Improvement of T_1 Accuracy with the Correction of Imperfect Excitation Flip Angle: Toward the Application of Arterial Spin Labeling

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INTRODUCTION

Accurate and fast T_1 information is crucial for non-contrast perfusion measurement with arterial spin labeling (ASL). The Look-Locker based single shot gradient echo (GRE) is a common method for fast T_1 measurement because of its fast data acquisition. However, even in a low field system, the accuracy of the quantitative T_1 is affected by the field inhomogeneity caused by the spatial non-uniformity of the transmitter and receiver, the RF transmitter calibration error (also leading to discrepancy of the nominal and actual flip angles), the nonideal RF slice profile, tissue diamagnetism and the dielectric properties of the subject imaged. In this study, a multi-variable T_1 regression algorithm adapted for the saturation effect and ECG triggered data acquisition based on Look-Locker scheme (1) was specifically investigated, aiming to increase the T_1 accuracy via a modified single shot GRE sequence and application of an excitation flip angle (α) correction factor. The effect of the B_1 field inhomogeneity and associated correction procedures on the T_1 accuracy was examined in simulation and in a stationary T_1 phantom, respectively.

MATERIALS AND METHODS

Pulse Sequence The T_1 in this study was measured by a hyperbolic secant inversion (IR) pulse prepared (non-selective (*NonS*) and selective (*Sel*) prepared separately and the two sequences were combined together) single-shot GRE acquisition based on the Look-Locker scheme. Considering the possibility of imperfect 180^0 inversion pulse, spoil gradients were also applied in all three-axis directions. To ensure fully recovery of the longitudinal magnetization caused by the inversion pulse β and saturation effect induced by the excitation pulse α train, a time interval of 3 s is added between the *Sel* and *NonS* IR prepared data acquisitions. Two initial inversion recovery times (TI_1, 100 and 140 ms) were used to sample the T_1 recovery curve more finely. The sequence was performed in a format of *Sel* ($TI_{1,1}$)- *Non-S* ($TI_{1,1}$)- *Sel* ($TI_{1,2}$)- *Non-S* ($TI_{1,2}$). The accuracy of T_1 was investigated in a serial of cylindrical phantoms (diameter = 2 cm) doped with different concentration of gadolinium-DTPA, with T_1 ranging from 400 to 1150 ms.

Simulation The dependence of the predicted T_1 using our proposed algorithm on the excitation flip angle α efficiency was simulated in Matlab (with signal intensity simulated at $\alpha = 5^0$, actual T_1 =900 ms, TR = 2.2 ms, k-space lines = 64, two initial inversion time TI_1s = 100ms and 140 ms, number of images after each IR N=12, RR interval = 700 ms, and assume $\beta = 180^0$). The nominal flip angle used in the T_1 fitting was varied based on different B_1 efficiency (60-110%, and the B_1 efficiency was defined as measured flip angle / nominal flip angle).

MRI Procedure and Data Analysis The studies were performed on a 1.5 T Siemens Sonata system, with body coil as transmitter and a 6-channel phased array coil as receiver. To obtain the actual B_1 efficiency map of the excitation angle α, a segmented EPI-GRE sequence was applied at flip angles = 60^0 and 120^0, TR = 3000 ms, EPI factor =5 and then the spatial distribution of the B_1 efficiency was calculated as described elsewhere (2). Then, the T_1 measurement was trigged by simulated ECG signal (RR interval = 700 ms), nominal flip angle $\alpha = 5^o$, FOV = 220 mm, slice thickness = 8mm, interpolated final image matrix = 256 × 160, and other imaging parameters were the same as in the simulation. For each pair of *Sel* and *NonS* IR prepared data acquisitions, the total duration could be completed within approximately 19 s. Pixel-wise T_1 map of the phantom was generated before and after the nominal flip angle correction (i.e. using the nominal or measured flip angle maps in the T_1 fitting) separately by the multi-variable T_1 regression algorithm.

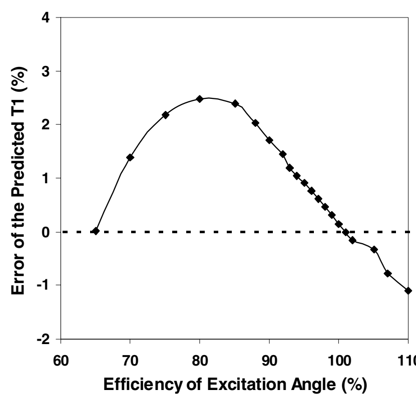

Fig. 1: Dependence of the predicted T_1 on the excitation angle efficiency

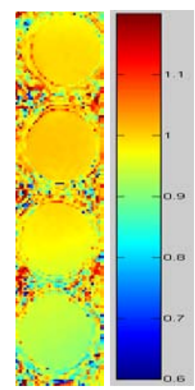

Fig. 2: Spatial distribution of the B_1 field (shown as ratio of actual & nominal flip angle)

Table: Summary of predicted T_1 before and after the nominal α correction

True T_1 (ms)	459.8	539.7	974.3	1119.9
Error of predicted T_1 using nominal α (%)	3.47	4.03	3.92	-0.43
Average α efficiency for this phantom	0.98	0.93	1.02	1.02
Error of predicted T_1 after α correction (%)	3.24	3.29	4.17	-0.26

RESULTS

For the simulation, as shown in Fig. 1, 90% efficiency of excitation flip angle α overestimated the predicted T_1 (1.5% of error). In the phantom study, the spatial B_1 efficiency varied from 1.02 to 0.93 from coil center to edge (Fig. 2).

The T_1 measured from our proposed single shot GRE sequence with a slice selective IR preparation was approximately 4% error of the true values for T_1 ranging from 460 ~1120 ms (measured with IR-SE) using our T_1 regression algorithm, the accuracy of the T_1 might improve after the excitation flip angle corrections depending on the specific B_1 efficiency for that phantom (specifically, for T_1 = 539.7, 18.4% improvement of T_1 was achieved, see Table).

CONCLUSION AND DISCUSSION

For an IR prepared single shot GRE, the T_1 regression algorithm adapted for cardiovascular application was highly affected by the actual B_1 field; a relatively accurate T_1-measurement may be obtained after the correction of the nonideal nominal flip angle. Though, in the phantom, the B_1 efficiency was relatively high (0.93~1.02 in our study), in the practical *in vivo* study, it could be as low as 0.80. Given the strong dependency of the calculated perfusion on the T_1 accuracy with ASL, correct information of the excitation flip angle should be obtained to improve the accuracy of the perfusion and it may provide a promising prospect for the ASL application. It should be noted that the accuracy of the measured T_1 also depends on many factors, such as the RR interval and selection of an optimal excitation flip angle for a specific T_1. Since we used a single flip angle ($\alpha = 5^0$) for this multiple T_1 phantom, we could see variations of T_1 accuracy (data in Table), which may need further investigation.

REFERENCES Magn Reson Med 2005;53(5):1135-1142. 2. Magn Reson Med 2005;53(3):666-674.