Single-Shot-Quantitative Perfusion Imaging of the Human Lung

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Introduction: One of the major drawbacks to quantitative perfusion imaging using arterial spin labelling techniques (such as FAIR and FAIRIER) is the need for two images (tag and control image). These "two-shot" techniques result not only in an increase of total acquisition time, but also in artifacts due to respiratory motion between the control and the tagged image. In contrast, the method presented yields quantitative perfusion information of the human lung by acquiring the perfusion weighted image in a single-shot. The described technique ensures the complete suppression of different background tissue (such as lung tissue and pathologies) while almost completely preserving signal from the blood.

Subjects and Methods: Experiments were performed on a 1.5 Tesla clinical scanner (Vision, Siemens, Erlangen, Germany). For signal detection, a 4-element body array was used. Five healthy volunteers (4 male, 1 female, age 23-29) were examined and informed consent was obtained before each measurement. The perfusion images were acquired using a slice-selective double inversion recovery HASTE sequence [1] (see figure 1). Imaging parameters: TI1=1200-1300 ms, TI2=150-300 ms, TE_{inter} =4.2 ms, TE_{eff} = 43 ms, slice thickness 10-20 mm, FOV 500 x 500 mm^2 , 128 x 256 HF imaging matrix, yielding a total acquisition time of ~2000 ms. To avoid flow artefacts, images were acquired in the end diastole cycle using ECG triggering. In contrast to the FAIR technique [2] a second inversion pulse is applied during preparation. The inclusion of this second inversion pulse renders the acquisition of a control image unnecessary as static tissue with various T1 values is completely suppressed. Neglecting T_2 effects, the evolution of the longitudinal magnetization for static tissue and blood at the end of the inflow time is given by the Bloch equations:

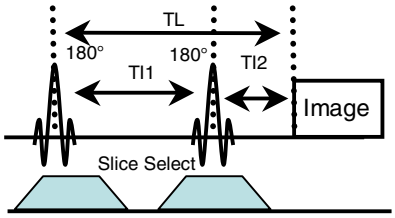

Figure 1: Slice-selective double inversion recovery sequence for single-shot quantitative perfusion imaging

$$M_z^{static}(TL) = (1 - 2e^{-TI_1/T_1^{static}}) \times e^{-TI_2/T_1^{static}}$$

$$M_z^{blood}(TL) = -2M_0^{blood} \times Q \times TI_2 \times e^{-TI_2/T_1^{blood}}$$

To ensure the complete suppression of the background tissues, validating scans were acquired before the actual imaging session. For this purpose, the first slice-selective inversion was changed to a global inversion in the preparation scheme. With manual adjustment of the inversion times, static lung tissue and blood signal can be completely suppressed, which results in no remaining signal intensity in the lung (see figure 2).

Coronal slices in a dorsal position were acquired using the adjusted inversion times. The calculation of the quantitative perfusion rates Q was performed using voxels completely filled with arterial blood as a reference (from the thoracic aorta) on the basis of the signal evolution of the longitudinal magnetization during preparation, yielding:

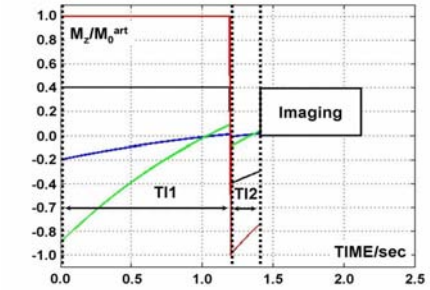

Figure 2: Time course of longitudinal magnetization for lung parenchyma (blue, T1=1500ms), representative pathologic tissue (green, T1=900ms) and lung blood (black, T1=1500ms) for an arbitrary voxel in the imaging slice. The reference signal (arterial blood from the aorta) is shown in red.

$$Q = \frac{S^{lung}}{2 \times S^{aorta} \times TL}$$

where S refers to the signal intensity in the lung and the thoracic aorta. An additional factor, estimated to be two, was inserted to account for the fact that not only arterial but also venous blood is detected (in contrast to CA-enhanced measurements). After segmentation of the large blood vessels, mean perfusion values of the lung parenchyma were obtained (see table).

Results: The imaging sequence yielded perfusion images from lung parenchyma with a high SNR (~ 40) and reproducible results. The quantitative perfusion values varied over the parenchyma of the lung in end expiration over the range of 0.5 to 3 ml/s/ml. The perfusion rates were slightly underestimated due to blood which moves in the imaging plane during the entire labelling time. As reported earlier, the perfusion rates were higher in expiration than in inspiration (20-70%, dependent on inspiration level) due to reduced blood volume per voxel and the relationship between pressure and flow of the pulmonary vasculature [3]. A correction factor is calculated from the percent difference of lung volume in the inspiration and expiration images, and the perfusion values are scaled with this factor to make the values comparable. After the correction of the perfusion values for the reduced blood volume a residual drop of the perfusion values between expiration and inspiration was observed (~10%). This effect can be attributed to pressure differences in the pulmonary vasculature. Furthermore, the dependence of pulmonary perfusion rates on gravity [4] could also be demonstrated in sagittal images (data not shown).

Conclusion: Non-invasive quantitative perfusion imaging can be performed in a single-shot using a slice-selective double inversion recovery sequence. The ability to suppress not only lung tissue, but also different tissue types with varying T1 values makes it a promising tool for diagnosis of several diseases. The slight fluctuations in perfusion values between different measurements and different volunteers arose from variations in the reference values due to residual blood flow in the aorta during the diastolic cycle as well as the effects discussed above. Future improvements include the development of multi-slice techniques and the usage of PPA to reduce the echo train length and total acquisition time. The time reduction due to PPA will minimize the error in the reference measurement, which is the major source of variations in the quantitative values. A study composed of patients with various diseases such as PE and COPD will be performed to determine the significance of the method in clinical applications.

Volunteer	1	2	3	4	5
Whole left	1.30 ± 0.26	1.69 ± 0.34	1.55 ± 0.31	1.11 ± 0.22	1.11 ± 0.22
Lower left	1.38 ± 0.28	1.65 ± 0.33	1.67 ± 0.33	1.13 ± 0.23	1.13 ± 0.23
Upper left	1.24 ± 0.25	1.67 ± 0.33	1.41 ± 0.28	1.05 ± 0.21	1.05 ± 0.21
Upper right	1.38 ± 0.28	1.73 ± 0.35	1.64 ± 0.33	0.95 ± 0.19	0.95 ± 0.19

Table 1: Lung perfusion values of the volunteers in end expiration in ml/s/ml (see text).

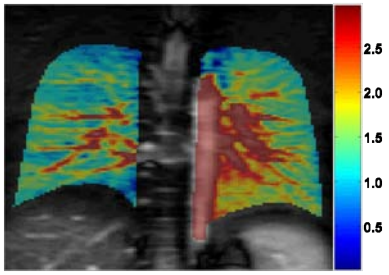

Figure 3: Quantitative Perfusion map of one volunteer in end expiration (ml/s/ml)

References:

1)Duyn et al, MRM 2001: 46,88-94

2) Kim et al. MRM 1997: 37,425-35

3) Fink et al, Invest Radiol 2005: 40, 72-79

4) Stock et al, JMRI 1999: 9,557-6

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