Slice profile effects in variable flip angle hyperpolarized 3He MRI

K. Teh[1], K. J. Lee[1], and J. M. Wild[1]
[1]Academic Radiology, University of Sheffield, Sheffield, Yorkshire, United Kingdom

Introduction In hyperpolarized (HP) gas MRI, the depletion of M_0 during the course of a multiple RF pulse sequence can cause blurring in the image through broadening of the PSF in the RF encoding dimension of k-space. One way of countering this is with constant transverse magnetization, Mxy(n) (M_t), created using variable flip angle scheme (1): **$\theta(n)=\tan^{-1}(1/\sqrt{(N-n)})$ Eq.[1]**, where N is the total number of excitations, n the nth excitation pulse and θ flip angle. Eq.**[1]** assumes a uniform distribution of θ across the slice in a 2D experiment. However, the slice profile in HP gas MRI is variable from view-view as a result of a non-uniform θ distribution causing differential rates of magnetization depletion across the slice (2). This can give rise to a "rabbit ear" profile shape at higher views in constant flip angle experiments. In this work we investigate the effect of ***slice profile*** on the magnetization response of the ***variable flip angle scheme*** and demonstrate a strategy to compensate for non-uniformity in magnetization response caused by the non-ideal view dependent slice profile by using ***variable slice select*** gradient between views.

Methods. ***Simulations*** of the magnetization response of a Gaussian-weighted sinc pulse excitation profile were performed in Matlab for variable flip experiments with N=4 (Fig. 1a) and N=128 views (Fig. 1b). The nominal θ in Eq.[1] was defined as the mean θ across the slice (z) between the limits of the FWHM (±Δz/2) of the slice profile as taken from the first n=1 view.

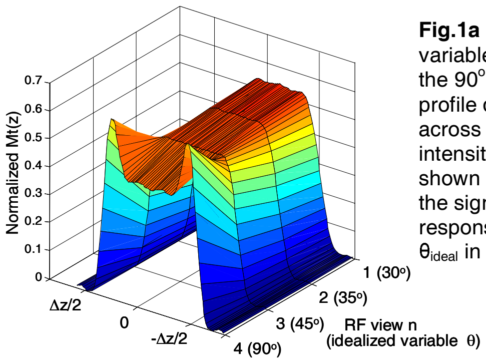

Fig.1a Simulated slice profile in a N=4 variable flip angle experiment. At n=4, the 90° pulse has a very non-uniform profile due to the flip angle distribution across the slice. Transverse signal intensity summed across the slice is shown as the open circles in Fig.2 note the significant deviation from the flat response predicted for an ideal uniform θ_{ideal} in the variable flip angle scheme.

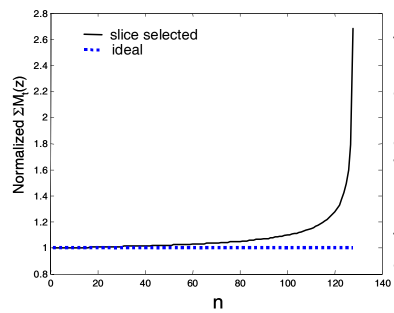

Fig.1b Response of transverse signal intensity summed across the slice for N=128 variable flip angle experiment with a realistic slice profile. Notice notable departure from a flat response at higher n.

Measurements were conducted on a 1.5T whole body MRI system (Eclipse-Philips Medical System). Studies were performed using a mixture of (100ml ^{3}He and 900ml N_2) contained in a 1*l* Tedlar plastic bag. The ^{3}He gas (Spectra Gases) was polarized on site to around 20% with rubidium spin exchange apparatus (GE). A quadrature T/R birdcage was used for all experiments, this coil (3) has homogeneous B_1, important in experiments sensitive to flip angle. An interleaved gradient echo sequence was used with N=4 pulses to investigate the magnetization response by imaging the transverse excitation profile of the slice with read gradient applied along the slice select direction. The sequence was run with 256 samples, 13 mm slice thickness and a TR of 20 ms. Diffusion effects between slices are negligible in these low N experiments due to the short TR. Values of θ from Eq.[1] were used to determine the theoretical amplitude of RF pulses needed, $\theta_{ideal}(n)$, per view to maintain constant M_t without any slice selection scaling. Scaling for non-uniform slice profile effects was then implemented by ***reducing slice thickness*** by the same factor as the M_t increase. To calculate the slice gradient scale factor, the transverse magnetization, $M_t(z)$ was summed over the FWHM limits which represents the multi slice experiment - see Fig.[2]. The limits of ± FWHM/2 represent the scenario in multi-slicing due to magnetization burnout on either sides of the excited slice through multi slicing.

Results

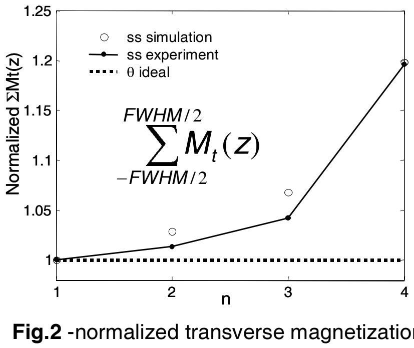

Fig.2 -normalized transverse magnetization versus pulse number, n, calculated from experiment by summing $M_t(z)$ over FWHM limits - for the values derived from from Eq.[1]: θ_{ideal} =30°,35°,45°,90°. Note the deviation from a flat response as predicted by the simulations of Fig.1a –open circles above. This curve enables determination of slice selection scaling needed for constant M_t with θ_{ideal}

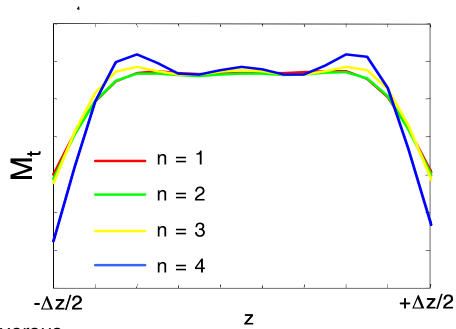

Fig.3 -plot of the slice profile $M_t(z)$, imaged using a variable slice thickness that was calculated from Fig. 2. The limits are the FWHM. Note the deliberate decrease in slice thickness to compensate for the over pulsing at the slice edges.

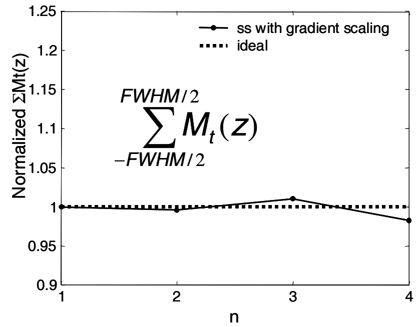

Fig.4- $M_t(z)$ of the variable flip angle/variable thickness scaled excitation. The normalized magnetization response from summing between the FWHM limits shows a virtually flat response indicating the desired effect of a constant transverse magnetization between views.

Conclusion Variable flip angle techniques previously used in 2D HP gas MRI (1) have been shown here to be prone to error due to non-uniform flip angle distribution across the slice (2) which causes a non-ideal, changing magnetization response between views. In previous work, sub optimum performance of the variable flip approach was attributed to imprecision in B_1 calibration [4], the effects described here are a possible cause of these observations. To counter the effect we have demonstrated a novel method of ***variable slice select gradient*** in conjunction with ***variable flip angle*** techniques to maintain a constant $M_t(n)$ throughout the multi-pulse experiment. The results presented here with N=4 pulses are directly applicable to the high acceleration factor parallel imaging techniques possible in HP MRI. Simulations performed with higher N (Fig.1c) also show the deviation from a constant magnetization in a fully RF encoded variable flip angle HP MRI sequence.

References [1] J Magn Reson Ser B 1996;113:179-183 [2] Magn Reson Med 2002;47:687-695 [3] Proc. ISMRM 2006. # 218. [4] Proc. ISMRM, 1999. # 2092 **Acknowledgement** EPSRC #GR/S81834/01(P) # EP/D070252/1, GE Health, Spectra Gases, Aerosol Society UK