Quantification of ventilation and perfusion using non-contrast enhanced quasi-randomly acquired DC gated ^{1}H lung imaging

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Introduction

Recently, Fourier Decomposition (FD) [1] has been demonstrated to allow for the determination of ventilation- and perfusion-weighted images using non-contrast-enhanced ^{1}H imaging. A combination of DC (= central k-space point) gated lung imaging without external gating and triggering techniques [2] using quasi-randomly acquired phase-encoding steps [3] and FD has been shown to also enable the reconstruction of ventilation- or perfusion-weighted images [4]. In this abstract, we present a theoretical concept called **A**bsolute **QUA**ntification of **P**erfusion-**I**nduced **C**hanges of the **S**teady-state **S**ignal (AQUAPICSS) to quantify the perfusion; furthermore, we take advantage of a recently published method to quantify ventilation [5]. Both functional parameters can be quantified on a voxel-by-voxel basis from cardiac and respiratory standard cycles reconstructed from quasi-randomly acquired data [4]. Moreover, the quantified perfusion maps were compared to maps obtained from additionally acquired SEEPAGE [6] datasets.

Methods

Data acquisition: For DC gated lung imaging and SEEPAGE, seven healthy volunteers (5m/2f, age 20-25) were included in the study on a 3.0 T clinical scanner (Magnetom Trio, Siemens Healthcare, Erlangen, Germany) after informed consent was obtained. The imaging parameters for DC gated imaging can be found in [4]. The SEEPAGE experiments were performed as described in [6]. ROIs were drawn in the left and the right lung. The mean and standard deviation were determined. For perfusion, an iterative procedure as proposed in [6] removes large pulmonary vessels to obtain perfusion rates solely from the parenchyma.
Perfusion quantification: In this paragraph, we describe the concept of AQUAPICSS. DC gated lung imaging as presented in [2] uses a FLASH sequence to acquire the data. Therefore, in the absence of flow, the blood in the imaging slice reaches a steady-state level M_∞ (after a short transient phase) which is dependent on the flip angle α, T_R and T_1 [7]. Unsaturated spins entering the slice due to blood flow cause signal variations which can be visualized as perfusion-weighted images as shown in [4]. The actual magnetization of blood in the imaging slice depends on the number of pulses which have been applied to the newly entered spins. This pulse number is dependent on the flow velocity. Using the assumption of plug flow and the approximation $T_R/T_1 << 1$, the magnetization of blood in the slice is well-described by the flip angle α and the average number of pulses k applied to the slice: $M = M_\infty + (M_0 - M_\infty)\cdot[\cos(\alpha)]^k$. Taking into account the pulsatile nature of blood flow, M_0 (= maximum flow) and M_∞ (= minimum flow) of blood can be obtained from the acquired data without any additional experiments if a completely blood-filled voxel is given (e.g. in the aorta). To obtain the perfusion-weighting in [4], the peaks of the DC signal depicting the beginning of cardiac cycles are identified. Then, a gating window covering a specific width of the cardiac cycle is shifted over all identified R-R-intervals in parallel. Data from all these windows are combined to obtain individual images of the cardiac phases. This results in one cardiac standard cycle. Therefore, the reconstructed signal after retrospective cardiac gating can be described by a convolution of the actual slice signal and the width of the gating window. Hence, if the actual slice signal is deconvolved from the reconstructed signal, the average number of pulses applied to blood in the slice can be determined. From this, using the assumption of plug flow, the average flow velocity can be derived; and, thus, the time-resolved perfusion rate in ml/min/ml can be calculated for each timeframe and voxel of the cardiac standard cycle. By calculating the mean of this quantified time-resolved data, a perfusion map directly comparable to the SEEPAGE map can be obtained.
Ventilation quantification: The simple approach from [5] has been used: $V = (S_{exp}-S_{insp})/S_{exp}$, where S_{exp} and S_{insp} are the signal levels in expiration and inspiration. This scheme can be applied to respiratory standard cycles reconstructed according to [4].

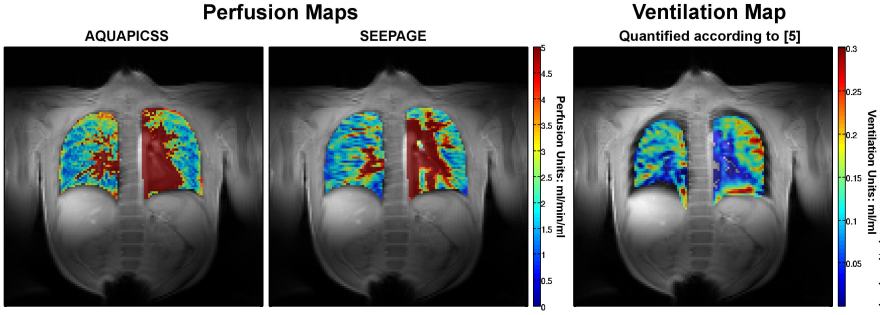

Figure 1: *Functional maps obtained from volunteer 5. Please note that the ventilation rate approaches zero where large vessels are visible in the perfusion maps.*

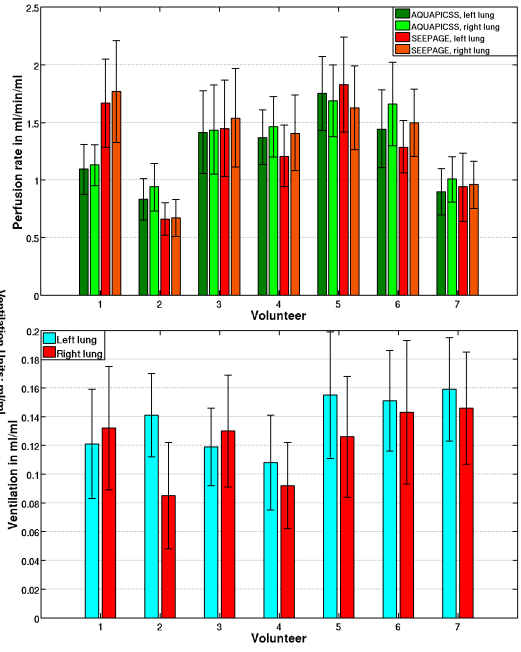

Figure 2: *In the upper diagram, a comparison of perfusion rates obtained with AQUAPICSS and SEEPAGE is given. The quantified ventilation rates are shown in the bottom diagram.*

Results

Fig. 1 shows that the mean perfusion map obtained with AQUAPICSS corresponds well to the SEEPAGE map. Perfusion values range from 0.5-2.5 ml/min/ml. As can be seen in Fig. 2, the two perfusion quantification techniques result in similar rates for all volunteers. The ventilation maps (an exemplary map is given in Fig. 1 on the right) result in rates between 0.05-0.20 ml/ml (ml air per ml lung parenchyma per breath) for all volunteers in this study.

Discussion and Conclusion

We described a technique which enables the determination of anatomical, functional and quantitative lung information using non-contrast-enhanced ^{1}H imaging without breath holds and ECG triggering. Thus, this method seems to be promising for patients who cannot hold their breath and/or are uncooperative. The perfusion rates obtained with AQUAPICSS are in accordance with literature values [e.g. 8] and correspond well to the quantified rates from additionally acquired SEEPAGE datasets. A study for direct comparison to quantitative contrast-enhanced pulmonary perfusion imaging is currently undergoing. The observed ventilation rates resulted from normal breathing and are, therefore, reduced compared to literature values [5] which were obtained in maximum amplitude respiration. Since a simultaneous quantification of ventilation and perfusion is feasible, this abstract is the first work enabling the determination of the V/Q ratio without the need for contrast agents.

References

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