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Original contribution

Conventional vs. reduced field of view diffusion weighted imaging of the prostate: Comparison of image quality, correlation with histology, and inter-reader agreement

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ABSTRACT

Purpose: To evaluate if Field of view Optimized and Constrained Undistorted Single shot (FOCUS) (GE Healthcare, Waukesha, WI) diffusion weighted images (DWI) provide more reliable imaging than conventional DWI, with non-inferior quantitative apparent diffusion coefficient (ADC) results.

Material and methods: IRB approval was obtained for this study of 43 patients (44 exams, one patient with two visits) that underwent multiparametric prostate MRI with two DWI sequences and subsequent radical prostatectomy with histology as the gold standard. Randomized DWI sequence images were graded independently by two blinded experienced prostate MRI radiologists with a period of memory extinction between the two separate reading sessions. Blinded images were also reviewed head to head in a later session for direct comparison. Multiple parameters were measured from a region of interest in a dominant lesion as well as two control areas. Patient characteristics were collected by chart review.

Results: There was good correlation between the mean ADC value for lesions obtained by conventional and FOCUS DWI ($\rho = 0.85$), with no trend toward any systematic difference, and equivalent correlation between ADC measurements and Gleason score. Agreement between the two readers was significantly higher for lesion ROI analysis with the FOCUS DWI derived ADC values (CCC 0.839) compared with the conventional ADC values (CCC 0.618; difference 0.221, 95% CI 0.01–0.46). FOCUS showed significantly better image quality scores (separate review: mean 2.17 ± 0.6, $p < 0.001$) compared to the conventional sequence (mean 2.65 ± 0.6, $p < 0.001$). In 13 cases the image quality was improved from grade of 3 + with conventional DWI to < 3 with FOCUS DWI, a clinically meaningful improvement. Head-to-head blinded review found 61 ratings showed strong to slight preference for FOCUS, 13 no preference, and 14 slight preference for the conventional sequence. There was also a strong and equivalent correlation between both sequences and PIRADS version 2 grading ($\rho = -0.56$ and -0.58 for FOCUS and conventional, respectively, $p < 0.001$ for both).

Conclusion: FOCUS DWI of the prostate shows significant improvement in inter-reader agreement and image quality. As opposed to previous conflicting smaller studies, we found equivalent ADC metrics compared with the conventional DWI sequence, and preserved correlation with Gleason score.

In 52% of patients the improved image quality with FOCUS had the potential to salvage exams with otherwise limited to non-diagnostic DWI.

1. Introduction

Magnetic Resonance Imaging (MRI) has been used for over thirty years to aid in the diagnosis and staging of many types of cancers. Recently, due to technological advances and introduction of multiparametric (mp) MRI, the ability to more accurately image and assess prostate cancer has drastically improved. Specifically, diffusion weighted imaging (DWI) of the prostate has played a large part in these advances and the ability to help predict clinical significance and underlying Gleason grade of prostate cancers [1,2]. Multiple studies have shown that apparent diffusion coefficient (ADC) values derived from DWI images have a direct correlation with cancer aggressiveness (Gleason score) [1,3–8]. Because of this specificity and clinical correlation, in the Prostate Imaging and Reporting and Data System, Version

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2 (PI-RADS v2) guideline [9], the overall assessment score within the peripheral zone of the prostate is almost entirely dependent on the ADC and high b-value DWI component score. DWI also plays a complementary role in evaluating the transition zone when the lesion is considered a PI-RADS 3 lesion on T2-weighted imaging which is the dominant sequence. Benchmarking of ADC values at an individual site can provide clinically powerful additional quantitative information beyond subjective assessment of DWI. These factors all underscore the importance of the need for a reliable and accurate DWI series and ADC map.

Unfortunately, diffusion-weighted MR imaging of the prostate utilizing single shot echo planar imaging (ss-EPI) can be technically challenging and is susceptible to limitations in clinical practice. A common major limitation is the high sensitivity to distortion due to susceptibility mismatches causing magnetic field inhomogeneity. For prostate MRI the principal causes of distortion are rectal gas or air in an inflatable endorectal coil or metal from pelvic/hip surgeries. The resultant inhomogeneities cause cumulative dephasing of off-resonance spins over the EPI readout which in turn leads to mismapping or distortion. This sensitivity of EPI to off-resonance has been described theoretically [10] and is dependent on the rate at which k-space is sampled along the phase encode direction, here taken to be Y. Because the sampling increment along k_Y is equal to the inverse of the field-of-view (FOV) along Y, reductions to FOV_Y reduce this sensitivity.

Reduced-FOV DWI of the prostate has been applied in small cohorts to improve performance, particularly with regard to image distortion. Initial clinical observations suggested that there may be differences in ADC map appearance and possibly quantitative values when compared to conventional EPI DWI [11–16]. However in these existing smaller studies of conventional DWI compared to reduced FOV DWI, the relationship of the ADC metrics derived from conventional versus reduced FOV DWI has been conflicting, with both increasing and decreasing ADC values from reduced-FOV imaging vs. conventional DWI being reported. Those studies are also variously composed of normal volunteers, patients with benign biopsies, and a smaller subset of patients with cancer in which many only have biopsy for correlation. This study is the largest comparison of patients with proven cancer and definitive pathology for correlation of ADC quantitation.

The primary goal of this study is to compare the image quality and quantitative data provided by two different DWI sequences of the prostate: a conventional DWI sequence and a limited FOV sequence. The latter used the Field of view Optimized and Constrained Undistorted Single shot [FOCUS] DWI sequence provided by the vendor (GE Healthcare, Waukesha WI). The hypothesis is that FOCUS provides better and more reliable image quality than conventional DWI, with quantitative ADC results that are non-inferior, thus making it an improvement to substitute in clinical practice. A secondary goal of this study is to assess any difference in performance of FOV reduction made along the left-right vs. anterior-posterior direction.

2. Materials and methods

2.1. Patient population

An IRB approved retrospective study was done of patients diagnosed with prostate cancer who had MR imaging of the prostate performed with both conventional DWI and FOCUS DWI as part of a mpMRI exam with subsequent radical prostatectomy. During a 6 month period from June 1, 2014 to December 15, 2014, 44 exams were identified who met inclusion criteria. The average age was 64 years (range 51–76) and the average PSA value was 14.9 ng/mL (range 0.1–91.6). The breakdown of Gleason scores from the pathology reports is shown in Table 1. Gleason scores (GS) of 6 (Gleason grade 3 + 3) are considered to be clinically insignificant whereas Gleason scores of 7 or greater are collectively considered as clinically significant cancers. Some further evaluations therefore compared GS 6 lesions (n = 7) vs. GS 7 or GS > 7 lesions combined. The dominant lesions were located in the peripheral zone in 32 patients. In 6 cases the lesion was large and involved multiple zones.

Table 1
Gleason score from pathology of the prostate samples and number of patients in each category for 37 of 43 patients where there were exact matched ROIs between the sequences for comparison of ADC metrics.

Gleason score	Number of patients
3 + 3	7
3 + 4	13
4 + 3	3
4 + 4	4
4 + 5	7
5 + 4	2
5 + 5	1

2.2. MRI acquisition

In addition to the localizer scan, the non-DWI sequences included T2-weighted spin-echo and a dynamic-contrast-enhanced (DCE) sequence. The DWI sequences were performed prior to administration of contrast material. The pathology of the prostatectomy specimen was the gold-standard histology correlation [Table 1]; patients with histology only from biopsy were excluded. All images were acquired on a 3.0 Tesla MR scanner (Discovery MR750w, GE Healthcare, Waukesha, WI). In all patients a single channel endorectal prostate coil (Medrad® Prostate eCoil, Bayer, Whippany, NJ) was used in combination with a four-element anterior and eight-element posterior external phased array coil. To reduce air artifacts, the endorectal coil was insufflated with approximately 50 mL of 60% weight/volume barium solution. Images for both diffusion sequences were acquired in multi-slice format in an approximate axial orientation with slight tilting to align the slice select direction with the central axis of the prostate gland as determined from a sagittal localizer. The Field of view Optimized and Constrained Undistorted Single shot (FOCUS) DWI (GE Healthcare, Waukesha, WI) acquisition is a recently developed pulse sequence utilizing a 90° 2D spatially selective, echo planar RF pulse to excite a limited extent in the phase FOV direction [17]. For the FOCUS-DWI the direction of the FOV reduction (the phase encode direction of the EPI sequence) was randomly selected as being either left-right (L/R) or anterior-posterior (A/P). For the conventional DWI the phase encode direction was always L/R per our standard practice. The acquisition parameters are detailed in Table 2. Acquisition time and total slices were variable dependent on patient anatomy.

In 24 of 44 exams FOCUS was acquired in the left-right phase direction, and 20 in the AP direction. The inconsistency in phase direction allowed for a direct comparison of the performance of FOCUS in both the left-right and anterior-posterior phase directions when compared to conventional DWI. ADC maps were originally generated from DWI on the MR console with standard vendor methods and reviewed singly in a blinded and randomized fashion (single review). However for the subsequent blinded head-to-head image comparison (described below) and quantitation, new ADC maps were generated using the b values of 100 and 1000 s/mm^2 encodings with a mono-exponential model equivalently to reduce potential variability introduced by dissimilar b-value inputs, as b0,100,1000 s/mm^2 encodings were acquired with conventional DWI and only b100,1000 s/mm^2 for FOCUS.

The methods of each of two reading sessions were as follows,

"Single review" reading session: For each patient the conventional or reduced-FOV DWI images and corresponding ADC maps generated by standard on-console vendor processing were individually evaluated by two blinded, independent radiologists, both GU subspecialized prostate MRI readers with 4 and 25 years of experience.