

Single-shot and Readout Segmented EPI: Geometric Fidelity of 3T Prostate DWI

Andriy Fedorov¹, Kemal Tuncali¹, Lawrence P. Panych¹, Janice Fairhurst¹, Clare Tempany¹, and Stephan E. Maier¹
¹Department of Radiology, Brigham and Women's Hospital, Boston, MA, United States

Target audience Abdominal radiologists, interventional radiologists, MR physicists.

Purpose Diffusion-Weighted Imaging (DWI) and DWI-derived Apparent Diffusion Coefficient (ADC) maps provide superior detection and visualization of Prostate Cancer (PCa)¹. Commonly used Echo-Planar Imaging (EPI) sequences, however, are sensitive to local B0 inhomogeneities that often occur at tissue interfaces. In prostate imaging, severe distortions result from the presence of air in the rectum (i.e., air-filled endorectal coils, or rectal gas). This renders their use during image-guided prostate interventions difficult. Recently introduced segmented EPI sequences² reduce such susceptibility distortions. In this study we evaluate and compare DWI geometric fidelity of the standard single-shot and readout segmented EPI sequences in a cohort of clinical patients undergoing 3T MRI-guided prostate biopsy.

Methods *Image acquisition:* The study was HIPAA compliant and approved by the institutional review board. All men gave informed consent prior to the procedure. MR images were obtained in a wide bore Siemens Magnetom Verio 3T MR scanner. The sedated patients (N=12) were positioned in a modified lithotomy and immobilized on the table top with Velcro wrap. Imaging studies for each patient used a combination of Siemens spine coil and body matrix coil elements without an endorectal coil: (1) axial FRFSE T2-weighted MRI (T2WI) (voxel size 0.5x0.5x3 mm, imaging time 4 min) (2) axial multi-shot readout segmented EPI DWI with 2D-navigator (RESOLVE) (further referred as MS-DWI) (TE=74ms, TR=6600ms, averages=2, segmentation=5, parallel coil phase-encode acceleration=2, echo spacing=340 μ s) and (3) axial single shot EPI sequence (SS-DWI) (TE=106ms, TR=5700ms, averages=5, no parallel coil acceleration, echo spacing=976 μ s). The RESOLVE sequence was installed as a research sequence; the other two sequences were standard clinical sequences. DWI was acquired for b=0 and 1400 s/mm² along three different directions. The geometric acquisition parameters were identical: matrix 128x128, pixel spacing 2.3x2.3 mm, spacing between slices 4 mm (no gap), and phase encoding direction AP. The patient was not moved between acquisitions. *Analysis:* b0 images were reviewed by an interventional radiologist to assess the overall quality of the images (IQ) (1: "poor/non-diagnostic", 2: "fair", 3: "good", 4: "excellent"), image artifact (IA) (1: "minimum", 2: "moderate", 3: "large") and presence of air in the rectum (1: "minimum", 2: "moderate", 3: "large"). For the images of diagnostic quality, image registration (3D Slicer³, <http://slicer.org>) between T2w and b0 images was used to identify matching slices. Difference in prostate gland size in the antero-posterior dimension between T2WI and DWI (dAP) was measured at the mid-gland level. Asymptotic Wilcoxon Mann-Whitney rank sum test (comparisons of the quality and artifact scores between MS- and SS-DWI) and Spearman rho statistics (correlation between the presence of air and image quality/artifact score) were used for statistical analysis.

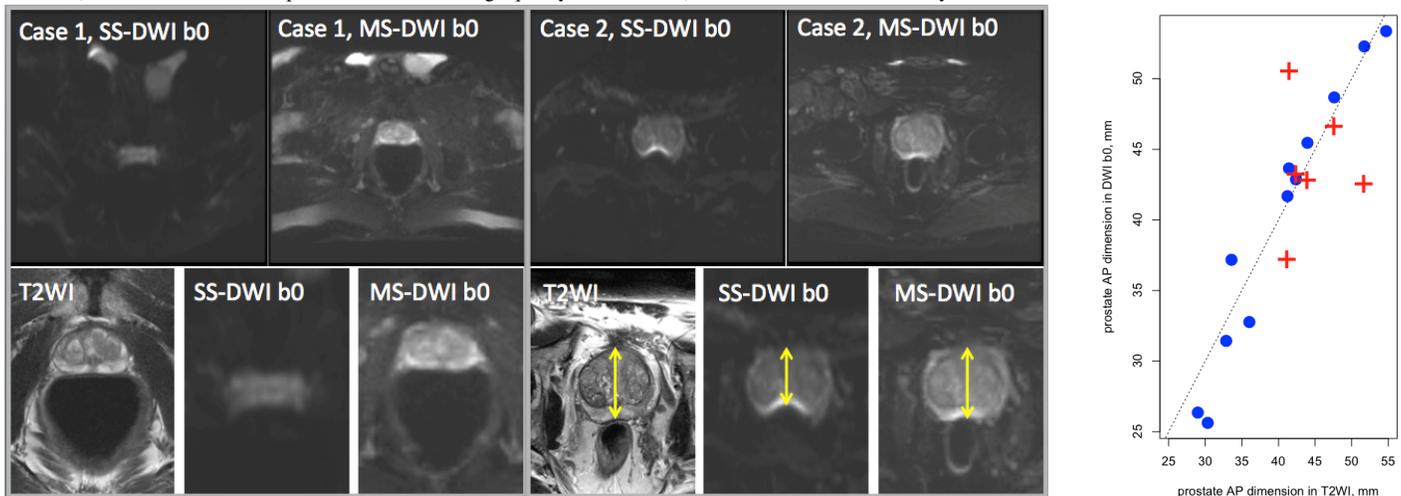


Fig. 1: Left: Illustrative examples demonstrating the differences between the quality and artifact severity in SS-DWI (Case1: IQ=1 (non-diagnostic), IA=3; Case2: IQ=2, IA=3) and MS-DWI (Case1: IQ=3, IA=2; Case2: IQ=4, IA=1) with different levels of air presence (Case1: large, Case2: moderate). AP dimensions (yellow) for Case 2 were 52mm (T2WI), 43mm (SS-DWI) and 52mm (MS-DWI). Right: Graph shows correlation of the AP measurements in T2WI with SS-DWI (red crosses, shown only images with IQ>1) and MS-DWI (blue circles). Dotted line corresponds to the perfect match between the T2WI- and DWI-based measurements.

Results Scan time was 2:01 min for SS-EPI and 3:33 min for MS-EPI. SS-EPI acquisition resulted in marked distortions of the image both within the prostate gland and more prominently at the periphery of the image (see Fig.1). Based on the qualitative assessment, only 6 of 12 SS-DWI studies and all of the MS-DWI studies were of diagnostic quality. Overall, MS-EPI resulted in images of better quality (average score 3.3 vs 1.9) and less prominent artifact (1.4 vs 2.5) as compared to SS-EPI (p<0.003). Strong correlation was observed between the presence of air and image quality ($\rho = -0.72$, p<0.008) and distortion ($\rho = 0.68$, p<0.015) for SS-EPI. Correlations were not statistically significant for MS-EPI. In the images of diagnostic quality, where image registration and identification of the prostate capsule at mid-gland level was feasible in both SS- and MS-DWI (N=6), the difference of AP dimension statistics of the gland between the measurements in T2w- and DWI were 2.6 (median) (range 0.8-9.2) mm for SS-DWI, and 0.8 (0.5-2.2) mm for MS-DWI. Considering all 12 cases for MS-DWI, dAP was 1.5 (0.5-4.7) mm.

Discussion Segmented diffusion imaging resulted in marked improvement of the geometric fidelity and overall number of diagnostic quality scans. With a five-fold readout segmentation the denser echo spacing reduces distortions by 2.9 (echo spacing ratio 976 μ s / 340 μ s). Together with parallel imaging, distortions are reduced by 5.8 (2x2.9). This expected reduction is in line with the observed reduction of T2WI-DWI prostate size differences for MS-EPI vs SS-EPI. The five-fold segmentation comes with a penalty of five-fold scan time. However, the reduction of echo-train length results in a considerably shorter TE and therefore higher SNR for MS-EPI. This SNR advantage was taken into consideration by performing fewer averages for MS-EPI than SS-EPI. A more profound SNR analysis for prostate tissue would be desirable, but was considered difficult due to tissue inhomogeneity and the masking of areas without signal.

Conclusions Prostate imaging using multi-shot readout-segmented EPI DWI leads to a dramatic reduction of image distortion as compared to SS-EPI DWI (only half of the SS-EPI images were deemed diagnostic) at the expense of moderately increased scan time. Further reduction of the acquisition time with the present MS-EPI protocol can be achieved by skipping signal averaging. Segmented diffusion-weighted EPI can lead to improved interpretation of PCa MRI in diagnostic applications, and facilitate interventional guidance in the prostate using intra-procedural DWI for target localization.

Acknowledgments: R01 CA160902, R01 EB010195, R01 CA111288 and P41 EB015898.

References [1] Kim et al. AJR. 2010 194(6):1461-69. [2] Porter and Heidemann. MRM. 2009 62(2):468-75. [3] Fedorov et al. MRI. 2012 30(9):1323-41.