Rapid In-vivo MRI Measurement of Fluorinated Gas Concentration in Lungs Using T_1- mapping

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Introduction

MRI techniques using hyperpolarized noble gases in order to scan lung morphology and function have considerably advanced pulmonary imaging, especially as a research tool. However, these techniques have not been established into the clinical routine. High expenses and problems of producing and reliably administering may be the cause. Therefore, interest in alternative methods such as MRI of fluorinated gases (e.g. SF_6, C_2F_6, C_4F_8) has grown. Recently, in vivo studies of dynamic pulmonary ventilation [Schreiber, Kuethe1] and diffusion weighted imaging [Perez] have been presented. However, the SNR provided by most of fluorinated gases and technical difficulties with the reproducing of the experimental conditions put strong limitations on the application of these MRI-agents for diagnostic purposes, particularly, extracting the reliable quantitative information about ventilation functions from spin density images. Thus, it becomes important to employ other NMR parameters to increase the reliability of the quantification of the functional lung MRI. One of these parameters is the longitudinal relaxation time T_1 which is known to be sensitive to the chemical and physical environment of the spins and therefore may bring information about properties of the contrast gas mixture and the environment which would be independent on spin density and hardware factors. The important property of the spin-rotational relaxation in gases is the dependence on partial pressures and the content of the gas mixture. For animal investigation in vivo T_1 measurements must be limited to breathe hold time (1 min.). The standard T_1-relaxation recovery-based measurement methods are hardly applicable under these limitations. A modified Look and Locker fast T_1 measurement sequence has been demonstrated by Kuethe et al [Kuethe2], before. However, the multiple pulse rf-irradiation excitations used in this method may lead to exceeding the allowed SAR and therefore can limit applicability for the patients. A variable flip angle (VFA) method, which has been successfully applied for brain T_1-map measurements [Cheng] owns the advantage of a short measurement time and simple implementation (standard GRE sequences can be used). In this study, the VFA method was applied to quantify local partial pressure using longitudinal relaxation time in a ventilated animal model.

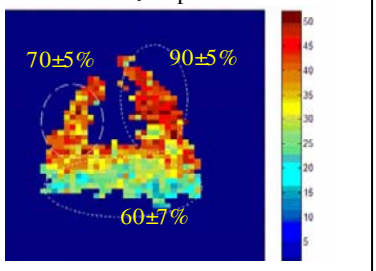

Fig 1. Ex-vivo T_1 map of rat lung, C_4F_8 concentration assigned according to phantom calibration

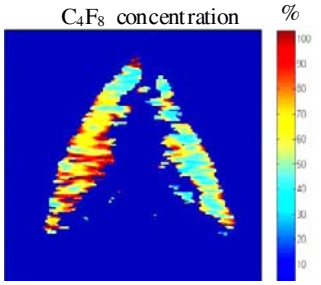

Fig 2. C_4F_8 concentratiom map in pig lungs determined from in-vivo T_1 measurement.

Materials and method

The main disadvantage of the VFA method is the sensitivity of the measurement precision to the SNR and RF-pulse imperfections. Due to this, the animal experiments were preceded with extensive phantom investigations aiming to proof applicability of the method for fluorinated gases and to estimate all essential errors. Two gases (C_4F_8 and C_3F_7H) mixed with air in different proportions were used. The linear dependence of T_1 time from the air-^{19}F-gas concentration relation has been confirmed. The proof of measured T_1 values by comparison with the results of saturation recovery experiment shows a good (within 5%) agreement of both methods. In a next step the ex-vivo measurements in rat lungs have been performed to test the method efficiency in animals taking into account intrinsically inhomogeneous RF-field distribution in tissues. In this case the rat lungs were filled with a mixture of 80% C_4F_8 with 20% of O_2 immediately after death. Finally, the experiments have been repeated in domestic pig (20-25kg) lungs in-vivo. The scan time in all measurements during inspiratory hold ranged from 60 to 70 seconds. All experiments were performed on Siemens Magnetom Vision 1.5T system using a custom build ^{19}F birdcage coil.

Results and conclusion

Experimental results are shown on Fig. 1 and 2. In ex-vivo T_1-map of rat lung 3 regions with various T_1 can be identified corresponding to variations of C_4F_8 concentration. This can be associated both with (i) redistribution of gas-mixing by gravity due to strong difference in densities (1:6) and (ii) partial adsorption/solution of oxygen by the lung tissues. The in-vivo results (Fig. 2) show essentially broad T_1- time distribution (and therefore related C_4F_8 concentration) that obviously reflects a metabolic processes of gas exchange. In this case metabolic changes of the proportions of gas mixtures (C_4F_8:O_2:CO_2) in different lung regions could lead to corresponding variations of T_1. The phenomena of local fluctuations of gas mixture concentration (“hot spots”) found in several in-vivo experiments needs further clarification. To sum up, the VFA method of T_1 measurement of heavy fluorinated gases in-vivo lungs is feasible. The sensitivity of the method is sufficient enough to detect 5-10% variations of gas mixture content in-vivo. Being combined with diffusion weighted imaging techniques this may open up new options for the study of lung function.

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