Clinical prostate T2 quantification using a magnetization-prepared spiral technique

W. Foltz[1], S. Chopra[1], P. Chung[1], A. Bayley[1], C. Catton[1], D. Jaffray[1], G. Wright[2], M. Haider[3,4], and C. Ménard[1]
[1]Radiation Medicine Program, Princess Margaret Hospital, Toronto, Ontario, Canada, [2]Sunnybrook Research Institute, Toronto, Ontario, Canada, [3]Medical Imaging, University Health Network, Toronto, Ontario, Canada, [4]Medical Imaging, University of Toronto

Introduction: T2 quantification may improve tissue characterization in longitudinal studies of prostate cancer, beyond what is achievable using diagnostic T2-weighted imaging (1). This research describes an adaptation of magnetized-prepared spiral imaging (2), termed T2prep, for reproducible clinical quantification of prostate T2, providing whole gland coverage within a 5-minute interval with robustness to thermal noise and RF field heterogeneity in region-of-interest (ROIs) analysis of zonal and tumor T2, with and without endo-rectal coil insertion. SNR analysis is applied to guide protocol design for future voxel-based analysis.

Methods: T2prep includes an interval for robust, global T2 contrast development of duration TE, and temporary longitudinal storage before imaging. The imaging interval consists of a spectral-spatial pulse with spiral imaging gradients and trailing spoiler gradient, which may then be repeated at frequent intervals (~ every 20ms) for multi-slice acquisitions. After completion of imaging, residual longitudinal magnetization is nulled using a BIR-4 adiabatic half-passage pulse. Shifting of the delay between the last spiral readout and BIR-4 pulse preserves the period of longitudinal recovery for acquisitions at different TEs. An additional adiabatic inversion pulse is applied prior to the imaging interval for every other sequence iteration, so that the subtracted signals are unbiased by the additive contribution to T1 relaxation during the period of longitudinal storage.

All experimentation used a 1.5T GE Signa, and a 5-minute two-TE T2prep acquisition (TE of 3 and 88ms, TR = 4400ms, 1.1x1.1x6mm voxels based on spiral k-space sampling at 125 kHz readout bandwidth). Reproducibility of the multi-slice acquisition was tested in vitro by prescribing a 12-slice acquisition covering 7.2cm in 6-mm sections across a 750ml bottle of MnCl2-doped water placed in a standard head coil. T2 reproducibility was quantified as the T2 standard deviation in a central placed ROI copied across slices, with measurements repeated at RF offsets between ±20%.

Clinical testing was performed in 2 cohorts. Cohort A consisted of 16 patients with low and intermediate risk localized prostate cancer, and Cohort B consisted of 8 men suspected to have local recurrence after radiotherapy. Cohort A were imaged supine with a torso-phased array placed anterior and posterior to the pelvis, while Cohort B also had an MRI endorectal coil (MEDRAD MRInnervu) inserted. Both groups were imaged using a conventional diagnostic axial T2-weighted FSE acquisition (Cohort A: TE/TR=96/5000ms, 320x256 matrix over 20cm; Cohort B: TE/TR =96/3450ms, 320x256 over 16cm).

Data analysis used MIPAV (NIH, Bethesda, MD) for manual contouring and histogram analysis of mean and standard deviation signals. Origin software (OriginLab, Northampton, MA) provided T2 regression analysis. For clinical data analyses of Cohorts A and B, central gland (CG), uninvolved peripheral zone (PZ), and tumor (T) regions of interest (ROIs) were delineated on FSE images by an experienced radiation oncologist, copied onto T2prep images, and manually adjusted to account for motion-related mis-registration. Significance testing used the Student's two-tailed t-test ($p<0.05$).

Results: As one would anticipate for the T2prep refocusing train (2), quality testing verified that the T2 offset across all slices of the multi-slice acquisition remained well within 2% for RF offsets of 10% or less, but elevate towards 3% for RF offsets of 15% or greater. T2 error accrued more rapidly at RF offsets of 15% or greater. For Cohort A, T2 increased significantly between CG and PZ ROIs (T2 values of 78±7ms and 96±14ms, $p=0.0045$). Regions of tumor-dense burden in the peripheral were found in 11 of 16 subjects (mean volume 0.5±0.3cc). Tumor T2 was 86±11ms, which was reduced significantly from uninvolved PZ by 13±11ms ($p=0.007$). For Cohort B, the mean ROI T2 values were 72±6ms for CG and 94±12ms for PZ. Tumor-dense regions were identified in 5 of 8 subjects (mean volume 2.5±1.7cc). Mean tumor T2 was 81±4ms, which approached a significant difference with the uninvolved PZ ($p=0.08$). From Monte Carlo simulation, T2 standard deviation ($\sigma T2$) from thermal noise reduces below 5%, 2.5%, 2%, 1.5%, and 1% for SNR values of 35, 70, 90, 115, and 170. From histogram analysis, 95% of the delineated voxels presented with per voxel SNR values of 28 (CG) and 27 (PZ) or more at TE of 3ms, so that a voxel-based analysis will be prone to thermal noise. Regions-of-interest containing 10 voxels (~73mm^3) would reduce noise standard deviation to 2%. For Cohort B, 95% of CG voxels had SNR greater than 62 and 95% of PZ voxels had SNR greater than 98. Consequently, thermal noise contributions to $\sigma T2$ approach 2% for voxel-based analysis.

Summary and Conclusions: A strategy is described for reproducible clinical prostate T2 quantification that provides full volumetric coverage at similar time and spatial resolution to other MRI examinations. Consistent with prior literature, cohorts with and without prior history of radiotherapy demonstrated significantly prolonged T2 relaxation in the uninvolved peripheral zone compared to the central gland zone, plus accelerated T2 relaxation in tumor-dense regions. SNR analysis was applied for acquisitions with and without an endo-rectal coil in tandem, to guide the design of future trials targeting voxel-based analysis of T2 relaxation in longitudinal studies of radiation response. Potentially, a voxel-based automated segmentation of tumor volume on T2 images could augment standard MRI techniques in prostate radiation oncology, including FSE T2-weighted imaging, diffusion-weighted imaging, and dynamic contrast enhancement.

References: (1) Langer et al. Radiology, 2008; (2) Foltz et al. Magn Reson Med, 1997.

Figure (a) Quality testing – Multi-slice T2 error as a function of global RF offset; (b) Representative clinical images, including FSE, late TE T2prep, and T2 prep map, for Cohorts A and B. Tumor locations are highlighted by the white arrows.