Real Data Reconstruction to Remove Rician Bias from DKI of the Prostate

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Introduction

Diffusional kurtosis imaging (DKI) may become a clinically useful tool for the diagnosis and risk stratification of prostate cancer[1] by providing a measure of tissue structure from the quantification of non-Gaussian behaviour (kurtosis)[2] in water diffusion. DKI acquisition protocols use diffusion weighted imaging (DWI) pulse sequences with a large range of b-values, where kurtosis measurements are especially influenced by higher b-values, associated with low SNRs. However, at low SNRs the Rician distribution of pixel intensities in magnitude images introduces an increased mean pixel value[3] (Fig. 1), resulting in inaccurate estimates of kurtosis. Body DWI images are typically calculated from 3 diffusion directions and 4-8 signal averages, averaging magnitude data rather than real data to avoid motion-related phase differences between the averages[4]. While magnitude averaging does reduce the apparent noise, it does not reduce the Rician bias, unlike when real data are averaged[5]. For this study, we remove the Rician bias from prostate DKI by reconstructing phase-corrected real images, and compare DKI metrics calculated from magnitude data, magnitude data with noise compensation[6] (NC), and phase-corrected real data.

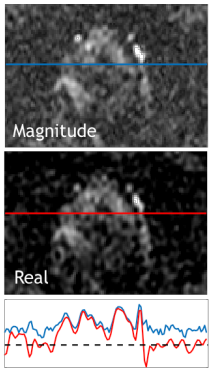

Fig. 1. Magnitude- and real-data prostate image (same windowing) for b=1500s/mm². The profiles pots illustrate the effect of Rician bias on the magnitude data, (dashed line = 0).

Methods

The DKI model[1] uses a second-order approximation to the exponential dependence of signal S with b: $S(b) = S(0)\exp(-bD_{app} + b^2D_{app}^2K_{app}/6)$ (1) where D_{app} and K_{app} are, respectively, the apparent diffusion coefficient and apparent kurtosis. 16 patients underwent DKI using a 3-T Signa HDx scanner (GE Healthcare, WI, USA) and a 32-channel phased-array cardiac coil. DWI-EPI images were acquired with parameters: TR 6000ms, TE 94ms, 6 NEX, 3.6mm slices, acq. matrix 128x96, ASSET acc. factor 2, 5 b-values 100, 450, 800, 1150, 1500s/mm² (each applied along 3 orthogonal directions). Additional noise-only images were collected by removing the RF pulses. We used GE's Orchestra SDK in MATLAB to adapt DWI reconstruction so that slow phase variations were removed with a low-pass filter as part of Homodyne reconstruction[7] and the real part of the data was taken rather than magnitude. Maps of D_{app} and K_{app} were calculated by voxel-wise LSQ fitting to Eq. 1, and mean values found in tumour (TUM), normal transition zone (NTZ) and normal peripheral zone (NPZ) regions of interest. Where NC was performed, the model fitted was an estimate of the noisy signal, S_n, where $S_n = \sqrt{S^2 + n^2}$ and n was estimated from the noise image.

*Table 1. Median (IQR) K_{app} metrics in TUM, NPZ, and NTZ across 16 patients. Also shown are percentage differences from median K_{app} values calculated with magnitude data without NC. Wilcoxon-test levels of significance for K_{app} metrics derived from the different methods are indicated as ***p<0.001.*

ROI label	Magnitude data	Magnitude data & NC		Real Data	
TUM	0.98 (0.18)	0.94 (0.17)	***-4%	0.82 (0.25)	***-16%
NPZ	0.54 (0.14)	0.52 (0.13)	***-6%	0.44 (0.11)	***-19%
NTZ	0.69 (0.17)	0.65 (0.13)	***-6%	0.60 (0.16)	***-13%

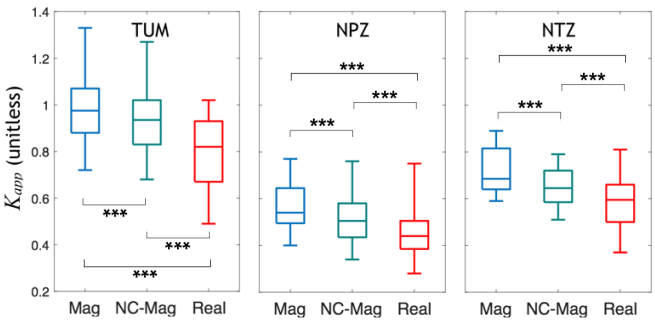

*Fig. 2. Boxplots illustrate the distribution of K_{app} metrics estimated using magnitude data without (blue) and with (green) NC, and real data (red). Wilcoxon-test levels of significance for K_{app} metrics derived from the different methods are indicated as ***p<0.001.*

Results and Discussion

Table 1 shows that relative to metrics estimated from magnitude data, median NC K_{app} are only ~4/6/6% lower while real-data K_{app} values are lower by ~16/13/19% in TUM/NPZ/NTZ. The IQR of these metrics (Fig. 2) across patients represents the variability of the results, which may be due to the uncertainty of the reconstruction/NC methods combined with the the natural variation of DKI metrics between patients. Therefore, it is unclear whether the differences in IQR arise from a more accurate representation of the true spread of K_{app} among patients.

Conclusions and Future Work

Compared to magnitude data without NC, large, significant (p<0.001) differences were seen for K_{app} metrics generated using real data. We hypothesise that phase-corrected real data might produce DKI metrics that better reflect the true diffusion behaviour and may ultimately improve DKI for prostate-cancer detection and grading. Future work will incorporate our method into prostate DKI clinical trials at CUH to assess whether the clinical value of K_{app} is improved.

References 1] Rosenkrantz et al. J Mag Res Im. 2015. 2] Jensen et al. Mag Res Med. 2005. 3] Nilsson et al. Magn Res Mater Phy. 2013. 4] McKinnon et al. Proc 8th ISMRM p 802. 2000. 5] Prah et al. Mag Res Med. 2010. 6] Dietrich et al. Mag Res Med. 2001. 7] Doll et al. IEEE Trans Med Imaging. 1991.