STEADY-STATE B1 MAPPING OF DYNAMICALLY CHANGING RF FIELDS

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Introduction In many circumstances the RF fields present inside a subject may vary temporally as well spatially, due for example, to physiological processes such as cardiac motion, respiration [1,2] or interventional procedures. Such variation may be investigated by acquiring time resolved B_1 maps. The actual flip angle imaging (AFI) method [3] is a popular mapping approach consisting of a steady-state spoiled gradient echo sequence with TR periods of alternating duration TR_1 and TR_2. The flip angle (and hence B_1) is a function of the ratio of signals (S_1 and S_2) acquired in each period and the ratio of TR periods $N=TR_2/TR_1$. We have investigated the capability of AFI to measure time varying fields by studying the effect of a sinusoidal temporal modulation of B_1 on the steady-state behaviour of this sequence. The results show that under certain conditions B_1 modulations can be faithfully measured using AFI.

Methods We investigated the effect of sinusoidal modulation of the form $B_1(t) = B_1^{nom}\times(1+\Delta\sin(2\pi t/T_{osc}))$, where B_1^{nom} is the nominal field amplitude and T_{osc} is the period of modulation. In the following discussion flip angles are calculated with respect to B_1^{nom}. There are essentially three relevant time-scales; the T1 of the sample, TR_1 and T_{osc}. Identical results can be obtained by scaling the latter times to the T1, therefore we have investigated the effect of systematically changing TR_1/T1 and T_{osc}/T1. The AFI sequence was simulated using the extended phase graph (EPG) [4] technique. Simulations were run for one cycle period T_{osc} after an initial settling time of 5×T1 to exclude early transient behaviour. The instantaneous estimated $B_1(t)$ was then calculated from the ratio of signals from successive TR periods.

Experiments were performed on a Philips 3T Achieva MRI system programmed to allow real time variation of the RF pulse amplitude. The AFI sequence was implemented including spoiling modifications proposed by Nehrke [5] with d=1 and RF spoiling phase increment 129.3°; these modifications were also included in the signal simulations. A small centrifuge tube phantom containing a solution of $MnCl_2$ in water (0.1mM; T1=930ms, T2=80ms) was imaged using single projections so that signal estimates could be measured from each TR period. For all experiments a fixed value of N=5 was used.

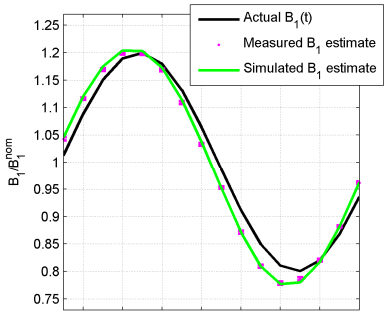

Fig 1 *Predicted AFI B_1 estimates closely match simulation. The Estimate slightly leads the true variation in this case*

Results Figure 1 shows an example comparison between simulation and measurement for flip angle θ=48° and T_{osc}/T1=3.10. The apparent $B_1(t)$ measured by AFI (pink points) match the simulated signals (green) very closely. Both appear to lead the actual variation slightly, leading to an inaccuracy in measured B_1. Figure 2 summarises the results from many simulations, showing the percentage RMS difference between simulated AFI B_1 measurement and true B_1 as a function of flip angle, TR_1/T1 and T_{osc}/T1.

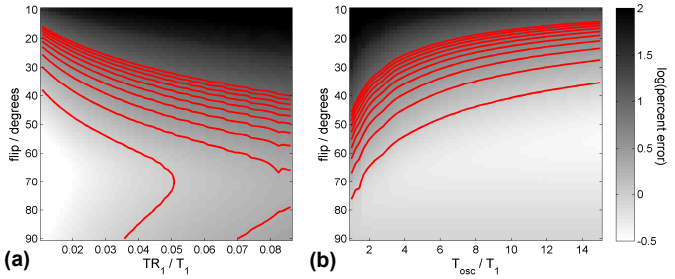

Fig 2 *(a) Percentage error for variable TR_1/T1 with T_{osc}/T1=4. (b) Error for variable T_{osc} with TR_1/T1=0.03. Contours are drawn for errors of 1% to 10%*

Figure 3 shows simulated signal profiles and apparent B_1 for a variety of flip angles with TR_1/T1=0.03, T_{osc}/T1=4. The signals S_1 and S_2 obtained in the presence of dynamic field variation are plotted alongside the "static" signals which would be received if each time point were instead a separate experiment with no temporal variation. We see that for lower flip angles the discrepancy between actual and estimated B_1 is greater. As the flip angle increases the signal variation undergoes a phase shift with respect to the oscillating field. Interestingly this degree of phase shift is not seen in the estimated B_1 which remains fairly stable for θ≥40°.

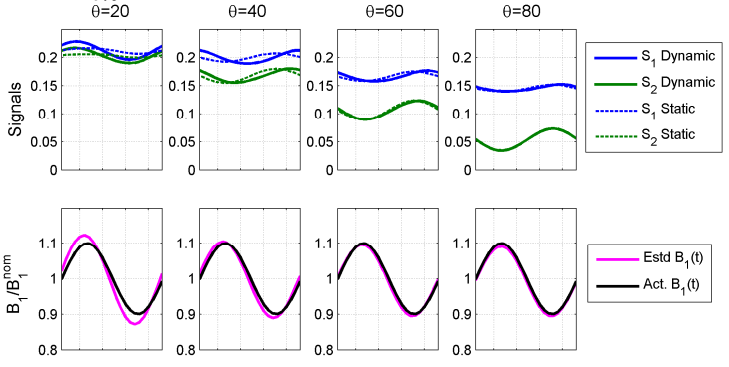

Fig 3

Discussion & Conclusions Close agreement between simulation and experiment has been observed; more generalised conclusions can therefore be drawn from simulations over a wide range of conditions. The impact of the observed effects depends on the method used for k-space sampling. If a gated acquisition is used then the measured variation could be expected to be as predicted here, allowing B_1 variation (if present) to be resolved with respect to whichever process is causing it (respiration, cardiac cycle etc). If data acquisition is not synchronised with the modulation then the signals will vary as depicted causing artifacts in the final images. The actual measured B_1 in this case would depend on these artifacts and is not easy to predict. For accurate imaging *in-vivo* in the presence of respiratory motion, taking for example T1=1sec, T_{osc}=4sec and TR_1=30ms we find that θ≥55° results in systematic error below 1%. We found that larger flip angles generally lead to lower error however TR_1 must remain short with respect to T1 and T_{osc}. The range of flip angles yielding low error increases as T_{osc} is increased with respect to T1.

References [1] Padormo F et al, Proc ISMRM 2009:753 [2] Graesslin I et al, Proc ISMRM 2009:752 [3] Yarnykh VL, MRM 2007 57:192-200 [4] Hennig J, JMR 1988 78:397-407 [5] Nehrke K, MRM 2009 61:84-92