Validation of ventilation- and perfusion-weighted Fourier Decomposition MRI with hyperpolarized ^{3}He-MRI and Dynamic Contrast-Enhanced MRI in an animal experiment

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Introduction

Despite physical and technical difficulties, MRI offers a broad spectrum of methods for the relative or absolute evaluation of the lung function. Recently, a non-contrast-enhanced technique of Fourier decomposition MRI (FD-MRI) was proposed to obtain regional lung perfusion and ventilation-related information during a single acquisition series [1,2]. The method utilizes a rapid free-breathing acquisition of time-resolved MR data using a balanced steady-state free-precession (bSSFP) sequence combined with the compensation of respiratory motion by non-rigid image registration. The Fourier analysis of the acquired data allows for a spectral separation of respiratory and cardiac signal variations, which are caused by changes of the regional proton density due to the lung parenchyma contraction and by flow dependent signal dephasing. Thus, FD-MRI provides an indirect approach for the assessment of ventilation and perfusion. The purpose of this study was the validation of FD-MRI against Dynamic Contrast-Enhanced MRI (DCE-MRI) [3] and hyperpolarized ^{3}He-MRI [4] in an animal experiment.

Methods

The study was approved by the local animal care committee. For the assessment of regional ventilation and perfusion using FD-MRI, DCE-MRI and ^{3}He-MRI three healthy pigs were studied in a 1.5 T whole-body MR-scanner (Magnetom Avanto, Siemens Healthcare, Erlangen, Germany). The pigs were placed in the supine position, intubated and maintained in general anesthesia throughout the experiment. Proton based MRI acquisitions were performed with a combination of 12-channel thorax and 24-channel spine receiver coils.

For the non-Contrast-Enhanced FD-MRI, sets of 198 coronal lung images per slice were acquired using an untriggered 2D+t bSSFP sequence to cover the chest volume. To increase the signal intensity from the lung parenchyma, centric phase encoding scheme as well as submillisecond asymmetric echo acquisition (factor s = 0.4) were applied to keep the TE and TR as short as possible. The imaging parameters were: TR/TE/TA = 1.9/0.8/116 ms, 3.33 images/s, FA = 75°, ST = 12 mm, FOV = 450^2 mm^2, GRAPPA factor = 3, matrix = 128 x 128, bandwidth = 1302 Hz/px. A time interval of TW = 190 ms was set between each single image acquisition, which allowed for partial recovery of the longitudinal magnetization. A total acquisition time per slice of T = 59.4 s, a spectral resolution of $\Delta f = 1/T = 0.017$ Hz and a spectral width of $f_B = 1/[2(TA+TW)] = 1.667$ Hz were achieved. Each image within every data stack containing a single slice was corrected for the respiratory motion using a non-rigid registration algorithm with respect to a chosen reference image [5]. Pixel-wise application of Fourier transform along the time axis of each data set produced a stack of n images representing spectral frequencies $f_n \in \{0, \Delta f, \ldots, f_B\}$. Spectral lines representing respiratory and cardiac frequencies were integrated to calculate ventilation- and perfusion-weighted images for every slice position. An example spectrogram containing the physiological frequencies is shown in figure 1. For DCE-MRI an acquisition with a 3D+t FLASH sequence (TR/TE=1.8/0.8 ms, FA=19°, ST=5.5 mm) was performed simultaneously with the administration of an intravenous contrast agent in form of gadopentetate dimeglumine (Magnevist, Bayer Vital, Germany) in dose of 0.1 mmol/kg body weight at rate of 5 mL/s.

The ^{3}He-MRI acquisitions were performed using a 50 cm double tuned (^{19}F/^{3}He) birdcage coil (Rapid Biomedical, Würzburg, Germany). A mixture of 200 ml of hyperpolarized ^{3}He (polarization P = 65-70%) and 300 ml N_2 was used. Morphological ^{3}He-MRI was performed with a spoiled gradient echo sequence using the following parameters: FOV = 270 x 270 mm^2, matrix = 64 x 64, slice thickness = 10 mm, TR/TE = 7.0/3.5 ms, α = 12°, 10 slices.

The first part of each examination was performed in a healthy animal using FD-MRI, DCE-MRI and ^{3}He-MRI. As the next step a pulmonary embolism (perfusion defect) was created by blocking the pulmonary blood flow in an artery using a balloon catheter. The perfusion measurements using FD-MRI and DCE-MRI were repeated. Subsequently, an obstruction of a bronchus (ventilation defect) was induced with a balloon catheter, causing an atelectasis. Afterwards ventilation measurements using FD-MRI and ^{3}He-MRI were performed.

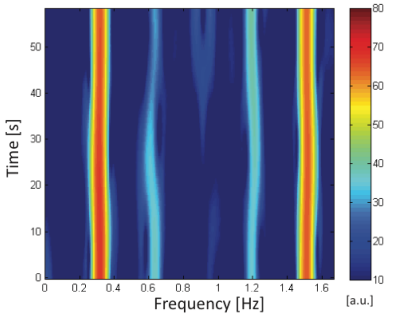

Fig. 1. The spectrogram calculated using short-time Fourier transform shows the amplitude of signal variations at different frequencies in lung parenchyma of a mechanically ventilated pig.

Results

Images acquired using FD-MRI, ^{3}He-MRI, DCE-MRI in all healthy animals before the catherization procedure showed homogenous distribution of ventilation and perfusion. Figure 2 shows images obtained in a corresponding slice position in an animal with pulmonary an embolism (upper row). The perfusion defect was detected by DCE-MRI and FD-MRI. The lower row shows images obtained after the artificial bronchial obstruction. The catheter blocked the airflow to one of the segments in the right lung causing a ventilation defect, which is visible in ^{3}He-MRI as well as in ventilation-weighted FD-MRI. Furthermore, the effect of redistribution of the pulmonary perfusion is noticeable in both the DCE-MRI and FD-MRI.

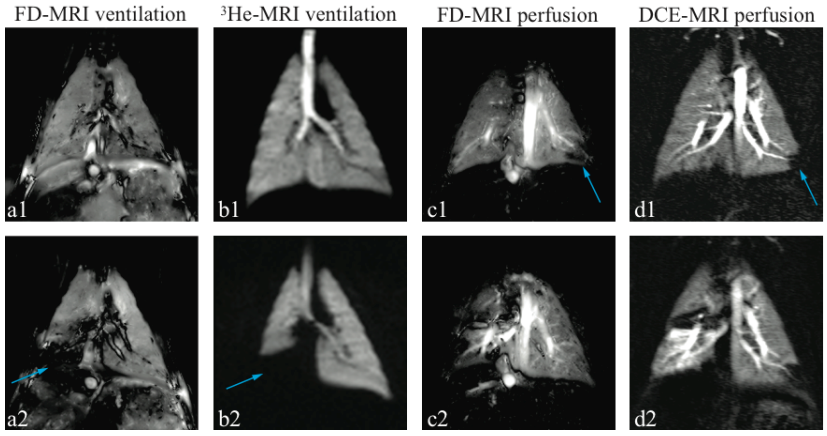

Fig. 2. The upper row shows ventilation-weighted (a1) and perfusion-weighted (c1) FD-MRI, ^{3}He-MRI ventilation (b1) and DCE-MRI perfusion (d1) at the identical coronal slice position obtained in a pig with pulmonary emboli (arrows). After the induction of a segmental obstruction in the lower lobe of the right lung, ventilation-weighted FD-MRI (a2) shows decreased change of the regional parenchyma density, while in the ^{3}He-MRI (b2) a ventilation defect is visible at the same location (arrows). The perfusion-weighted FD-MRI (c2) and DCE-MRI perfusion (d2) show similar changes in the distribution of pulmonary perfusion.

Discussion

In this study we validated a new approach for the assessment of pulmonary function in an animal experiment under controlled conditions. The comparison of this functional imaging method to the ^{3}He-MRI ventilation and DCE-MRI perfusion showed good visual correlation. Artificially induced defects in all animals were detected by the gold-standard MR methods for ventilation and perfusion imaging as well as by the contrast free Fourier decomposition MRI. In the experimental setting of this work the usefulness of FD-MRI as an alternative, non-invasive and easily implementable technique for assessment of changes in the lung function was shown. Further clinical studies are needed for the evaluation of this technique in different lung diseases.

References:

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