An RF pulse with spoiled sidebands improves the accuracy of T1 measurement in DCE-MRI

D. K. Ragan[1], and J. A. Bankson[1]

[1]Imaging Physics, M. D. Anderson Cancer Center, Houston, TX, United States

Introduction Dynamic contrast enhanced MRI is a technique for interrogating the vascular state of tissue by applying pharmacokinetic models to the uptake of contrast agent into tissue. It has found use in both drug research and patient management [1]. The technique relies upon rapidly and accurately quantifying T_1, and as such is susceptible to quantification errors resulting from the excitation process. One such type of error arises in the edges and tails of the slice profile, which contain a distribution of flip angles. This results in inconsistent T_1 weighting across the slice and can cause an error in the measured T_1 if left uncorrected. Recently Parker et al. demonstrated that by measuring the slice profile and with knowledge of the coil transmit field, these effects could be compensated for[2]. However, this method requires both additional preliminary measurements and the use of a look-up table. Moreover, it requires good knowledge of in vivo RF field maps, which at high fields need to be measured for each specimen or subject.

We propose an alternate approach which relies upon a radio frequency (RF) pulse that generates spoiled sidelobes, minimizing the contribution from unintended flip angles and allowing a more accurate measurement of T_1. By creating a spatial suppression band on each side of the excited slice that is not refocused simultaneously with the main lobe, we cause the sidelobes of the slice profile to contribute no net signal. This restricts the apparent slice profile to the narrow and relatively flat central band, avoiding the T_1 shortening effect from the lower-flip angle sidelobes. This allows both more accurate quantification and can directly generate images with proper T_1-weighting.

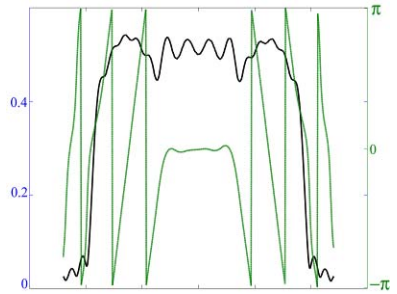


Figure 1: Profile of the proposed pulse

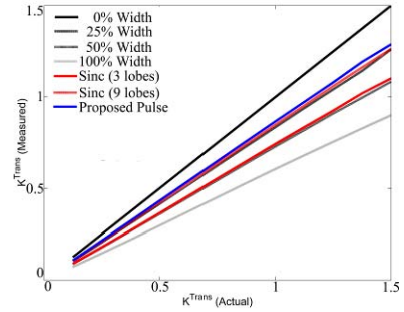


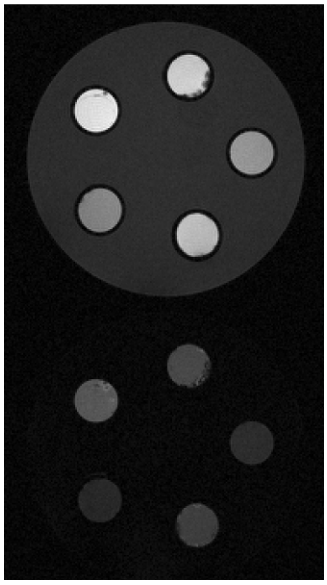
Figure 2: Simulated vs. Actual K^{Trans}

Methods Excitation of a selected portion of the sample followed by spoiling is a common technique for suppressing the signal from certain regions of an image. By considering the sum of the excitation pulse with a sine modulated pulse to excite the regions on both sides of the main slice, it is possible to generate a composite pulse. This composite pulse excites a slice in which sidebands are spoiled. Varying the time between the centers of the two pulses varies the degree of spoiling. For this work, we used a sinc with three positive lobes for each component of the pulse, and a time shift sufficient to create a 4π modulation across each sideband was used, which was a compromise between a maintaining small offset between the two pulses, which improves the envelope of the profile, and a large phase modulation across the profile, which reduces the effect of signal inhomogeneities in the slice direction.

The waveform was modeled using a Bloch equation simulator, and results are shown in figure 1. The profiles for both the proposed pulse and a 3-lobe sinc pulse were calculated at 30°. Additionally, hypothetical trapezoidal slice profiles with ramp widths equal to 0%, 25%, 50%, and 100% of the base width were calculated.

From an assumed arterial input function (AIF), consisting of a short linear ramp and an exponential decay, simulations of uptake for a K^{Trans} values from 0 to 1.5 min^{-1} were performed; v_e was kept constant at 0.3. From the simulated uptake curves and the slice profiles, the signal from a spoiled gradient echo sequence was calculated. From these signal curves, which include the T_1 altering effect of the slice profiles, apparent T_1 maps were calculated using a two-point calculation based on the signal equation for a spoiled gradient echo sequence. From those, apparent pharmacokinetic parameters were calculated. The results are shown in figure 2. For comparison, a 9-lobe sinc, is also plotted. This pulse provides excellent slice profiles, but requires a duration three times the length of either the composite pulse or 3-lobe sinc pulse to excite the same bandwidth.

The technique was validated in phantom. Five samples of distilled water doped with gadopentate dimeglumine were prepared and scanned using a saturation-recovery spin-echo sequence (TE = 10.8 ms, TR = 30 to 4590 ms). Via a FLASH sequence, images were acquired using both the composite pulse and the sinc pulse. Parameters for the acquisition were: TE/TR = 3.5/40 ms, matrix size = 256x256, flip angle = 30°. Using the 0.40 mM sample and its reference T_1 as a baseline, the T1 of the other samples was calculated via the two-point gradient technique. This was done to simulate repeated measurement of a single sample over the course of a dynamic experiment as its concentration varied. Data was acquired on a Bruker 7T Biospec MRI system using the G060 gradient coil system and the 35-mm RF birdcage RF coil.



Results Figure 2 shows a plot of the actual K^{trans} value used in simulation against the apparent value calculated for each pulse. The composite pulse performed modestly better than the trapezoid with a total base width of 25%, and was comparable to the 9-lobe sinc, which requires three times the pulse duration for a comparable excitation bandwidth. The 3-lobe sinc pulse performed slightly better than the trapezoid with a base width of 50%.

The T_1 measurements are summarized in the table, and the images used in the calculations are shown in Figure 3. The high background signal in the sinc image is most probably due to the presence of sidelobes in that slice profile. The nominal flip angle of 30° is above the Ernst angle at this TR for water, while the sidelobes are at a lower flip angle which causes them to contribute more signal at steady state.

Expected results, calculated using the same algorithm as the earlier simulations, are stated in parentheses. The composite pulse displayed more accurate measurements of T_1 in this experiment than did the conventional sinc excitation, although neither approached the accuracy of the saturation recovery sequence.

Conclusions We have developed a method for reducing the limitations of slice profiles on T_1 measurement and have demonstrated that it in some situations it provides a more accurate estimate of T_1 than does a conventional pulse. This may lead to improved measurement of pharmacokinetic parameters. The method relies upon using a modified RF pulse for excitation which provides comparable bandwidth in a given amount of time to a 3-lobe sinc pulse, but with superior effective sidelobe suppression.

Concentration	T1 (Sat. Recov.)	T1 (Comp. Pulse)	T1 (Sinc Pulse)	% Error (Comp. Pulse)	% Error (Sinc)
0.40 mM	1104 ms	—	—	—	—
0.50 mM	902 ms	911 (915) ms	948 (918) ms	1 (1)%	5 (2)%
0.75 mM	488 ms	547 (517) ms	708 (533) ms	9 (6)%	45 (10)%
1.00 mM	397 ms	432 (427) ms	625 (448) ms	12 (8)%	57 (13)%
1.25 mM	271 ms	307 (305) ms	563 (329) ms	13 (11)%	108 (21)%

References

1. Padhani, A.R. and J.E. Husband, Clinical Radiology, 2001. **56**(8): p. 607-20.
2. Parker, G.J., G.J. Barker and P.S. Tofts, Magnetic resonance in medicine, 2001. **45**(5): p. 838-45.