Introduction of global specific ventilation as a reference for specific ventilation derived by Fourier Decomposition MRI

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Purpose: Fourier Decomposition (FD) is a method to calculate ventilation-weighted images of the lung without the need of any contrast agent [1]. By using the approach of Zapke [2] the ventilation can be quantified by the dimensionless specific ventilation (SV). By definition this parameter is dependent on the depth of respiration and the individual pulmonary physiology. This may not only impede the comparison of the SV between different patients but also between images taken at different time points, especially when dealing with different breathing maneuvers. Therefore, in a volunteer study the variability of SV in combination with a respiratory flow measurement was investigated.

Method: The study included twelve healthy non-smoking volunteers between 21 and 29 years (6 male, 6 female). The protocol contained multiple scans of three coronar (anterior, mid, posterior) and two sagittal slices (left and right) of the lung. FD was applied for four different breathing maneuvers: In addition to free breathing, the volunteers were asked to breathe as deeply as possible and to follow specific breathing frequencies (16 and 8 breaths per minute) announced via head set. The reproducibility of free breathing was tested for all 5 slices of the 12 volunteers by repeating the measurement after a short break outside the scanning room.

For FD, 200 images were acquired using a spoiled gradient echo sequence on a 1.5T scanner with FOV 500 x 500 mm², matrix size 128 x 96, slice thickness 15 mm, T_E / T_R: 0.67 ms / 3 ms, flip angle 8° over a period of one minute at a temporal resolution of 288 ms.

After a non-rigid image registration (ANTS [3]) of the dynamic series of images to a reference image in mid position between end-inspiration and end-expiration a low-pass filter was applied to generate a series of ventilation-weighted images. SV was calculated by averaging the signals of the end-inspiratory and end-expiratory images and using following formula: $SV = \frac{S_{exp}-S_{insp}}{S_0}$ with $S_0 = (S_{exp} + S_{insp})/2$.

Lungs were segmented manually, excluding the great central vessels. Thereby, mean SV values for the whole lung were determined.

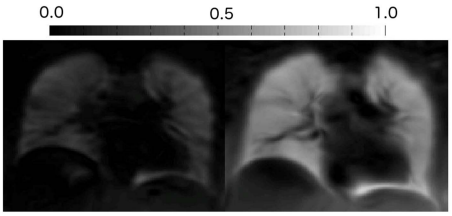

Figure 1 Specific ventilation (SV) maps of the same lung during free breathing (left) and deep breathing (right). For free (deep) breathing a mean SV value of 0.2 (0.5) and a volume change of 0.65 l (2.41 l) was obtained.

A spirometer connected to a closed face mask recorded a flow time series during MR image acquisition. Thereby, a mean change in volume (ΔV) between end-inspiration and end-expiration for each SV map was assigned. Additionally, coronar images from anterior to posterior were acquired during free breathing covering the whole lung using a balanced steady state free precession sequence with FOV 400 x 400 mm², matrix size 256 x 168, slice thickness 3 mm, T_E / T_R: 1.33 ms / 328 ms, flip angle 70°. These images were manually segmented to estimate the lung volume V_0 in mid-position of the respiration. In analogy to the signal based SV of FD a global SV can be derived in terms of the volume change ΔV with the underlying assumptions that the volume changes occur symmetrically around V_0: $SV = \frac{S_{exp}-S_{insp}}{S_0} \Rightarrow SV_{Global} = \frac{\Delta V}{V_0}$

Results: The SV derived by the FD method, exemplarily shown in Figure 1 for the same volunteer at the same slice position, depends on the depth of the respiration. The Bland-Altman plot in figure 2 illustrates the results from the first and second measurement during free breathing. There is neither an evidence for a systematic error nor a visible dependency on the SV value. Including only data with respiratory depth differences between the two measurements $\frac{\Delta V_1-\Delta V_2}{\Delta V_1}$ (color code of the dots in figure 1) of maximal 20% and 10% the coefficient of determination increased from 0.61 to 0.78 and 0.91 and the variation coefficient decreased from 16% to 12% and 7%, respectively.

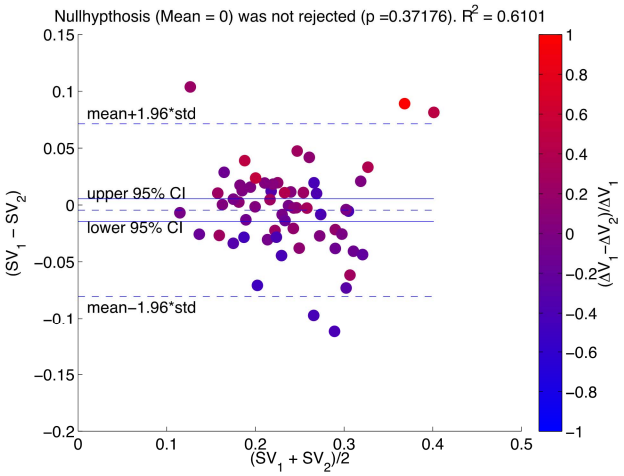

Figure 2 Bland-Altman plot showing the deviations of SV calculated from the first and the second measurement. All 5 slices of the 12 volunteers are included. The color bar indicates the different respiratory depth of the two measurements.

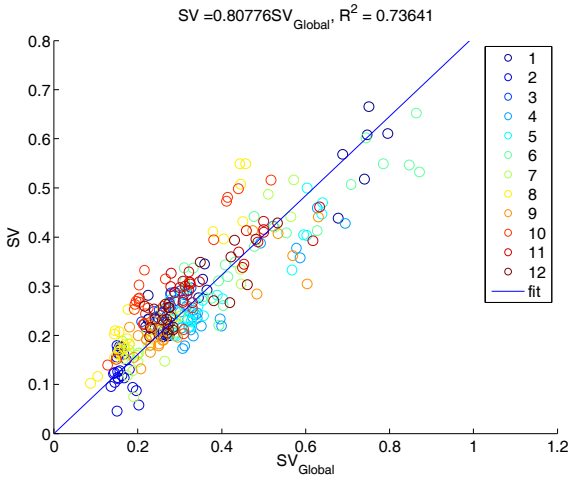

Figure 3 A scatter plot illustrating the correlation between SV and SV_{Global} of the 27 scans for each volunteer.

Figure 3 shows a positive correlation between SV and SV_{Global} with an $R^2 = 0.74$ and a slope of $a = 0.81$ for all scans and volunteers. Therefore, an exact equivalence cannot be observed. Nevertheless, applying the found correlation to FD data reduces the variation coefficient of SV to 0.22 in comparison to 0.41 when dealing with the raw SV data.

Discussion: The results show that SV determined by FD varies highly with the depth of respiration. The respiratory pattern can change from one scan to another and thereby reduces the reproducibility of SV. Additionally, the global SV is of some uncertainty because the volume in mid-position of the respiration was estimated by manual segmentation of lung MRI in free breathing. Measuring the lung volume by body plethysmography could increase the accuracy. Furthermore, the additional information of the spirometer suggested that some volunteers did not change their breathing as commanded. Being undetected this would have a great impact in a study relying on respiratory commands only. In this case, normalization to a fixed volume change using the presented correlation could be beneficial in future studies.

Conclusion: This study shows that the combination of MRI and real-time respiration detection is of relevance for the comparison of absolute SV values. We assume that the SV_{Global} could be utilized to normalize the SV maps in cross-sectional and longitudinal studies.

References: [1] Baumann G. et al.; MRM V. 62, pp. 656-664 (2009); [2] Zapke M. et al.; Resp Research V. 7, pp.106-114 (2006); [3] Avants B.B. et al; Neuroimage V. 54(3), pp. 2033-44 (2011);

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