The Effect of 2D Excitation Profile on T1 Measurement Accuracy Using the Variable Flip Angle Method

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Purpose

Measurements of T1 using the Variable Flip Angle method, which is based on the steady state relationship of the measured signal to TR, T1, and flip angle[1], are subject to errors introduced by inaccuracy in the flip angle used. In addition to the error from uncompensated variations in $B1^{+}$ [2], another potential source of error is the non-uniform slice excitation profile which causes a large variation in flip angle within every single voxel in a 2D acquisition. To deal with the non-constant excitation profile across the slice, it is assumed that the signal depends on an average flip angle. The assumption of an average flip angle may work well for small flip angles, but may not work for angles that exceed the Ernst angle. The purpose of this study was to evaluate the dependence of the signal equation on the excitation profile and determine the resulting accuracy in T1 measurements in 2D acquisitions.

Methods

Simulations were performed to test the effects of the slice excitation profile on the dependence of the measured signal on flip angle. The shape of the frequency response to a sinc excitation pulse, a good estimate of the excited slice profile, is dependent on the time-bandwidth product (TBP). This profile affects the amount of signal generated as a function of position through the slice. The slice profile represents the flip angle achieved as a function of position through the slice. In steady state, the excitation profile is dependent on several factors such as the flip angle (local B1), the TR/T1 ratio, and the TBP. Therefore excitation profiles for several TBP and T1 values were simulated using the steady state flash equation $S = M_0 \frac{(1-E_1)\sin(\alpha)}{1-E_1\cos(\alpha)} E_2$, where $E_1 = e^{-TR/T_1}$ and $E_2 = e^{-TR/T_2}$ and α is the flip angle at each slice position. All simulations shown use a TR of 20 ms and slice thickness of 3 mm. The total signal measured in the scanner is the integral of the profile. T1 values were calculated using the linear form of the signal equation $\frac{S}{\sin(\alpha)} = E_1 \frac{S}{\tan(\alpha)} + M_0(1-E_1)E_2$. Two measurements at different flip angles are used to find the slope m of S/sin(α) vs S/tan(α). T1 is then calculated by $T_1 = -TR/\ln(m)$. This calculation is done using the total signal from the simulated profiles, and for different combinations of flip angles. The calculated T1 values are compared with the true values.

An experiment was performed to evaluate the signal vs flip angle for different TBP in 2D using a homogeneous gelatin phantom with 2x2x3 mm resolution, TR/TE = 20/5 ms. Signal values were averaged over a 5x5 roi at the center of the slice. Multiple inversion time inversion recovery data was collected to accurately calculate T1.

Results, Discussion, and Conclusions

Figure 1 shows the frequency response for several TBPs. A larger TBP results in a more rectangular profile. Figure 2 shows the simulated steady state excitation profile for several flip angles with TBP 4. For flip angles larger than the Ernst angle, the outside regions of the slice contribute a significant amount of signal having experienced less than the desired flip angle. This anomalous increased signal for large flip angles leads to an underestimation of T1. Figure 3 shows the total signal vs flip angle for TBPs of 2, 4, 6, 8, and 10. Figure 4 shows the total signal vs flip angle for TBPs of 2, 4, 6, 8, and 10 for the gelatin phantom. Figures 5 and 6 display the calculated T1 value as a percent of true T1 for every combination of flip angles for TBP 4 and 10 respectively. Calculating T1 using flip angles 5 and 15 for TBP 4 and 10 results in an estimate of T1 that is 64% and 84% of the true value of 400, respectively. Figure 7 plots the T1 estimate vs T1 true for TBP 2, 4, 6, 8, 10. For any TBP, the underestimation of T1 becomes larger as the ratio of TR/T1 becomes smaller.

References 1. Christensen J Phys. Chem. 1974;78:1971–1977. 2. Deoni JMRI 2007;26:1106-1111.

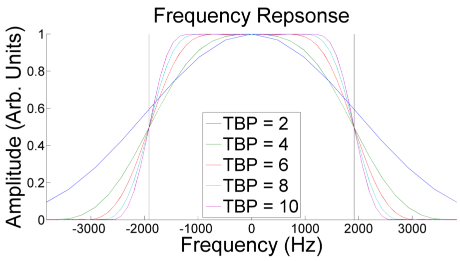

Figure 1. Frequency response to Hamming windowed sinc pulse with different TBP.

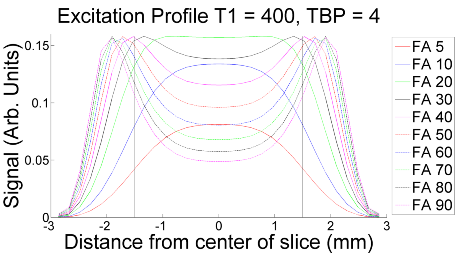

Figure 2. Excitation Profile for TR=20, T1 = 400, TBP=4

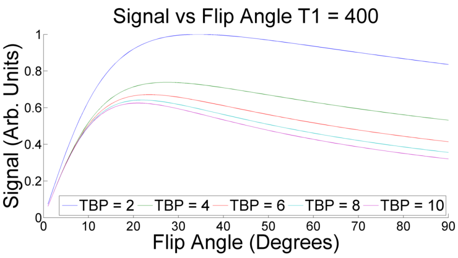

Figure 3. Total signal vs flip angle for TBP of 2, 4, 6, 8, 10

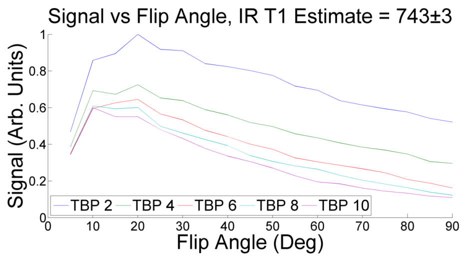

Figure 4. Total signal vs flip angle for TBP of 2, 4, 6, 8, 10 for gelatin

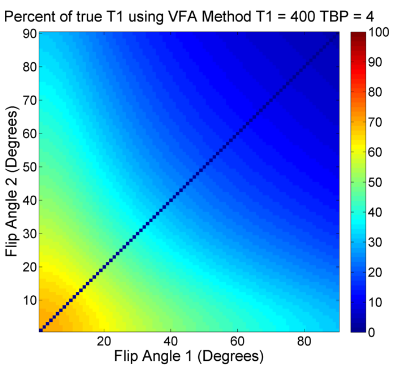

Figure 5. Percent of true T1 for different combinations of flip angle TBP 4, $T1_{true}$=400

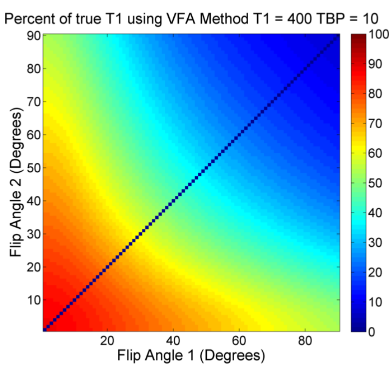

Figure 6. Percent of true T1 for different combinations of flip angle TBP 10, $T1_{true}$=400

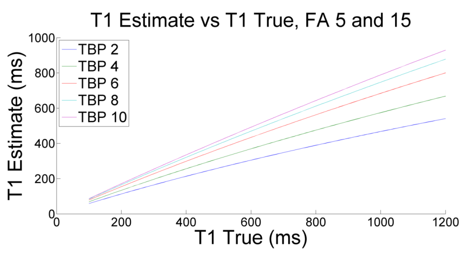

Figure 7. T1 True vs T1 Estimate using flip angles 5 and 15 for TBP 2, 4, 6, 8, 10