Fast Three-Dimensional T2-weighted Imaging with Transition Into Driven Equilibrium balanced SSFP at 3T

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PURPOSE: Three-dimensional (3D) T_2-weighted imaging is used clinically for high resolution imaging of small tumors and for acquiring thin slices that are amenable to multi-planar reformatting, which is useful for multi-modal registration applications during biopsy, surgical, or treatment planning. The clinical standard for 3D T_2-weighted imaging is fast spin echo (FSE) based techniques, which are limited by their long acquisition duration due to limited echo train lengths and the long inter-shot delays required between adjacent echo trains to minimize T_1 contributions. Our current clinical 3D FSE protocol for prostate imaging is long, which increases the likelihood of rectal motion artifacts. Our objective was to develop a fast 3D T_2-weighted sequence to minimize rectal motion artifacts, while maintaining image quality for prostate imaging at 3T.

THEORY: The decay rate (λ) of the *transient signal* for on-resonance spins in bSSFP[1] can be expressed as $\lambda = E_2 \sin^2(\alpha/2) + E_1 \cos^2(\alpha/2)$, where $E_{1,2} = \exp(-TR/T_{1,2})$ and α is the flip angle. λ becomes purely T_2 weighted if α=180°, but 180° flip angle is not practically feasible due to SAR limitations at higher field strengths (≥3T). However, T_2-weighting can be attained when $TR/T_1\sim0$ (i.e., $E_1\sim1$), which is better accommodated at higher field strengths due to increased T_1 and a short TR that concomitantly reduces banding artifacts and improves sequence efficiency.

METHODS: We propose to use a variable flip angle (VFA) scheme similar to 2D T_2-TIDE[2], which varies the flip angle (α) from α_{high} to α_{low} (Fig.1a) to reduce the overall SAR of the sequence. A $\alpha_{high}/2$ prep pulse was followed by N_{prep} α_{high} prep pulses to control the T_2-weighting contrast. A higher N_{prep} results in increased T_2-weighting. N_{high} α_{high} pulses maintain T_2-weighting, then smoothly ramped down to α_{low} to reduce SAR. The 3D Cartesian trajectory used interleaved k_y-k_z spiral sampling[3] to acquire the central *k*-space lines with α_{high}=60° (SAR limited) during the T_2-weighted transient state followed by the acquisition of the outer *k*-space lines with α_{low}=30° in order to reduce SAR, but maintain sufficient signal levels for acquiring the outer *k*-space lines. The acquisition along the k_y-k_z plane was interleaved (multiple shots) with an inter-shot delay (t_D) to allow for recovery of M_z. Multi-shot interleaved acquisitions improve the image sharpness by broadening the transition of the transient signal (Fig. 1b). The N_{prep}, N_{high}, N_{ramp} were chosen to be 50, 20, and 200 respectively based on Bloch simulations of the signal for prostate tissue with T_1/T_2=1500/150ms.

Prostate images were acquired in five (N=5) healthy subjects on a Siemens 3T (Trio, Erlangen, Germany) scanner subsequent to informed consent. 3D T_2-TIDE images were compared to our standard clinical 3D FSE protocol (FOV=200×200×96mm, resolution=0.8×0.9×1.5mm, GRAPPA factor=2 (24 reference lines), phase partial Fourier=6/8, averages=2, echo train duration=565ms, BW=315Hz/px and acquisition duration (T_{acq})=7:02min). The phase encoding (PE) direction was right-to-left to reduce rectal motion artifacts with 100% phase oversampling to avoid aliasing. The imaging parameters for 3D T_2-TIDE were identical to 3D FSE except that BW=930Hz/px, N_{shots}=24,TR/TE=4.8/2.4ms, shot duration=1112ms and T_{acq}=2:54 min. The SNR efficiency (SNR_{Eff}) and CNR efficiency (CNR_{Eff}) were calculated as the ratio of SNR or CNR to the square root of T_{acq}. ROIs were drawn in four different regions: peri-prostatic fat (PPF), gluteal fat (GF), peripheral gland (PG), and anterior fibromuscular stroma (AFS) by a uroradiologist having read over 1000 prostate MRI studies. The CNR_{Eff} was calculated between the AFS and the PG as the ratio of the difference between their SNR to the sum of their SNR.

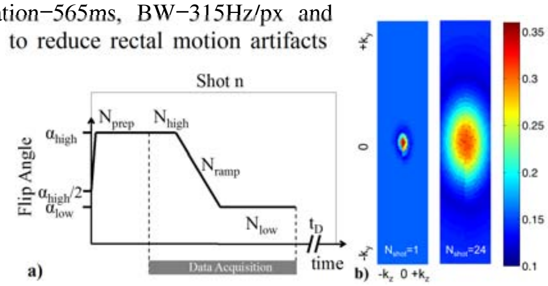

Figure 1: a) VFA scheme of a shot of 3D T_2-TIDE sequence. b) Signal of prostate tissue with T_1/T_2=1500/150ms in ky-kz space for N_{shots} =1 and 24.

RESULTS: Fig. 1b shows the Bloch simulation for prostate tissue signal as a function of the k_y-k_z space for N_{shots}=1 and N_{shots}=24. The broader transition of the transient signal along k_y-k_z for interleaved acquisitions (N_{shots}=24) improves the T_2-weighting and image sharpness compared to N_{shots}=1. Fig. 2 shows a single matched axial slice for 3D FSE and 3D T_2-TIDE reformatted into coronal and sagittal planes. The capsule of the prostate is clearly visible in both image acquisitions (yellow arrowheads). The SNR_{Eff} of 3D T_2-TIDE vs. 3D FSE is given in the following table:

Location	PPF	GF	PG	AFS
3D T_2-TIDE	73±15	94±8	59±8*	39±9*
3D FSE	50±13	69±19	40±14	9±3

where * indicates significant differences (P<0.05) in SNR_{Eff}. The CNR_{Eff} between the AFS and the PG using 3D T_2-TIDE is 0.12±0.08 and 3D FSE is 0.23±0.05.

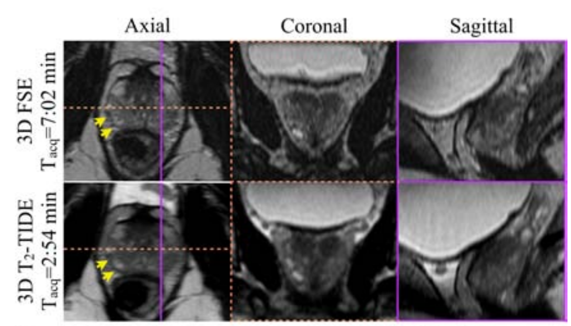

Figure 2: Single slice of 3D FSE and 3D T_2-TIDE acquired in axial plane and reformatted into coronal and sagittal planes. The T_2 contrast is preserved in 3D T_2-TIDE.

DISCUSSION: 3D T_2-TIDE achieves the same level of diagnostic image quality as 3D FSE. 3D T_2-TIDE imaging has T_2-weighting comparable to the 3D FSE with acquisition duration reduced by 59% and improved SNR_{Eff}. The decrease in CNR_{Eff} using 3D T_2-TIDE compared to 3D FSE is due to the reduced maximum FA due to SAR limitation. The reduced acquisition duration of 3D T_2-TIDE will reduce the frequency of apparent rectal motion artifacts and may limit the need for glucagon. The 3D T_2-TIDE PE direction was chosen right-to-left to match our clinical 3D FSE protocol, which aims to minimize anterior-posterior (AP) rectal motion artifacts. However, because of the reduced T_{acq} for 3D T_2-TIDE the PE direction could be changed to AP with a concomitant reduction in T_{acq} to 1:33min.

CONCLUSION: 3D T_2-TIDE bSSFP imaging can be used for fast, T_2-weighted imaging with SNR_{Eff} that exceeds that of 3D FSE imaging.

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REFERENCES: **1.** Scheffler, MRM. 2003;49:781-783 **2.** Paul D, et al. MRM. 2006;56:82-93 **3.** Vogt FM, et al. ISMRM. 2007; 92.