Sensitivity of transmit coil B1+ to lung inflation in hyperpolarised 3He MRI

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Introduction: Hyperpolarised gas MRI is highly sensitive to RF flip angle (FA) and $B1^+$ homogeneity, thus accurate knowledge of the delivered flip angle and a spatially homogeneous $B1^+$ field are highly desirable. Chest birdcage coils have been developed for both ^{3}He and ^{129}Xe lung MRI at 1.5T and 3T providing homogenous $B1^+$ fields over the lung FOV [1]. In ^{1}H multi-transmit coil imaging of the abdomen at 3T, modulation of the delivered $B1^+$ has been reported as a function of breathing cycle [2]. In this work the effect of lung inflation upon the $B1^+$ field delivered by two ^{3}He chest birdcage coils was investigated at 1.5T and 3T.

Methods: ^{3}He MRI was performed at 3T (97.1 MHz) on a Philips Achieva whole body system with a non-shielded symmetric quadrature birdcage T-R coil (Rapid Biomedical). The same experiments were performed at 1.5T (48.6 MHz) on a GE HDx whole body system with a shielded asymmetric elliptical birdcage quadrature T-R coil [1]. ^{3}He gas was polarised under regulatory licence with SEOP apparatus (GE) to ~ 25% and was mixed with N_2 gas and delivered to the subjects via a 1 l bag. Experiments were performed on 3 healthy male volunteers (75kg, 75 kg and 85 kg) with ethics committee approval. Four experiments were performed on each subject: two at an inspiratory state of functional residual capacity plus 1l (FRC + 1l), the other two at total lung capacity (TLC). Global (both lungs) FA calibration was measured following inhalation of 50 ml ^{3}He mixed to 1 l with N_2at both inflation states with a series of hard pulse-acquire experiments with TR 4ms and spoiling between pulses. The signal was fitted to: $M(n)=M(1)\cos\theta^{n-1}$ (1), where n is the RF pulse number. $B1^+$ mapping was performed at both inflation states following inhalation of 100 ml ^{3}He mixed to 1 l with N_2 using a 2D spoiled gradient echo sequence with 3 successive time frames (sequence parameters: 64×64 matrix, centric encoding, FA ~ 7°, BW 62.5 kHz, whole lung coronal slice). Pixel signal decay was fitted to the relation in Eq.(1) to generate $B1^+$ FA maps. Measurements of the coils return loss (S11) and port isolation (S21) were made at both ports using a network analyser (Agilent) with the coil in the magnet bore and with the subjects repeating the inspiratory states. Estimates of the coils Q were made in the loaded and unloaded state: 3T coil average Q_{unload}/Q_{load} ~ 9, 1.5T coil average Q_{unload}/Q_{load} ~ 2.

Results and Discussion: The Table shows the S11 measurements from the 3T coil, with the associated predicted change in FA as calculated from the forward power measured at both ports and quadrature combination of the associated $B1^+$ fields.

3T coil S11 measurements	85 kg		75 kg	
	Port 0	Port 90	Port 0	Port 90
S11(FRC+1)	-17.02	-21.31	-21.20	-19.23
S11(TLC)	-17.09	-20.95	-22.18	-18.88
Ratio change in B1+	1.01	0.96	1.10	0.96
Predicted ratio change in quad FA	0.98		1.03	

Fig. 1

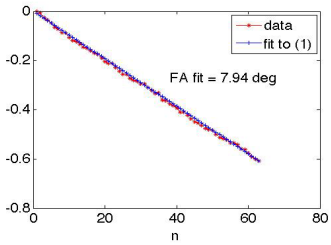

Fig.2

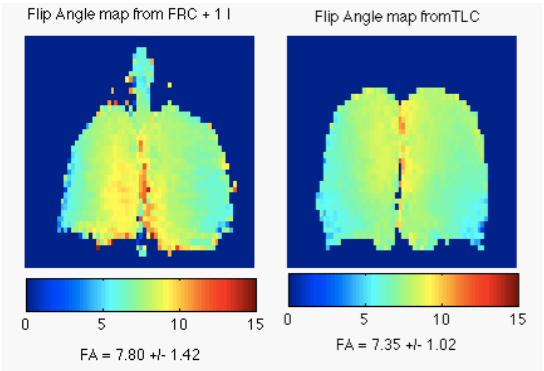

Fig. 1 (above right) shows the 3T global (whole lung FID) FA calibration data (7.94°) from the 85kg volunteer at FRC+1l, a reduction in FA (7.59°) was observed at TLC. This trend is reflected in the coil $B1^+$ maps **Fig. 2 (right),** although the maps have a greater s.d. than the global measurement, the trend of decreasing FA (around 6%) is clear. In the case of the 85kg subject, a net decrease in FA is predicted from the coil S11 at TLC which is consistent with the direction of the trends measured with MR. In the case of the 75kg subject, the S11 of the two ports change in different directions to those observed with the 85 kg load. An increase in FA is predicted from the S11 data, however the mean global FA decreases from 7.77° at FRC + 1l to 7.38° at TLC. The $B1^+$ maps from the 75 kg volunteer also show a mean decrease of FA from 7.86° at FRC+1l to 7.37° at TLC. This suggests that although the coil matching contribution to $B1^+$ is clearly changing in the opposite direction to the change in observed FA, there are additional effects contributing to the variability in delivered $B1^+$. One of these is likely to be changes in tuning and Q with inflation, which could be greater then the effect of reflection. The other likely effect is that the apices and bases of the inflated lungs are sampling region of lower coil $B1^+$ at TLC at the ends of the coil. Although the coils ports isolation (S21) remained constant with lung inflation, the Q was not accurately measured so the effect of coil Q is unknown. However from the measured Q_{unload}/Q_{load} it is clear the 3T coil is more sensitive to loading in this respect. The 1.5T coil showed no significant changes in global or mapped $B1^+$ at FRC+1l versus TLC. These differences with B_0 can be explained with three possible contributing factors; first the sample is less inductively coupled to the coil at 48 MHz compared to 97 MHz (which is consistent with it lower ratio of Q_{unload}/Q_{load}). This could be in part due to the fact the 1.5T coil has an outer shield so the relative effect of the change of inductive coupling of the load with lung inflation is offset to a degree by the fixed and significant mutual inductance of the coil to its shield. Secondly the asymmetric elliptical 1.5T coil has a larger inner volume, giving it an inherently better $B1^+$ homogeneity in the lung FOV, this also means that the subject's coil filling factor is less making it less sensitive to subtle changes in loading. Thirdly the radiation wavelength interference effects observed in ^{1}H transmit at 3T [3], may well start to become important for ^{3}He at 3T as the 3T $B1^+$ maps certainly show signs of spatial interference.

Conclusion: Variability in average delivered FA of around 5% was observed with lung inflation at 3T with an elliptical ^{3}He birdcage coil. The same effects were not observed at 1.5T. The effect is worth investigating when testing new transmit body coil designs at higher B_0. The effects observed here at 3T are small and are unlikely to have any bearing on standard ^{3}He ventilation imaging SNR, but could influence quantification of flip angle sensitive imaging strategies such as lung pO2 mapping [3] and parametric quantification of dynamic gas inhalation [4].

References: [1] de Zanche et al Magn Reson Med, 60, 431-438, 2008. [2] Padormo et al, 753 Proc ISMRM 2009. [3] Deninger et al, JMR, 141, 207-16, 1999. [4] Koumellis et al, JMRI, 22, 420-6, 2005.

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