A Simple Noise Correction for Rapid T_1 Measurements

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Introduction: Time resolved monitoring of the transient phase after an inversion pulse in RF-spoiled unbalanced GRE (Look-Locker, (1)) or balanced SSFP (2,3) sequences has become an important tool for rapid T_1 measurements. To minimize systematic deviations of the measured effective T_{eff} from the sought-after relaxation time T_1, the flip angle α should be small in both methods. For low SNR, T_1 estimates without consideration of noise can be associated with a large bias if the Rayleigh noise becomes too large near the zero crossing (magnitude images) as shown in Fig. 1. To address this problem, more sophisticated methods were proposed (4,5), which usually rely on independent noise measurements. The latter can be very difficult, in particular, if parallel imaging is used, as is the case with abdominal imaging. In such cases, noise fitting seems to be a better alternative.

Methods: The measured, time-dependent signal $S = S_t + N$ is the sum of a true signal $S_t(T_1,c)$, which (apart from fixed sequence parameters) depends on T_1 and some proportionality factor c, and a noise term N. The signal S then follows a Rician distribution

$$p(S;S_t,\sigma) = \frac{S}{\sigma^2} e^{-(S^2+S_t^2)/2\sigma^2} I_0\left(\frac{SS_t}{\sigma^2}\right),$$

where σ denotes the standard deviation of the complex magnetization and I_0 is a modified Bessel function. The idea is now, to use not $S_t(T_1,c)$, but the expectation value of S,

$$\langle S\rangle(T_1,c,\sigma) = \int_0^\infty dS\, S\, p(S;S_t,\sigma),$$

as a fit function, with T_1, c and σ as fit parameters. The least square fits were done using selfwritten software, based on a C++ implementation of the Levenberg-Marquardt algorithm. All required partial derivatives could be referred to function calls from the GNU scientific library. The experiments were done on two 1.5T clinical scanners (Achieva/Philips, Avanto/Siemens). For eight tubes of saline water, doped with varying concentrations of Gd-DTPA (Magnevist, Schering), T_1 values (51, 101, 195, 364, 546, 813, 1044, 2621 ms) were obtained in a reference measurement (MIX-sequence). In the T_1 experiments, a 180° inversion pulse was applied every 4 seconds (software triggered), followed by a train of α pulses (5° and 10°) with the segmented acquisitions. Time resolution of the phases and repetition times were 40/40 ms (Look-Locker, EPI factor 11) and 57/3 ms (IR-TrueFISP). To obtain different SNR ratios, the slice thickness was adjusted in the range from 3 to 10 mm, keeping all other parameters unchanged. The dynamic signal of equally sized ROIs was recorded to files for each measurement and tube.

Results and Discussion: For high enough SNR values, good agreement between fitted and reference T_1 values could be obtained for both sequence types and fitting methods in the T_1 range between 100 and 1000 ms. For $\alpha = 10°$ and large T_1, the Look-Locker fit underestimated T_1 slightly (acceleration effect of the RF pulses). With σ as fit parameter, the relative deviation between estimated and reference T_1 values was always below 10%, in most cases even below 5%, while disregarding noise caused considerable systematic errors for small SNR. Fig. 1 shows a typical example.

Conclusion: Fitting against the expectation value of the signal, with noise as a fit parameter, produced robust and reliable results, even for very poor SNR.

References: (1) Look DC, Locker DR. Rev Sci Instrum 1970; 41:250, (2) Scheffler K, Hennig J. MRM 2001; 45:720, (3) Bokacheva L et. al. MRM 2006; 55:1186, (4) Karlsen OT et. al. MRM 1999; 41:614, (5) Sijbers J, den Dekker AJ. MRM 2004; 51:586

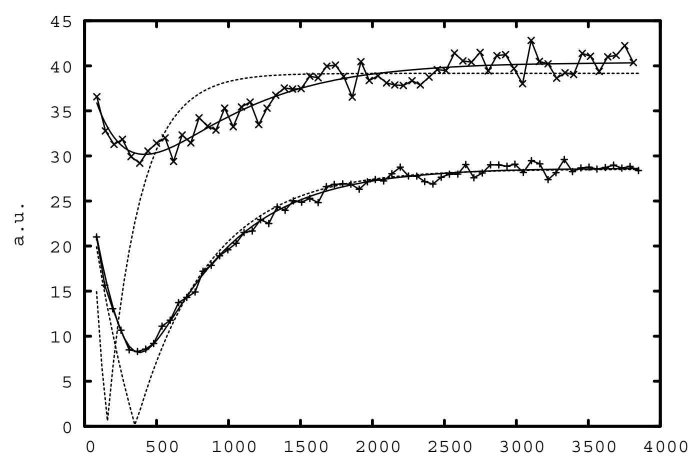

Fig 1: IR-True FISP ($\alpha = 5°$) signal (as a function of time after the last inversion pulse) of the tube with $T_1 = 364$ ms (reference value) for two different slice thicknesses (3 and 10 mm), corresponding to low (upper curve) and moderately high (lower curve) SNR. The solid lines, where σ was fitted, show a very good visual agreement with the measured data, and good T_1 estimates (365 ms for low SNR and 362 ms for high SNR). In contrast, the dashed lines, where noise is neglected, deviate considerably, especially at low SNR. The fitted T_1 values (141 ms for low SNR and 335 ms for high SNR) reflect this.