Validation of Variable Flip Angle Imaging-Based Simultaneous B1+ and T1 Mapping in the Prostate at 3T

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Introduction: Accurate maps of B1+ inhomogeneity are essential for robust quantitative multi-parametric MRI, such as T1 relaxation time measurements. However, B1+ mapping sequences are not widely available in practice and also increase the imaging protocol time[1]. Recently a technique that can simultaneously measure both B1+ and T1 maps from gradient echo (GRE) images with variable flip angle (VFA), named as reference region VFA (RR-VFA), was proposed and validated in the breast[2]. RR-VFA relies on fat-water separation and the assumption that the T1 of fat is known, and B1+ inhomogeneity is estimated from any deviations in the assumed fat signal intensity. The goal of this study was to optimize the RR-VFA method for prostate MRI and validate the resulting B1+ maps by comparing them with conventional B1+ maps in the prostate.

Methods: A variable flip angle imaging protocol was optimized to scan ten healthy volunteers feet-first on a 3.0 T MAGNETOM Skyra system (Siemens AG, Erlangen, Germany) using a 3D GRE sequence with a dual-echo Dixon acquisition and the following flip angles (FA): 2°, 5°, 10°, 15°. Other imaging parameters common to all protocols were: TR = 4.17 ms, TE1/TE2 = 1.22/2.46 ms, FOV = 26 cm, partition thickness/spacing = 3.6/0.7 mm, 20 partitions, acquisition matrix = 160×160, averages = 3/2/2/2 for FA = 2°/5°/10°/15°, scan duration < 1 min for each acquisition. The conventional B1+ maps were acquired for comparison using the manufacturer's B1+ measurement sequence based on a spin echo and a stimulated echo acquisition[3], with the following parameters: TR = 500 ms, TE = 14 ms, FOV = 26 cm, acquisition matrix = 128, scan duration ~ 40 s.

Maps of relative FA (rFA) as a percentage of the prescribed FA were calculated using the RR-VFA method implemented using in-house software (Matlab R2013, The Mathworks, Natick, MA; OsiriX 5.9, Pixmeo SARL, Geneva, Switzerland). T1 of fat was empirically determined at 320 ms. Fat- and water-only images were used to create a partial volume-corrected mask of fat pixels where the rFAs were initially calculated. As the fat signal is unevenly distributed in the pelvis, a three-dimensional linear interpolation step was performed in the regions not containing fat, with the assumption that the B1+ contribution varied smoothly over the prostate. The performance of the interpolation technique was carefully evaluated by applying the fat tissue mask on the conventionally acquired RF map and comparing the result after interpolation with the original, unmasked, images. All four FAs were used to improve the estimation of rFA by using two sets of two FAs each (2°, 10° in one set and 5°, 15° in another) and using the average rFA from the two sets to reduce bias. Maps of rFA obtained using RR-VFA were compared with that from conventionally acquired B1+ maps. To demonstrate benefits of including B1+ correction, T1 maps were calculated two ways using all four FAs: 1) without any correction for B1+ inhomogeneity and 2) after correcting for the B1+ inhomogeneity using RR-VFA. Comparisons between the two rFA maps and resulting T1 measurements before and after correction were performed by selecting regions of interest (ROIs) in the prostate (7.6 cm^2). Student's *t*-tests and *f*-tests were performed to compare the means and standard deviations of rFA and T1 using these techniques.

Results: Signal intensity variations due to B1+ inhomogeneity are visually apparent on the GRE images (Fig. 1, left) and both rFA maps show corresponding variations (Fig. 1, center), with minimal differences between the two maps toward the center of the imaged volume (Fig. 1, right). rFA maps obtained using RR-VFA and the conventional approach were consistent with average relative FAs of 103 % and 105 % in the prostate (p=0.58). Further, results after applying the interpolation largely matched the underlying data, evidenced by a high correlation in the conventional maps before and after masking and interpolation (r ~ 0.9 in all cases). Average prostate T1 values decreased from 2133 ms before correction (Fig. 2, left) to 1959 ms using the RR-VFA rFA map (Fig. 2, right). T1 calculated using RR-VFA B1+ correction did not show statistically significant mean differences from the T1 measured without B1+ correction; however, this might be explained by the larger spread of T1 values calculated without B1+ inhomogeneity correction (σ = 17%, versus 6% after RR-VFA correction). RR-VFA T1 values showed significantly lower standard deviations (p<0.01) than uncorrected T1, indicating the robustness of the T1 measurement using RR-VFA for B1+ correction in the prostate.

Table 1: (a) Comparison of rFA using RR-VFA and conventional sequence (b) Comparison of T1 before and after B1+ correction

(a)	*Conventional*	*RR-VFA*	*Difference*
rFA (%)	104.7 ± 5.47	102.9 ± 8.44	1.78 ± 5.34
(b)	*Uncorrected*	*RR-VFA*	*Difference*
T1 (ms)	2133 ± 369	1959 ± 120	174 ± 343

Conclusion: Relative FA maps were effectively estimated from variable flip angle GRE images acquired with four flip angles and match closely with rFA maps obtained from a conventional sequence readily available on all scanners from this manufacturer. The prostate T1 value after RR-VFA correction was lower than T1 calculated without B1+ correction, indicating that T1 quantification is very dependent on B1+ estimations. Using the RR-VFA method can eliminate the need to acquire an additional scan to measure B1+ inhomogeneity, facilitating shorter total scan durations in multiparametric quantitative MRI protocols.

References: (1) Cunningham, *et al.*, *MRM*, 2006 (2) Sung, *et al.*, *MRM*, 2013 (3) Jiru *et al.*, *MRM*, 56: 1375, 2006.

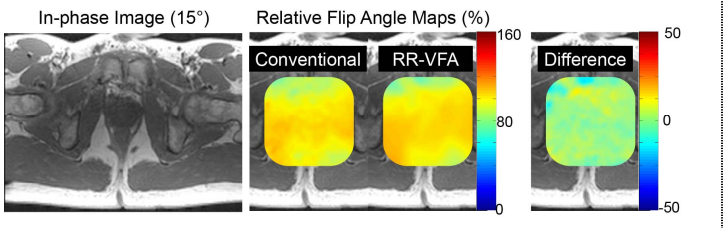

Figure 1: (LEFT) T1w image (in-phase, 15°) for anatomical reference, (CENTER) relative FA distribution of conventional and RF-VFA in percentage, and (RIGHT) the difference between conventional and RR-VFA.

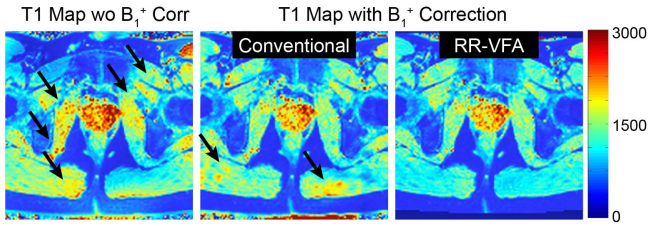

Figure 2: VFA-based T1 maps are shown (LEFT) without B1+ correction, and corrected with (CENTER) conventional and (RIGHT) RR-VFA in prostate. Arrows indicate regions of inaccurately estimated T1 measurements due to B1+ inhomogeneity.