# A Method for Correcting $T_1$ maps of Prostate at 3T Obtained by Variable Flip Angle Imaging

Sandeep N Gupta[1], Ehud J Schmidt[2], Robert Mulkern[3], Andriy Fedorov[2], Ileana Hancu[1], Yingxuan Zhu[1], Clare Tempany-Afdhal[2], and Fiona Fennessy[2]
*[1]GE Global Research Center, Niskayuna, NY, United States, [2]Radiology, Brigham and Women's Hospital, Boston, MA, United States, [3]Radiology, Boston Children's Hospital, Boston, MA, United States*

**Introduction**

Dynamic Contrast Enhanced (DCE) MRI has shown promise in non-invasive assessment of tumor vascular properties with application to prostate cancer staging and treatment monitoring [1]. MR signal intensity versus time curves during the uptake of Gd-DTPA are measured in pixels of interest to be used in conjunction with pharmacokinetic (PK) models to provide a number of tumor vascular properties. A primary step in the PK analysis requires conversion of signal intensity vs. time curves into contrast-agent concentration vs. time curves. Since signal intensity changes are non-linearly related to contrast agent concentration, this conversion requires knowledge of the pre-contrast tissue $T_1$ values.

Variable Flip Angle (VFA) imaging is a preferred $T_1$ mapping method since it provides $T_1$ maps using the same 3D SPGR sequences that are commonly used for DCE acquisition, so that identical spatial resolution and coverage can be obtained in reasonable acquisition times. VFA analysis fits the Ernst equation [2] $SI(\alpha) = M0*\sin\alpha *(1 - \exp(-TR/T_1))/(1 - \cos\alpha *\exp(-TR/T_1))$, to the measured SI to obtain pixel-wise $T_1$ values. However, VFA suffers from large errors at higher field strengths due to $B_1$ field inhomogeneity and resultant flip angles ($\alpha_{applied}$) differing from the actual flip angles ($\alpha_{actual}$) seen by the tissue with $K= \alpha_{actual} / \alpha_{applied}$ varying spatially within the imaged volume. Several methods have been proposed to provide accurate $T_1$ mapping by estimating K. These methods are generally time consuming, and are not yet widely available. In this paper, we propose a simple method for improved $T_1$ mapping from VFA imaging by estimating K from an assumed reference $T_1$ in pelvic muscle proximal to the prostate.

**Methods**

***Acquisition:***8 patients with known prostate cancer were scanned on a 3T Signa HDx MRI scanner (GE Healthcare, Waukesha, WI) under IRB approved protocols, using a VFA $T_1$ mapping sequence (3D SPGR with spectral fat suppression: TR/TE/ = 8.8/2.7ms, $\alpha_{applied}$ =18,15,12,9,6,3°. BW ±30 kHz, FOV 26x26 cm, Matrix 256 x128 x16, slice thickness 6 mm, 20 dummy cycles) prior to routine dynamic contrast enhanced imaging. In 3 subjects, an additional 3D SPGR scan was performed at 3 times the TR for a single flip angle (TR=26.4ms and $\alpha_{applied} = 12^0$). The Signal Intensity Ratio between the 3TR and TR images for TR << $T_1$ may be approximated as $SIR_{(3TR\text{-}to\text{-}TR)} = 3*[(1-\cos\alpha_{actual})+(TR/T_1)*\cos\alpha_{actual})]/[(1-\cos\alpha_{actual})+3*(TR/T_1)*\cos\alpha_{actual}]$ provides a good estimate of the actual flip angle since it is strongly dependent on $\alpha_{actual}$ but only weakly on $T_1/TR$ (Fig. 1 shows $SIR_{3TR\text{-}to\text{-}TR}(\alpha_{actual})$ for $T_1$s of 1300-1700ms). In one subject, we also performed $B_1$ mapping using the Bloch-Siegert method [3] (BSG, 2D Spin Echo TR/TE= 300/26ms, 128x128, 40cmx40cm FOV, slice thickness 5 mm, 2 KHz off-resonance).

***A*nalysis**: An estimate of K is made by using a literature value of 1420 ms for the pelvic-muscle enveloping the prostate gland with the further assumption that K in prostate closely approximates K in the pelvic muscle. This latter assumption is justified from a study of $B_1$ maps obtained by Bloch-Siegert method [Fig. 2], which shows that the $B_1$ map (and hence K) is uniform over the prostate region and is similar to that in the pelvic muscle region. The value of K so estimated is used to correct the applied flip angles within the prostate, and then fit the VFA $SI(\alpha_{actual})$ data to obtain corrected $T_1$ values. Fig. 3 shows a prostate $T_1$ map before and after correction.

**Results**

In the 8 subjects analyzed with the VFA $T_1$ mapping, the mean $T_1$ in the prostate before VFA correction was 758 ms (±175.8), and 1385 ms (±217.3) after correction. The uncorrected values are severe under-estimations of prostate $T_1$, while corrected values are in agreement with published results [4]. In these subjects, the mean K was 0.74. Verification of the correction factor was performed in 5 patients using the $SIR_{(3TR\text{-}to\text{-}TR)}$ measurement ratio at 12 degrees, similar to the method of [5]. The mean correction factor obtained using this approach was 0.77.

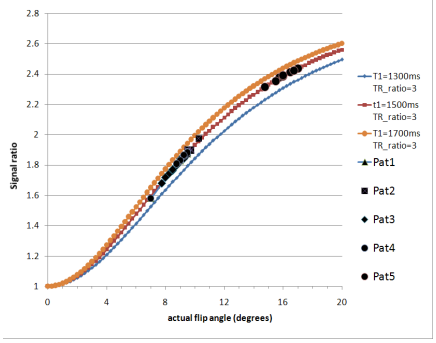


Fig.1: Signal $SIR_{3TR\text{-}to\text{-}TR}$ vs. $\alpha_{actual}$ for T1s of 1300-1700ms, and results for 5 patients (9 slices/Pat) for $\alpha_{applied}=12^0$ degrees, $0.65<K<1.3$ ($7.7<\alpha_{actual}<16^0$)

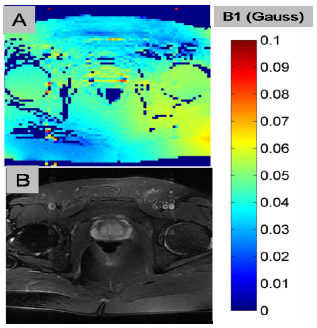


Fig.2: (A) B1 map and (B) anatomic prostate image using BSG (K=0.65)

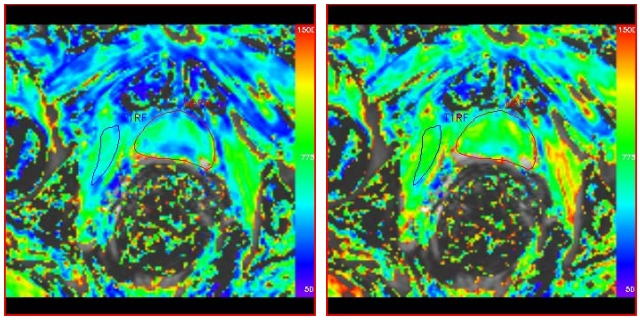

Fig.3: Patient T1 maps showing the prostate and pelvic muscle reference ROIs. Uncorrected (left), and Corrected (right), after determining that K=0.75

**Conclusion**

We presented a simple, computationally efficient approach for performing $T_1$ mapping using the VFA method at 3T and in the presence of inherent B1 inhomogeneities. Our method utilizes known reference tissue $T_1$ values of pelvic muscle to estimate a local flip angle correction factor, enabling more accurate and clinically useful $T_1$ maps of the prostate. We have validated our method using multiple TR approaches as well as Bloch-Siegert. It may be possible to use variable flip angle along with multiple TR to determine the correction iteratively without requiring a reference tissue $T_1$.

**References**

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**Acknowledgement of Support:** This work was supported in part by NIHU01CA151261 from the National Cancer Institute. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Cancer Institute or the National Institutes of Health.