Rapid Pulmonary Proton ZTE Imaging in the Mouse

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Introduction MRI of the lung is challenging due to low water proton density and very short transverse relaxation times T2*, typically on the order of one millisecond or below. The rapid decay of transverse magnetization is associated with susceptibility differences at the many tissue-air interfaces. Therefore, hyperpolarized gases have been proposed to make the lung visible with MRI[1]. Alternatively, projection techniques with ultra-short[2-7] or zero echo time[8,9] which enable capturing signal with very short T2 or T2* have been employed for pulmonary proton imaging. However, in this approach, the low and rapidly decaying signal as well as physiological motion aggravate the tradeoff between spatial resolution, scan time, image quality, and signal-to-noise ratio (SNR), a task which is even more demanding for small-animal applications. Therefore, in the present work, zero echo time (ZTE) imaging[10,11] with high efficiency is optimized for the mouse lung, thus enabling robust, high-quality pulmonary MRI with short scan times.

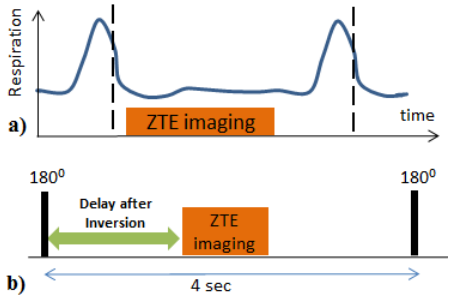

Figure 1 Schemes for ZTE imaging a) with respiratory-triggering, and b) employed for inversion-recovery-based T1 mapping.

Methods ZTE imaging employs 3D radial center-out encoding where RF excitation is applied with a short hard pulse while the projection gradient is already on. Hence, rapidly decaying signal is detected with high efficiency and robustness. The small overhead in the sequence enables the implementation of very short repetition times (TR), thus leading to short total scan times. For mouse MRI with isotropic geometry, a matrix size of 160 was chosen within a FOV of 50 mm, thus leading to an isotropic spatial resolution of 0.31 mm. With a TR of 1 ms and 80889 radial spokes as required for full Nyquist encoding, the scan time per volume was 1 m 21 s. The flip angle of 3.7° of the 1 µs-hard pulse was optimized for maximum lung signal. A spectral bandwidth of 200 kHz was chosen with a readout duration of 400 µs, which provided better image quality than lower bandwidth. ZTE data was acquired with four-fold radial oversampling and reconstructed algebraically to address the central k-space gap[11], which was 1.5 nominal dwells in the present case. Concerning SNR and respiratory motion, two different strategies were investigated: averaging by a factor of two and respiratory triggering with a train of ZTE acquisitions of fixed duration of 900 ms during end-expiration (Fig. 1a), as well as their combination, leading to accordingly increased scan times. Moreover, ZTE imaging was utilized to map T1 of lung tissue using the inversion recovery scheme depicted in Fig. 1b). After inversion with a 180° hard pulse of 50 µs duration a variable delay time was set per volume before a ZTE imaging block of 500 ms duration. Using an interval of 4 s between the inversion pulses and a matrix size of 128, the total measurement time per volume amounted to 7 m 48 s. 11 different delay times were employed. T1 in the lung was determined by fitting the signal recovery in a region-of-interest excluding large vessels. All quantitative data analysis was performed on magnitude images after bias correction for both magnitude noise[12] and signal background. The measurements were conducted on a 4.7 T Bruker small animal scanner equipped with a linearly polarized transmit-receive whole-body mouse coil with an inner diameter of 38 mm. Two healthy mice which were approved by the institutional animal care committee were used in this study. They were anesthetized with isoflurane and held at a breath rate of 40-50 per minute. The respiratory motion was observed via a pressure sensor.

Results Figure 2 assembles the results acquired with the different protocols. In contrast to FLASH, the ZTE images show significant signal for the lung tissue. Furthermore, even without respiratory control, they exhibit no prominent artifacts due to motion. Nevertheless, by using respiratory-triggering, image quality is improved with slightly increased sharpness of fine structures but more clearly an increase in SNR. The latter is not only due to reduced motion but also signal recovery during the breaks, which notably do not cause artifacts or contrast alteration. The SNR values in lung tissue are 8, 11, 12, and 18 for the images in Fig. 2 b) – e), respectively, which is further illustrated in the intensity profiles in Fig. 3. T1 in the lung tissue is identified as 660 ms.

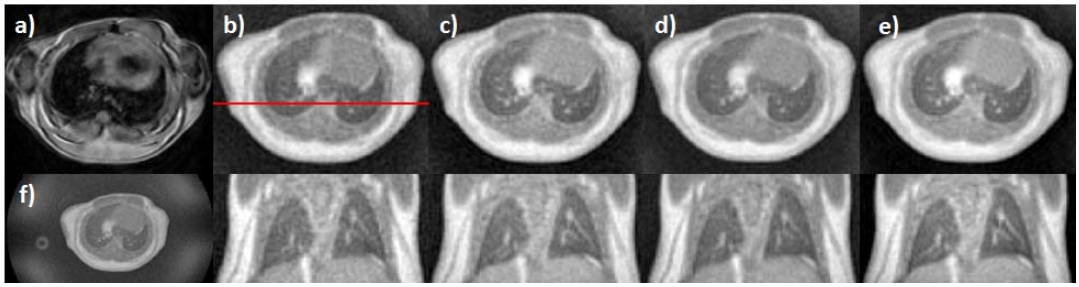

Figure 2 Axial and coronal slices from 3D data of the mouse lung acquired with a) FLASH (TE = 4.7 ms) and ZTE imaging with b) no averaging, c) respiratory-triggering, d) averaging, e) both respiratory-triggering and averaging. The full FOV displayed in f) also exhibits background signal from the RF coil.

Discussion In this work, rapid, isotropic 3D ZTE imaging of the mouse lung was demonstrated. Good image quality with high robustness against motion was already obtained without triggering for the shortest scan time of 81 s. Both averaging and respiratory control provided further improvements at the expense of longer scan times, whereas replacing triggering by gating will improve the scan efficiency. A dedicated and optimized RF coil design is expected to deliver higher SNR and negligible background signal (see Fig. 2f). Thus, a smaller FOV could be chosen which further reduces scan time. Moreover, the background signal does not need to be taken care of in a quantitative analysis. In an additional experiment it was shown, how ZTE imaging can be utilized to determine T1 in tissue with very short T2 or T2*, which would not be possible with conventional imaging techniques. The demonstrated general efficiency of the technique does not only enable to enhance pre-clinical animal studies but can also be translated to pulmonary MRI in humans without using hyperpolarized gases.

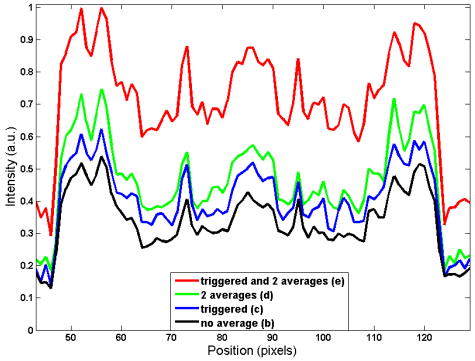

Figure 3 Intensity profiles of ZTE images from the row depicted in Fig. 2b. The values are normalized for equal statistical noise.

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