T_1 estimation using variable flip angle spoiled gradient echo for dynamic contrast-enhanced MRI: Arterial input measurement improves accuracy in the presence of B_1 error

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Introduction.

An essential step in the quantitative analysis of contrast agent uptake is the assessment of changes in tissue T_1. The rapid acquisition times often required for these measurements dictate that they are made using gradient echo pulse sequences with flip angles < 90°. Quantitative measurements made using such sequences rely on accurate knowledge of B_1 and it is well known that many transmit coils can produce inhomogeneous B_1 fields and this can be compounded by slice profile and dielectric resonance effects [1,2]. In this study, the effect of a systematic error in B_1 on the measurement of contrast agent uptake in tissues is examined.

Methods.

For these simulations input data ($1/T_1$ against time) were taken from regions encompassing a prostate tumour, normal peripheral zone and an external iliac artery (to provide an arterial input function, AIF) following the administration of 0.1 mmol/kg Gd-DTPA-BMA. The original data were acquired on a 1.5 T Philips MR system every 2.3 s for 4 minutes using a 3D T_1-weighted gradient echo pulse sequence with a TR of 2.5 ms and a flip angle of 30° [3]. Baseline T_1 had been estimated using 4 acquisitions at 2°, 10°, 20° and 30° flip angles [4]. From the temporal changes in $1/T_1$ signal intensity time courses were simulated for a series of acquisitions with ±10% and ±30% errors in B_1. That is, for acquisitions with true flip angles of 21°, 27°, 33° and 39° instead of the nominal 30°. These errors applied equally to the data used for baseline T_1 estimates (e.g. a -10% error in the flip angle will result in acquisitions at 1.8°, 9°, 18° and 27° instead of the nominal 2°, 10°, 20° and 30°). The data resulting from these simulations were subsequently converted to temporal changes in $1/T_1$ (using the erroneous assumption of correct flip angles) and analyzed using a two-compartment model providing estimates of K^{trans}, v_e and v_b [5]. Two analyses were performed: 1. By assuming an independently measured AIF (errors in the flip angle do not affect the AIF and it remains in its original form), 2. By assuming the AIF is measured by the same method used to image the tissue (errors in the flip angle affect the AIF and tissue equally).

Results.

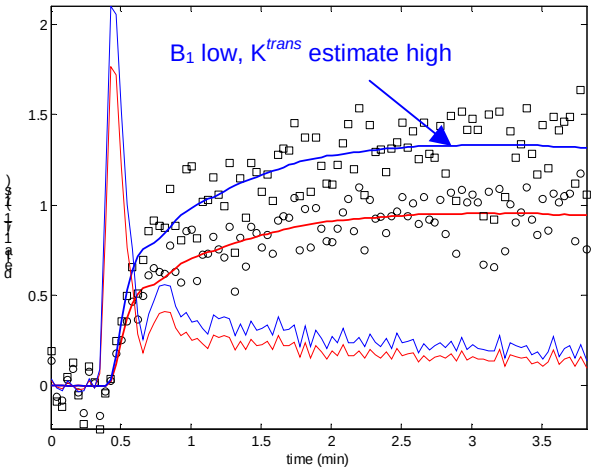

Fig. 1 True $1/T_1$ time course in an artery (faint red line, scaled down by a factor of 10) and normal prostate (circles with model fit in red). Estimated $1/T_1$ time course in artery (faint blue line) and prostate (squares with model fit in blue) when flip angle error = -30%.

The true baseline T_1 of the prostate and artery was 1000 ms and 1500 ms, respectively. A -30% error in the flip angle results in baseline T_1 estimates of 486 ms and 728 ms, respectively, and an overestimate in the amplitude of the $1/T_1$ time courses. Positive errors in the flip angles led to overestimates of T_1 (up to 1713 ms for the prostate) and concomitant underestimates in the amplitude of the $1/T_1$ time courses. When the simulated data were presented for fitting by method 1 errors in K^{trans}, v_e and v_b were of the same magnitude and ranged from -24% to +40% (resulting from +30% to -30% flip angle errors). When presented for fitting by method 2 errors in K^{trans} ranged from -3% to +10%; errors in v_e ranged from -3% to +1% and errors in v_b ranged from -6% to +21%.

Discussion.

Systematic errors in the amplitude of flip angles are common in the clinical setting [6]. Correction of the ensuing errors can be accomplished by careful system calibration [2,6] but this may be impractical in many situations. When encountered in dynamic contrast-enhanced studies corrections can be made using a bookend T_1 measurement approach [7]. However, this requires accurate baseline and post-contrast T_1 measurements that are insensitive to B_1 errors. When left uncorrected errors propagate into the estimates of $1/T_1$ (Fig. 1) and thereby into estimates of contrast agent concentration. When the data are later analysed using a tracer kinetic model the parameter estimates will be inaccurate. Errors in K^{trans} of 40% result from a -30% error in B_1. These errors are magnified as TR increases or the nominal flip angle used for the dynamic acquisition decreases. However, if measurements of the AIF and tissue residue curve are made simultaneously then subsequently used for tracer kinetic analysis, errors in the resultant parameter estimates are significantly reduced. Hence a -30% error in B_1 results in only a 10% error in K^{trans}. This improvement arises since the B_1 miscalculation affects the AIF and tissue $1/T_1$ to a similar degree. Hence the use of a measured AIF not only improves the underlying accuracy of parameter estimates [5] but also reduces sensitivity to B_1 error.

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References. **1.** Alecci M et al. *Magn Reson Med* 46:379-85 (2001). **2.** Parker GJ et al. *Magn Reson Med* 45:838-45 (2001); **3.** Buckley DL et al. *Proc 11th meeting ISMRM,* Toronto, 461 (2003); **4.** Zhu XP et al. *J Magn Reson Imaging* 11:575-585 (2000); **5.** Buckley DL *Magn Reson Med* 47:601-606 (2002); **6.** Brookes JA et al. *J Magn Reson Imaging* 9:163-171 (1999); **7.** Cron GO et al. *Magn Reson Med* 42:746-753 (1999).