Time Resolved Lung Ventilation Imaging by Fourier Decomposition

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Introduction: The established MRI method to visualize the ventilated lung spaces is the use of hyperpolarized noble gases like ^{3}He [1]; but the available MR tomographic diagnostic methods for ventilation deficit like oxygen [2] and ^{3}He are either not sufficiently fast or not applicable in the clinical routine. A possible very simple alternative is the application of Steady State Free Precession (SSFP) sequences in the low field because T2* relaxation times are much longer as compared to high-field values, e.g. at 1.5T [3,4]; this sequence was used to generate a time-resolved 2D data stack. A Fourier analysis along the time axes will allow the separation of breathing / ventilated regions from disturbing signals from heartbeats, and also the description of the pathologic breathing pattern seems possible. This kind of analysis was also used for artifact correction in fMRI [5], but here we represent the data comparable to the depiction of 2D-CSI data (Chemical Shift Imaging).

Materials and Methods: Multiple time-resolved scans with a centric-reordered *TrueFISP* sequence were performed on a 0.35 T Magnetom C! scanner (Siemens,Erlangen,Germany), using a product 2-channel RX cp body coil. Imaging parameters were common to all studies: TR= 3.6 ms, TE = 1.5 ms, slice thickness = 20 mm, field of view = 400^2 mm^2, matrix interpolated to 148*256 with partial k-space, TA = 0.29 s per image. To get a sufficient SNR, n = 100 consecutive measurements were chosen. Because of the transient signal behaviour of the SSFP magnetization, the first 4 images out of 100 were omitted, therefore the total measurement time was T = 96*0.29 s = 27.8 s. The spectral resolution according to the total acquisition time was 1/T = 0.018 Hz and the spectral width 1/TA = 1.9 Hz; hereby the Nyquist sampling rate is fulfilled to avoid spectral aliasing from the heart rate of 1.03 /s.

Each individual image from this time series is registered to a reference image. The algorithm computes a dense deformation field by composition of small displacements. These displacements are designed to maximize the local correlation between the intensity values of the current (floating) image and the reference image. This local similarity measures allows coping with non-stationary behaviours in the intensity profiles of MR images. Regularization is achieved by low-pass filtering of the resulting displacement fields [6]; the result of this calculation is shown in Fig.1. The lung reformation due to this procedure is thereby transformed into a signal variation along the time series: $\mathbf{S(x_i,y_j;\ t)}$ **(**i,j pixel index). A one-dimensional Fourier transform of the magnitude data along the time evolution **t**: $\mathbf{FFT\ |S(x_i,y_j;\ t)| = \mathit{s}(x_i,y_j;\ \omega)}$ deliver n spectral images ***s*** at the frequency ω_n**.** The representation of the pulmonary function is possible by a single spectrum from a single region of interest (RoI) (Fig.2), or by maps from the whole FoV within a chosen spectral range (Fig.3).

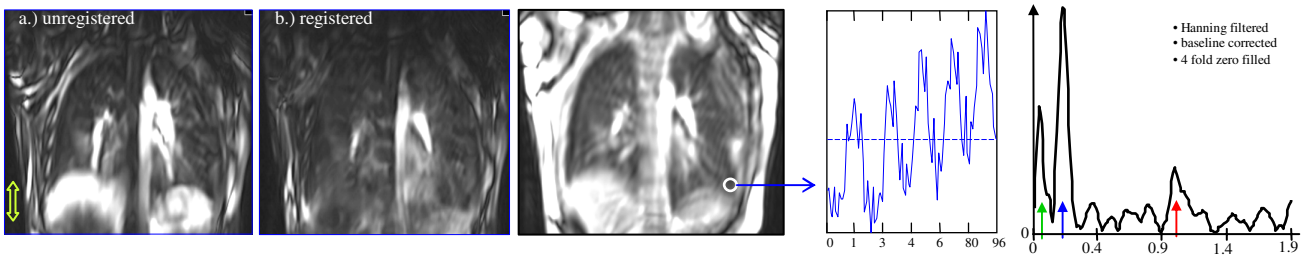

Fig.1: Standard deviation along 96 images 5 deep inspiration and expiration cycles.

Fig.2a) Volunteer study: RoI **b)** RoI signal vs time **c)** corresponding spectra after magnitude FFT. The line at 0.24 Hz is attributed to the respiration rate, or 4.2 s per breathing cycle (blue arrow), the unresolved lines at N 1.1 Hz induced by the heart activity N 62 /min (red); the very low frequency component close to 0.05 Hz may result from a typical baseline drift only in the caudal regions (green).

Results and Discussion: In summary, we have shown that MR ventilation imaging is possible without any exogen means like polarized gases, oxygen administration or contrast media. The very fast protocol and simple post processing technique allows the selective depiction of blood, stationary- and shifted tissue, it shows promise to improve the diagnosis of pulmonary diseases. The elegance of the *True FISP* sequence are its high temporal and sufficient spatial resolution compared to all spin echo based methods as e.g. the HASTE sequence because of the necessity for a rather long magnetization recovery period [7]. Ventilation distribution maps and also lung parenchyma itself can be characterized with help of the afore-mentioned separation of blood from the tissue, even with higher resolution. Using very fast non-spin echo based sequences like SSFP schemes, the method maybe extended to higher field strength, e.g. 1.5T [8].

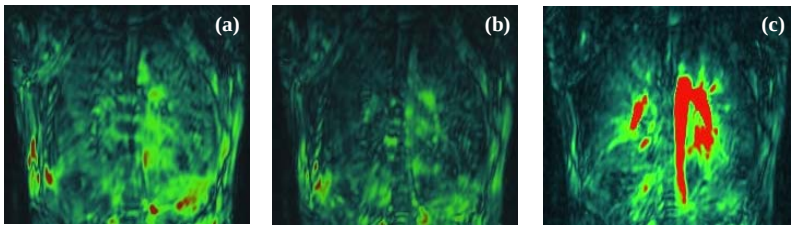

Fig.3: colour-encoded maps:
(a) integration of the spectral line in the frequency range of 0.20 - 0.30 Hz → lung tissue;
(b) in the frequency range of 0.05 - 0.10 Hz → density gradient of lung tissue?
(c) in the frequency range of 0.90 - 1.20 Hz → blood only.

References:

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Conclusion: The results of this Fourier-based spectral decomposition technique applied on non-rigid image registration demonstrate the feasibility of human lung ventilation imaging within very short examination times. This technique does not use triggering or gating and is used without any exogenic media. More trials with a larger number of subjects and patients are needed to optimize this potentially useful method.