# Quantitative $T_1$ estimation using Tissue Specific Imaging

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## Introduction

The longitudinal relaxation time ($T_1$) of tissues plays an important role both as a contrast mechanism for anatomical imaging and as a disease marker. While several dedicated $T_1$ measurement techniques exist, they require additional imaging time, so it would be beneficial if equivalent information could be extracted from other diagnostic imaging sequences. Tissue Specific Imaging (TSI-[1]) has been previously applied for the characterization of Multiple Sclerosis (MS) lesions [2] and white matter integrity [3]. TSI can be considered a variant of Double Inversion Recovery, used for the detection of cortical lesions in MS [4]. This study addresses the potential application of TSI for the measurement of $T_1$.

## Theory and Methods

TSI uses a combination of two inversion pulses and three 3D EPI acquisitions to produce three different $T_1$ weighted images whose linear combination results in three single tissue type images (figure 1); imaging time is approximately 10 minutes for whole brain coverage. The same TSI raw images can be used to estimate tissue $T_1$ as follows: assuming single experimental behavior, it is possible to calculate, based on the Bloch equations and knowledge of the sequence parameters, the expected signal levels for each image as a function of $T_1$ and $M_0$ using the following equation: ($M_z$ is calculated after the $N^{th}$ pulse, and $M_z^{eq}$ is the equilibrium magnetization as described in [1]).

$$M_z(t) = M_0[1 + \{\sum_{i=1}^{N-1}[(\cos(\phi_i)-1)(\prod_{j=i+1}^{N}\cos(\varphi_j))e^{t_i/T_1}] + (\cos(\varphi_N)-1)e^{t_N/T_1} + (M_z^{eq}-1)\prod_{i=1}^{N}\cos(\varphi_i)\}e^{-t/T_1}]$$

We applied least squares fitting to calculate $T_1$ and $M_0$ of each voxel. $B_1$ information is used to correct for the flip angle variation on a voxel-by-voxel basis. While simulated signal levels are real signed numbers, TSI data as acquired from magnet are complex. Real values are calculated based on signal magnitude, and sign information is estimated by the sign of the inner product of each voxel by the respective one in the first TSI raw image.
Accuracy and precision of the proposed technique were estimated using the Monte Carlo simulation and varying levels of white Gaussian noise. SNR was calculated as $M_0$ divided by the standard deviation of noise; signal levels were adjusted for TE=35ms. Results were compared to DESPOT1 [5], with SNR levels adjusted for both echo time and bandwidth. We used the technique in order to estimate $T_1$ from previously acquired TSI (as described in [1]) and $B_1$ mapping [6] data from 5 healthy volunteers.

## Results

Figure 2 shows an estimation of precision of the presented technique as a function of $T_1$ for SNR of 250 and 500, corrected for $T_2^*$ relaxation time. Monte Carlo simulation results show that the precision is comparable to that of DESPOT1 for SNR of 500 and 1000 (adjusted for bandwidth) for $T_1$ values corresponding to healthy tissue. Mean estimation error was less than 1% for normal tissue $T_1$ values. Figure 1 shows TSI image and the resulting $T_1$ map. Average $T_1$ values for white matter, gray matter (ROI placed in the head of the caudate nucleus) and cerebrospinal fluid were 822(21) ms [mean (standard deviation)], 1399(48.24) ms and 4065(282) ms respectively.

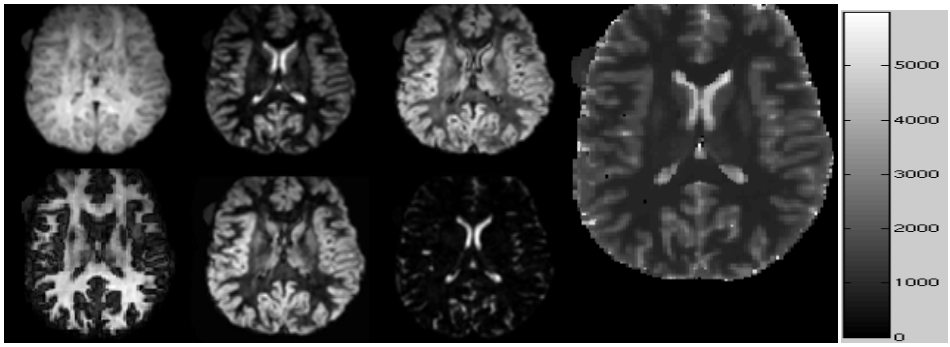


Figure 1: Raw (first row) and synthesized (second row) TSI images, and resulting $T_1$ map

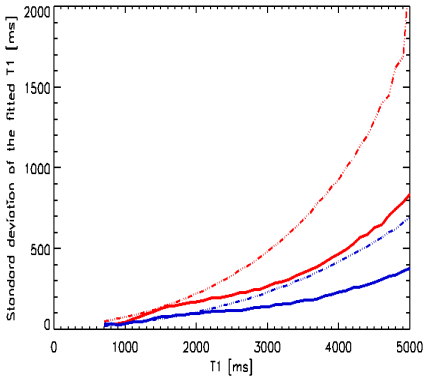


Figure 2: Monte Carlo generated standard deviation of estimated $T_1$ values using the proposed method (solid line) and DESPOT1 (dashed line) of equivalent SNR levels (red-1000/500, blue-500/250)

## Conclusion

We have shown that TSI can be used for quantitative estimation of tissue $T_1$, with results comparable to DESPOT1 over the normal $T_1$ range for healthy tissue. Possibly due to a longer TR of 6 ms, it shows good stability for longer $T_1$ values (figure 1), making it an attractive solution for estimation of longer $T_1$ values, such as the ones encountered in advanced MS lesions.

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## References

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