SSFP imaging of hyperpolarised 3He in the lungs at 3T

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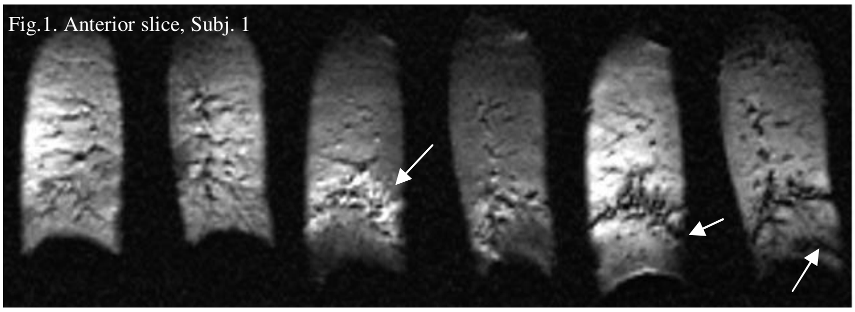
Introduction In previous work at 1.5T the magnetisation response of hyperpolarised (HP) ^{3}He gas to a SSFP sequence was simulated using matrix product operators [1]. SNR gains over SPGR methods were also theoretically and experimentally demonstrated, with off-resonance artifacts observed due to B_0 inhomogoneity over the lungs. In recent years there has been a focus on multi-nuclear MRI at higher B_0 largely in response to the SNR demands of thermal spectroscopy. Although high B_0 is not necessarily optimum for hyperpolarised lung imaging, it is of technical interest to evaluate the methods at higher B_0. In this work a 2D SSFP sequence was evaluated for HP ^{3}He lung MRI at the higher B_0 of 3T. The results obtained with 2D SSFP in HP ^{3}He phantoms and human lungs are compared with 2D SPGR and the effects of B_0 and B_1 inhomogoneity at the higher B_0 are discussed.

Methods ^{3}He gas was polarised to 25% with rubidium spin-exchange apparatus (GE) under regulatory licence from the MHRA. MRI was performed on a 3T system (Philips, Intera) with max. gradient 40 mT/m & max. slew 200 mT/m/ms. The system has T-R capabilities for ^{3}He at 97 MHz with a broadband RF amplifier (4kW CPC). A linear Helmholtz T-R coil (2 x 20 cm loops) was used for in-vivo ventilation imaging, which was performed with ethics committee approval on 2 healthy subjects (1. m, 25 yr, 70 kg & 2. m, 38 yr, 80 kg). A home built linear birdcage coil of diameter 19 cm was used for the phantom imaging (50 ml syringe 10ml 3He/40 ml N_2). Prior to imaging the ^{3}He spectrum was centred and shimmed with a global FID from a 50 ml sip of gas taken from a Tedlar bag (mixture of 300 ml ^{3}He/700 ml N_2). The remainder of the gas was then used for breath-hold imaging. A 2D SSFP sequence was programmed with an $\alpha/2$ – TR/2 start-up pre-pulse followed by n=1:128 α pulses, the phase of which were cycled: $(-\alpha_x)^n$. The BW was 32 kHz, phase encoding was sequential. The readout gradient was asymmetric in order to minimise TE to mitigate both; off-resonance artifacts and diffusion dephasing [1]. For SSFP imaging, different combinations of α/TE/TR were investigated as the RF amplifier and system SAR limits the maximum B_1 deliverable to the coil under a given loading and hence limits the flip angle for a given TE. (Subject 1; i. 7°/1.3 ms/4.6 ms and ii. 20°/1.8 ms/5.2 ms, Subject 2; 16°/2.0 ms/5.4 ms). The in-vivo SSFP images were compared to those acquired with a 2D SPGR sequence with 7.2°/1.3 ms/4.5 ms and the same spatial resolution and BW. To investigate the role of the Helmholtz coil B_1 homogeneity the flip angle was mapped in an axial plane by evaluating the attenuation due to RF depletion between successive low resolution (64x64) SPGR images. Data from phantoms were acquired with the phase encoding gradient nulled so as to investigate the SNR and k-space filter as a function of α [1]. The TE/TR was 1.61/6.1 ms and α was varied between 10° and 90° in these phantom experiments.

Results and Discussion



SPGR, α = 7.2°, TE = 1.3 ms SNR 28 — SSFP i, α = 7.2°, TE = 1.3 ms SNR 23 — SSFP ii, α = 20°, TE = 1.6 ms SNR 28

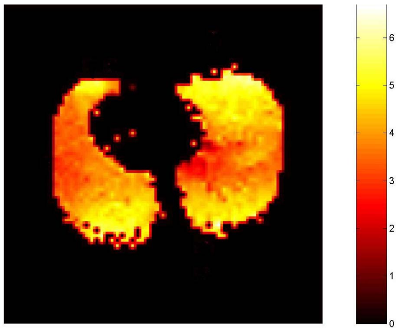
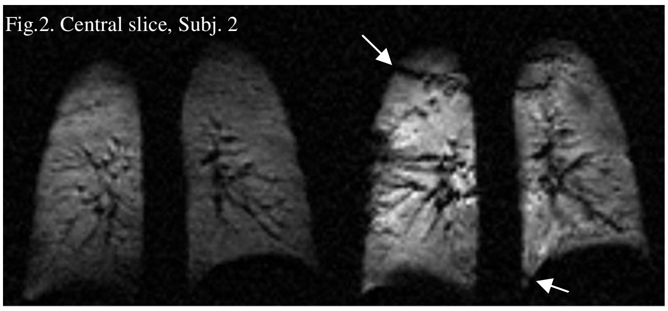


Fig. 3. B_1 α° map from a 2 cm axial slice, the coil transmit inhomogeneity is evident.



SPGR, α = 5.7°, TE = 1.3 ms SNR 15 — SSFP, α = 16°, TE = 2.0 ms SNR 22

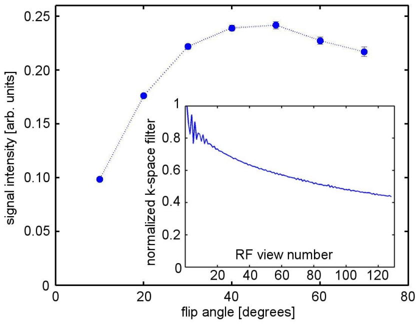


Fig. 4. SNR of SSFP as a function of flip angle in the phantom experiments. The optimum SNR occurs for α = 50° which is larger than was optimised for a longer TE (5 ms) symmetric echo SSFP sequence at 1.5T [1]. The shorter TE used here limits diffusion attenuation of the transverse magnetisation and thus permits a higher flip angle. Inset is the typical k-space filter as a function of RF view number.

Fig.1 Subject 1, SSFP images (centre) acquired at the same TE and α as the optimised SPGR images (left), SSFP have slightly lower SNR which could be due to differential levels of inspiration between scans and variability in gas polarisation. The SNR was measured from the mean signal from the whole lung in each of the slices, the coil inhomogeneity (Fig.3) changes from slice to slice which will effect SNR (see Conclusion). The characteristic off-resonance banding artifacts are evident. In the TE= 1.6 ms images (acquired at slightly higher TE so as to increase the flip angle) the SNR is higher, consistent with work at 1.5T and the phantom data acquired here with a homogeneous B_1 field (Fig.4). However the banding artifacts at the lung apices and base are more pronounced (arrows). In the images from Subject 2 (Fig.2) a similar trend is observed although the different coil loading meant that the SPGR flip angle of α =5.7° was slightly less than the optimum 7.2°. Nevertheless increased SNR through higher flip angle in SSFP is obvious, although banding artifacts are once-more evident. From the phantom data, a trend of increasing SSFP SNR with α was observed with optimum α=50° for the TE/TR 1.61/6.1 ms combination used. This optimum α is higher than observed previously at 1.5T, because the effective T2 from diffusion dephasing is shorter with this highly asymmetric short TE readout.

Conclusion It has been demonstrated experimentally that SSFP can provide high spatial resolution images of lung ventilation at breath-hold with HP ^{3}He at 3T with the potential for higher SNR than SPGR methods. Although HP gas M_0 is not renewable, under the right conditions of long effective T2, a pseudo-steady state can be achieved by recycling transverse and longitudinal magnetisation more effectively than a spoiled approach [1]. A comprehensive comparative study of SNR over all slices was not performed here, as the coil has an inherent B_1 inhomogoneity which will introduce spatial variability in to both the SPGR and SSFP image intensities as a function of position. Moreover the flip angle was calibrated from a global spoiled signal from the whole of the lungs and the B_1 map indicates that the regional flip angle is inhomogeneous. Therefore it is inevitable that both the SPGR and SSFP sequences will receive non-optimum values in many of the slices making side by side SNR comparison problematic. One solution for this is the build of a more homogeneous transmit coil for ^{3}He at 3T which is in progress [2]. Although the SSFP images show high SNR, their diagnostic utility at 3T remains questionable, largely because of the high prevalence of banding artifacts in most slices, which may be misdiagnosed as ventilation defect. This may be further reduced by ultra-short TE SSFP sequences [3] with radial ramp sampling; however the B_0 homogoneity of the magnet over the FOV of the lungs may ultimately limit the utility of the sequence.

References [1] . J Magn Reson. **2006**;183:13-24. [2] Magn. Reson. Med. **2008** 60:431–438. [3] ISMRM **2008** p. 1664

Acknowledgements Funding: EPSRC # EP/D070252/1, GE, EU Phelinet.