Towards quantitative T2- and ADC-mapping in prostate using diffusion weighted 3D DESS MRI

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Purpose:

The central component of prostate cancer MRI is a high-resolution T2w acquisition. This can be further improved by quantitative T2-mapping, however current methods are limited by compromises between spatial resolution and scan time. Complementary to T2w MRI, diffusion MRI can detect increases in local cellular density and is correlated with histological Gleason scores. To achieve high diagnostic accuracy, quantitative T2 and diffusion MRI should be combined. However, the low spatial resolution and geometric distortion of current echoplanar-based diffusion MRI inhibits direct image fusion. Recent work has shown that diffusion weighted 3D dual echo steady state (DESS) MRI can achieve co-registered high-resolution distortion-free quantitative mapping of T2 and ADC in the knee [1, 2]. The purpose of our work was to develop diffusion-weighted 3D DESS MRI for quantitative prostate imaging.

Methods:

The DESS sequence was modified by a diffusion gradient between the S^+ (fid) and S^- (echo) signal acquisitions [1,2]. A healthy volunteer was scanned at a 3T system (Skyra, Siemens, Healthcare Erlangen, Germany) using a spine and body matrix coil. Local IRB and informed consent was obtained. Two scans were acquired with higher (S_1: total gradient momentum M_1 = 70 ms x mT/m, flip angle FA 10°) and lower (S_2: M_2 = 0 ms x mT/m, FA 10°) diffusion weighting. Other imaging parameters were TR/TE=13.9/3.3 ms, slice thickness=5 mm, 16 slices, resolution=1.56x1.56 mm^2, matrix=192x192, avg 4, BW=220 Hz/px, and 4 min 30 s per DESS scan. Ratios of the four signals (S_1^-/S_1^+, S_2^-/S_2^+, S_1^+/S_2^+, [2]) were fit to a diffusion DESS model [3] to obtain T2 and ADC for each voxel. In addition, Monte Carlo simulations were performed to study the accuracy ((mean(X_{sim}) − X_{true})/ X_{true}) and precision (std(X_{sim}) / mean(X_{sim})) of parameter estimates for the in vivo experiment setting (M_1 = 70 ms x mT/m, SNR = 20), as well as for two simulated setups (M_1 = 140, SNR = 20 and M_1 = 70, SNR = 40).

Results:

Figure 1 shows the four images for the $S^\pm_{1,2}$ acquisitions. In the echo images ($S^-_{1,2}$, Fig.1c,d) T2 and diffusion contrast was more pronounced than in the fid-images ($S^+_{1,2}$, Fig.1a,b). Fitting to the model yielded quantitative T2- and ADC-maps (Fig. 1e,f). As expected, T2 in the peripheral zone (PZ) was longer than in the central zone (CZ). Drawing an ROI in the PZ yielded T2 (mean ± std) = 120±20 ms and in the CZ T2 = 70 ± 10 ms. For ADC, an ROI in the center of the prostate yielded ADC = (1.7 ± 0.6) *10^{-9} m^2/s. Monte-Carlo simulations showed reasonable accuracy and precision for T2-mapping, however this was less so for ADC (**Figure 2**). In simulated scenarios with either twice the diffusion moment or twice the SNR, accuracy and precision for T2 and ADC improved overall by roughly a factor of 2.

Discussion:

Higher gradient diffusion moments improve the accuracy/precision of quantitative DESS, but it is very challenging to do so in the prostate due to motion, which causes artifacts and limits the SNR (especially for the diffusion weighted echo-signal S^-_1). We empirically tested a range of settings and found that a moderate moment of 70 ms x mT/m achieved a good balance between diffusion weighting, low motion artifacts, and acceptable SNR in the S^-_1-image (SNR ~20). Quantitative T2 and ADC values were within the expected range for healthy prostate [4, 5]. However, as previously noted [1, 2] and seen in our simulations, ADC quantification using low diffusion weighting and low SNR is limited in accuracy and precision. Future work will focus on strategies to compensate for motion to accommodate higher diffusion moments and increase SNR. More extensive simulations of extrinsic parameter settings (diffusion moment and flip angle) will help guide sequence design.

Conclusion:

We have demonstrated the feasibility of quantitative diffusion weighted 3D DESS MRI of the prostate. Co-registered distortion-free quantitative T2 and ADC maps were obtained and the values were within the expected range for healthy prostate. Quantitation accuracy, especially for ADC-mapping, has to be improved by strategies to increase diffusion sensitivity and/or SNR.

References: [1] Bieri O, et al. MRM 2012;68:720-9. [2] Staroswiecki E, et.al. MRM 2012;67:1086-96. [3] Freed DE, et.al. J Chem Phys. 2001;115(9):4249-58. [4] Liu W, et.al. MRM 2011;65:1400-6. [5] Gibbs P, et.al. Invest Radiol. 2009;44(9):572-6.
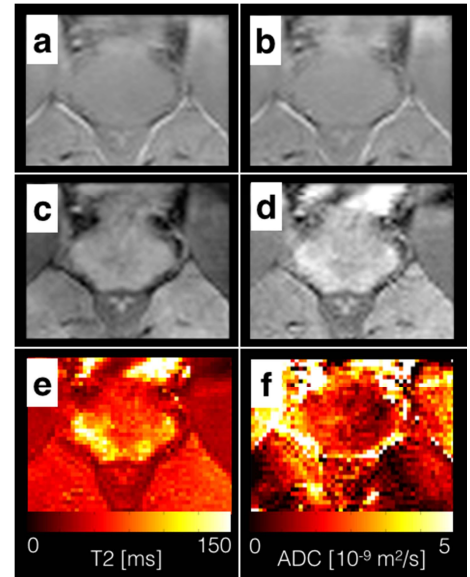
Figure 1: Diffusion weighted DESS acquisition in the prostate. FID (a,b) and echo (intensity scaled by 3x for c,d) with high (a,c) and low (b,d) diffusion weighting. Fitting ratios of these images yield T2- (e) and ADC-maps (f).
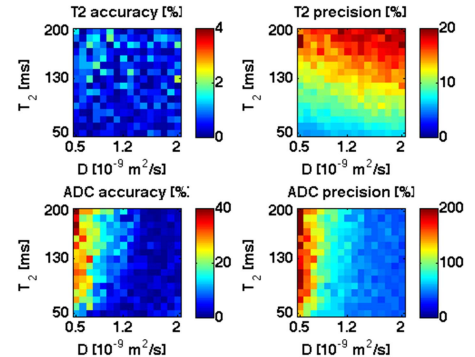

Figure 2: Monte-Carlo simulations for imaging parameters (M_1 = 70 mT/m/ms, SNR = 20) show good accuracy and precision for T2-mapping, however less so for ADC-mapping.