Regional pulmonary pressure over volume curves of the rat lung measured by polarized 3He magnetic resonance imaging

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Introduction
We are proposing a method to measure regionally pulmonary pressure over volume curves with spin density weighted 3He images. Tests have been performed on healthy rats.

Methods
Experimentation protocol has been approved by the local ethical committee. Five male healthy Wistar rats were anesthetized, tracheotomised, had a tube firmly attached to their trachea and were connected supine to the respirator, inside the MRI scanner, which was set to a breathing rate of 60/min, a positive end-expiratory pressure equal to zero and a maximum pressure at the end of each inspiration approximately equal to 9 mbar. The animals were kept to this respiration mode until image acquisition [1]. For image acquisition the respirator was programmed to provoke a 3.2 sec inhalation of 3He with a maximum pressure limit fixed to approximately 20 mbar. The MRI trigger was launched by the ventilator the same time that the 3He inhalation started. This way image acquisition started upon inspiration; data were continuously acquired over 3.2 sec. Imaging was performed in a Bruker Biospec 47/40 (Bruker, Ettlingen, Germany) using a FLASH sequence with TE/TR of 0.8/1.8 ms. Images had a field of view of 5x5 cm, 5 cm slice thickness and a resolution of 128x128 pixels. 41 k-space lines were acquired per image, image acquisition went on 80 ms per image and 40 images were totally acquired. The image acquisition described above was performed while the animal was inhaling; after this acquisition another one was executed, this time in apnea. The acquisition in apnea was identical to the previous one, only the 3He inspiration was quick and the trigger was launched after the end of the inhalation, whilst the animal in breath-holding. This sequence of images is used to calculate relaxation due to the RF pulse and spin-lattice relaxation phenomena.

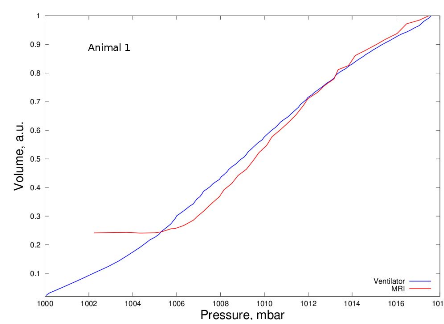
Data analysis
Let us consider that pressure and volume in the lungs are steady for each image. The ideal gas law for 3He for each image of the lungs can therefore be expressed as ni(t)RT=P(t)Vi(t), where ni(t) is the amount of 3He substance contained in volume Vi(t) that corresponds to the region of interest (ROI) i, P(t) the pressure that is considered homogeneous in the whole lung, R the ideal gas constant and T the absolute temperature assumed to be steady in the lungs during the whole experiment. Parameters ni, P, and Vi are functions of time t, which is a discrete variable whose values are multiples of 80 msec; that is t=k**T**, where **T**=80 msec and k is a natural number that stands for the image being processed. Because the images are spin density weighted, it follows from the ideal gas equation that Vi(t)=Ii(t)/P(t), where Ii(t) is the sum of image intensities in the ROI i, and P(t) measured by the respirator. The MRI pressure volume curves are then fitted by a sigmoidal function to calculate the inflection point pressures. The inflection point is the point where the sigmoidal PV graph changes curvature and where the first derivative (dV/dP), which is defined as the lung compliance, is maximized. It is thus also known as the maximum compliance point and it is believed to represent the pressure of maximum alveoli recruitment. As a parameter that characterizes lung elasticity, it is expected to change according to the disease state of the animal [2].

Results and discussion
In the three figures herewith appear with red the MRI pressure over volume curves for the whole lung for three different animals. The blue lines represent the pressure over volume curves as measured by the sensors of the respirator. Volumes are normalized. The comparison of the pressure over volume curves of the respirator sensors with the same curves as appraised by the post-processing of 3He images shows good agreement for pressures greater than 7 mbar. For lower pressures the image SNR is too low, as there is little 3He in the lungs yet, to give a sufficient estimate of volume.

The ROI are static: the left lung, the right lung and the whole lung. In the first two rows of table 1 appear the inflection point pressures for the respective ROI. The inflection point pressures for the two different lobes of the same animal show that the estimation is reproducible under the similar conditions in the two healthy lobes.

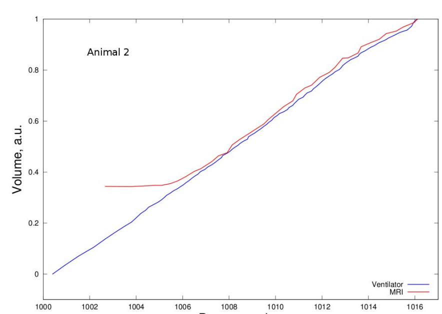
The global inflection point is estimated based on the sensor signals (row "ventilator"') and by MRI (row "entire lung"). The two figures should be equal as they are estimates of the same quantity; however there is a difference of 1.5-2 mbar between them in every animal, which we believe that is due to the lack of MR signal until 7 mbar for the MRI method. Nevertheless, it appears that the error is persistent in such a way that it can be compensated for, since the MRI estimate follows the respirator estimate.

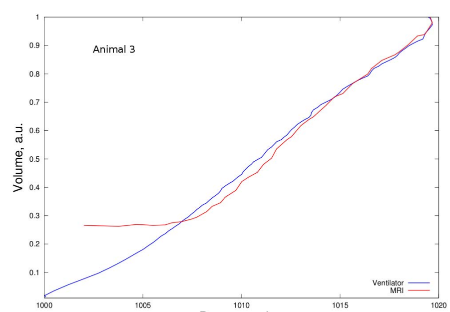
This methodology has the potential to characterize the disease state of even smaller areas of the lungs. For this purpose, a region tracking algorithm has to be developed. Moreover, it may be applied to humans, with the development of appropriate hardware that constantly registers pressure, and sends a trigger to the MR scanner upon detecting the beginning of 3He inspiration by the patient.



animal nr	1	2	3	4	5
left lung	10.3	10.8	11.4	10.8	13.9
right lung	10.4	11.4	10.9	10.7	13.4
entire lung	10.3	10.9	11.8	10.6	13.5
ventilator	9	9.1	9.1	8.5	11.7

Table 1: Inflection point pressures in mbar.





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