Reliable free breathing 3D multiple breath gas wash-out with hyperpolarised ^{3}He lung MRI

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Target audience: hyperpolarised MRI, Lung MRI

Purpose: Multiple-breath inert gas washout (MBW) is a pulmonary function test that has been shown to be sensitive to ventilation heterogeneity in early stages of lung disease [1]. Whilst measuring the concentration of gas at the mouth returns a global parameter, regional ventilation parameters can be acquired with hyperpolarised gas MRI. Regional fractional ventilation (r = % gas exchanged per breath) has been demonstrated with HP ^{3}He in mechanically ventilated animal experiments [2, 3]. Monitoring of MBW with ^{3}He was demonstrated in free breathing volunteers following imaging of lung ventilation using a single dose of gas [4]. This approach was extended to 2D and 3D ^{3}He washout imaging sequence capable of producing maps of *r* [5,6]. In this work, wash-out of ^{3}He is performed with a 3D sequence in free breathing subjects. The values are compared with the gas turn over globally measured at the same time.

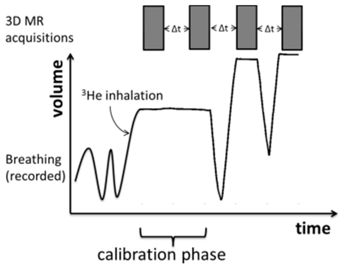

Figure 1: Schematic: Lung volume over time and MRI acquisitions during the wash-out experiment. After inhalation of helium volunteers were breathing through a Pneumotachograph (PT) after inhalation of the ^{3}He.

Materials and Methods: Experiments were performed on a GE HDx 1.5 T scanner with a quadrature ^{3}He flex coil. Imaging was performed in three healthy volunteers (2 male, 26/35years, 1 female, 31 years). The schematic of a free breathing MBW experiment is shown in Figure 1. After a 1l breath of a mixture of ^{3}He (~20% polarisation) and N_2 (1:4 mixture) two 3D images are acquired at a breath-hold followed by free breathing cycles interrupted by breath-hold data acquisitions. The images were segmented and motion-corrected [7] before calculating the fractional ventilation maps. The calibration breath-hold is necessary to calculate a correction factor for RF depolarisation and T_1 decay (assuming a constant T_1 throughout the experiment). The remaining signal decay reflects the wash-out of the hyperpolarised gas. For the 3D acquisition a matrix size of 32x32x32 was chosen resulting in a t_{acq} = 2.6 sec using a FA = 1° and TE/TR=0.75/2.5. The delay (Δt in Fig.1) between acquisitions was chosen 5 sec to keep a full breathing cycle between acquisitions. A global value was obtained by calculating the mean value and standard deviation of fractional ventilation over the whole lung. The global value for fractional ventilation is defined as *f* = TV/TLV, where TV is the tidal volume and TLV the lung volume at inspiration [4]. The tidal volume is measured using a pneumotachograph (Hans Rudolph, Shawnee, KS) at the mouth during the experiments. The TLV was obtained by segmentation of the ventilated lung volume from the 3D MRI acquisitions. Errors derive from small volume changes between the acquisitions, seen with the pneumotachograph as asymmetric TV, where the inhalation is not equal to the exhalation. Those errors are quantified in Table 1.

Fractional ventilation	Volunteer1	Volunteer2	Volunteer 3
mean ±std (wash-out)	0.35±0.14	0.50±0.17	0.51±0.14
TV/TLV	0.28±0.02	0.48±0.01	0.52±0.04

Table 1: Comparison of fractional ventilation values from hyperpolarised gas multiple breath wash-out MRI (mean(r)±standard deviation(r) with fractional ventilation f (f±errors from asymmetric TV) as a global value obtained from the pneumotachograph (TV) and segmented ^{3}He-MRI volumes (TLV).

Results: All volunteers could follow the breathing protocol without problems. Allowing volunteers to breathe freely without a controlled volume or restrictions in the first breath after an apnoea of 10.2s breath-hold results in a small exhalation followed by a deep inhalation as seen in Fig. 1. This is confirmed by supine pneumotachograph measurements. In the following breath the exhalation volume matches the inhalation one, enabling reliable measurement of comparable fractional ventilation values. The two acquisitions at time points before and after this breathing cycle are used to fit a mono-exponential on a pixel-by-pixel basis to compute values of fractional ventilation. From the slope of the exponential decay the regional fractional ventilation parameter *r* was calculated.

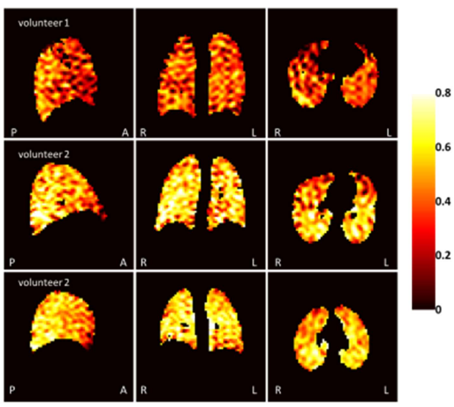

Figure 2: Fractional ventilation maps from all volunteers.

Discussion: The reliability of the values from fractional ventilation of hyperpolarised ^{3}He is demonstrated by comparing the values obtained from the MBW images to the gas turn over in relation to the lung volume. Changes between inhalation and exhalation result in errors for the fractional ventilation of 1%, 1% and 7% in case of the volunteers. The relatively high values of fractional ventilation in volunteer 2 and 3 (~50% gas exchange per breath) can be explained by the raised TV post apnoea. A comparison of the breathing manoeuvres related to the acquisitions with the TV at rest shows that values are increased by as much as 3 fold resulting in high fractional ventilation values compared to what would be expected in free breathing at rest. The mean *r* value of volunteer 1 is higher than the TV/TLV-ratio. In the case of this volunteer, the change in lung volume between the two acquisitions used to obtain *r* does not match the change between exhalation and inhalation, which could indicate a small leak in the measurement with the pneumotachograph. Maps of fractional ventilation *r* are shown in Figure 2. Slices of each plane are shown from 3D datasets of all volunteers. The effects of gravity with higher ventilation in dependent parts of lung can qualitatively be seen in the sagittal and axial slices of the volunteers.

Conclusion: A method is demonstrated to acquire fractional ventilation maps in 3D using MBW hyperpolarised gas MRI. The reliability is shown by comparing fractional ventilation values to a global value obtained using a pneumotachograph. Future work will improve the wash-out with shorter acquisition times in order to decrease breath-holds using Compressed Sensing techniques [8] and k-t-BLAST acquisition with reconstruction using principal component analysis [9]. This will result in a shorter breath-hold and a faster return to equilibrium breathing pattern after the apnoea.

References: [1] Thorax. 59(12): 1068-732004(2004); [2] Mag. Reson. Med. 48:223-232 (2002); [3] Magn. Reson. Med. 2010 ;63(1):137-5; [4] Mag. Reson. Med. 65(4): 1075-83(2011); [5] Proc. ISMRM 2011 p 910;[6] Proc. ISMRM 2012 #4811;[7] Medical Image analysis. 11(6): 648-662(2007); [8] Mag. Reson. Med. 63(4):1059-69;[9]Mag. Reson. Med. 62(3):706-16;

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