Non-Contrast-Enhanced High Resolution MRI of the Pulmonary Blood Volume Using a Two Compartment Model and T1 Mapping

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Introduction

The accurate assessment of the pulmonary blood distribution is becoming increasingly important for specific diagnostic problems. The current standard, clinically applied approaches comprise the following techniques: nuclear scintigraphy, single-photon emission computer tomography (SPECT), positron-emission tomography (PET), computed tomography (CT) (1,2) and dynamic contrast enhanced MRI (DCE-MRI) (3). However, the limited temporal and spatial resolution of nuclear medicine imaging, as well as an increased patient risk due to the presence of ionizing radiation and possible allergic reactions in case of DCE (4) make an alternative non-contrast-enhanced MRI technique highly desirable. Consequently, the aim of this work is to introduce and validate a new approach (TCIR) to measure the blood volume fraction within the lung parenchyma using a high-resolution anatomical sequence without the application of intravenous contrast agents.

Methods

It is assumed that the measured total signal in the lung parenchyma arises from intravascular and extravascular protons with different T_1 relaxation times T_{1int} and T_{1ext}, respectively. It can be shown that the intercompartment proton exchange process within the lung is negligibly slow. Thus, the total signal is given by (5):

$$S_{tot} = M_0 \cdot \left| fPBV \cdot \left(1 - 2\cdot \exp\left(-\frac{TI}{T_{1int}}\right) + \exp\left(-\frac{TR}{T_{1int}}\right)\right) + (1 - fPBV)\cdot \left(1 - 2\cdot \exp\left(-\frac{TI}{T_{1ext}}\right) + \exp\left(-\frac{TR}{T_{1ext}}\right)\right)\right|$$

where M_0 is the equilibrium magnetization, which is determined by an initial measurement without an inversion pulse. The parameter *fPBV* denotes the fractional pulmonary blood volume, that is, the fraction, blood occupies in each voxel. Hence *fPBV* can be extracted from a series of measurements with alternating inversion times.

Ten healthy volunteers (6 women, 4 men) of age 25.6 ± 2.8 y were examined in a 1.5 T MR-scanner (Siemens MAGNETOM Avanto, Siemens Healthcare, Erlangen, Germany) using a HASTE sequence: TR/TE = 4000/17 ms, slice thickness = 10 mm, BW = 590 Hz/px, flip angle = 180°, TI = 0, 100, …, 1200, 1500, 2000, 3000 ms, total TA = 5min. To compensate motion artifacts the images were acquired in apnea and an ECG triggering was used.

In order to assess the feasibility and reproducibility one coronal slice (FOV=378x384mm^2, matrix=256x252) was acquired three times with a time interval of 10 min. Subsequently, the mean *fPBV*-values within two regions of interest (ROI) in the right and left lung were calculated. A Wilcoxon signed paired rank test, as well as a Friedman test were used to assess the statistical significance of similarities between the three sequent measurements. In general, a correlation coefficient value of <0.05 was considered as statistically uncorrelated and a P value of <0.05 as statistically significant.

To prove the sensitivity to the gravitational effect on blood within the pulmonary one axial slice (FOV=204x384mm^2, matrix=136x256) within the lung of the subjects was measured in supine and prone position, respectively. Afterwards the progression of the *fPBV*-values in anterior-posterior direction was examined.

Additionally, a patient suffering from an emphysematic destruction of the middle lobe following severe pneumonia was examined. A TCIR-series of a single transversal slice was acquired using the aforementioned parameters. To validate the results, a dynamic contrast enhanced (DCE) MRI based subtraction image was acquired.

Results

Figure 1 (a-c) presents the threefold-acquired coronal *fPBV*-map of a healthy volunteer. The parameter maps sufficiently depict the heterogeneous structure of the pulmonary parenchyma. Due to pulsation artifacts the hilar region shows scattered noticeably small *fPBV*-values. The fractional PBV value within the lung averaged over all ROIs and volunteers was 0.842 ± 0.058 (table 1, col. 1). Table 1 presents the results of the statistical evaluation of the three sequent acquired coronal *fPBV*-maps. The Spearman coefficients and the corresponding P-values (Col 2-4) state a strong similarity between the acquisitions with a high statistical significance. This is also confirmed by the Friedman coefficient (Col. 5), which represents the correlation between all three measurements. A comparison of images in supine (FIG.2a) and prone (FIG.2b) position shows a correlation between the *fPBV* value and the anterior-posterior pixel position. Figure 3 shows a comparison of a DCE subtraction image (FIG.3a) and an *fPBV* map (FIG.3b) of a patient after pneumonia. Position and area of the defect correlate well in both images.

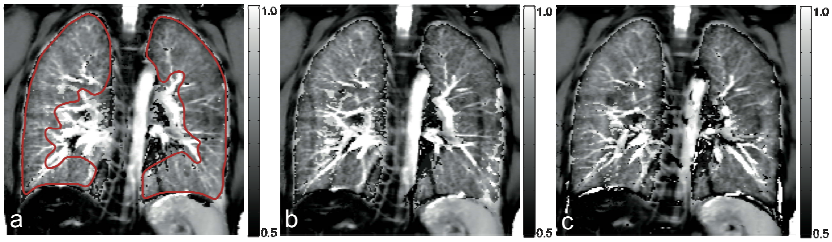

Fig. 1 Three sequent acquired maps of the parameter *fPBV* based on an image series of a single coronal slice within the lung of a healthy volunteer; the red area (a) represents one of the ROI, used for statistical evaluations

fPBV	$r_s(1\|2)$	$r_s(1\|3)$	$r_s(2\|3)$	r_f
0.84 ±0.06	0.64 ($P = 2\cdot 10^{-3}$)	0.92 ($P = 1\cdot 10^{-4}$)	0.78 ($P = 4\cdot 10^{-3}$)	0.19

Table 1 **(col. 1)** *fPBV* averaged over all ROIs and volunteers. **(col. 2-4)** The mean Spearman correlation coefficients and the corresponding P-values for the paired correlations. **(col. 5)** The mean Friedman correlation coefficient considering all three measurements simultaneously.

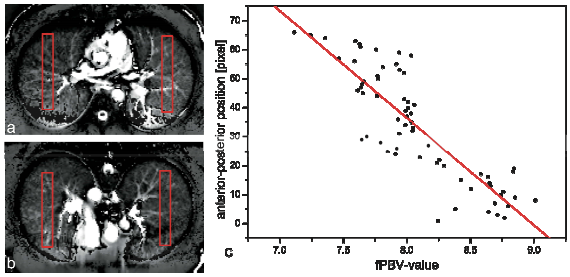

Fig. 2 a/b: *fPBV*-map in supine position and prone position. The red rectangles border the 10x66 pixel area within the *fPBV* value development was evaluated. c: Change of the mean *fPBV*-values along the anterior-posterior direction within the pulmonary parenchyma of one volunteer in supine position. The red line shows the result of a linear fit.

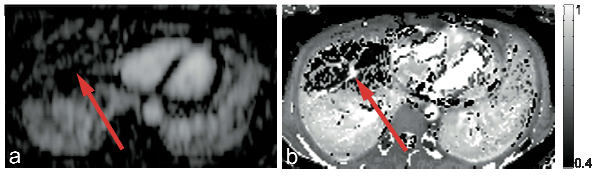

Fig. 3 A patient with pneumonia; (a) Dynamic contrast enhanced MRI subtraction image; (b) *fPBV* map of a comparable slice

Discussion

We have shown that, using the TCIR method it was possible to generate high-resolution maps of the fractional pulmonary blood volume in a clinically feasible acquisition time without using a contrast agent. Because of its superior spatial resolution, image sharpness and sensitivity TCIR poses a promising approach in diagnostics. Furthermore, TCIR offers an additional possibility to evaluate certain arterial spin labeling (ASL) techniques, such as FAIRER. This could lead to a compensation of some of the drawbacks ASL is faced, especially in lung imaging. Future work will concentrate on a further reduction of the acquisition time in order to make this method even more readily applicable for clinical purposes. A detailed quantitative assessment of the *fPBV*-maps will be prospectively addressed using imaging techniques such as SPECT.

References: [1] Zhang G. et al. Cancer Control 2008; 15:112-119. [2] Van Beek EJ. et al. Clin Chest Med 2008;29:195-216, vii. [3] Hatabu H et al. Magn Reson Med 1999; 42:1033-1038 [4] Grobner T. et al. Nephrol Dial Transplant 2006 21:1104-1108 [5] J. R. Zimmerman et al J. Phys. Chem 1957,61:1328-1333