Dynamic Helium-3 MRT: Bolus-independent Analysis of Lung Ventilation by Deconvolution

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Introduction:

Hyperpolarized 3He imaging of the lung has proved its ability to visualize the regional distribution of lung ventilation with a high temporal and spatial resolution [1, 2, 3]. However, the observed signal intensities are largely influenced by the duration of the 3He bolus, in particular in normal lungs or in lungs with minor degree of disease. In this study a deconvolution approach is presented to calculate the signal response in the lung for an infinitely short 3He bolus to increase the sensitivity of the method to short delays. Simulations were performed to test the technique. Subsequently, the feasibility of the new algorithm was tested in *in-vivo* data from a lung-healthy volunteer.

Material and Methods:

Assuming that all 3He is visible in the lung, we assume that the measured 3He signal-time-curve (STC) can be modeled as the convolution of the trachea input function (TIF) with a tissue response curve (TRC). The TRC can, thus, be calculated from the STC by deconvolution. However, numerical deconvolution techniques like singular value decomposition (SVD) [4] are usually unstable ("ill-posed problem") due to their large dependency on experimental errors like noise. To circumvent this drawback we convolved several different TRCs with the TIF. These artificial STCs were then compared to the measured 3He STCs on a pixel-by-pixel-basis. The TRC which gave the smallest deviation was considered the solution of the deconvolution.

Simulation of TRCs:

In a first step, simulations were performed to investigate the performance of the deconvolution technique. For that purpose TRCs were modeled by Fermi functions $r(t)=a+b*[1+\exp(-(t-c)*d)]^{-1}$ where t denotes time and a, b, c, and d are parameters. The parameters rise time (RT) and peak flow (PF) [5] were calculated for each TRC. RT was varied between 0.12 and 1.08 (step=0.03) and PF between 0.00024 and 2.24024 (step=0.07). Realistic STCs were then obtained by numerical convolution of these synthetic r(t) curves with a representative TIF from a 3He ventilation measurement. To test for the influence of noise on the deconvolution algorithm Rician-distributed noise was added subsequently to these curves (signal-to-noise-ratios of 20, 10, and 8). In addition, curves without noise were analyzed.

Then nearly 40000 different TRCs with varying parameters a, b, c, and d were calculated. Each of these curves was then convoluted with the input function and the resulting curve was compared with each of the original STCs. For each pair of curves the reduced Chi^2 was calculated and the TRC with the smallest Chi^2 was determined. RT and PF of the respective TRC were then compared to those of the originally simulated TRCs.

Image Acquisition and Analysis:

300 ml of hyperpolarized 3He followed by normal room air were administered to the volunteer via a nasal CPAP-mask using a dedicated application system. During continuous respiration a series of 42 coronal projection images was acquired. A Siemens Magnetom Vision 1.5 T scanner was used with a rapid gradient-echo pulse sequence (2D FLASH, TR = 2.0 msec, TE = 0.7 msec, Flipangle = 1°) with a temporal resolution of 128 msec [3]. The raw data (75x128) were *sinc*-interpolated to a 256x256 matrix. After elimination of radio-frequency artifacts, correction of noise and of the lung motion during inspiration the deconvolution algorithm was applied to the 3He signal during inspiration in every pixel. The parameters RT and PF were then calculated from the respective TRCs and displayed as parameter maps for the whole lung.

Results:

In the simulations it was found that the original TRCs can be recovered with great accuracy. In Fig. 1 representative curves are depicted. The RTs calculated from the TRCs were much shorter than those obtained from the STCs. Moreover, calculation was feasible on a pixel-by-pixel basis in *in-vivo* data (c.f., Fig. 2). The deconvoluted map of RT shows more regional variation than the conventional map calculated as described in [5]. However, in some pixels the temporal resolution appears not sufficient to measure the rapid inflow of 3He in normal lungs.

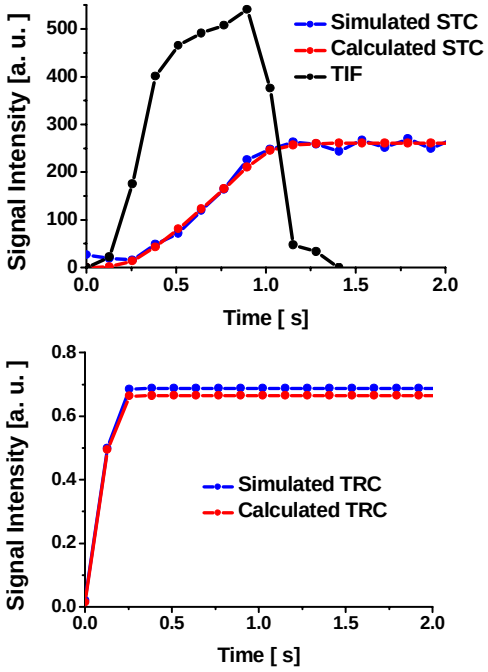

Fig. 1: Simulated and calculated STC (top, SNR=20) and respective TRCs (bottom)

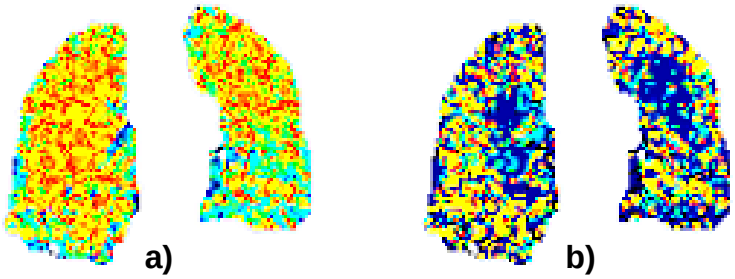

Fig. 2: Parameter maps of RT, original (a) and deconvoluted (b)

Discussion and Conclusion:

We have shown that deconvolution analysis of signal-time-curves from 3He lung ventilation measurements can be performed reliably in synthetic and in *in-vivo* data. This new approach appears to be promising in the assessment of lung ventilation based on rapid MRI data. It may lead to a better quantification of rapid ventilatory processes and, thus, a better understanding of the (patho-) physiology of lung ventilation.

References and Acknowledgements:

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