Multi-shot Diffusion-Weighted PROPELLER MRI of the Abdomen

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Introduction:
Diffusion-weighted imaging (DWI) techniques use water mobility as an exogenous probe for non-invasive interrogation of microstructural tissue properties. Single-shot DW-EPI techniques are routinely used for neuroimaging applications due to relative insensitivity to bulk motion artifacts. However, these single-shot techniques can suffer significant image distortion, chemical shift artifacts, and reduced spatial resolution particularly when extending the imaging field-of-view (FOV) as necessary for abdominal imaging applications. These limitations have significantly complicated routine clinical DWI of the visceral organs. The recently introduced DW-PROPELLER strategy offers the potential to overcome these limitations \cite{1,2}. The PROPELLER sequence uses a multi-shot acquisition strategy while permitting segmental phase correction to reduce bulk motion artifacts. In this study, we evaluated the feasibility of using the multi-shot DW-PROPELLER sequence for diffusion-weighted imaging of the abdomen. We tested the hypothesis that DW-PROPELLER provides accurate quantitative diffusion measurements while improving qualitative image sharpness, distortion, and artifact levels compared to single-shot DW-EPI.

Methods:
The PROPELLER technique uses a multi-shot turbo-spin echo (TSE) acquisition strategy with each segment of data acquired as a single rectilinear blade along a ‘propeller-shaped’ k-space trajectory. From each k-space blade, a low-resolution image is reconstructed permitting phase correction of motion artifacts. Following data correction, k-space blade segments are combined using k-space regridding for high resolution image reconstruction. Our implemented pulse sequence was based upon the BLADE sequence (Siemens Medical Solutions implementation of PROPELLER TSE). Motion-probing gradients separated by a slice-selective 180° refocusing pulse provided the requisite diffusion-weighting. Phantom experiments were performed to test the accuracy of DW-PROPELLER quantitative diffusion measurements (three cylindrical vials consisting of distilled water, acetone and ethanol at room temperature). For abdominal imaging studies, DW-PROPELLER image series were compared to corresponding single-shot spin-echo EPI (SS-SE-EPI) diffusion-weighted image series.

Results:
Representative diffusion-weighted images (b=0 and 502 s/mm\(^2\)) with reconstructed ADC maps acquired using DW-SS-SE-EPI and DW-PROPELLER sequences are shown in Fig. 1 along with an additional 192x192 matrix image series demonstrating the feasibility of improving spatial resolution with DW-PROPELLER. Overall, no image distortion or motion artifacts were observed in the DW-PROPELLER images which provided improved spatial resolution. DW-SS-SE-EPI images were commonly distorted and provided inferior spatial resolution.

Phantom Studies: Representative ADC values of water, acetone and ethanol as measured by the DW-PROPELLER sequence were 2.3x10\(^{-3}\) mm\(^2\)/s, 4.9x10\(^{-3}\) mm\(^2\)/s and 1.3x10\(^{-3}\) mm\(^2\)/s, consistent with those reported previously (2.25-2.51x10\(^{-3}\) mm\(^2\)/s, 4.5-4.8x10\(^{-3}\) mm\(^2\)/s and 1.1-1.2x10\(^{-3}\) mm\(^2\)/s) \cite{3-5}.

Qualitative Comparison: Sharpness, distortion, and ADC organ homogeneity scores were significantly improved for DW-PROPELLER images in each category; artifact level scores were improved at b=0 s/mm\(^2\) but not statistically different at b=502 s/mm\(^2\).

Quantitative Comparison: The ADC map of each organ obtained using the DW-PROPELLER sequence was more homogenous than the ADC map obtained using SS-SE-EPI. Mean D\(_{\text{mean}}\) of liver and pancreatic tissues measured using the DW-PROPELLER sequence were (1.37±0.19)x10\(^{-3}\) mm\(^2\)/s and (2.06±0.23)x10\(^{-3}\) mm\(^2\)/s respectively compared to (1.17±0.14)x10\(^{-3}\) mm\(^2\)/s and (1.82±0.23)x10\(^{-3}\) mm\(^2\)/s as measured using the DW-SS-SE-EPI sequence (mean±SD, no significant difference, p>0.05).

Conclusions:
The DW-PROPELLER sequence is a promising technique for multi-shot diffusion-weighted imaging of abdominal organs. DW-PROPELLER improved image sharpness and reduced distortion while providing accurate isotropic water diffusion measurements. Future pre-clinical studies will evaluate the use of DW-PROPELLER techniques for abdominal oncologic imaging applications (lesion detection, characterization, and therapy assessment).

\[\text{ADC} = \frac{1}{\text{b}} \ln \left( \frac{1}{S_b} \right)\]

Figure 1. Diffusion-weighted images and reconstructed ADC maps acquired using DW-SS-SE-EPI (left), DW-PROPELLER (center) and increased spatial resolution DW-PROPELLER (right, 192x192 matrix).

\[\text{ADC}_{\text{DW-SS-SE-EPI}} = \frac{1}{b} \ln \left( \frac{1}{S_{b=0}} \right)\]

\[\text{ADC}_{\text{DW-PROPELLER}} = \frac{1}{b} \ln \left( \frac{1}{S_{b=0}} \right)\]
