# Modified PROPELLER Approach for T2-Mapping of the Abdomen

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**INTRODUCTION:** T2-weighted (T2W) contrast plays an important role for abdominal imaging. However, fully quantitative T2 measurements may offer additional information to improve the accuracy of tissue characterization. The SE sequence is commonly used for T2 quantification; however, SE sequences require long imaging times. TSE sequences can reduce imaging time but may be inaccurate due to stimulated echo accumulation [1]. Furthermore, echoes not occurring at the effective TE may result in complex T2W signal contribution. T2 mapping in the abdomen using SE or 2DFT-TSE sequences is particularly challenging due to respiratory, cardiovascular, and visceral motion. Multi-shot TSE-based PROPELLER techniques [2,3] have been shown to be less sensitive to motion artifacts due to intrinsic properties of segmental phase correction and oversampling in *k*-space. In this study we modified the PROPELLER sequence and acquisition approach to perform T2 mapping of the abdomen. We demonstrate that our modified PROPELLER approach permits robust acquisition of accurate, high-quality abdominal T2 maps.

**METHODS:** **Sequence Modifications** Two modifications were made to the PROPELLER sequence. *(i) Repeated measurements with echo reordering:* For each blade with echo train length (ETL) of N, the echo train was reordered N times sequentially so that every echo was acquired once in each position of the echo train. As an example of ETL=5, 5 measurements with reordering schemes of {-2,-1,0,1,2}, {-1,0,1,2,-2},{0,1,2,-2,-1},{1,2,-2,-1,0},{2,-2,-1,0,1} were acquired, where 0 referred to the zero phase-encoded (PE) line and ±1and ±2 referred to outer k-space lines. Different PE echoes at a certain TE were extracted from that echo position from each of the N measurements and combined in *k*-space for image reconstruction at that exact TE. Therefore, N images at $TE_i$ (i =1,2,…,N) were reconstructed, where $TE_i$ = i × echo spacing. *(ii) Reducing stimulated echo effects:* The slice thickness ratio (STR) between refocusing and excitation RF pulses was set to be 3:1 [4]. Additionally, we modified a short ETL sequence (e.g. ETL=5) to permit echo train shifts for acquisition of images at the requisite TEs to investigate stimulated echo effects compared to longer ETL sequences.

**MRI** All imaging experiments were performed using a 1.5 T clinical scanner (Magnetom Sonata, Siemens Medical Solutions). In a phantom model consisting of 6 specimens with different T2, SE images were acquired as the reference standard. Modified PROPELLER sequences were preformed with the following parameters: FOV=200 $mm^2$, matrix=128×128, TR=2000ms, BW=400 Hz/pixel, echo spacing = 6.9ms, excitation slice thickness = 5mm. Five acquisition schemes (S1-S5) were performed separately (as shown in **Table**). Note: in S5 the echo train (ETL =5) were shifted 5 times by a step of ETL× echo spacing. In order to shorten the imaging time for S1 (N=25), we reconstructed images at $TE_i$ by selecting *j* (*j*=1,2,…25) central k-space echoes at the exact $TE_i$ from the 25 measurements, while keeping the outer k-space echoes from only a single measurement. Based on the minimal *j* determined for accurate T2 measurement, we derived S6 with *j* repeated measurements. Based upon phantom validation, we performed PROPELLER abdominal imaging in 9 volunteers using S1, S2 and S6 acquisition schemes. In volunteer studies, imaging parameters were identical to phantom imaging except that FOV=400 $mm^2$. We used a free-breathing acquisition with respiration bellows triggering.

| Acquisition Scheme | ETL | # of Blade | Slice Thickness Ratio (STR) | # of Repeated Measurements | Imaging Time (s) |
|---|---|---|---|---|---|
| S1 | 25 | 10 | 3:1 | 25 | 22×25 = 550 |
| S2 | 25 | 10 | 1:1 | 25 | 22×25 = 550 |
| S3 | 15 | 17 | 3:1 | 15 | 36×15 = 540 |
| S4 | 45 | 6 | 3:1 | 45 | 14×45 = 630 |
| S5 | 5 | 50 | 3:1 | 25 | 102×5×5 = 2550 |
| S6 | 25 | 10 | 3:1 | 15 | 22×15 = 330 |

**Image Analysis** For each acquisition scheme, T2 parametric maps were reconstructed from images acquired at TE = 6.9×[1,3,6,9,12,15,17,20,25]. Phantom studies validated the accuracy of PROPELLER T2 measurements by calculating the % error = |SE T2-PROPELLER T2|/SE T2 ×100%. For volunteer studies, ROIs excluding vessels were placed in liver, spleen and kidney cortex. A matched pair *t*-test was used (α=0.05) to test for statistical differences between acquisition schemes for each organ.

**RESULTS** In phantom studies, T2 of 6 specimens (37-239 ms) were measured using SE as a reference standard. The accuracy of PROPELLER T2 measurements using S1-S5 were plotted in **Fig. 1**. S2 with STR = 1:1 showed the worst accuracy with error = 29.0±5.9% due to stimulated echo effects. In comparison, S1 with STR =3:1 showed much higher accuracy with error = 3.4±1.9%. S3 and S4 showed similar accuracy as S1 with error = 3.3±1.8% and 3.8±2.1%, respectively. S5 with ultra-shot ETL=5 increased the accuracy with error = 2.4±1.7%, which indicated that the stimulated echo associated with longer ETL can be further reduced with ultra-short ETL. However, S5 required much longer imaging time. In **Fig. 2**, the errors of T2 measurements using S1(ETL=25) were plotted as a function of the number of central k-space echoes at exact TEs used for image reconstruction. The error leveled off when the number of central echoes approaching 15, therefore the number of measurements was reduced to 15 in S1 (i.e. S6) used in volunteer studies. In 9 volunteers, T2 of liver, spleen and kidney were shown in **Fig. 3.** S2 measurements were significantly different than S1; however, S6 can be an alternative to S1 without loss of accuracy. The imaging time was ~20-25 min for S1/S2 and ~10-15 min for S6. Representative PROPELLER T2 maps of the abdomen are shown in **Fig. 4.** There were no motion artifacts or blur observed in these images. Abdominal organs and anatomic structures were clearly delineated.

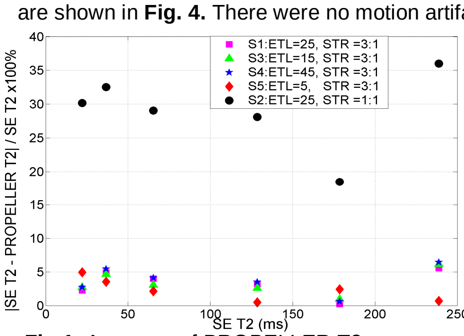


**Fig.1.** Accuracy of PROPELLER T2 measurements using S1-S5 acquisition schemes

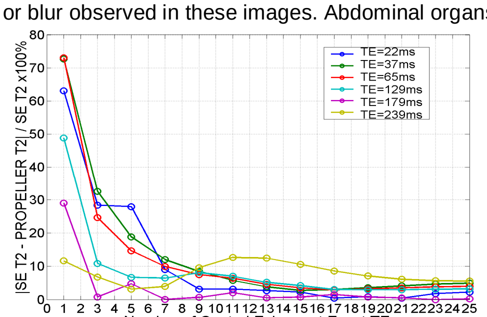


**Fig.2.** Accuracy of PROPELLER T2 measurements using S1 with 1~25 central k-space echoes at exact TEs

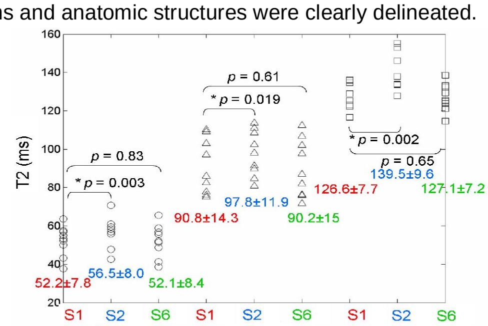


**Fig.3.** T2 values of abdominal organs measured using PROPELLER

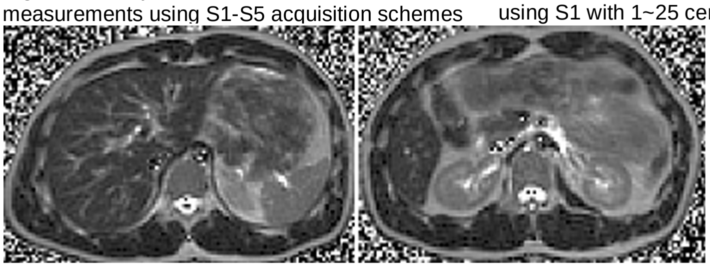

**Fig.4.** PROPELLER T2 mapping of the abdomen

**CONCLUSIONS** Our modified PROPELLER approach provides accurate T2 measurements of the abdomen with excellent image quality and no motion artifacts. The proposed method permits accurate, robust T2 mapping for body imaging applications where conventional SE and TSE approaches are particularly prone to failure.

**References:**
[1] Majumdar et al. MRM. 1986;3:397–417. [2] Pipe et al. MRM.1999;42:963-9.
[3] Deng et al. Invest Radiol. 2006;41:769-75. [4] Pell et al. JMRI. 2006; 23 :248-52