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

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PURPOSE: Three-dimensional (3D) T2-weighted imaging is used clinically for high resolution imaging of small tumors and for acquiring thin slices that are amenable to multi-planar reformating, which is useful for multi-modal registration applications during biopsy, surgical, or treatment planning. The clinical standard for 3D T2-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 TI contributions. Our current clinical 3D CSE protocol for prostate imaging is long, which increases the likelihood of rectal motion artifacts. Our objective was to develop a fast 3D T2-weighted sequence to minimize rectal motion artifacts, while maintaining image quality for prostate imaging at 3T.

METHODS: We propose to use a variable flip angle (VFA) scheme similar to 2D T2-TIDE3, which varies the flip angle (α) from αhigh to αlow (Fig.1a) to reduce the overall SAR of the sequence. A αhigh/2 prep pulse was followed by Nprep αhigh prep pulses to control the T2-weighting contrast. A higher Nprep results in increased T2-weighting, Nhigh αhigh prep pulses maintain T2-weighting, then smoothly ramped down to αlow to reduce SAR. The 3D Cartesian trajectory used interleaved ky-kz spiral sampling3 to acquire the central k-space lines with αhigh=60° (SAR limited) during the T2-weighted transient state followed by the acquisition of the outer k-space lines with αlow=30° in order to reduce SAR, but maintain sufficient signal levels for acquiring the outer k-space lines. The acquisition along the ky-kz plane was interleaved (multiple shots) with an inter-shot delay (td) to allow for recovery of Mx. Multi-shot interleaved acquisitions improve the image sharpness by broadening the transition of the transient signal (Fig. 1b). The Nprep, Nhigh, Namp were chosen to be 50, 20, and 200 respectively based on Bloch simulations of the signal for prostate tissue with T1/T2=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 T2-TIDE images were compared to our standard clinical 3D FSE protocol (FOV=200x200x96mm, resolution=0.8x0.9x1.5mm, GRAPPA factor=2 (24 reference lines), phase partial Fourier=6/8, averages=2, echo train duration=565ms, BW=315Hz/px) and acquisition duration (Tacq)=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 T2-TIDE were identical to 3D FSE except that BW=930Hz/px, Nshor=24, TR/TE=4.8/2.4ms, shot duration=112ms and Td=2.54 min. The SNR efficiency (SNREff) and CNR efficiency (CNREff) were calculated as the ratio of SNR or CNR to the square root of Tacq. ROIs were drawn in four different regions: peri-prostatic fat (PPF), gluteal fat (GF), peripheral gland (PG), and anterior fibromuscular stroma (AFS) by a urolaryngologist having read over 1000 prostate MRI studies. The CNREff was calculated between the ASFS and the PG as the ratio of the difference between their SNR to the sum of their SNR.

RESULTS: Fig. 1b shows the Bloch simulation for prostate tissue signal as a function of the ky-kz space for Nt=1 and Nt=24. The broader transition of the transient signal ky-kz for interleaved acquisitions (Nt=24) improves the T2-weighting and image sharpness compared to Nt=1. Fig. 2 shows a single matched axial slice for 3D FSE and 3D T2-TIDE reformatted into coronal and sagittal planes. The capsule of the prostate is clearly visible in both image acquisitions (yellow arrowheads). The SNREff of 3D T2-TIDE vs. 3D FSE is given in the following table:

<table>
<thead>
<tr>
<th>Location</th>
<th>PPF</th>
<th>GF</th>
<th>PG</th>
<th>AFS</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D T2-TIDE</td>
<td>73±15</td>
<td>94±8</td>
<td>59±8</td>
<td>39±9</td>
</tr>
<tr>
<td>3D FSE</td>
<td>50±13</td>
<td>69±19</td>
<td>40±14</td>
<td>9±3</td>
</tr>
</tbody>
</table>

where * indicates significant differences (P<0.05) in SNREff. The CNREff between the AFS and the PG using 3D T2-TIDE is 0.12±0.08 and 3D FSE is 0.23±0.05.

DISCUSSION: 3D T2-TIDE achieves the same level of diagnostic image quality as 3D FSE. 3D T2-TIDE imaging has T2-weighting comparable to the 3D FSE with acquisition duration reduced by 59% and improved SNREff. The decrease in CNREff using 3D T2-TIDE compared to 3D FSE is due to the reduced maximum FA due to SAR limitation. The reduced acquisition duration of 3D T2-TIDE will reduce the frequency of apparent rectal motion artifacts and may limit the need for glucagon. The 3D T2-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 TAcq for 3D T2-TIDE the PE direction could be changed to AP with a concomitant reduction in TAcq to 1:33min.

CONCLUSION: 3D T2-TIDE bSSFP imaging can be used for fast, T2-weighted imaging with SNREff that exceeds that of 3D FSE imaging.

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