Introduction
Magnetic resonance imaging of the lung is challenging because of low proton density, respiratory and cardiac motion and susceptibility effects at air-tissue interfaces on small scales. The latter cause a transverse relaxation time $T_2^*$ of lung tissue in the order of one millisecond [1] which makes high-resolution lung images difficult with conventional Cartesian sampled spoiled gradient echo sequences. Spin-spin relaxation $T_2$ of lung tissue is in the order of 40-80 ms at 1.5 T. But $T_2$-weighted spin echo sequences are prone to blood flow and not suited for higher resolutions due to SAR limitations. Radial $k$-space sampling schemes should be beneficial for lung imaging since they are robust to motion [2] and they provide sub-millisecond echo times independent of resolution. The relaxation rate $1/T_2^*$ increases linearly with magnetic field strength [3]. However, higher field strength also provides higher signal. In this work, proton MRI of the human lung using a 2D radial spoiled gradient echo technique is compared at field strengths of 1.5 T and 3.0 T.

Materials and Methods
Measurements were performed on a 1.5 T and 3.0 T whole-body MR system (Siemens MAGNETOM Avanto and Trio, Erlangen, Germany) using a 12-channel thorax/spine coil as receiver. A healthy subject (male, age 27) was examined. All images were acquired during one breath-hold in end-expiration. Neither ECG triggering nor contrast enhancement was required. For measurement a 2D radial sequence was used with the following parameters: $TR = 9.0 \text{ ms}$, $FOV = 480^2 \text{ mm}^2$, in-plane resolution $= 0.8^2 \text{ mm}^2$, slice thickness $= 5.0 \text{ mm}$, $FA = 9.0^\circ$, $BW = 303 \text{ kHz}$, radial samples $S = 600$, radial projections $N = 1200$, pulse duration $= 520 \mu\text{s}$, TA $= 22 \text{ s per slice}$. On both MR systems, one measurement was performed with ultrashort echo time $TE = 0.02 \text{ ms}$, no averages. For each measurement, the minimal echo time was chosen which was stipulated by the duration of the slice-selective pulse and the transmit/receive switching time of the coils. Images were reconstructed using Kaiser-Bessel gridding ($W = 4.0$), Hanning filter and zero-filling from matrix size 600 x 600 to 1200 x 1200.

Results
Fig. 1 shows the comparison between 1.5 T and 3.0 T with $TE = 0.77 \text{ ms}$. Eight regions of interest were distributed (upper and lower lobes of both lungs) in the lung parenchyma separated from observable vessels. Average signal-to-noise ratio (SNR) resulted in $6.1 \pm 34\%$ for $B_0 = 1.5 \text{ T}$ and in $5.6 \pm 38\%$ for $B_0 = 3.0 \text{ T}$. This is an average decrease in SNR of 8% in lung parenchyma using 3.0 T compared to 1.5 T with $TE = 0.77 \text{ ms}$. Fig. 2 shows the comparison between 1.5 T and 3.0 T with $TE = 0.02 \text{ ms}$ (half RF pulses). Average SNR in the same regions as above resulted in $5.2 \pm 13\%$ for $B_0 = 1.5 \text{ T}$ and in $8.1 \pm 30\%$ for $B_0 = 3.0 \text{ T}$. This is an average increase in SNR of 56% in lung parenchyma using 3.0 T compared to 1.5 T with $TE = 0.02 \text{ ms}$.

Discussion
The results show that SNR in proton MRI of human lung at 3.0 T is superior to 1.5 T when using a 2D radial sequence with ultrashort echo time. Images of lung parenchyma with sub-millimeter in-plane resolution can be obtained in a single breath-hold with no contrast enhancement and no ECG triggering needed. The signal from lung parenchyma is not significantly different for 3.0 T compared to 1.5 T with $TE = 0.77 \text{ ms}$. However, the visibility of lung vasculature at 3.0 T is increased. With $TE = 0.02 \text{ ms}$, SNR of lung parenchyma is higher at 3.0 T than at 1.5 T. Only half RF pulses with ultrashort echo time show a gain in SNR at 3.0 T. The results suggest that lung imaging with a 2D radial sequence at higher field strengths than 3.0 T might be feasible or even beneficial in terms of SNR and/or resolution. Studies in patients with lung diseases are necessary to validate the clinical impact of the findings presented.

References