Rapid Hyperpolarized-Gas Lung Imaging using a Parallel-Spiral Acquisition with BOSCO reconstruction

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Introduction: Hyperpolarized-gas MRI using ^{3}He can provide quantitative information about lung structure and function. This noninvasive method is of great interest for studying lung diseases such as COPD and asthma [1]. However, ^{3}He gas is expensive and its supply is limited, and thus it is critical to improve the efficiency of ^{3}He gas usage. Towards this goal, we developed two variable-density spiral sequences for parallel imaging, both of which have the potential to provide very rapid acquisitions and high SNR values. The first sequence used a three-interleaf spiral for readout and the second used a single-shot spiral. Parallel image reconstruction based on successive convolution operations (BOSCO) [2] was used for both.

Methods: The sequences were tested on healthy volunteers on a 1.5T Siemens Avanto scanner using a 24-channel ^{3}He coil (Medical Engineering & Technology Co., New York, NY). The maximum gradient amplitude and slew rate used for the spiral readouts were 18 mT/m and 200 mT/m/ms, respectively. ^{3}He gas was polarized by collisional spin exchange with an optically-pumped rubidium vapor using a commercial system (Magnetic Imaging Technologies, Inc.). All experiments were performed under a Physician's IND for imaging with hyperpolarized ^{3}He following a protocol approved by our institutional review board. Informed consent was obtained in all cases.

First, the multi-shot spiral sequence was tested with acceleration factors up to 4. A three-shot spiral with 16.4 ms per interleaf permitted spatial resolution down to approximately 1.2 mm over a 250 mm FOV. Subsequently, the single-shot spiral sequence was tested with acceleration factors up to 4.

The training data for BOSCO reconstruction requires an undersampled target. In single-shot imaging, the target data cannot be generated by discarding interleaves as is possible in multi-shot imaging. Therefore, inverse gridding [3] was used to generate this training target from the fully-sampled central portion of k space. This procedure is accomplished in three steps: (1) grid the fully-sampled k-space center to a regular grid; (2) synthesize a multi-shot spiral trajectory covering the same area in k-space; and (3) use convolution to interpolate the data to the multi-shot spiral trajectory. For instance, for an acceleration factor of 3, a multi-shot spiral with at least three interleaves is needed. The multi-shot and single-shot spiral should have similar resolution and FOV in the image domain, and therefore similar coverage and sampling density in k space. Finally, inverse gridding is used to obtain the undersampled data. Fig. 1 shows a variable-density spiral example. In Fig. 2, the fully-sampled portion of a single-shot spiral and a single interleaf from a three-shot spiral are plotted together for illustration. Note that the fully-sampled center needs to have enough samples for BOSCO training. Ideally, the number of fully-sampled points should be proportional to the acceleration factor, although this slightly decreases the resolution.

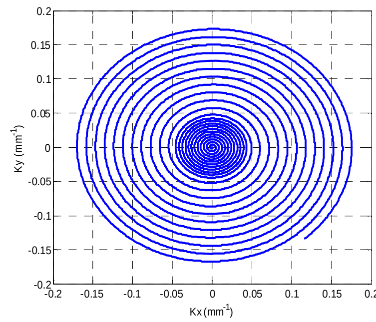


Fig. 1. Single-shot spiral with acceleration factor 3.

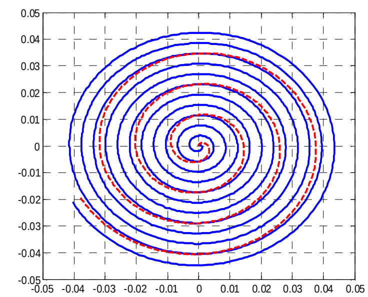
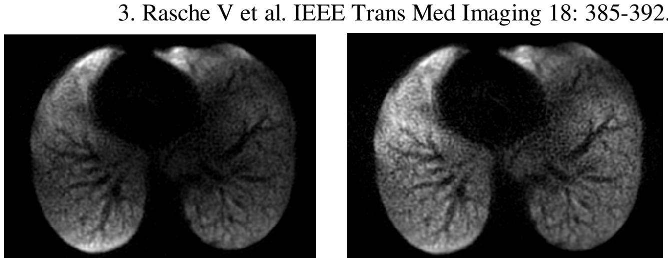


Fig. 2. Fully-sampled trajectory (solid blue) and undersampled trajectory (dashed red) for inverse gridding that covers similar area.

Results and Discussion: Representative imaging results from healthy volunteers are shown in Figs. 3 and 4. For Fig. 3, the data was collected using a three-shot spiral and acceleration factor 3 (acquisition time per slice ~75 ms, nominal in-plane resolution 1.2 mm), and for Fig. 4 a single-shot spiral with acceleration factor 2 was used (acquisition time per slice ~40 ms, nominal in-plane resolution 2 mm). The images in Fig. 3(a) and Fig. 4(a) were reconstructed using BOSCO and inhomogeneity correction from [4]. The images in Fig. 3(b) and Fig. 4(b) were improved by using a polynomial fit to reduce coil intensity variations.

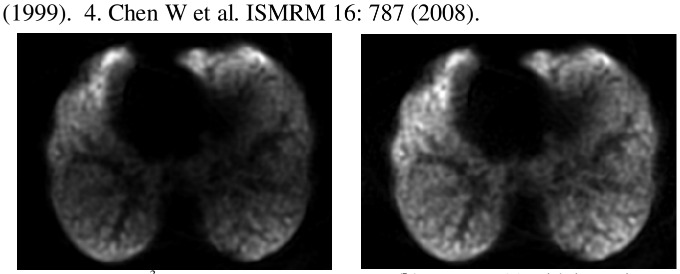
Conclusion: We developed two variable-density parallel-spiral sequences with BOSCO reconstruction for rapid lung imaging using hyperpolarized ^{3}He. These sequences yielded images with spatial resolution and image quality comparable to standard GRE images. We also developed the first BOSCO image reconstruction technique for single-shot spiral, using inverse gridding for BOSCO training. Future work will concentrate on optimizing the flip angles to maximize SNR, and on developing a 3D parallel-spiral acquisition.

References: 1. Fain SB et al. JMRI 25:910–923 (2007). 2. Hu P et al. ISMRM 14: 10 (2006).
3. Rasche V et al. IEEE Trans Med Imaging 18: 385-392. (1999). 4. Chen W et al. ISMRM 16: 787 (2008).



(a) Axial ^{3}He image from BOSCO reconstruction **(b)** Image (a) with intensity variations corrected

Fig. 3. Results from three-shot parallel-spiral sequence



(a) Axial ^{3}He image from BOSCO reconstruction **(b)** Image (a) with intensity variations corrected

Fig. 4. Results from single-shot parallel-spiral sequence

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