Clinical Application of 3D High Resolution Multi-shot Diffusion-Weighted MRI in Prostate Cancer Patients undergoing Active Surveillance Protocol for Low-Risk Prostate Cancer

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Target Audience – MR scientists, MR engineers, Urologists, and Radiologists specializing in pelvic imaging

Introduction – Diffusion-weighted (DW) MRI has been proposed for noninvasive monitoring of low risk prostate cancer (lrPC) in patients on active surveillance (AS-PC) for possible grade progression (e.g. Gleason grade 3 to 4) or increase in tumor volume [1-3]. Although conventional single shot (SS) DW echo planar imaging (EPI) may be adequate for evaluating bulky tumors typically managed with radical surgery, accuracy and sensitivity is limited for monitoring lrPC seen in AS patients because of limited spatial resolution and poor image quality [4]. Recent technical work in preliminarily applying a 3D multi-shot high resolution diffusion MRI technique in AS-PC patients has demonstrated that improved image quality (reduced susceptibility-related artifacts and geometric distortion) and higher spatial resolution can lead to better detection of suspicious lesions [5]. However with only a small number of patients (N = 8) being studied, the clinical potential of the technique remains to be fully investigated. Therefore, we present a follow-up study that doubles the amount of patients in evaluating the lesion detection of the novel proposed 3D high-resolution diffusion MRI technique and conventional 2D SS DW EPI with standard 12-point biopsy.

Methods – In a group (N=17) of AS-PC patients, we compared the lesion detection performance of the proposed 3D high-resolution diffusion prepared technique (0.9x0.9x3.5mm^3, TE_{prep}=60ms, FA=90°, 48 segments, 5 Kaiser ramp-up, centric encoding, parallel imaging R=2, TR_g/TR/TE = 1200/3.5/1.74ms, 4 shots) with 2D SS DW EPI (2.1x2.1x3.5mm^3, TR/TE=4700/80ms, parallel imaging R=2, NEX=13). Both diffusion sequences encoded 3 orthogonal DW directions at 2 b-values (300 and 600 s/mm^2) and a b0 image (7 measurements, 7.5 minutes). The diffusion scans were integrated into a routine clinical pelvic MR scan that included T2-weighted TSE (0.5x0.5x3.5mm^3, TR/TE=4800/125ms) and dynamic contrast enhanced (DCE) T1-weighted gradient-recalled echo (GRE) scan (1.3x1.3x3.5mm^3, TR/TE=3.02/1.09ms, temp res = 40s). Two hours following imaging, a standard 12-point biopsy was performed blinded to the imaging results and acted as gold standard. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and area under the receiver-operator curve (AUC) of the pelvic MR protocol using SS DW EPI or the proposed technique was compared with biopsy in identifying regions positive for lrPC. The MRI reading was blinded to biopsy and consensus PIRAD scoring was used to determine suspicious lesions (PI-RADS > 3 [6]). The lesions were mapped to 6 zonal regions (L/R apex, L/R mid, and L/R base) corresponding to the 12-point biopsy.

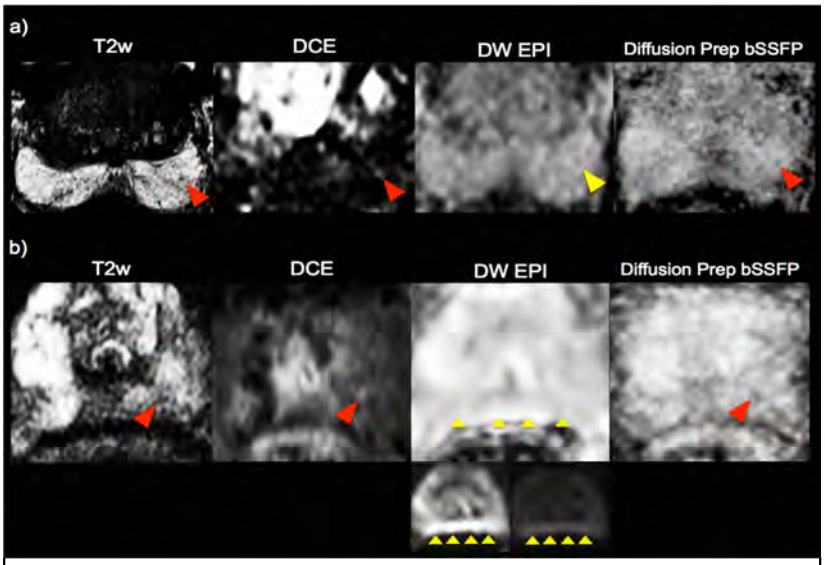

Figure 1 – Representative cases of diffusion-prepared bSSFP having improved lesion detection over SS DW EPI because of improved spatial resolution and image quality. In both cases, PI-RADS score was affected adversely downgrading biopsy concordant lesions. (a) A suspicious lesion is detected (PI-RADS 4) by diffusion-prep bSSFP because of its higher spatial resolution (red arrow), but is undetectable (PI-RADS 3) due to partial voluming in SS DW EPI (yellow arrow). (b) Another suspicious lesion detected (PI-RADS 4) by diffusion-prep bSSFP, but is obscured (PI-RADS 2) in SS DW EPI due to the presence of a severe "signal-pile-up" susceptibility-related artifact (yellow arrows).

Results – Of the total 102 zones across all patients, only 23 were found to have lrPC according to biopsy. Sensitivity, PPV, NPV, and AUC of the clinical MR protocol using the proposed technique (0.96, 0.61, 0.98, and 0.87) was significantly higher ($p < 0.05$) than the protocol using SS DW EPI (0.61, 0.54, 0.86, and 0.71). Specificity was marginally lower for the proposed technique (0.80) compared with SS DW EPI (0.82). In comparison to the previous study, sensitivity, specificity, PPV, NPV, and AUC increased for the proposed method (% change: +1%, +21%, +13%, +1%, and +9%). For SS DW EPI, specificity, PPV, NPV, and AUC had increased (+15%, +13%, +5%, and +6%) but sensitivity decreased (-3%). The previously observed dramatic increase in sensitivity and AUC of the proposed technique over SS DW EPI was also found in this study (this study: 0.95 vs 0.61; previous study: 0.87 vs 0.67) and the previously observed marginal decrease in specificity was less pronounced (this study: 0.80 vs 0.82; previous study: 0.66 vs 0.71). Specific examples shown in Figure 1 demonstrate the clinical impact of improved image quality for 2 lesions found in biopsy-positive zones. PI-RADS scores were correctly changed upgrading "most likely benign" (PI-RADS 2) or "indeterminate" (PI-RADS 3) lesions to "most likely malignant" (PI-RADS 4) lesions.

Conclusion – In a significantly larger patient cohort, we have demonstrated that the proposed 3D diffusion-prepared multi-shot bSSFP technique still maintains a better lesion detection potential than conventional 2D SS DW EPI. By improving lesion detection, the proposed technique may allow DW MRI to potentially monitor lrPC in AS-PC.

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