Dynamic Ventilation 3He MRI of Human Lung: Correlations and Reproducibility Study using Free-Breath Administration with Volumetric Bolus Monitoring

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Motivation

Dynamic Ventilation of lung measured with hyperpolarized ^{3}He MRI (^{3}He-DV-MRI) is an efficient tool to visualize and quantify the intrapulmonary gas inflow[1]. DV measurements give information on a gas temporal and spatial distribution in lung airways and parenchyma, that is of great importance for the diagnostics and studies of airways obstructions e.g. asthma and COPD. Usually, to characterize the gas delivery in the lungs a set of parameters extracted by the fitting of ^{3}He signal-time profile (^{3}He-S(t)) with the model function are used[2]. The reproducibility of these values is important when considering the usage of ^{3}He-DV data in clinical diagnostic. The reproducibility of ^{3}He-S(t) is influenced by the (1) input bolus volume-time profile $B_{He}(t)$ and (2) variability of the lung function parameters of a patient. We performed systematic study and analysis of reproducibility of measured gas delivery parameters as measured by ^{3}He-DV-MRI and correlations between this parameters and shape of applied ^{3}He-bolus measured both by MRI and volumetrically. The study was done on n=10 healthy volunteers with permission of local Ethic Committee using custom-built application unit (AU) for the controlled gas bolus administration. The spirometer lung function test was done several hour prior measurements to get standard lung function parameters (VC, FEV1, RV, etc).

Materials and method

The study was done on 1.5T MRI system (Sonata, Siemens, Germany) with a double tune ^{3}He/^{19}F birdcage resonator (Rapid Biomedical). The 2D SGRE sequence, TE=0.9/TR=2.2ms/FA=2^0, matrix 128x64, FOV=400mm was used. The boluses of ^{3}He:N_2 (200:300ml) mixed during the breath with ambient air were administered to volunteers and MR-images of ^{3}He inflow to the lungs was continuously acquired. Two repetition scans was done for each individual. The ambient air and bolus flow was monitored by flow-meter. Further, the ^{3}He signal in parenchyma $S_p(t)$ was analyzed from images on pixel basis. The extracted by fitting $S_p(t)$ parameters were: rise-up time RT-(interval between $S_p(t)$ reaches 10% and 90% of maximum (S_p^{max})), maximal flow FM = max($dS_p(t)/dt$) and delivery time TD ($S_p(TD)=0.9\cdot S_p^{max}$). The data were analyzed for correlations between bolus dispersion D_t (calculated as bolus curve $B_{He}(t)$ second moment) and statistics of RT,TD and FM histograms (1-st and 2-nd moments, inter-quartile range). Additionally, the variability and correlations between parameters series measured and evaluated for the first and second repetition were analyzed. The variability of parameter p was calculated as $V(p)=2*|p_1-p_2|/(p_1+p_2)$.

Results and Discussion

Fig 1a shows exemplary the ^{3}He bolus shapes measured by MRI and by flow-meter. The changes in profile of the MRI-measured bolus in comparison with volumetric profile are in good agreement with predictable low-pass filtering effect introduced by k-space encoding [3]. The dispersion of the bolus profile D_t varies both for different individuals and within two repetitions with the same person (the average variability $\langle V(D_t)\rangle=0.8$). The similar variations are observed for the RT values. The RT histogram parameters in the first repetition is not reproduced in the second one and both series for 10 volunteers does not correlate to each other (R<0.5). However, a very strong **correlation** (R>0.9) are observed between D_t and first 2 central moments of RT histogram. The mean and standard deviation values of RT taken for 10 persons follow the variation of the input bolus dispersion in both repetitions (Fig 2b). In contrast, the FM values does not correlate with bolus dispersion but are very well reproducible between 2 scans for all 10 individuals. Therefore, the evaluated series (1-st and 2-nd repetition values for all individuals) of FM histograms descriptors (1-st and 2-nd moments) are strongly correlated to each other(R>0.95). In the same time, no correlation is observed between series of RT and FM histogram statistics values.

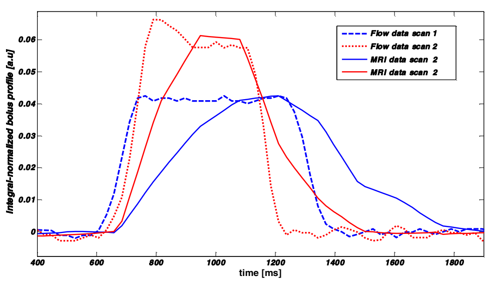

Fig 1 Flow-meter data and MRI-measured input bolus profiles. MRI measured data is averaged from 3x3 pixel region in the top of trachea. MRI profile shows characteristic „time-integration" low-pass filtering effect in comparision with „real-time" flow-meter data.

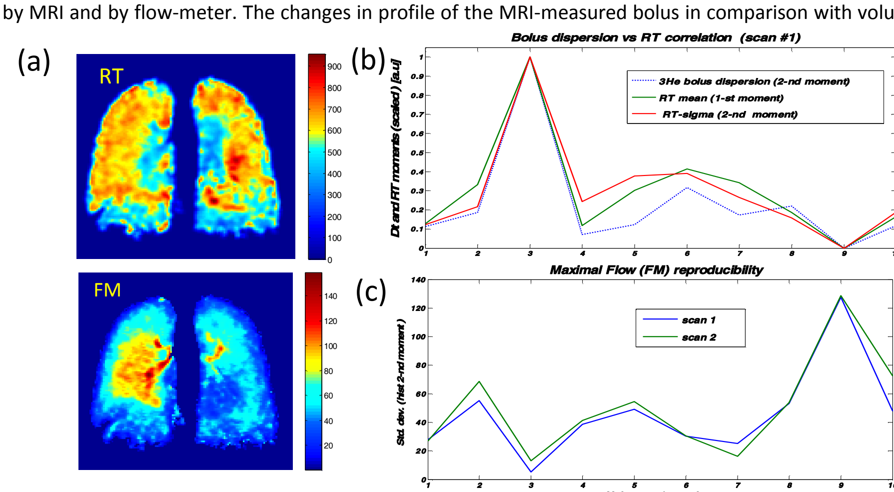

Fig 2 (a) Exemplary RT and FM-parameter map. (b): correlations between bolus dispersion Dt and 1-st and 2-nd moments of RT histograms .The sufficient correlation (R>0.9) for both moments of RT are observed. (c) Reproducibility of FM value, both moments of FM shows very good reproducibility between scans 1 and 2 over whole 10 patients group

Conclusion

The non-resistant AU-administration of ^{3}He bolus makes possible observing direct correlations between parameters characterizing signal-time profile of input bolus and statistical parameter characterizing the gas delivery in parenchyma. Important for the physiological interpretation of ^{3}He-DV-MRI measured values is that the independently measured temporal distribution of 500ml bolus (D_t) in localized volume of flow-meter is reproducibly correlated with rise-up time RT measured by ^{3}He-DV-MRI within total volume of lung parenchyma (5-6 liters). Also, it is remarkable that the maximal flows FM being perfectly reproducible within two scans is "uncoupled" from the bolus dispersion and, thus, probably characterize purely the lung function (e.g. airways resistance and lung compliance) which are of great importance for the diagnostic of the airways obstruction diseases. To our knowledge this is the first study over the large group of human volunteers with validation of ^{3}He-DV-MRI with volumetric data.

References:

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