Sequence considerations for 2D radial MRI of hyperpolarized gases

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Introduction Radial MRI of hyperpolarized (HP) ^{3}He gas has shown to be effective in imaging ventilation dynamics in the human lungs [1]. With angular undersampling, the number of views Nφ, can be reduced in favour of increased temporal resolution, provided the streak artifacts (spatially correlated noise) can be tolerated. In this work, factors effecting the SNR, spatial resolution and streak prevalence in undersampled short TE spoiled radial imaging are considered for HP gas MRI. Simulations of the effect of gradient diffusion dephasing and RF undersampling for constant and variable flip angle radial schemes are presented and compared with experiments in gas phantoms and human lungs with HP ^{3}He.

Methods: ***Simulations*** were performed in Matlab. The effect of the echo asymmetry (echo time) upon SNR and spatial resolution was investigated by calculating the *b*(t) value for radial waveforms of progressively increasing asymmetry (decreasing TE). SNR (k=0 point at *t*=TE) and blurring in the radial frequency encoding direction were predicted from the radial k-space filter $\boldsymbol{H(k_r) = exp(-b(t)D)exp(-t/T2^*)}$. For ^{3}He, D=0.88 x10^{-4} cm^{2}s^{-1} in the major airways and 0.2 x10^{-4} cm^{2}s^{-1} in the alveoli were assumed with T2*= 30 ms. For the angular RF encoding dimension (φ), simulations were performed for both fixed and variable flip angle schemes [2], for progressively more undersampled experiments Nφ = 128, 64, 32, 16 and 8. For the fixed flip angle scheme, blurring in the φ dimension was predicted from the RF k-space filter $\boldsymbol{H(k_\varphi) = sin\alpha cos\alpha^{n-1}}$, this was modulated with respect to flip angle α, to give the same shaped filter function for all Nφ.

Experiments with ^{3}He MRI were performed on a 1.5 T system (Philips, Eclipse). The system had single quadrature T-R capabilities for ^{3}He at 48.5 MHz. Gas was polarised to 24% with Rb spin-exchange apparatus (GE). Phantoms consisted of 100 ml ^{3}He mixed with 900 ml N_2 in a Tedlar bag. A low pass quad. T-R birdcage coil was used for phantom work, an elliptical quad. T-R birdcage body coil was used for volunteer studies [3]. A 2D radial sequence was used based upon [1], no trajectory compensation was applied. To investigate diffusion dephasing effects in phantoms, the echo asymmetry (TE) was varied between a pure ***FID*** and a full ***echo*** by altering the gradient waveform asymmetry. The waveform was a linear ramp up of 280 ms followed by a flat plateau of 760 ms, the dwell time was 8ms and the gradient strength was 19.5 mTm^{-1}. In between acquisitions a single pulse-acquire (1°) was made to track the diminishing M_0 to normalize for polarization decay. Undersampling was investigated by varying Nφ with fixed flip angle values derived from the simulations: Nφ=8,16,32,64,128 and 256 with α =30°, 20°, 15°, 11°, 8° and 6°. The undersampling experiments were repeated in volunteers for Nφ=64 &128 multislice (5x10 mm) acquisitions in two separate breath holds. **Results:**

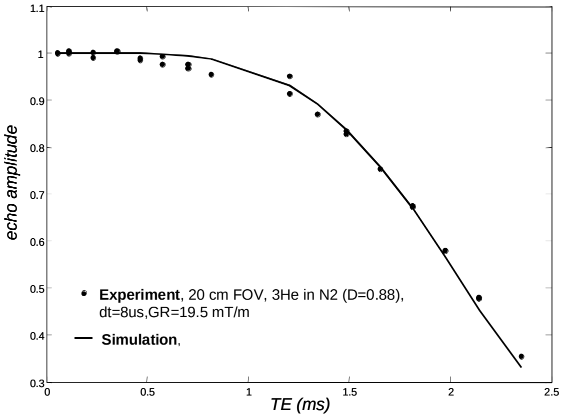


Fig. 1 Effect of diffusion dephasing caused by the radial readout gradient –experiment (circles) and simulations for a given gas and gradient configuration note the benefits of a short echo time (*FID* sampling) in minimising attenuation in SNR when gas diffusion is significant.

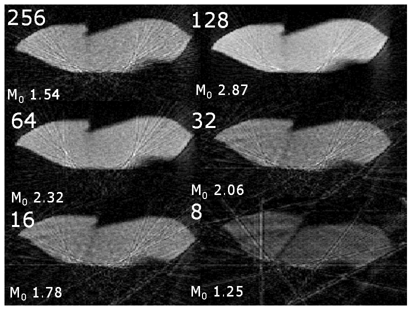


Fig. 2 Angular undersampling effects in ***(i) phantoms***. Radial images acquired with Nφ = 8,16,32,64,128 and 256 with the flip angles described. Also shown are the relative M_0 of the starting polarization. Despite the streaks in the highly undersampled images the increased flip angles provide bright images whose peak normalized signal intensity relates linearly to the mean transverse magnetization from theory : <H(k$_\varphi$)> see ***Fig. 3*** . This is because each projection samples **k**=0.

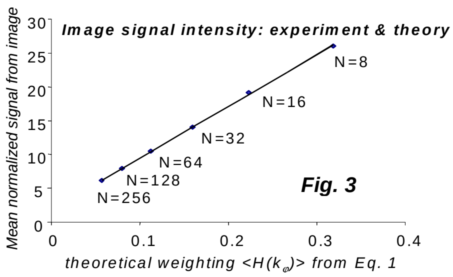


Fig. 4 below: SNR as measured from the phantom experiments. Note that the relation is not linear in $\sqrt{N_\varphi}$ as would be observed for a thermally polarised experiment. The increased prevalence of streaks in the low N_φ experiments make measurement of "noise" in undersampled radial MRI difficult as the streaks are spatially correlated and of higher intensity for low N_φ.

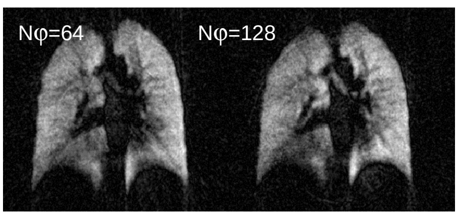
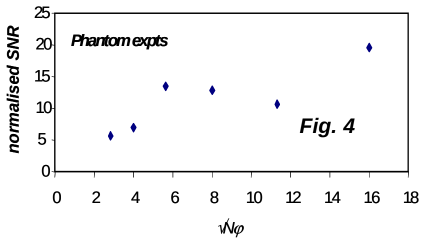


Fig. 5 (right) in vivo data collected from 15 mm slice at breathhold of 250 ml of ^{3}He. Images acquired with α =11° and 8° to deliberately produce a k-space filter H(k$_\varphi$) of the same shape. The SNR in the undersampled Nφ=64 image (SNR=16) is comparable with that in the Nφ = 128 image (SNR=17), indicating undersampling offers better SNR/t for a HP sample. Also note that streaking in the undersampled image is not excessive.



Discussion Fig. 1 shows that short TE (FID) radial sampling can offer higher SNR when gas diffusion and gradient strengths are significant, the drawback being it requires full 360° φ coverage which necessitates more RF views and works against the SNR/t benefits gained from undersampling – Fig's. 2-5. The need for ultra-short TE to minimize T2* dephasing is less critical than in ^{1}H lung MRI since the ^{3}He T2* is an order of magnitude larger than that of lung parenchyma (~ 2ms). The undersampling experiments focused on a constant flip angle during the acquisition, simulations (not shown for space) indicate that a variable flip angle scheme gives better SNR and spatial resolution since all the magnetization is used and blurring and streaking in the φ dimension is fairly distributed by a constant magnetization (flat *H*(k$_\varphi$)). Variable flip angles may be less compatible with dynamic studies of gas flow where the fixed flip angle can be used to bias signal in the airways or lung periphery [1]. The best solution for optimum SNR/t (for e.g. dynamic radial MRI or scans requiring interleaved acquisition such as ADC) would therefore appear to be undersampled trajectories with asymmetric echoes that rely on 180° coverage or use partial k-space sampling and sample a sweep of φ <180° [4]. If acquisition time is less important than SNR and artifact free spatial resolution across the whole FOV, a fully sampled data set with a variable flip angle gives good results for static imaging but offers no obvious advantage over Cartesian sampling.

References [1] MRM 2003; 49:991-7. [2] J Magn Reson Ser B 1996;113:179-183 [3] ISMRM #240, 2007 [4] Proc ISMRM #1666 (2007)

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