Accelerated, Segmented Diffusion-Weighted Imaging in the Prostate achieves High Resolution, Speed and Geometric Fidelity

Pelin Aksit Ciris[1,2], Jr-yuan George Chiou[1,2], Andriy Fedorov[1,2], Clare M. Tempany-Afdhal[1,2], Bruno Madore[1,2], and Stephan E. Maier[1,2]
[1]*Brigham and Women's Hospital, Boston, MA, United States,* [2]*Harvard Medical School, Boston, MA, United States*

Target Audience: Researchers and physicians with an interest for fast diffusion-weighted imaging in the prostate with improved geometric fidelity.

Purpose: Multi-parametric MRI (mpMRI) is considered the most accurate approach for detecting, characterizing and staging of prostate cancer[1,2]. Diffusion-weighted imaging (DWI) is an essential component of mpMRI, along with T2-weighted (T2W) and dynamic contrast-enhanced imaging. Due to high motion sensitivity of DWI, single-shot echo-planar imaging (EPI) is employed to obtain 'snapshot' images. Single-shot EPI, however, is prone to geometric distortions due to low acquisition bandwidth (BW) in the phase-encoding (PE) direction, especially in the presence of local magnetic field variations. Multi-shot diffusion EPI[3,4] has become an important tool for situations where single-shot EPI might fail to provide adequate geometric fidelity. A critical component of multi-shot EPI is the correction of shot-to-shot phase variations introduced by rigid body motion or tissue deformation. Typically, this is accomplished using phase information from a low-resolution 2D navigator echo that samples the central portion of *k*-space every TR period. The main drawback of multi-shot imaging is the associated increase in scan time. A method was recently proposed to accelerate multi-shot acquisitions[4], achieving improvements in geometric fidelity at potentially no cost in scan time. The method is based on the observation that diffusion-encoded data is sparse when represented in the x-y-k_b-k_d space, where k_b and k_d are the Fourier transform duals of b and d, the b-factor and the diffusion direction, respectively. Aliasing artifacts are displaced toward underused regions of the k_b-k_d plane, allowing non-aliased signals to be recovered. The navigator information is fully utilized in the reconstruction: The magnitude is used for regularization purposes and the phase is used for motion correction. Unlike parallel imaging which requires multi-channel coils for acceleration, this accelerated approach can even work (albeit less effectively) with single channel coils, such as the endo-rectal coil typically used for prostate imaging. The approach is employed here to achieve relatively-fast scan times with low distortion, as confirmed from prostate size.

Methods: Five patients undergoing prostate cancer staging participated in this IRB-approved study (ages: 61±4 years). Imaging was performed at 3T (MR750w system, GE Healthcare) using an endo-rectal coil (Medrad). The protocol included T2W imaging: FRFSE, TE/TR=94/4425ms, ETL=13, FOV=14x14cm, 288x192 matrix, 3mm slices with 0.5mm gap, 2 averages. Conventional DWI was acquired with b-values of 500 and 1400 s/mm^2 (single-shot EPI, FOV=18x14.4cm, 96x77 matrix, pixel size=1.9mm, 22x4mm slices with 0 gap covering the prostate and seminal vesicles, 3 directions, readout (RO) BW=167kHz, PE BW=1.31kHz; for b=500: TE/TR=61.8/6350ms, 8 averages, scan time=5min 30s; for b=1400: TE/TR=75.8/7550ms, 16 averages, scan time=6min 18sec). Accelerated DWI imaging sampled 12 evenly spaced b-values ranging from 0 to 2000 s/mm^2, with a segmentation factor equal to the acceleration factor, acquiring a single shot per image (multi-shot segmented EPI, segmentation and acceleration factor=4, FOV=18x18cm, 128x128 matrix, pixel size=1.4mm, 17x4mm slices with 0 gap covering the prostate, 6 directions, 1 average, TE/TR=87.8/4000ms, (RO) BW=167kHz, PE BW=4.37 kHz, navigator matrix size=32×32, navigator TE=128.4ms, scan time=5min 4s). Geometric distortion was assessed by comparing the prostate gland size along the PE direction (anterior-posterior) in T2W, conventional DWI and accelerated DWI acquisitions.

Results: The accelerated method allowed acquisition of 12 b-values, at a higher spatial resolution, and with less geometric distortion, in a scan time of ~5min, a scan time comparable to that of a single b-value at lower resolution using conventional DWI. All accelerated segmented diffusion images were of diagnostic quality (Fig. 1), with no evidence of ghosting or signal loss. As seen from Table 1, geometric distortion was reduced by a factor of 2.53 ± 0.76 using the proposed segmented-accelerated approach, as compared to conventional single-shot EPI scans. In theory, based solely on imaging bandwidth, the improvement should have been slightly greater at 3.33-fold.

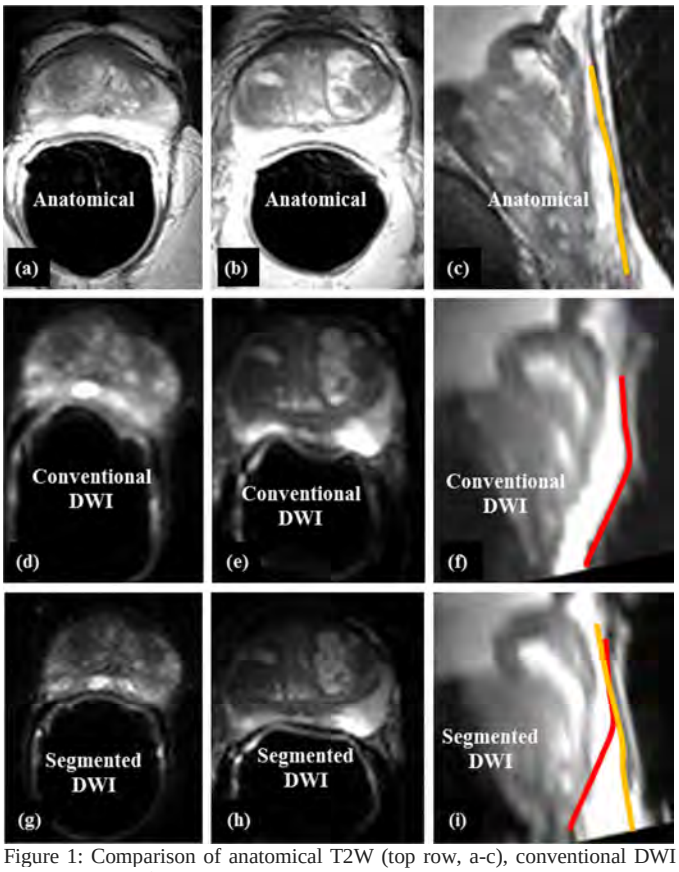

Figure 1: Comparison of anatomical T2W (top row, a-c), conventional DWI (middle row, d-f), and accelerated segmented DWI (g-i). Accelerated segmented DWI provides high-resolution images with good geometric fidelity and SNR. The left and middle columns show images in the axial plane, the rightmost column in the sagittal plane. The 'reference' rectal wall shape is seen in (c), orange line, and the distorted shape in (f), red line. In the segmented-accelerated results in (i), the rectal shape (bright signal) is in much closer agreement with the correct shape of (c), orange line, than that of (f), red line. In other words, geometric fidelity is considerably restored using accelerated segmented DWI (i).

	Prostate size measures on 5 patients				
T2W (mm)	45.8	31.8	33.1	41.4	35.0
Segmented DWI (mm)	43.5	32.7	36.5	45.6	38.5
Conventional DWI (mm)	42.4	34.9	42.0	52.2	43.6
Conventional/Segmented Distortion Ratio	1.4	3.6	2.6	2.6	2.4

Table 2: Distortion was reduced by 253% ± 76% (mean ± sd over patients)

Discussion: We have demonstrated that high spatial resolution and low geometric distortion diffusion images in prostate can be obtained with accelerated multi-shot diffusion scans. The total scan time for acquisition of 12 b-values with high-resolution and reduced distortions was only 5min, in contrast to acquiring only 2 b-values in 12min using conventional DWI.

Conclusion: In a relatively short 5min interval, good-quality results were obtained with high geometric fidelity.

References: (1) Tempany et.al. Cancer. 2014 Sep 9. doi: 10.1002/cncr.29012. (2) Hegde et al. J Magn Reson Imaging 2013;37:1035 (3) Holdsworth et al. Magn Reson Med 2009;62:1629. (4) Madore et al. Magn Reson Med 2014;72:324. Support from NIH grants R01CA160902, R01EB010195, 5R25CA089017-10, P41EB015898 and R01CA149342 is acknowledged.