Optimized Gridding Reconstruction for 3D Radial MRI of Hyperpolarized ^{129}Xe

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Target Audience: Hyperpolarized ^{129}Xe MRI, Preclinical Lung MRI

Purpose: Hyperpolarized (HP) ^{129}Xe has enabled high-resolution in vivo MRI of pulmonary anatomy and function in a variety of diseases. However, HP gas MRI also faces well-known challenges, notably its small, transient, and non-recovering signal. These problems are well addressed by 3D radial acquisition, which is insensitive to magnetization dynamics, robust to undersampling, exhibits minimal gradient-induced diffusion attenuation, and achieves ultrashort TE and short TR. However, despite its advantages, 3D radial MRI has not been broadly adopted for HP gas. One likely cause for this lies in the challenge of reconstructing non-Cartesian data. Briefly, radial reconstruction requires using a convolution kernel to distribute radially acquired data into evenly spaced k-space samples such that the image can be reconstructed by the computationally efficient fast Fourier transform. This seemingly benign process must be carefully tuned to minimize reconstruction error. Specifically, one must consider oversampling ratio, density compensation, kernel function, kernel sharpness, and kernel extent, each of which requires tradeoffs. Such reconstruction issues have been extensively considered for proton MRI applications[1], but similar attention has not been paid to the unique constraints of HP gas imaging. This work explains and optimizes non-Cartesian reconstruction parameters specifically for radially acquired HP gas MRI.

Methods: A high-resolution, 3D radial ^{129}Xe MRI test data set was acquired from a 6-week old, mechanically ventilated Balb/c mouse on a 2T preclinical MRI scanner. ^{129}Xe ventilation images were acquired using the following parameters: FOV = 2 cm, BW = 8 kHz, 2501 rays, 64 samples/ray, 5 rays/breath, TR/TE = 10/0.384 ms, $\alpha = 30^0$, and a 132 µs hard pulse. This data set was reconstructed while varying and optimizing oversampling ratio, density compensation, kernel function, kernel sharpness, and kernel extent.

Results: Firstly, HP gas ventilation MRI is uniquely affected by the long extent of the trachea, which causes wrap around artifacts that can be largely removed by oversampling (Fig 1). Secondly, the non-uniform sampling of k-space over emphasizes densely sampled low spatial frequencies, which is ideally mitigated using an iterative density compensation algorithm[2] (Fig 2). Finally, the large amount of undersampling often required in HP gas imaging causes high frequency aliasing. Such aliasing can be reduced during the iterative density compensation process by tuning the gridding kernel to appropriately penalize aliased frequencies (Fig 3). Compared to our prior reconstruction[3], our fully optimized reconstruction maintains SNR while exhibiting reduced artifacts and improved resolution. Whereas, our prior reconstruction could resolve only 4-5 generations of airways in the mouse lung, the optimized reconstruction readily reveals 6 generations, despite sampling only ~5% of the rays required to meet the Nyquist limit.

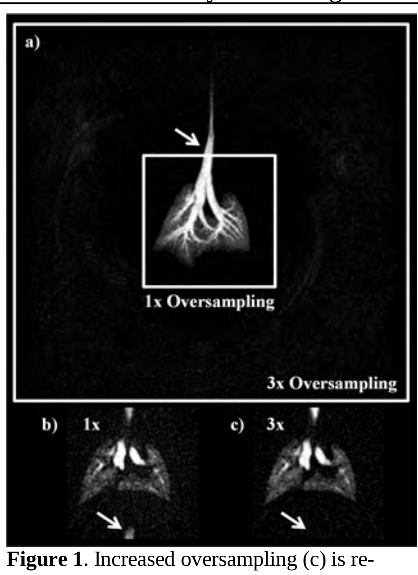

Figure 1. Increased oversampling (c) is required to avoid wrap around artifacts (b) caused by the long extent of the trachea.

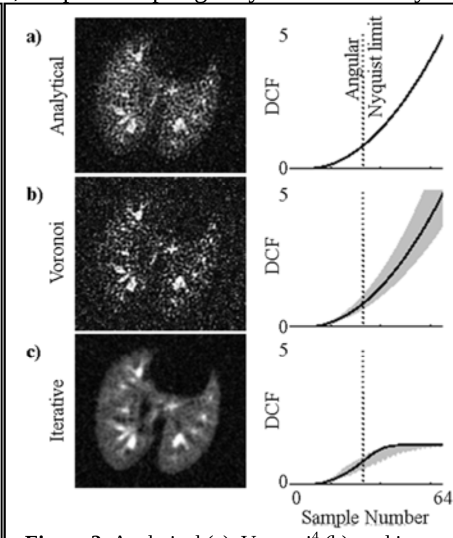

Figure 2. Analytical (a), Voronoi[4] (b), and iterative[2] (a) methods vary in compensation of k-space undersampling and nonuniform sampling. Grey shading illustrates the range of DCF values.

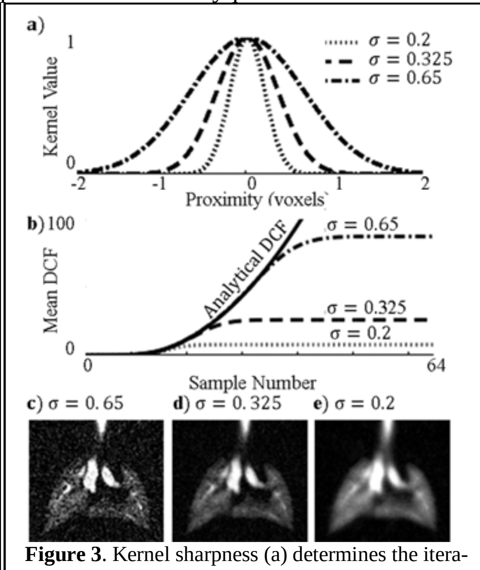

Figure 3. Kernel sharpness (a) determines the iterative DCF rolloff (b). Broad kernels (c) result in noisy images. Sharp kernels (e) result in blurry images.

Discussion and Conclusion: This study shows the importance of tuning 3D radial image reconstruction parameters specifically for HP gas applications. Future work will apply the optimized reconstruction to clinical ^{129}Xe MRI with a focus on compensating for the decay of magnetization and using iterative reconstruction techniques to image temporal dynamics and gas exchange.

Acknowledgements: R01HL105643 and NIBIB P41 RR005959

References: [1] Beatty et al., IEEE T Med Imaging 2005; 24(6): 799-808; [2] Pipe et al., MRM 1999; 41(1): 179-186, [3] Song et al. IEE T Bio-Med Eng 2009; 56(4): 1134-1142; [4] Rasche et al., Med Imaging 1999; 18(5): 385-392.