

Transient RF Spoiling for 3D Look-Locker Acquisitions

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Introduction: In spoiled gradient-recalled echo pulse sequences, the standard RF spoiling scheme uses an ever increasing phase angle of the RF pulse and crusher gradients to spoil the transverse magnetization [1]: $\phi_n = \phi_{n-1} + n\phi_{\text{seed}}$. Optimal ideal seed values have been arrived at either from experimentation or simulation for a particular set of imaging parameters or cost function [2,3]. The parameter space has been investigated for both steady state and transient cases, and optimum values of 117° and 84° [2], respectively, were found based on minimizing the sum of the squared differences between ideally spoiled and RF-spoiled pulse trains for different values of ϕ_{seed} . These values, and in particular the transient case (84°) value, were optimized for fairly short T1 values and fairly long TR times, and therefore may not be ideal for fast sequences such as the accelerated 3D Look-Locker (3DLL) sequence [4], where TR values can be very short, or for very high field strengths, where T1 values can be very long. Here, we investigate optimal RF spoiling for the transient magnetization case over a broad range of parameters that includes very short-TR, very long-T1 regime.

Methods: As in [2], Bloch simulations were used to simulate the signal along the recovery curve that would be acquired using an accelerated 3D Look-Locker read out scheme. This allowed for comparison between an ideally spoiled recovery curve (by setting M_{\perp} before each small tip angle pulse to zero) and an RF spoiled recovery curve based on different values of ϕ_{seed} ranging from -180° to 180° in 0.5° increments. In Epstein the goal was to minimize the sum of squared differences (R^2) between the ideally spoiled curve and the simulated curve for a range of T1, T2, and alpha values. Here we extend the work by exploring the parameter space including T1(ms) = [500, 1000, 2000, 3000, 4000], T2(ms) = [30, 50, 100, 200], TR(ms) = [3, 5, 10], and $\alpha(\text{deg}) = [6, 20, 30]$, which are more typical of the values encountered when using an accelerated 3DLL sequence. The spoiling was assessed with respect to minimizing R^2 , as well as minimizing the fractional error in the T1* estimate ($\Delta_{T1^*} = |T1^*_{\text{fit}} - T1^*| / T1^*$) from non-linear least squares fitting. No value of ϕ_{spoil} was found that minimized R^2 or Δ_{T1^*} for all cases, so the value that minimized those values for the most cases was chosen.

Based on the optimal spoiling values obtained above, accelerated 3D Look-Locker imaging (128 samples between inversions, TR = 3.9 ms, segmented into 8 T1 volumes) was performed on a saline phantom containing nine agarose phantoms doped with NiCl₂ to obtain T1's ranging from 185-3000 ms. In the first experiment, all phase encoding gradients were turned off, making it possible to track the magnetization evolution for each of the 128 small tip angle pulses between inversions in a bulk saline sample, which could then be compared to the LL TI images reconstructed when phase encoding was turned back on. To validate whether there was really an improvement in transient spoiling, imaging was conducted on the multi-T1 phantom using 2 sampling angles (10° and 20°) for a total of 18 T1* values. Experimental T1* values were obtained from non-linear least squares fitting to the LL TI images for each of the suggested ϕ_{seed} [84,117,137.5,162] values and were compared with theoretical values.

Results: Figure 1 shows the experimentally measured recovery curve if imaging gradients are turned off for the spoiling values recommended by Epstein, along with the values for the 8 reconstructed images at their effective TI time (boxes). The variations in the curves and deviation from an ideal exponential are due to imperfect spoiling of the transverse magnetization of the chosen RF spoiling scheme. The reconstructed images lie along the recovery curve, and show contrast that is dependant on the spoiling, leading to inaccuracy in the measured T1*. For minimizing R^2 a value of 137.5° was found to be optimal from the simulations, and for T1* it was 162° . Figure 2 shows the error associated with each spoiling scheme. Using the value for steady state (117°) leads to the greatest error in nearly all cases. The value suggested by Epstein (84°) for transients shows a significant improvement, but in most cases, either 137.5° or 162° is a better choice. For this parameter set, optimizing for the intended purpose (measuring T1*) leads to the best experimental T1* value in approximately the same number of cases as optimizing for R^2 .

Discussion and Conclusion: A number of new quantitative relaxometric sequences employ fast SPGR sequences with short TR times and acquisitions during the transient phase of magnetization recovery. Our work shows how important it is in these cases to choose the correct RF spoiling scheme. The scheme suggested earlier [2] does improve on the transient response, but optimization over a larger and more appropriate parameter space produces even better accuracy when measuring driven recovery time constants.

References: [1] Zur, Y., Wood, M.L., Neuringer, I.J., *Magn Reson Med*, 1991 21:251-263; [2] Epstein, F.H., Mugler, J.P., Brookeman, J.R., *Magn Reson Med*, 1996; 35:237-245; [3] Preibisch, C., Deichmann, R., *Magn Reson Med*, 2008; 61:125-135; [4] Henderson, E., McKinnon, G., Lee, T-Y., Rutt, B.K., *Magn Reson Imag*, 1999; 17:1163-1171.

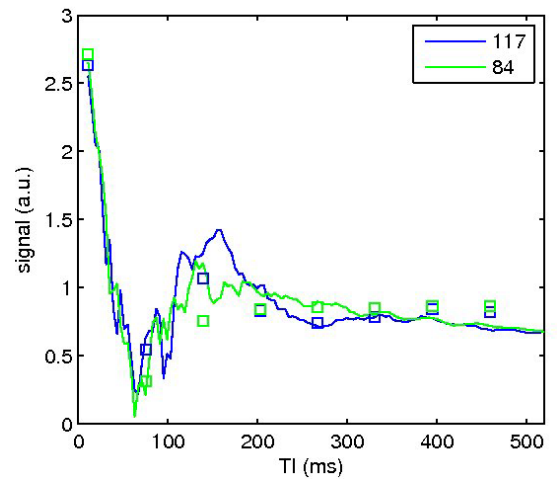


Figure 1

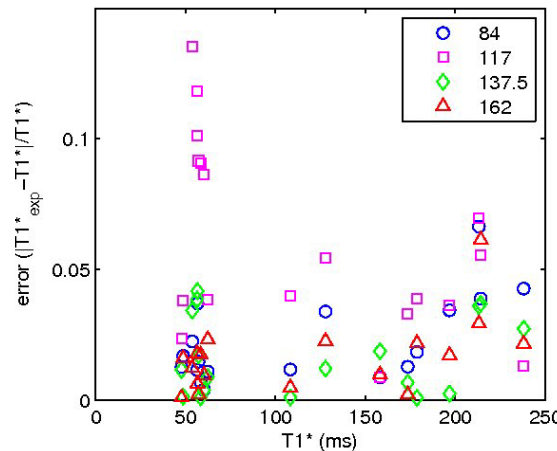


Figure 2