Lung imaging at ultra-high magnetic fields in rodents

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Introduction: High field MRI has shown promising results and useful applications for the diagnosis and investigation of several pathologies in different organs (e.g., brain, kidneys, liver). The higher signal-to-noise ratio (SNR) enabled by these systems is related to their magnetic field strength and generally increases proportionally to B_0. MRI preclinical studies with 4.7 T up to 12 T spectrometers are becoming increasingly common. Nonetheless, the proportionality between SNR and Bo does not hold in the case of lung imaging. The huge number of interfaces between air and tissue, intrinsic property of this organ, causes the fast dephasing of the spins and reduces the NMR signal that can be measured with MRI, especially at high fields.
In this work, we aim at showing the feasibility of pre-clinical lung imaging at ultra-high magnetic fields (11.7 T) using 3D ultra-short echo time (UTE) and zero echo-time (ZTE) imaging. The results obtained at 11.7 T were compared with the one acquired at 7 T. Furthermore we performed calculation of T_2* values for lung parenchyma with 3D UTE sequences at the two field strength.
Material and methods: Female Balb/c mice (n = 12, 6 week-old, 21.5 ± 0.5 g) were used in the experiment. Six animals were imaged at 7 T and other six at 11.7 T. Anesthesia (isofluorane 1.5-2.5% in a mixture of N_2:O_2 80:20) was varied to maintain respiration constant at about 50 breaths/min. All images were acquired in *freely-breathing* mice.

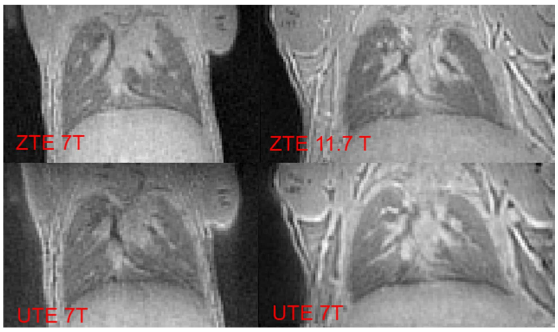

Fig. 1. *Typical coronal MR images obtained at 7 and 11.7 T with ZTE and 3D UTE sequences.*

MRI Protocol: Images were acquired with a 7 T and 11.7 T Biospec spectrometer (Bruker, Ettlingen, D), equipped with the same gradients, using transmitter/receiver quadrature coils of 38 mm and 40 mm inner diameter, respectively. For each animal and B_0, a 3D UTE image (205634 projections, 1 average, 256 isotropic matrix) was acquired with a TE 8µs, FOV 5x5x5 cm^3, TR 4.4ms and FA 3°, BW 300 kHz, for a total acquisition time of about 15 minutes. Similarly for each animal and B0, a ZTE image was acquired using the same geometry and parameters employed for the UTE images acquisition. It should be noted that ZTE intrinsically performs an oversampling of 4 on the explicit BW and has a null TE. Five lower resolution 3D UTE images (isotropic matrix 128x128x128, FOV 4x4x4 cm^3) were acquired with different echo times (8µs, 0.05ms, 0.1ms, 0.25ms, 1.5ms) to compute the T_2* values at the two magnetic fields, for a total acquisition time of ~15min. For all UTE acquisitions, the trajectory needed for reconstruction was acquired in a static phantom prior to in-vivo acquisitions.
MR image analysis: For each animal, lung parenchyma was identified in 4 different slices excluding the main vessels and regions of interest *(ROI)* were manually segmented to measure the total average signal. The noise of the images was quantified as the standard deviation of the mean signal of a ROI selected in the image background and the signal-to-noise ratio in the parenchyma was calculated. T_2* values were computed on ROIs compassing the parenchyma, fitting with a non-linear least-squares algorithm the equation: $S(TE)= S_0*\exp(-TE/T_2*) + NL$, where NL is the noise level established from the dataset acquired at TE=1.5ms. Data obtained at different magnetic fields with UTE and ZTE MRI were compared using a two-way ANOVA test with Sidak's multiple comparison and a 0.05 significance level.
Results: Typical MR images obtained at 7 and 11.7 T are shown in *Fig. 1*. Images of similar quality were achieved with the two magnetic fields, with no significant difference in lung parenchyma SNR, as shown in Fig. 2. Higher SNRs were observed using 3D UTE compared to ZTE both at 7T (SNR UTE: 32.0±0.4, SNR ZTE: 27.9±1.2, p<0.05%) and 11.7 T (SNR UTE: 31.4±1.2, SNR ZTE: 25.8±0.7, p<0.001). Three-dimension UTE showed higher sensitivity to cardiac motion artifacts compared to ZTE, as shown in *Fig. 3*. T_2* values in lung parenchyma resulted being 0.191 ± 0.02ms at 11.7T and 0.235 ± 0.02ms at 7T.

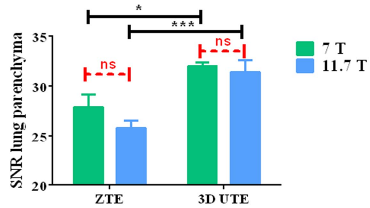

Fig. 2. *Bar plot showing the SNR measured in lung parenchyma at 7and 11.7T with ZTE and 3D UTE.*

Discussion: In recent years, UTE MRI was shown to be an effective sequence to image lung parenchyma. While at lower magnetic fields 2D UTE sequences can be employed to obtain excellent images, at higher magnetic fields the decrease in T_2* is such that extremely low TEs are needed, such as the ones provided by 3D UTE and ZTE. In this work, we have shown for the first time that lung imaging is feasible at ultra-high magnetic fields (11.7 T), and images with SNR in lung parenchyma higher than 30 can be achieved. The SNR obtained at 7T and 11.T were similar: this result may be due to a compensatory effect between higher loss of signal at 11.7 T due to the faster dephasing of the transverse magnetization and the increase in the signal due to the higher magnetic field. This hypothesis is supported by the observation that the T_2* at these two magnetic fields differs of only 20%. Also, it must be noted that, even if care was taken in acquiring data in the most similar conditions possible at the two magnetic fields, two different coils with slightly different inner diameter were used, and this may have had an impact on the comparability of the results. Overall, SNRs in 3D UTE were very close to the one reported at 4.7 T with a 2D UTE sequence of similar acquisition time[1].With respect to the different imaging sequences, ZTE images presented a lower SNR compared to 3D UTE. This is partially due to the intrinsic oversampling of 4 in ZTE, which is needed to compensate for the lack of direct acquisition of k-space center. This should result in a SNR ratio of 2 between UTE and ZTE, which is higher than found here. Other factors which may have a significant impact on SNRs are the lower eddy current artefacts in ZTE and the necessary trajectory acquisition needed for UTE reconstruction, which is a sensitive measurement that strongly effect image quality. Furthermore, SNR in ZTE images could be increase by using the subtraction method proposed by Weiger et al.[2], which may cancel out some of the noise present in the images.

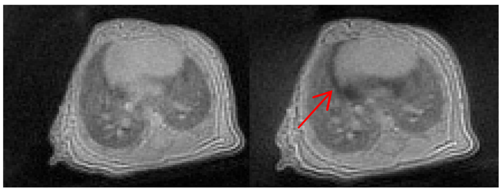

Fig. 3. *Typical axial MR images obtained with (left) ZTE and (right) 3D UTE sequences. The red arrow underlines cardiac motion artefact in the 3D UTE acquisition.*

An interesting result of the comparison is the lower sensitivity of ZTE to motion artifacts, most evident in the heart region: this may be related to the different acquisition and reconstruction methods used in ZTE, where the k-space center, which is the data most sensitive to motion, is estimated from the motion-insentive background signal, and not directly acquired.
Conclusion: In this work we have shown for the first time that lung imaging at ultra-high magnetic fields is a concrete possibility. The decent image quality and the high SNR of lung parenchyma achievable with 3D UTE and ZTE make these protocols suitable for imaging lungs in animal models of respiratory diseases.
References: [1] Bianchi et al., NMR Biomed. 2013; 26(11):1451-9 [2] Weiger et al., NMR Biomed. 2014 Sep;27(9):1129-34.