Absolute Quantification of Pulmonary Perfusion Rates Using Flow-Sensitive Alternating Inversion Recovery with an Extra Radiofrequency Pulse (FAIRER)

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Introduction

Perfusion MR imaging of the lung has been successfully demonstrated using arterial spin labeling (ASL) techniques (1-3). However, absolute quantification of pulmonary perfusion rates has not been performed. Several factors impede this process. A T1 map, M0, and ASL perfusion-weighted images are generally required for the quantification of absolute perfusion rates. Ideally, these images should be obtained within one breathhold to minimize spatial misregistration between images. The acquisition time, therefore, becomes prohibitively long for a single breathhold. To achieve an acceptable and sustainable breathhold duration, image acquisition has to be streamlined. Taking advantage of the homogeneous distribution of the T1 of the lung, we report a simplified procedure for the calculation of the absolute perfusion map using FAIRER.

Materials and Methods

All experiments were performed on a VISION 1.5 T Magnetom system (Siemens Medical Systems, Iselin, NJ). Five normal volunteers were imaged. Cardiac triggering was incorporated, and breathholding on expiration was used. M0 (without preparatory rf pulses) and FAIRER perfusion-weighted images at T1 of 1400 ms were acquired, since maximum signal enhancement occurs at T1 of 1400 ms (1,3). A HASTE sequence was used with a FOV of 400-500 mm and a matrix of 128x256. A time delay, TD, of 2-4 s was selected, which is the time period after image acquisition and before the next tagging period.

Pulmonary perfusion rates were calculated on a pixel-by-pixel basis according to the equation (4),

\[ f = \frac{\Delta M}{M_0 \cdot 2T1 \cdot \exp(-T1/T1)} \]  

where \( f \) is perfusion rate (ml/100g/min); \( \Delta M \), FAIRER signal; \( M_0 \), signal intensity at full equilibrium; \( \lambda \), the tissue-blood partition coefficient (ml/g), which was assumed to be 1; \( T1 \), the time delay after spin labeling; and \( T1 \), the longitudinal relaxation time of the lung, which was assumed to be 1.4s.

To validate the assumption of a constant T1, T1 maps were calculated from a series of nonselective IR images acquired at TIs ranging from 100 ms – 3000 ms. Their signal intensities were then nonlinearly fitted to the equation \( M(T1) = A \cdot B \cdot \exp(-T1/T1) \) to calculate for T1 using the Marquardt-Levenburg nonlinear least square minimization algorithm.

Results and Discussion

A T1 map is shown in Fig. 1. The lung appears relatively homogeneous. The average T1 is 1371 ms ± 90 ms. This gives credence to our assumption of the value of T1 of 1.4 s for the lung used in the calculation of the pulmonary perfusion rates.

The absolute perfusion maps of the lung from a healthy female volunteer are shown in Fig. 2. The maps were obtained at different anatomical positions. The average perfusion rates were measured to be 631.9 ± 83.2 ml/100g/min. This average perfusion rate is reasonable considering that the average cardiac output is on the order of 4-5 l/min and that the average wet weight of the lung is 1 kg in a normal human. This indicates an average perfusion rate of approximately 400-500 ml/100g/min. Our results thus slightly overestimate pulmonary perfusion rate.

This overestimation of perfusion rates may be due, in part, to contributions of large pulmonary vessels in the ROI measurements, even though effort was made to minimize this effect in the selection of the ROIs. Consequently, signal contribution from these large vessels would tend to skew the average.

Conclusion

Quantification of pulmonary perfusion rates has been successfully demonstrated using FAIRER.

Figure 1. T1 map from a healthy volunteer.

Figure 2. FAIRER absolute perfusion maps of the lung from a healthy female volunteer at three different anatomical positions.

References


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