Hyperpolarized Xe129 Ventilation Imaging using an Optimized 3D Steady-state Free-precession Pulse Sequence

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Introduction: MRI using hyperpolarized gases (HPG) provides unique functional and structural information about the lung. However, the agent that has been most commonly used in humans, He3, is in limited world supply and thus, if widespread clinical application of HPG-MRI is to occur, it likely will require the alternative agent, Xe129. The solubility and chemical-shift characteristics of Xe129 permit dissolved-phase measurements that are not possible with He3. Nonetheless, even considering this potential advantage of Xe129, it would be very desirable to perform gas-space measurements with Xe129, which were pioneered in humans using He3 (e.g., ventilation, ADC, dynamic, pO_2), with quality similar to that demonstrated by using He3. To achieve this goal, it is necessary to take advantage of every opportunity to increase the SNR, since the gyromagnetic ratio for Xe129 is about 3 times smaller than that for He3. It was recently demonstrated with He3 that an optimized, 3D steady-state free-precession (SSFP) pulse sequence can yield 3-4 times higher SNR than widely-used low-flip-angle spoiled-GRE methods [1-3]. In this work, we explored the potential of using 3D SSFP for ventilation imaging with Xe129.

Methods: A 3D-SSFP (TrueFISP) pulse sequence was implemented for Xe129 imaging on 1.5T (Avanto, Siemens Medical Solutions) and 3T (Trio) whole-body MR scanners. Based on the design approach outlined in reference 3, the flip angle was optimized to (theoretically) yield maximum SNR given selected limits on the data sampling period (and, hence, TR), assuming an apparent diffusion coefficient of 0.04 cm^2/s for Xe129 in the lung. A flexible chest RF coil (Clinical MR Solutions, Brookfield, WI) was used for imaging at 1.5T and a 32-channel array chest RF coil (custom built) [4] was used at 3T. Enriched xenon gas (87% Xe129) was polarized by collisional spin exchange with an optically-pumped rubidium vapor using a prototype commercial system (Xemed LLC, Durham NH). All experiments were performed under a Physician's IND for imaging with hyperpolarized Xe129 using a protocol approved by our institutional review board. Informed consent was obtained in all cases.

3D TrueFISP image sets were acquired in 4 subjects: one healthy subject (3T), two asthmatics (3T for one subject; 1.5T and 3T for the other subject) and one subject with mild COPD (3T). Each subject inhaled approximately one liter of gas containing a mixture of hyperpolarized Xe129 (~ 0.5 L), room air and oxygen; the Xe129 polarization was ~20%. Pulse sequence parameters were: TR, 2.9-4.8 ms; TE, 1.3-2.1 ms; flip-angle, 9-12°; bandwidth, 400-1000 Hz/pixel; matrix, 64 x 48-56 x 60; PE order, sequential; spatial resolution, 6.3 x 6.3 x 6.3 or 6.4 x 6.4 x 6.4 mm^3; acquisition time, 8-14 s.

Results and Discussion: The SNR obtained in central sections of the lung (which, overall, had the lowest values within a given dataset) ranged from 35 to 67, resulting in good quality images in all cases. Example coronal images from a subject with asthma are shown in Fig. 1. Reconstructions in 3 orthogonal planes and a 3D surface-rendering of the lung from the 3D TrueFISP acquisition in a healthy subject are shown in Fig. 2. Numerous ventilation defects were seen in the subjects with asthma (e.g., Fig. 1) and COPD; the disease-specific findings are presented elsewhere.

Previous results indicated that a TR no greater than approximately 2 ms is required for He3 at 1.5T to suppress intensity banding artifacts near the diaphragmatic border [3]. Given that these artifacts arise from the bulk magnetic susceptibility difference at the interface between the lung and abdominal organs, and that the gyromagnetic ratio for Xe129 is about 3 times smaller than that for He3, one would estimate that a TR no greater than approximately 3 ms would be required for Xe129 at 3T to suppress such artifacts. Our results support this supposition; intensity banding artifacts were seen near the diaphragmatic border for a TR of 4.8 at 3T as shown in Fig. 3, whereas they were suppressed for a TR of 2.9 at 3T (Fig. 2).

Conclusions: An optimized implementation of 3D-SSFP imaging combined with ~0.5 L of Xe129 polarized to 20% provides good quality 3D ventilation images of the lung with 6-mm isotropic spatial resolution. These results demonstrate that Xe129 ventilation images can be obtained with quality and spatial resolution similar to that demonstrated by using He3. By using larger inhaled volumes of Xe129 and/or obtaining higher polarization, such as already demonstrated with prototype systems [5], further significant improvements are anticipated.

References: **1.** Mugler JP et al. ISMRM 10 (2002); 2019. **2.** Wild J et al. JMR 2006; 183:13. **3.** Mugler JP et al. ISMRM 16 (2008); 2644. **4.** Dregely I et al. ISMRM 17 (2009); submitted. **5.** Hersman FW et al. Acad Radiol 2008; 15:683.

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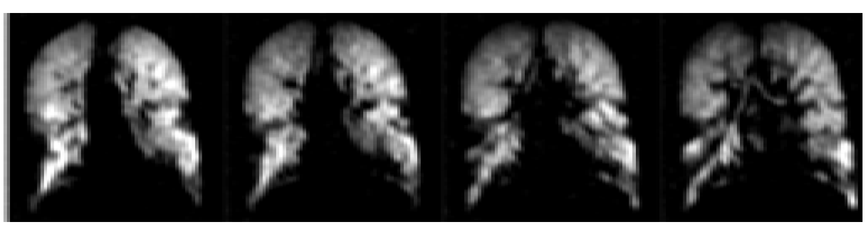

Fig. 1. Contiguous coronal Xe129 images of the lung of an asthmatic from a 3D TrueFISP (TR/TE/FA 4.8/2.1/9°) acquisition with isotropic 6.3-mm spatial resolution.

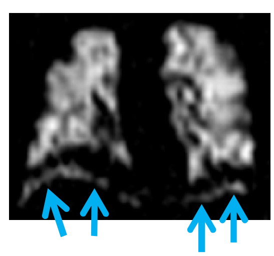

Fig. 3. Coronal Xe129 images of the lung of a subject with mild COPD from a 3D TrueFISP (TR/TE/FA 4.8/2.1/9°) acquisition, illustrating intensity band artifacts (areas of signal loss just above the diaphragm, arrows) that appear when the TR is too long.

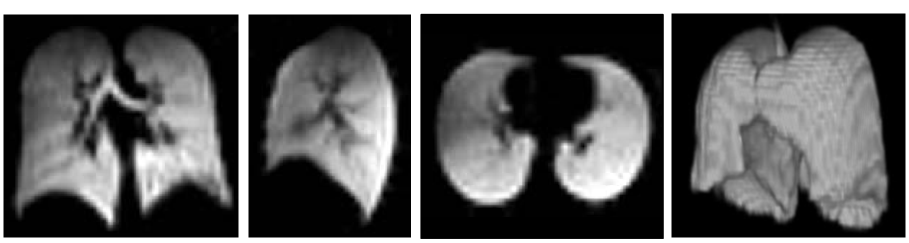

Fig. 2. Coronal, sagittal and axial Xe129 images, and a 3D volume rendering, from a single 3D TrueFISP (TR/TE/FA 2.9/1.3/10°) data set of the lung with isotropic 6.4-mm spatial resolution.