3D Variable Flip Angle Fast-Low-Angle-Shot Experiments in the Presence of B1 Inhomogeneity and Slab-Select Gradient

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INTRODUCTION

Variable Flip Angle (VFA) Fast-Low-Angle-Shot (FLASH) experiments are commonly used for T1 and B1 mapping in vivo [1,2]. Due to the effect of non-ideal pulse shape on signal intensities, 3D experiments are often used in place of 2D multi- or single-slice experiments. While it is typically understood that the signal in the outer slices will vary from that expected, we show differences occurring in all slices, and the resulting T1 errors. In this work, simulations and data show that even at the centre slices, the shape of the slab select pulse alters the shape of the VFA curve non-trivially. Further, a zero crossing will only be observed in the real part of the signal – not in the magnitude – of a FLASH VFA curve.

METHODS & THEORY

In the presence of an ideal excitation with flip angle α, the signal resulting from a FLASH experiment is:

$$S = S_0 \sin(\alpha)\frac{1-\exp(-TR/T1)}{1-\cos(\alpha)\exp(-TR/T1)} \qquad (1)$$

where TR is repetition time, and S_0 is a constant containing proton density, gain, and receiver coil profile. This equation does not, however, describe the signal in the case of a non-ideal excitation. With knowledge of the RF excitation pulse shape, the true signal may be calculated [3]. Here, the simulation methods employed by Parker et al [3] are extended to allow for simulation of a 3D excitation. The slice shape from that simulation is taken as the slab shape, and divided into slices. Each slice is integrated individually. Simulations were performed using the same T1/TR, gradient strength, and slice thickness as experiments.

To verify simulations, a variable flip angle experiment was performed with a range of flip angles (FLASH; TR/TE = 100/2.847; matrix = 128 x 64 x 16; FOV = 2.5000 x 2.5000 x 2.5000 cm^3; α = {5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 210, 240}; hermite pulse excitation; slab select gradient = 2.8 kHz/cm) on a Bruker Biospec 70/30 using a combination of volume (Tx) / surface (Rx) coil. This experiment was repeated with a non-selective excitation. Both sets of VFA data were used to calculate T1 and FA corrections. In both cases, fitting assumed Equation 1 applies.

To verify true T1, a non-imaging inversion recovery experiment was performed.

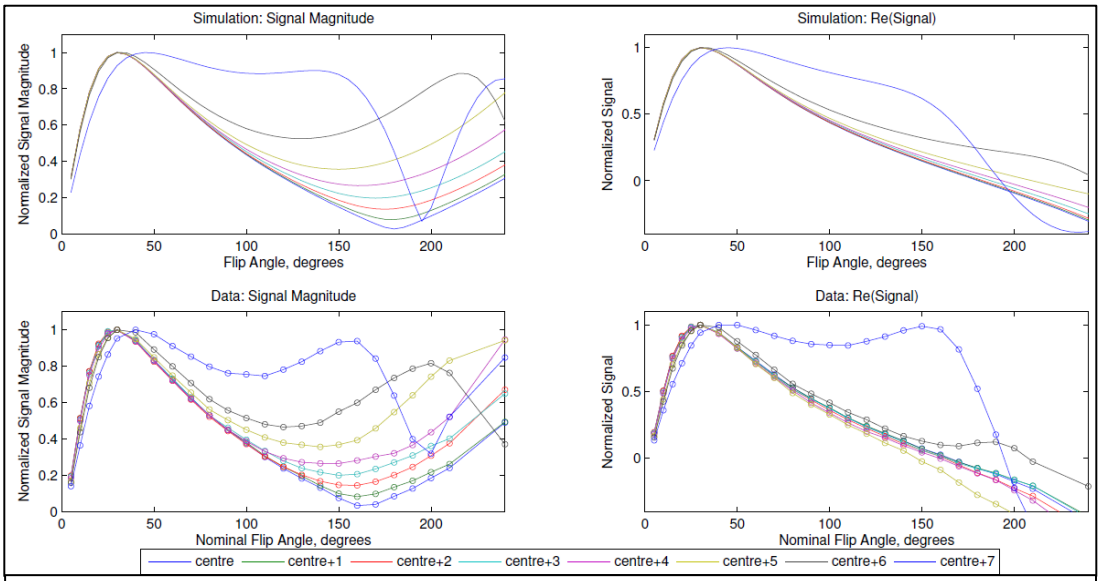

Figure 1: Simulations and data are show both real and magnitude data for an experiment with TR/T1 = 100/680ms. The centre slice is slice 8 of 16 slices. centre+1 would indicate slice 7. and so on.

RESULTS & DISCUSSION

The phantom's true T1 was measured to be 680 ± 20 ms. Simulations are compared to collected data in Figure 1. No signal null occurs in the signal magnitude. In order for a signal null to be observed, the real part of the phased signal must be viewed. Curves further out than the centre slice differ from that expected by the FLASH equation. The outermost slice in the data (real signal) does not agree particularly well with the simulation, possibly due to errors in phasing. Both signal shape, and the location of the zero crossing are changed, depending on the slice location.

T1 and flip angle map values are calculated from both selective and non-selective acquisitions (Table 1), assuming Equation 1 applies. While the T1 measurements with non-selective excitation have relatively constant standard deviations in T1 and FA map values, the values from the data set with selective excitation have much larger standard deviations (in addition to errors). These outer slices are also furthest from the receive coil, and this may be an additional source of error.

Slice	T1 VFA measurements		FA map	
	Non-selective	Selective	Non-selective	Selective
centre	560 ± 30	220 ± 30	1.118 ± 0.009	1.02 ± 0.01
centre+3	560 ± 30	500 ± 100	1.109 ± 0.009	1.13 ± 0.08
centre+7	570 ± 30	600 ± 500	1.09 ± 0.01	1.1 ± 0.2

Table 1: T1 and FA map measurements are made from VFA data sets with selective and non-selective excitation. T1 measurement errors increase for slices further from the centre of the selected volume.

CONCLUSIONS

We show that even a 3D VFA experiment used in place of a 2D multi-slice equivalent does not avoid gross T1 errors, mainly due to inhomogeneous excitation in large parts of the slab. Simulations of the Bloch equation taking into account RF excitation profiles may be used to recover T1. However, the signal magnitude may not be fit using these simulations because of strong coupling, unless prior knowledge of B1 exists. However, with knowledge of the true signal curve shape, and therefore also the true zero-crossing location, it may be possible to extract the correct T1 and B1 simultaneously, using the real part of the signal.

REFERENCES

[1] Haacke, E. M. et al, Magnetic Resonance Imaging: Physical Principles and Sequence Design (1999). [2] Dowell & Tofts, MRM (2007) 58:622. [3] Parker et al, MRM (2001) 45(5):838.