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


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Introduction: Hyperpolarized-gas MRI using 3He 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, 3He gas is expensive and its supply is limited, and thus it is critical to improve the efficiency of 3He 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 3He 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. 3He 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 3He 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.

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 3He. 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.


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