# High-resolution abdominal diffusion-weighted imaging based on multi-shot and multiplexed sensitivity encoded echo-planar imaging

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**TARGET AUDIENCE:** Researchers and clinicians whose investigations require high-resolution and high-quality diffusion-weighted imaging (DWI) of abdominal organs

**PURPOSE:** Recent studies have demonstrated the value of abdominal DWI for both clinical research and differential diagnosis (e.g., detecting hydatid cysts, metastases and other types of lesions of the liver). In order to reduce motion-related artifacts, abdominal DWI data are routinely acquired with either respiratory-gated single-shot echo-planar imaging (EPI) or breath hold single-shot EPI.

Single-shot EPI based abdominal DWI protocols, however, have several limitations: First, it is difficult to achieve high-resolution single-shot EPI; Second, single-shot EPI data are usually geometric distorted; Third, the echo time is usually long and thus the signal-to-noise ratio (SNR) is less than optimal. As a result, it is difficult to reliably detect subtle lesions with single-shot EPI, even after incorporating parallel MRI methods [1].

The above-mentioned limitations can be addressed using the recently developed multi-shot EPI based DWI procedures [2], capable of producing data with higher resolution, reduced distortions, and improved SNR. Although multi-shot DWI can be reliably achieved in brain imaging (after correcting shot-to-shot phase variations), it is challenging to acquire multi-shot abdominal DWI data because of the enhanced motion related artifacts.

Here we report a new imaging protocol, integrating 1) navigator-based respiratory-gating, 2) multi-shot EPI acquisition, 3) multiplexed sensitivity encoded (MUSE [3]) reconstruction, and 4) complex averaging of repeated scans, suitable for high-resolution abdominal DWI in clinical settings. Experimental results demonstrate that high-resolution and high-quality abdominal DWI can be achieved using the developed protocol.

**METHODS:**

**Navigator-based respiratory-gated multi-shot DWI:** A four-shot spin-echo EPI pulse sequence was used to acquire T2-weighted imaging and DWI data from two healthy volunteers using 3 Tesla scanners (General Electric: equipped with a 16-channel RF coil in one scanner and an 8-channel coil in the other scanner). Scan parameters included in-plane matrix size = 192 x 192, FOV = 38.4 x 38.4 mm², 20 axial slices with thickness = 8 mm, TE = 71 ms, and effective TR ~ 5 sec. Nine DWI images (b-value = 500 s/mm²) and three baseline images (b-values = 0 and 50 s/mm²) were acquired during a 4 min scan. The acquired images were processed with the following procedures. First, RF coil sensitivity profiles and the phase parameters required for EPI Nyquist artifact correction were derived from the four-shot spin-echo EPI k-space data. Second, odd-even-echo inconsistencies in four-shot DWI data were corrected to remove Nyquist artifact. Third, the conventional SENSE algorithm [1] was used to reconstruct full-FOV images from each DWI segment, from which shot-to-shot phase variations were measured and then spatially smoothed. Fourth, the DWI k-space data, RF coil sensitivity profiles, and shot-to-shot phase variations estimated from step 3 were processed with the MUSE algorithm, to produce aliasing-free full-FOV DWI images without the undesirable noise amplification in the conventional SENSE algorithm. The MUSE-DWI data from nine repetitions were averaged.

**Comparison of four-shot MUSE-DWI and single-shot parallel DWI :** We also acquired breath hold four-shot DWI data (scan time = 40 sec) and breath hold single-shot parallel DWI data (with acceleration factor = 2; scan time = 10 sec) from a healthy volunteer for comparison. Four-shot DWI data were reconstructed with the MUSE algorithm described in the previous section, and single-shot DWI were reconstructed with the conventional SENSE algorithm.

**RESULTS:** Navigator-based respiratory-gated four-shot T2-weighted EPI and four-shot MUSE-DWI, of two chosen slices, are shown in Figure 1. It can be seen that the aliasing artifacts that usually degrade multi-shot DWI image quality can be effectively removed with the MUSE, even in the presence of enhanced level of motion in abdominal MRI.

Breath hold MRI data, obtained with multi-shot MUSE and single-shot EPI sequences, are shown in Figure 2. It can be seen that the anatomic resolvability in multi-shot MUSE data is higher than that in single-shot data.

**DISCUSSION:** Our experimental data demonstrate the feasibility of achieving high-resolution abdominal DWI, by integrating 1) navigator-based respiratory-gating, 2) multi-shot EPI acquisition, 3) multiplexed sensitivity encoded (MUSE) reconstruction, and 4) complex averaging of repeated scans. The developed protocol should prove valuable for clinical MRI that requires high spatial-resolution and reduced geometric distortions to resolve subtle lesions in abdominal organs.

**REFERENCES:** [1] Pruessmann KP, et al. Magn Reson Med, 42:952-962 (1999), [2] Bammer R. European Journal of Radiology, 40:169-184 (2003), [3] Chen, NK et al. *NeuroImage* 72:41 (2013).

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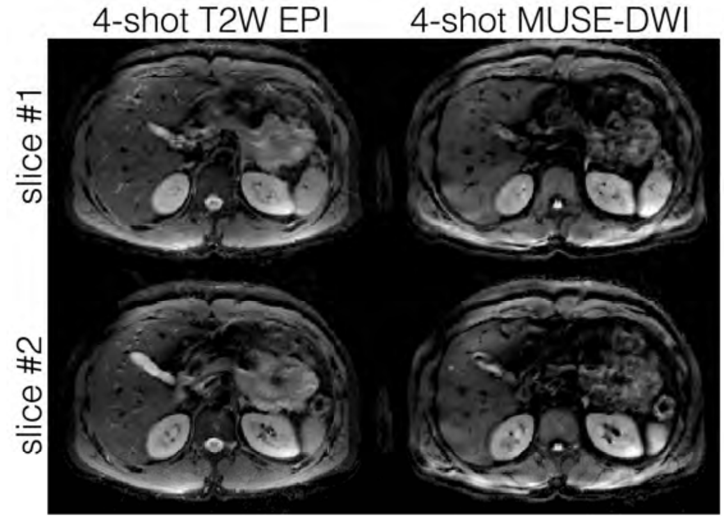


Figure 1: Navigator-based respiratory-gated multi-shot EPI based T2-weighted imaging and diffusion-weighted imaging (3 Tesla; b-value = 500 s/mm²)

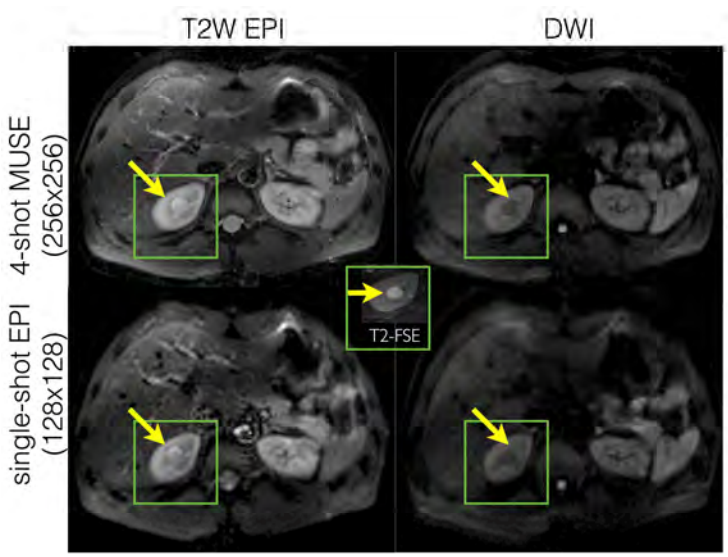


Figure 2: Comparison of breath hold multi-shot (upper row) and single-shot (lower row) EPI data (3 Tesla; b-value = 500 s/mm²)