mm$^2$/s)</td>
<td>PROPELLER</td>
<td>2.8±0.32</td>
</tr>
<tr>
<td></td>
<td>SP_PROPELLER</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>SP_PROPELLER</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>PROPELLER</td>
<td>2.4±0.05</td>
</tr>
</tbody>
</table>

**Reference:**