Pulmonary MRI of Infants in the Neonatal Intensive Care Unit: Initial Experience with 3D Radial UTE

Andrew D. Hahn[1], Nara S. Higano[2,3], Laura L. Walkup[2], Xuefeng Cao[2,4], Robert P. Thomen[2,3], Jean A. Tkach[5], Charles L. Dumoulin[6,7], Kevin M. Johnson[1], Scott K. Nagle[1,8], Jason C. Woods[2,3], and Sean B. Fain[1,8]

[1]Department of Medical Physics, University of Wisconsin - Madison, Madison, Wisconsin, United States, [2]Center for Pulmonary Imaging Research, Cincinnati Children's Hospital Medical Center, Cincinnati, Ohio, United States, [3]Department of Physics, Washington University in St Louis, St. Louis, Missouri, United States, [4]Department of Physics, University of Cincinnati, Cincinnati, Ohio, United States, [5]Department of Radiology, Cincinnati Children's Hospital Medical Center, Cincinnati, Ohio, United States, [6]Imaging Research Center - Department of Radiology, Cincinnati Children's Hospital Medical Center, Cincinnati, Ohio, United States, [7]Department of Pediatrics, University of Cincinnati, Cincinnati, Ohio, United States, [8]Department of Radiology, University of Wisconsin - Madison, Madison, Wisconsin, United States

Rationale: The paucity of effective options for imaging the neonatal lung has limited our understanding of structural pathologies associated with neonatal lung diseases and development. Access to MR imaging technologies and protocols for patients in the neonatal intensive care unit (NICU) is particularly challenging given the risk associated with removal from the NICU for imaging. Locating an MRI scanner with a smaller footprint in the NICU at Cincinnati Children's Hospital (CCHMC) has enabled safe access for patients; this unique system combines an extremities magnet and gradient system (ONI, now GE Healthcare) with a commercial sate of the art MRI measurement control platform and rf chain (HDx, GE Healthcare). A 3-D radial ultra-short echo time spoiled gradient echo (UTE SPGR) acquisition sequence[1,2] has further allowed imaging of pulmonary structural pathologies at high isotropic spatial resolution while mitigating motion artifact. The small size and increased respiratory rates in neonates make common approaches for respiratory gating, such as respiratory bellows or pencil navigators, unreliable or unacceptably inefficient. For this work, retrospectively gated reconstructions were also achieved using the inherent self-navigation of the center-out radial trajectory, which repeatedly samples the k-space center, which is modulated by respiration and intermittent bulk motion.

Methods: A 1.5T MRI scanner[3] specifically designed for neonatal imaging (21.8cm bore diameter) and located within the Cincinnati Children's NICU was used with a single channel 16-18cm transmit/receive volume coil to acquire 3-D UTE MRI data in a total of 6 infants (4 with bronchopulmonary dysplasia, BPD; 2 controls) with gestational ages of 36-40 weeks. Patients were tidal-breathing quietly without sedation during image acquisition. The UTE implementation details are similar to those described by Johnson et al.[1]. Specifically, a field-of-view limiting slab selective excitation with a minimum-phase Shinnar-Le Roux RF pulse and variable density readout with ≥2x radial oversampling (TE=~250μs; FA=10°; TR=4.4ms-5.2ms; isotropic resolution = 0.68 mm-0.86 mm, slab thickness=120 mm - 220 mm). The number of radial projections acquired per scan was 108,000-120,000, with total time per scan of 5-10 minutes. The dc component of the FID, acquired as the first sample of each projection readout, was used to construct a temporal waveform capturing subject motion. The waveform was first visually inspected to identify and remove projections corrupted by intermittent bulk motion. The rest of the data were retrospectively gated to the respiratory waveform present in the dc component time course using a 50% acceptance window to end-expiration. For comparison, axial 3-D fast gradient echo (FGRE) images using a commercial pulse sequence were acquired (TE=1.9ms; TR=7.7ms; FA=10°, resolution=0.70x0.70mm, 28-32 3mm partitions; 5 averages).

Results: Axial and coronal reformats from scans acquired from 3 patients are shown in **Figure 1** and demonstrate our capability to achieve diagnostic quality at resolutions approaching that of x-ray CT. Parenchymal lung signal is apparent in the T_1-weighted UTE images but less so due to T_2*-weighting in FGRE images. Coherent motion artifacts are not seen in the radial UTE images but are apparent in FGRE images due to the long acquisition time and Cartesian view order. The true volumetric, 3-D, and isotropic nature of the UTE data is apparent through coronal reformats, where similar presentation in the FGRE is heavily interpolated and spatially blurred. Radial acquisition and retrospective gating are effective in reducing respiratory motion blurring and increasing effective resolution, but at the cost of an expected decrease in SNR due to use of only half the acquired samples.

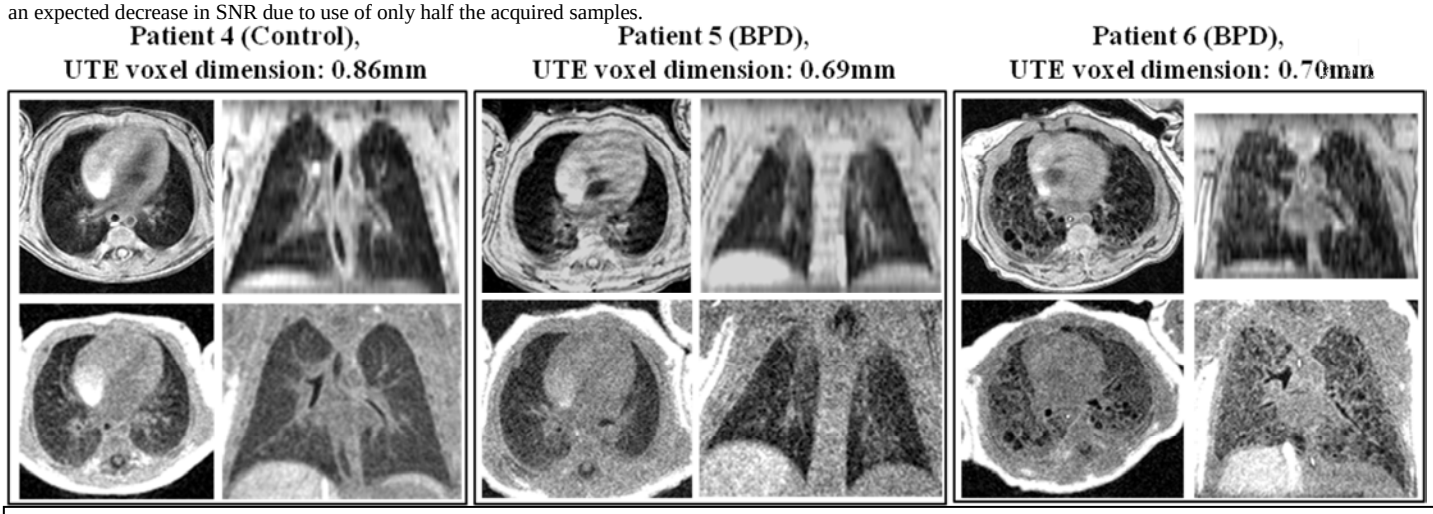

Figure 1. Axial and coronal reformats in data acquired from patients 4-6 from the 3-D FGRE acquisition (top row) and the 3-D UTE acquisition (bottom row). Specific scan parameters for each UTE scans were: *Patient 4 (control)*: UTE: 0.86 mm resolution , ~108,000 total radial projections *Patient 5(BPD):* UTE: 0.69mm resolution, ~108,000 total projections, *Patient 6(BPD)*: UTE: 0.7mm resolution, ~120,000 total projections

Discussion: These results demonstrate good sensitivity to parenchymal lung structures while mitigating bulk and respiratory motion, all at spatial resolutions comparable to CT (0.69 mm). The 3D UTE images in the first 6 patients demonstrate the potential to obtain high resolution, isotropic voxel dimension with reduced coherent motion artifact and blurring compared to FGRE. However, the SNR is qualitatively lower (parenchymal SNR ~10) than desired in 3D UTE MRI, which may be offset by extending acquisition time to acquire more radial projections, possibly in combination with improved parameter settings more appropriate for the T_1 and T_2* values in the lungs of this patient population. The optimal sequence design is related to biophysical parameters in the lungs, most notably the parenchymal T_1 and T_2^* relaxation times, which drive the optimal choices for flip angle, TR and readout duration. Our parameter choices in these data are largely based on published values in adults, with some empirical adjustments.

Conclusion: We present strong evidence of the feasibility of diagnostic imaging of parenchymal structure in non-sedated quiet breathing NICU patients with 3-D UTE MRI at resolutions as high as 0.69 mm isotropic. Self-navigated properties of the acquisition allow mitigation of bulk and respiratory motion, which is a particular challenge in non-sedated infants. Longer acquisition times should allow improvements in SNR and allow more tightly windowed retrospective respiratory gating, yielding further improvement in spatial resolution.

References: 1) Johnson et al,*Magn Reson Med* 2013 Nov;70(5):1241-50. **2)** Togao et al. *Magn Reson Med* 2010;64:1491–1498. **3)** Tkach et al., AJR *Am J Roentgenol*, 2014 Jan;202(1):W95-W105.