Self-Gating of Respiratory Motion for Pulmonary Ultra Short Echo Time MRI of Infants in the NICU

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Rationale: Radial 3D pulmonary magnetic resonance imaging (MRI) with ultra-short echo time (UTE) enables high resolution imaging of the lung parenchyma without ionizing radiation using breath-hold and/or prospective respiratory gating[1,2]. However, pediatric subjects cannot reliably perform a breath hold, and their small size and increased respiratory rates (>15 breaths per minute (bpm)) make respiratory bellows or pencil navigators unreliable or unacceptably inefficient. Additionally, the high likelihood of intermittent bulk motion in this population, especially in non-sedated or minimally sedated infants, makes use of these strategies even more problematic. In this work we demonstrate the feasibility for performing retrospective respiratory gating in quiet-breathing, non-sedated neonates, using the self-navigation properties of a 3-D center-out radial UTE trajectory for high resolution pulmonary structural imaging. This acquisition scheme repeatedly samples the k-space center (i.e. dc component), which is modulated by respiration and intermittent bulk motion. Using this signal we are able to mitigate the effects of intermittent bulk motion and retrospectively reconstruct images at both end-expiration and end-inspiration.

Methods: 6 neonatal intensive care unit (NICU) patients were imaged without sedation while quietly breathing using a unique, small footprint, 1.5T MRI[3] scanner located within the NICU at Cincinnati Children's Hospital using a 3-D UTE MRI pulse sequence, similar to that described by Johnson et. al.[1] (TE=~250μs; FA=10°; TR=4.4ms-5.2ms; isotropic resolution = 0.68 mm-0.86mm). Subjects included patients diagnosed with bronchopulmonary dysplasia (BPD) (N=4) and patients with putatively normal lung function serving as controls (N=2). The magnitude of the dc signal component was extracted from the raw acquired projection data and processed in MATLAB (Mathworks, Natick, MA.) to remove noise and high frequency components unrelated to respiration. The dc time course was smoothed, first using a 200ms sliding window average, followed with a locally weighted least squares regression (LOWESS)[4], fit at each point using the surrounding 1 second of data. The smoothed waveform was then baseline-corrected using a 10 sec sliding window median filter, and periods of intermittent bulk motion were manually identified and excluded. The resulting data were binned at end-expiration and end-inspiration with 50% acceptance windows. Ungated and retrospectively gated images were compared for qualitative assessment, and lung volume changes between inspiration and expiration.

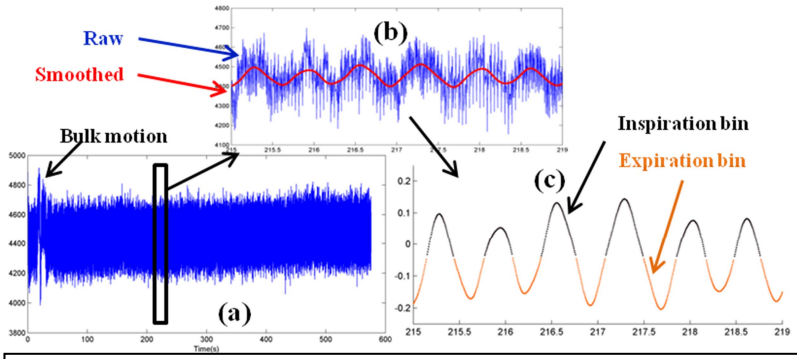
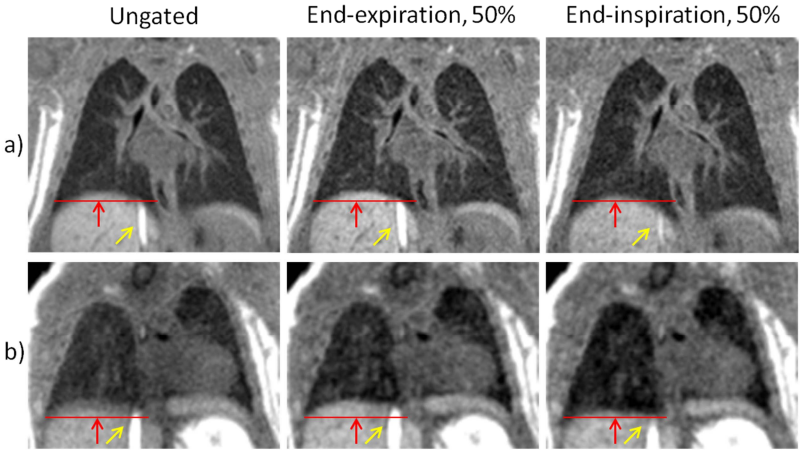


Figure 1 (above): **(a)** Magnitude time course of dc-component for a single subject, with a period of bulk motion identified. **(b)** magnified portion of dc-component time course, along with smoothed result. **(c)** Smoothed dc-component time course from (b) color coded to indicate expiration or inspiration bin assignment.

Figure 2 (below): Ungated coronal reformat from control patient, subject number 4, (a) and patient with BPD, subject number 3, (b), and the same image retrospectively gated at end-inspiration and end-expiration with 50% acceptance. Red arrows indicate diaphragm position; yellow arrows identify the inferior vena cava.

Table 1. Tidal volume and breaths-per-minute in each of the 6 imaged subjects

Subject Number	Control/BPD	Breaths-per-minute (bpm)	Tidal Volume (mL)
1	BPD	56	13.37
2	Control	50	6.10
3	BPD	60	10.50
4	Control	28	10.03
5	BPD	94	12.12
6	BPD	44	5.59



Results: The raw dc magnitude signal from a single acquisition in a single control subject, as well as the result of the smoothing process is shown in **Figure 1a** and **1b**. The bin assignments for end-inspiration and end-expiration binning at 50% acceptance are also shown in **Figure 1c.** It is clear that the diaphragm position is higher (superior) at end-expiration than at end-inspiration **(red arrow in Figure 2)**. Tidal volume was measured in this control patient as 10mL and differed among subjects (**Table 1**). Average tidal volume among the subjects was measured as 9.6±3.2mL, corresponding to differences in lung volume of 11.0±6.5%.

Discussion: Respiratory gating at end-expiration and end-inspiration within the respiratory cycle and removal of data corrupted by bulk motion are possible using the dc-component as a self-navigator. This enables quantitative evaluation of tidal volume in infants with disease. Of note for future work, the dc component is also modulated by the cardiac cycle[5], making cardiac gating in neonatal subjects also possible.

Conclusion: We have shown for the first time the ability to perform retrospective respiratory gating of 3-D UTE MRI data acquired in non-sedated neonates with high respiratory rates using the repeatedly-sampled dc component of k-space as a self-navigation waveform. Future studies will further refine the approach to automate bulk motion detection and data removal, include cardiac gating, and improve spatial resolution through narrower acceptance windows and compressed sensing reconstructions to increase signal to noise ratio.

References: 1) Johnson et al,*Magn Reson Med* 2013 Nov;70(5):1241-50. **2)** McConnell et al., *AJR Am J Roentgenol* 1997;168:1369–1375. **3)** Tkach et al., AJR *Am J Roentgenol*, 2014 Jan;202(1):W95-W105. **4)** Cleveland, William S., *Journal of the American Statistical Association 1967*;**74**(368):829–836. **5)** Larson et al., *Magn Reson Med* 2004 Jan;51(1):93-102.