Free vs Forced : Gas Transport Differences in 3He MRI Dynamic Ventilation Measurements of Lungs Induced by Gas Mixture Application Regime.

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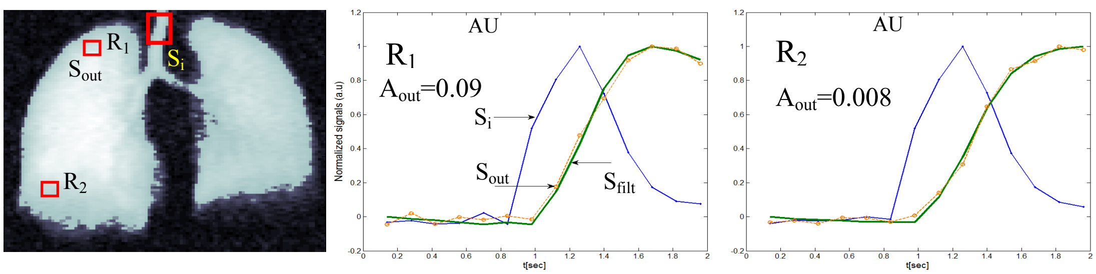
Motivation and Theory

Dynamic ventilation (DV) of lung measured with ^3He MRI is an efficient tool to visualize and study the intrapulmonary gas inflow processes in lungs. The common approach to data analysis is using model function to fit the signal-time curve [1]. The fitting parameters (rise-times and mean slope), being obtained by multiple-parameter non-linear fit, are ambiguous. More important is that the curve parameters are strongly dependent on the "tracheal input" (TI) determined by the applied bolus shape and volume [1]. In current work we performed a comparison of two ways of ^3He application which leads to extremely different form of bolus input: short bolus (SB) delivered by Application Unit (AU) [2] without resistance in free breathing mode and 2) forced inspiration from Tedlar bag (TB) via fine tube with high resistance and prolonged bolus (PB) shape.

To analyze the signal-time dependence of 3He signal in lung we suggest that 1) the MR-signal in lung parenchyma is linearly connected with amount of gas passed through trachea and 2) the transport of gas in parenchyma is diffusive and therefore the signal in certain ROI grows proportionally to the difference of ^3He concentrations between input and this ROI. In this case the ^3He signal could be described as $S_{out}(t+dt)=S_{out}(t)+A_{out}\cdot(S_i(t) - S_{out}(t)) \cdot dt$. Here A_{out} denotes the "regional transport constant" (RTC) which characterize the rate and amount of ^3He delivery in ROI. This first order differential equation can be solved in terms of linear transfer function TF(z) of order Discrete–Time Filter (DTF) which transforms the input signal $S_i(t)$ into regional output $S_{out}(t)$. The TF will be fully determined by the value A_{out}: $TF(z)=A_{out}^{-1}z^{-1} / (1-(1-A_{out}^{-1})z^{-1}$. Thus, the regional gas delivery could be characterized by the single parameter A_{out} without using model functions and multiple parameter fitting.

Materials and method

All measurements were performed using Siemens Magnetom Sonata MRI Scanner (Siemens Biomedical, Erlangen, Germany) and double tune $^3He/^{19}F$ birdcage resonator (Rapid Biomedical, Rimpar, Germany). Mixture of 200/300ml $^3He/N_2$ was applied. The sequence was SGRE, w/o slice selection, TE=0.9/TR=2.2ms/FA=2^0, matrix 128x64, (7 fps temporal resolution), FOV=400mm. Data analysis was performed with MATLAB. The tracheal input $S_i(t)$ was



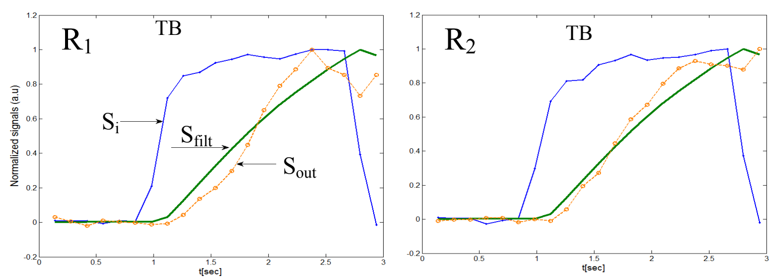


Fig 1 Signal-time dependence of 3He signal in selected lung regions for short (AU-application) and prolonged (TB-application) bolus in regions R_1 and R_2 The S_i (blue) shows the tracheal input. The DTF-transformed signal (green) fits the actual „output"profiles (orange) to get transfer function coefficient A_{out}.

determined in ROI of cranial trachea part where the profile of bolus shape measured by MRI is close to the volumetric data provided by AU [2]. The value A_{out} for ROI/pixel was searched by "golden section" minimization of the standard deviation between transformed input $S_{filt}(t)=DTF[A_{out}, S_i(t)]$ and measured signals $S_{out}(t)$.

Results and Discussion

For the SB application using AU the regional signals S_{out} can be very well fitted with first order DTF in whole lung parenchyma (Fig 1 top). The regions with low values of A_{out} correspond to slow diffusive gas transport, whereas the higher values of A_{out} are detected in regions closer to large airways with contribution of convective exchange. The TB application with prolonged bolus and forced inspiration brings very different results. The parenchyma signal S_{out} could not be reasonably fitted with first order DTF transfer function (Fig 1 bottom). The discrepancy from linear first order model increases especially in regions close to large airways. The shape of the signal shows that higher order derivations have to be taken into account to describe output signal form. This will lead also to higher order transfer function. In this case the DTF filter design algorithm could be applied to determine the TF(z) coefficient to describe regional transfer.

Conclusion

The first results shows that the concept of LTF can be effectively applied to characterize data of lung DV measured with hyperpolarized ^3He MRI. The discrepancy between the two application modes in terms if TF approach shows that in the case of TB-application with prolonged bolus and high resistance leads to strong changes of gas transport in parenchyma. The kinetic of delivered ^3He amount could not be described by first order differential equation, probably because the fine tube and high pressure gradient required to overcome the tube resistance leads to much higher velocity of gas stream in trachea and convective mechanism has stronger effect in parenchyma in comparison with non-resistive application with AU.Therefore, the higher order derivations of "input function" should be accounted for to build the appropriate model difference equation and regional transfer function.

References

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