Measuring quantitative regional lung ventilation by alveolar ventilation imaging (AVI) – Phantom data and results of a feasibility study in 50 patients.

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Introduction: During the last decade tremendous efforts have been made to visualize the ventilated lung spaces by MRI. At present, the use of hyperpolarized noble gases like ^{3}He seems to be the most promising approach (1). Recently our group developed a fast low field MRI technique allowing theoretical 'real time' pulmonary ventilation studies in which the ventilation is calculated from MRI signal differences between inspiration and expiration (3).

Methods and patients: According to our former attempts (3) a 'real-time' true FISP SSFP sequence (TR=4.2ms,TE=2.0ms,FA=90°, SL=60mm, FOV=450mm, Matrix=128 x 128, AC = 2, TA=1,2 s) at 0.2 Tesla (Magnetom Open) was used.
In a first step we built a lung phantom consisting of a sponge soaked in silicon oil which allows the calculation of the real ventilation in compressed stage according to the volume change (the volume change during compression is equal to the change in air content).
In the second step 50 patients (with and without pulmonary disease, aged from 3 to 35 years, mean 11 years) were examined. Patients were investigated at spontaneous breathing over 50 acquisitions, according to 59 seconds. For computation of the ventilation data and the colour coded maps each individual image in the sequence was registered to a reference image. The registration algorithm computed a dense deformation field by composition of small displacements, which were designed to maximize the local correlation (2). Afterwards regions of interest (ROI) were chosen manually and the mean signal values were determined during the ventilatory cycle for both upper (uF) middle (mF) and lower lung fields (lF). Quadratic ROIs (10x10cm) were placed in the center of the upper, middle and lower third of the longitudinal lung diameter. Using previously published formulas the values for the local pulmonary ventilation were calculated for each ROI and each voxel. An increase in air content was coded green in the ventilation maps; a decrease in air content was coded red.In each patient a lung function study was done to compare the global lung function with the MRI results.

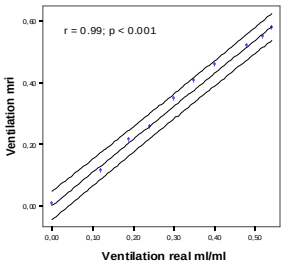

Fig.1: Results of phantom measurements 20x5x12.5 cm sponge soaked with Silicon oil Merck Nr 7742. Linear Regression +/- standard error of the estimate

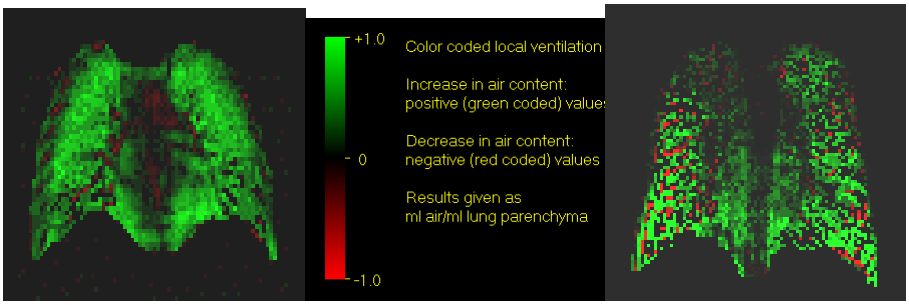

Fig 2: Ventilation map in a 6 years old asthmatic girl. Besides some discrete ventilation defects in both lower lung fields all lung regions are homogenously ventilated.

Fig.3: Ventilation map in a 35 years old patient with cystic fibrosis revealed severe disseminated ventilation defects (black) and an overall clearly reduced ventilation.

Results: The results of the phantom experiments are shown in fig.1 There was an excellent correlation between the ventilation values calculated from the volume variation of the sponge and the values measured by the MRI method ($r=0.99$; $p \leq 0.001$). It can be concluded that the method correctly determined the ventilation of the pulmonary phantom.
In 45 of the 50 patients (90%) the registration procedure was successful. The investigation of the 20 healthy children revealed mean ventilation values from 0.41 ml air/ml parenchyma in the upper field (uF), 0.44 in the middle field (mF) up to 0.49 in the lower lung fields (lF; $p \leq 0.005$ Friedman test). The color coded ventilation maps showed equal ventilation and no ventilation defects in all of the healthy children.
On contrary the color coded ventilation maps revealed discrete ventilation defects in all of the 15 children with asthma (see fig. 2) despite the clinical sufficient medical treatment. The quantitative ventilation values were similar to the values in the healthy cohort (uF=0.43; mF=0.43; lF=0.44) but interestingly the ventilation values did not increase statistically significant from the upper to the lower lung regions. This could be interpreted as an abnormal ventilation distribution.
The 10 patients suffering from cystic fibrosis showed significant diminished ventilation values for all lung regions (uF=0.22; mF=0.25, lF=0.28; $p \leq 0.001$). In these patients the ventilation maps demonstrated disseminated severe ventilation defects as shown in fig. 3. The results were concordant to the lung function studies which revealed a mean decrease of FEV1 to 50% in these children. Again the increase in the ventilation from the upper to the lower parts of the lung was significant ($p<0.05$).

Discussion: In this study we present a novel technique for quantitative calculation of regional pulmonary ventilation. The measured values were in concordance to the phantom experiment, the clinical expectations and the lung function studies. In our opinion a great advantage of this approach (besides simplicity and low cost) is the fact that there is no need to use any external contrast agents, which may influence the pulmonary ventilation. Ventilation maps demonstrated local airtrapping in pulmonary obstruction and regional diminished ventilation in cystic fibrosis patients. The image registration is one of the difficulties it has to be improved; because up to now-about 10% of the patients are difficult to evaluate. Although further studies are undoubtedly necessary our data suggest that the AVI-method could become an alternative promising method for functional lung MRI.

Bibliography:

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