^{129}Xe Lung Imaging with a Single-Shot Circular RARE Sequence

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Introduction

The measurement of gas exchange processes in the lung using hyperpolarized ^{129}Xe is a powerful technique with the potential to detect lung pathologies earlier and with higher spatial resolution than currently feasible. One approach is the creation of depolarization maps with the help of Xenon polarization Transfer Contrast (XTC) MRI (1). This method selectively manipulates the magnetization of ^{129}Xe dissolved in tissue (dissolved phase) to encode information about certain lung tissue parameters in the magnitude of the gas-phase longitudinal magnetization, which can then be detected by using a spin-density weighted pulse sequence.

In this work a different approach is presented that employs a prototype of a single-shot circular RARE pulse sequence (2,3) to capture regional gas exchange properties of the lung in the form of a T2 contrast. It takes advantage of the large chemical shift difference (~200ppm) between the ^{129}Xe gas and dissolved phases. At 1.5T the frequency difference of about 3,500 Hz results in dephasing of any transverse magnetization that diffuses into the tissue and subsequently returns to the airspaces (i.e, exchanges between the tissue and gas compartments). Through this mechanism, the gas-phase signal decays rapidly in lung regions with substantial gas exchange. This contrast is generated without specific manipulation of the dissolved-phase magnetization. The technique appears particularly promising because of its inherently high SNR and applicability to lower magnetic field strengths where XTC MRI would be less feasible.

Methods

All experiments were performed on a 1.5-T commercial whole-body imager (Sonata, Siemens Medical Solutions, Malvern, PA). The RF coil was a custom-made transmit-receive birdcage coil (IGC Medical Advances, Milwaukee, WI). The circular *k*-space trajectory consisted of 32 (64) concentric rings along which 256 (512) data points were sampled. The data were gridded onto a subsampled 64×64 (128×128) matrix and Fourier transformed. The following sequence parameters were used: flip angle 90°, effective-TE 9, 81, 288 or 576 ms, FOV 400 or 500 mm, 100-mm slice thickness, 390 Hz bandwidth. The acquisition order of the circles was either inside-out (i.e., from the center of *k* space outward) with 0 or 8 echoes skipped, or outside-in for maximum T2 weighting and resolution.

Four-kg New Zealand rabbits were anesthetized with a mix of Xylazine 1mg/kg and Ketamine 0.1mg/kg and intubated with an endotracheal tube. Over the course of 4 weeks one of the animals had received multiple small injections (0.15ml) of elastase into a segmental right bronchus, mostly in the lower lobe, to induce emphysema. The animal was imaged in the eighth week after treatment began. The animal protocol was approved by our Institutional Animal Care and Use Committee. The animals were ventilated with 60 cc of natural abundance (27% ^{129}Xe) or isotopically enriched (85% ^{129}Xe) xenon gas, polarized to approximately 10-15% via spin exchange with an optically pumped rubidium vapor (Model IGI 9600Xe Xenon Polarizer, MITI, Durham, NC). The polarizer had been modified to boost the achievable polarization levels.

Results

Figure 1 depicts the dependence of the image appearance on the amount of T2 weighting. The stronger the weighting (longer the effective-TE), the more magnetization inside the alveoli was destroyed by the gas exchange processes, enhancing the major airways. Due to the T2 decay along the echo train, centrically-ordered images appear blurred. Reversing the acquisition order results in strongly T2-weighted images without blurring. A shorter echo train (32 echoes or fewer) provides more flexibility and yielded a higher image quality.

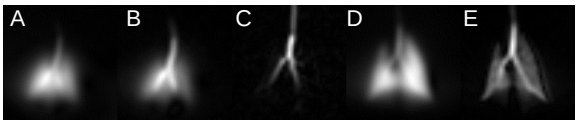

Figure 1: Circular RARE images with different acquisition parameters. A) TE 9 ms, 64 echoes, FOV 500 mm; B) TE 81 ms, 64 echoes, FOV 500 mm; C) TE 576 ms, 64 echoes, FOV 400 mm, outside-in; D) TE 9 ms, 32 echoes, FOV 400 mm; E) TE 288 ms, 32 echoes, FOV 400 mm, outside-in.

Figure 2 illustrates how the exchange dependent contrast can be used to detect regions of lung tissue destruction, for instance, in emphysematous lung. By varying the threshold for the pixel intensities that are displayed, areas of tissue breakdown are highlighted (lower row). No such regions are enhanced in normal lung (upper row). The lung region detected as emphysematous by our technique is in excellent agreement with independently acquired apparent diffusion coefficient (ADC) maps that showed a concomitant ADC elevation.

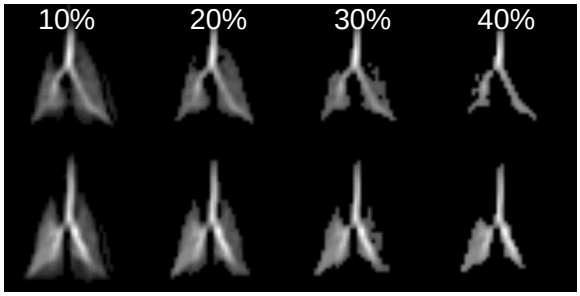

Figure 2: Signal intensity at 4 different threshold levels for a healthy (upper row) and emphysematous (bottom row) lung. All pixel values below the shown percentage of the maximum intensity are set to zero. The residual asymmetric signal intensity outside the major airways in the emphysematous lung at 40% outlines the region with the most lung tissue destruction.

Discussion

Spin-echo sequences are not commonly employed in hyperpolarized gas MRI. The most promising approach might be that of a single-shot RARE-type sequence because in this case the inevitable imperfections of the refocusing pulses are inconsequential for subsequent excitations. Our results suggest that a particularly interesting application for a T2-weighted RARE-type circular pulse sequence could be ^{129}Xe imaging of the lung where the low inherent diffusion-weighting results in an image contrast that is dominated by the regional gas exchange properties of the lung parenchyma. With this contrast, for instance, all areas with reduced tissue density will appear brighter, which could make the technique suitable for the early detection of emphysema.

References

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Acknowledgements

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