Time-resolved lung perfusion- and ventilation-weighted MRI by Wavelet Analysis

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Introduction

Non-contrast-enhanced assessment of the pulmonary function remains a challenge in the developement of suitable MR techniques. Recently a Fourier Decomposition (FD) MRI was proposed to obtain regional lung perfusion and ventilation-related information during a single acquisition series [1, 2]. The method utilizes rapid acquisition of time-resolved MR-data using a Steady-State Free Precession (SSFP) sequence and allows for a spectral separation of respiratory and cardiac signal changes caused by lung parenchyma contraction and blood pulsation. We propose an alternative post-processing method based on the Wavelet Analysis (WA). The Wavelet transform allows for a robust analysis of physiological signals, which most often show a non-stationary behavior [3]. Signal contribution from the respiratory and cardiac cycles can be separated in the time-scale plane. The aim of this study was to show feasibility of the proposed method.

Methods

Five healthy volunteers were examined on a 1.5 T whole-body MR-scanner (Siemens MAGNETOM Avanto, Erlangen, Germany) using a 12-channel thorax/spine coil as receiver and transmitter. To obtain non-contrast-enhanced perfusion and ventilation images, time-resolved sets of 198 images in five coronal slices were acquired using a 2D+t SSFP sequence to cover the volume of the thorax (Fig. 1a). The imaging parameters were: TR/TE/TA = 1.9/0.8/116 ms, 3.33 images/s, FA=75º, ST = 15 mm, FOV = 450^2 mm^2, GRAPPA = 3, matrix 128 x 128, total acquisition time per slice T = 59.4 s. Neither respiratory nor ECG triggering was used. Each image within every data stack containing a single slice was corrected for the respiratory motion using a non-rigid registration algorithm [4]. Rapid data acquisition allowed observing intensity changes in corresponding lung areas with respect to the cardiac and respiratory cycles. For the WA method, the temporal resolution of the MR-data sets was increased using cubic spline interpolation to 576 samples. The level-four db4 Discrete Wavelet Transform was performed pixel-wise along the temporal direction of all time-resolved stacks producing different sets of wavelet coefficients. The signal was upsampled and reconstructed from every single branch
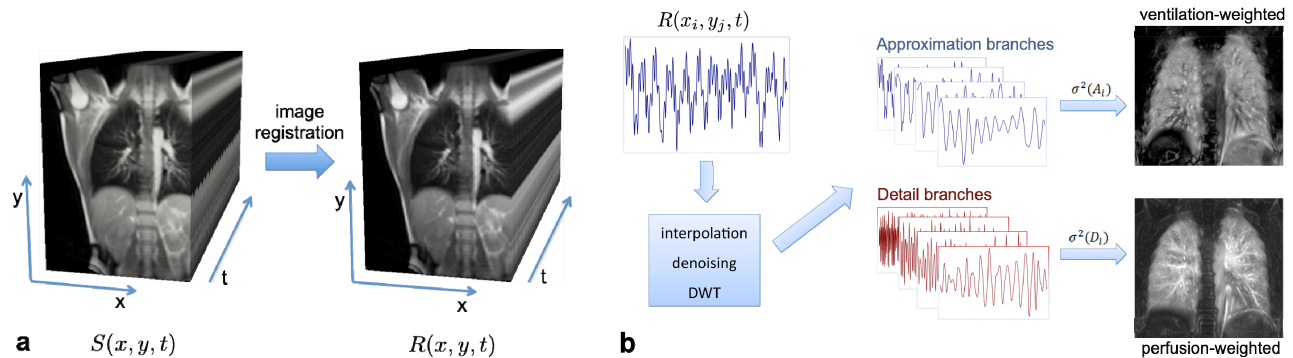

Fig. 1. Image registration of a MR-data set (**a**), Pixel-wise wavelet analysis of the signal along the temporal direction of a MR-data set (**b**).

using the 1D coefficients. To reduce noise, soft thresholding was performed in the wavelet domain [5]. Respiratory and cardiac signal courses were identified in the approximation and detail branches. The standard deviation of the wavelet coefficients was proportional to the averaged signal intensity change caused by respiration or blood pulsation (Fig. 1b). The Continuous Wavelet Transform was performed on a signal summed over the spatial dimensions to create a scalogram (Fig. 2). Pseudo-frequencies corresponding to given scales were determined knowing the approximated period of the mother wavelet. For the FD imaging, Fourier transform was applied pixel-wise along the time-axis of data sets after removing the DC-component and autocorrelation of the signal. Respiratory and cardiac peaks were identified on a frequency spectrum. Perfusion and ventilation images calculated using WA and FD methods were compared measuring the 2D correlation. Data was processed using fMRLung (Siemens Corporate Research) and MATLAB (The Mathworks, Inc.).

Results

Images post-processed with Wavelets showed very good 2D correlation with those obtained using the FD method r=0.97±0.03 for perfusion and r=0.96±0.02 for ventilation. WA improved image quality in cases of strong frequencies variability of physiological signals. Figure 3 presents a comparison of lung perfusion images in a volunteer obtained using WA and FD post-processing methods for strongly varying (1.0 – 1.4 Hz) cardiac cycle frequency.

Discussion

Post-processing using WA improved robustness against non-stationary signal behavior during the acquisition of time-resolved MR-data sets. Due to the limited acquisition rate of the time-resolved data sets (Nyquist criterion), harmonics of the respiratory and cardiac signals may be folded back into the frequency spectrum in case of a simple Fourier analysis. The application of WA helped to eliminate the risk of frequency overlapping and mixing of various signal harmonics, which may occur in e.g. hyperventilating patients, children or for a misfortune combination of respiratory and cardiac frequencies. A drawback of the WA method was a longer calculation time. Wavelet spectral analysis can be combined with the time-resolved MR-scanning technique to assess the regional pulmonary function.

Fig. 2. Scalogram created using the Continuous Wavelet Transform for a signal time-course in pulmonary parenchyma from a sample time-resolved MR data set.
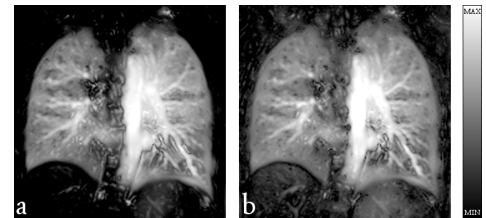
Fig. 3. Comparison between lung perfusion images post-processed using Wavelets (**a**) and Fourier analysis (**b**).

References:

[1] Deimling M. et al. Proc. 16th annual meeting ISMRM, 2008, Toronto, Canada, p. 2639
[2] Bauman G. et al. Magn Reson Med 2009 Sep, 62(3):656-64
[3] Weiss L. et al. Proc. of SPIE annual meeting, Vol. 3813:540, 1999, Denver, USA
[4] Chefd'hotel C. et al. VLSM'2001, ICCV Workshop, 2001, Vancouver, Canada
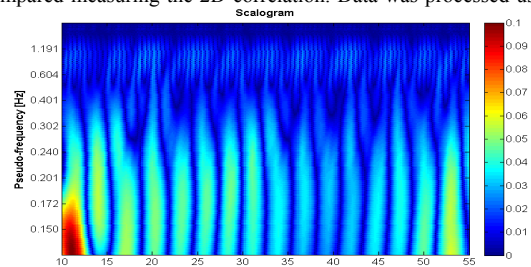[5] Alexander M.E. et al. Proc. 8th annual meeting ISMRM, 2000, Denver, USA, p. 842