Transverse Relaxometry with non-180° Refocusing Pulses

J. Sénégas[1], N. Neu[2], and J. Keupp[1]
[1]Philips Research Laboratories, Hamburg, Germany, [2]Ecole des Mines de Paris, France

INTRODUCTION - Quantitative T_2 measurements provide important information about the mobility and chemical environment of water. Most frequently, a multi-echo spin-echo (MESE) sequence incorporating multiple refocusing pulses in each repetition time is used [1]. Unfortunately, estimation based on exponential fits may lead to strongly overestimated T_2 values due to the presence of stimulated echo pathways depending on the actual slice profile of the refocusing RF pulses [2-3]. Recently, a more accurate model based on the extended phase graph (EPG) approach [4-5] has been proposed to fit the signal curve of MESE acquisitions with imperfect refocusing pulses. Given the flip angle profile across the slice computed from the known RF pulse shape, initial magnetization, T_2 and B_1 field are jointly estimated using a non-linear least-squares algorithm, while T_1 is assumed to be infinite. While the EPG approach has been proposed primary to correct for B_1 inhomogeneities and imperfect refocusing pulses, we investigate here whether this approach can be applied with sufficient accuracy and precision in the case of pulses with refocusing angles below 180˚ with the benefit of reduced power deposition and shorter echo spacing.

METHODS - The fitting model proposed in [5], denoted thereafter EPG, was applied with the following modifications: a quadratic penalty function adapted for Rician noise statistics as encountered in magnitude images was used in the fit [6] and the flip angle profiles were computed with the hard-pulse approximation [7]. Furthermore, instead of assuming infinite T_1, optimal T_1 values minimizing the T_2 error over a given interval of T_1 were used as input in the fit, thereby allowing the computation of T_2 with a known accuracy without acquiring a separate T_1 map.
Monte Carlo simulations were performed to assess accuracy (bias) and precision (standard deviation) of the T_2 estimates for refocusing angles between 180˚ and 100˚ and different T_1 (700 – 1000 ms) and T_2 (50 – 400 ms) values, assuming an echo train length of 16 and an echo-spacing of 16 ms. Gaussian noise was added to the complex signal, with the standard deviation chosen to reach a SNR of 40 at TE = 0 ms. The accuracy of T_2 estimates for refocusing angles between 180˚ and 100˚ was further evaluated in phantom experiments using the Eurospin relaxometry test object (Diagnostic Sonar, Livingston, Scotland) and in volunteer experiments in the brain. Slice-selective MESE acquisitions were performed on a 1.5T MR scanner (Achieva, Philips Healthcare, The Netherlands) with the following parameters: TE = 16, 32,.., 256 ms, TR = 1500 ms, resolution = 1.2x1.2 mm^2 / 1.0x1.0 mm^2 (phantom / brain), slice thickness = 8 mm. In both experiments, reference T_2 values were measured at a lower resolution with a 3D MESE sequence with non-spatially selective refocusing pulses. Both simulations and MR experiments were performed with the standard refocusing pulses for multi-slice fast spin-echo imaging available on the MR scanner; the ratio between excitation and refocusing slice widths was close to 1.0 in all cases.

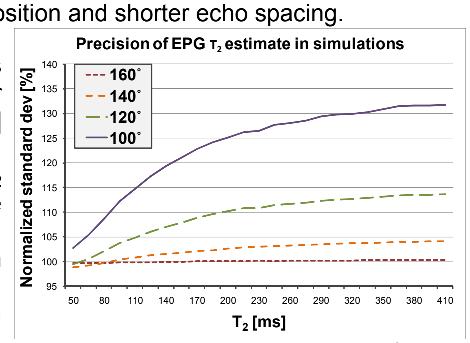

Fig 1 – Normalized standard deviation of T_2

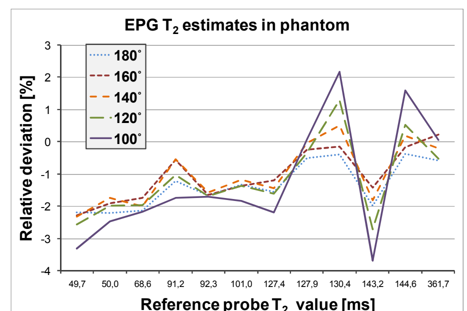

Fig 2 – Relative T_2 estimation error in phantom

RESULTS – In the simulations, the bias of the EPG T_2 estimates increased slightly with decreasing refocusing angle. When using the numerically computed optimal T_1 value (825 ms in this case), it remained below 2.5%, compared to 10% with EPG based on infinite T_1. A standard exponential fit led to overestimations up to 35%. The standard deviation of the EPG estimates, when normalized to the 180˚ case, increased with decreasing refocusing angle and with T_2 (Fig. 1), but not significantly with T_1. Overall, the noise penalty resulting from non-180˚ refocusing pulses was limited: e.g. for T_2 below 200 ms, the standard deviation increased by less than 10% for refocusing angles down to 120˚**.** Mean T_2 values measured in each phantom probe with the EPG method are shown on Fig. 2: relative error with respect to the T_2 estimates obtained with the 3D sequence was below 4% for the different values of the refocusing angle. In the brain, the EPG method yielded T_2 estimates much closer to the 3D reference case over the range of tested refocusing angles than the usual exponential fit (Fig. 3).

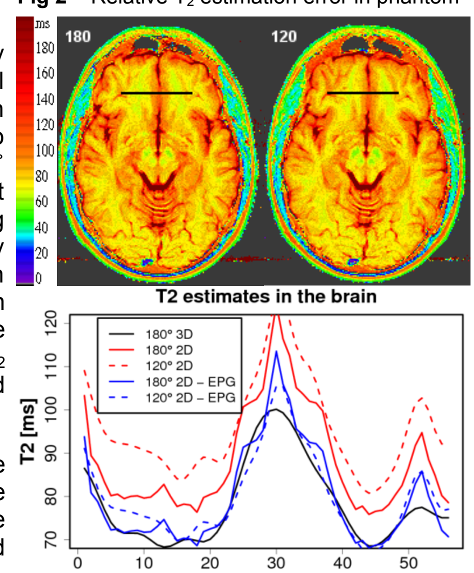

Fig 3 – Top: Example of brain T_2 maps obtained with spatially selective 2D 180˚ and 120˚ refocusing pulses and the EPG model. **Bottom:** T_2 profiles (location: black line) obtained with the 3D and 2D sequences, with (blue) and without (red) EPG model. The 3D profile is smoother due to its lower resolution.

DISCUSSION / CONCLUSIONS – For MESE sequences with spatially selective refocusing pulses, the EPG-based model may not only improve T_2 accuracy in the presence of B1 inhomogeneities and imperfect slice profiles, but also open the door to sequences with reduced refocusing angle that are less power-limited and more time-efficient, without significantly sacrificing accuracy and precision.

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