Diffusional kurtosis imaging of prostate cancer: Effect of b-values and noise compensation on quantitative parameters, relative contrast, and short-term repeatability

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Target Audience: Physicists and clinicians interested in advanced analysis of diffusion-weighted imaging in the body.

Purpose: Diffusional kurtosis imaging (DKI) is a type of diffusion-weighted imaging that attempts to better quantify water movement by accounting for a non-Gaussian distribution.¹ While DKI has been investigated in the setting of prostate cancer using biopsy results² no comparison with whole-mount pathology has been made and no investigation into the effect of the b-values used and short-term repeatability of the quantitative parameters has been performed. The purpose of this study was to (1) evaluate differences between tumor and matched normal tissue, (2) investigate the influence of b-values or noise compensation on DKI-based quantitative parameters, and (3) compare short-term repeatability of the different methods and parameters.

Methods: Eighteen patients, all with biopsy-confirmed prostate cancer and scheduled for prostatectomy, were recruited for an IRB-approved prospective study. Ten non-consecutive patients were additionally included in a test-retest sub-group. Diffusion-weighted dual-spin echo EPI (TE/TR=89/5000ms; b-values: 0,150,600,1050,1500,2000 s/mm²; 8+ averages; ASSET factor 2; FOV 32x32cm; Matrix 128x128; 4/1 mm slice thickness/gap) was acquired using a 3T Signa HDx scanner (GE Healthcare, Waukesha, WI) using an 8-channel phased array coil. An additional acquisition without RF pulses was used to measure the noise floor (*n*). For the retest subgroup, an identical DW-MRI acquisition was performed with the patient getting off the scanner bed in between the scans. Slice locations were matched to the initial scan using anatomical landmarks.

The diffusional kurtosis model uses a second-order approximation to the dependence of signal *S* with b: $S = S_0 \exp(-bD_{app} + b^2D_{app}^2K_{app}/6)$, where D_{app} is the apparent diffusional kurtosis. Quantitative maps of D_{app} and K_{app} were calculated by nonlinear fitting of the measured signals, compensating for the impact of the noise floor¹ by fitting the measured signal to $\sqrt{S^2 + n^2}$ where *S* is given by the above equation. Maps were calculated using four different DKI methods: [1, standard] b-values 150–2000 using noise compensation; [2, low b=0] bvalues 0–2000 (not including 150) with noise compensation; [3, high b = 1500] b-values 150–1500 using noise compensation; [4, no noise comp] bvalues 150–2000 without noise compensation. Regions of interest were drawn on the method [1] D_{app} maps by an experienced reader, in the index tumor and contralateral matched normal tissue for each patient, with reference to T₂W-MRI and whole-mount pathology. Voxels with a K_{app} value that was zero or negative were excluded from quantitative analysis due to fit failure. Repeatability was evaluated using coefficient of variation (CV). Relative contrast was calculated by using the equation (A-B)/(A+B) where A and B are the values from tumor and matched normal ROIs, respectively. Paired t-tests, with Bonferroni correction as necessary, were used to compare matched normal and tumor ROIs along with relative contrast from different techniques.

Results: Evaluation included 12 peripheral zone tumors (Fig. 1) and 6 transition zone tumors. The quantitative parameters obtained from the different groups, for both peripheral and transition zone

Table 2: Mean relative contrast

for D _{app} and I	showed			
Method	D_{app}	Kapp	differen	
1: Standard	-0.16 ± 0.09	0.14 ± 0.09	both D _a	
2: Low b=0	-0.13 ± 0.09*	0.16 ± 0.08	but sign	
3: High b=1500	-0.14 ± 0.09*	0.18 ± 0.09*	while n	
4: No noise comp	-0.16 ± 0.10	0.11 ± 0.07*	K _{app} . Ir	
Data are mea *Significant di standard met	improve contras			

separately, are presented in Table 1. All methods d a significant nce between tumor atched normal for $_{\mbox{\scriptsize app}}$ and $K_{\mbox{\scriptsize app}}.$ Methods 3 showed a small, nificant, decrease in ative contrast for D_{app} nethod 4 showed a ant decrease for nterestingly, method wed a significant ement in relative st, compared to the rd method, for Kapp

Table 1: DKI parameters from different met	hods and tissue type
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	<i>Mean D</i> _{app} (×10 ⁻³ mm ² /s)		Mean K _{app}			
Method Number	Matched	Tumor	Matched	Tumor		
	nml		nml			
Peripheral Zone						
1: Standard	2.02 ± 0.21	$1.53 \pm 0.31^{\dagger}$	0.52 ± 0.07	0.68 ± 0.17*		
2: Low b=0	2.10 ± 0.19	$1.69 \pm 0.32^{\dagger}$	0.51 ± 0.08	$0.69 \pm 0.17^{\dagger}$		
3: High b=1500	2.09 ± 0.19	$1.62 \pm 0.32^{\dagger}$	0.54 ± 0.09	$0.77 \pm 0.21^{\dagger}$		
4: No noise comp	1.99 ± 0.24	$1.50 \pm 0.31^{\dagger}$	0.65 ± 0.08	0.80 ± 0.15*		
Transition Zone						
1: Standard	1.88 ± 0.17	1.31 ± 0.32*	0.57 ± 0.06	0.84 ± 0.21*		
2: Low b=0	1.97 ± 0.16	1.42 ± 0.31*	0.57 ± 0.06	0.85 ± 0.19*		
3: High b=1500	1.93 ± 0.13	1.40 ± 0.31*	0.60 ± 0.09	0.96 ± 0.28*		
4: No noise comp	1.84 ± 0.20	1.29 ± 0.35*	0.68 ± 0.10	0.92 ± 0.23*		
Note: Data are means ± standard deviations						
Significant difference between matched normal and tumor (*p<0.01; 'p<0.001)						

(Table 2). Both parameters showed good short-term repeatability \Box Significant difference be regardless of method with CVs of less than 7.5% for D_{app} and less than 15% for K_{app}.

Discussion: Tumor ROIs showed significantly decreased mean D_{app} and increased mean K_{app} , when compared to matched normal tissue, regardless of method used. Quantitatively, mean D_{app} was increased for both tumor and normal regions when a low b-value of 0 or a high b-value of 1500 was used. This change resulted in a significant decrease in relative contrast for these two methods (method 2 and 3). While the mean K_{app} values for matched normal tissue remained similar between method 1 and method 3, the use of a high b value of 1500 (method 3) resulted in an increased mean K_{app} in the tumor region and a significant increase in relative contrast (Table 2 and Fig. 1). In the re-test group, all methods showed good short-term repeatability.

Conclusion: DKI is a clinically robust technique with significant differentiation of tumor, regardless of method or tumor location, and good short-term repeatability. The highest relative contrast between tumor and matched normal was gained through the K_{app} maps using a high b-value of 1500 s/mm².

References: 1. Jensen JH, Helpern JA, Ramani A, Lu H, Kaczynski. Diffusional kurtosis imaging: the quantification of non-gaussian water diffusion by means of magnetic resonance imaging. Magn Reson Med. 2005:53(6):1432-40.

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Figure 1: 64-year old man with peripheral zone prostate cancer. A) DW-MRI trace image B-E) K_{app} maps F) Whole-mount pathology (Tumor outlined in red).