Accelerated Whole-Lung Specific Ventilation Imaging in Large Species with Hyperpolarized Gas MRI

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INTRODUCTION: Pulmonary ventilation is an important marker in obstructive lung diseases, and its non-invasive imaging can provide useful information to investigate the onset and severity of these pulmonary disorders, as well as to assess response to therapy. Hyperpolarized gas MRI has provides a sensitive and noninvasive platform to directly image distribution of respiratory gas at a high resolution. However quantitative imaging of ventilation still remains as one of the least developed methodologies based on this technology. An improved technique for regional measurement of specific ventilation (r) developed by authors attempted to address this unmet need based on early work of Deninger, *et al.* [1]. This work integrates a parallel acquisition acceleration scheme to extend the utility of this method to whole-lung ventilation imaging in large species with pulmonary volumes comparable to humans.

METHODS: The multi-slice specific ventilation imaging technique is schematically shown in **Figure 1**, for the case of three slices covering the entire lung. Extension to higher number of slices is straightforward. However imaging acquisition time needs to be considered to avoid an undesirably long breath-hold between each pair of acquisitions. For this purpose a GRAPPA undersampling scheme [2] was used along with an 8-channel receive RF coil to accelerate the image acquisition with 16 reference phase encode lines and a undersampling ratio of 4, for an effective acceleration factor of 2 (to acquire a 64×48 matrix per slice). Specific ventilation, r, defined as the ratio of the inspired gas volume to the total end-inspiratory volume, was measured on a regional basis using the technique described earlier [1], with unique features for large species. Briefly the signal buildup in breaths 1–N are fit to a dynamic recursive signal buildup equation to yield specific ventilation on a regional basis. The image train at the last breath uses the almost saturated airways with HP gas to obtain an estimate of B_1 field for the loaded RF co-registered with the ventilation map. The technique was tested on male Yorkshire pigs (n=5, BW=20~25-kg) intubated with 6.5-mm ET tube and mechanically ventilated on room air at V_T=200mL @ 14~18BPM and I:E=1:2. The breathing gas was switched to ^{3}He:N_2 over N=7 breaths for imaging. A multi-slice gradient echo MRI pulse sequence was used on 3 coronal slices with: FOV=24×24cm^2, α=3~4°, ST=30mm, and T_R/T_E=7.0/3.3ms. Voxels with SNR< 6 were excluded from analysis. Correction for intraslice diffusion effects during the breath-hold was judged negligible compared to imaging time and was not pursued.

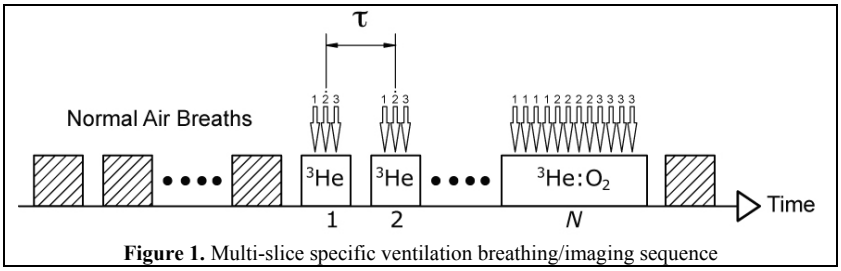

Figure 1. Multi-slice specific ventilation breathing/imaging sequence

RESULTS AND DISCUSSION: Whole-volume (3-slice) accelerated maps of r (versus single-slice images shown in earlier works) were acquired in ventilated Yorkshire pigs in approximately 1 sec per breath – half the time of the standard technique, with r = 0.24±0.15, 0.21±0.14, 0.24±0.14, 0.20±0.13 (standard) compared to 0.21±0.13, 0.19±0.14, 0.23±0.11, 0.16±0.13 (accelerated), as shown in **Figure 1** for middle slice only. Accelerated technique underestimated the r value by approximately 13%. This observation is most likely a systematic function of the accumulated RF pulse effect. The acceleration scheme reduced the number of RF pulses by half (24 vs. 48), which may require a further adjustment in the signal dynamic model to correct for the accumulative effect of this irrecoverable source of depolarization. The flip angle estimation scheme (performed over the final breath-hold) can be responsible for overestimation of the α value in the accelerated scheme. Nevertheless the two measurement techniques correlated very well throughout the entire lung for all five animals as shown in **Figure 2**, except for pig #5 which suffered from a poor SNR due to technical difficulties.

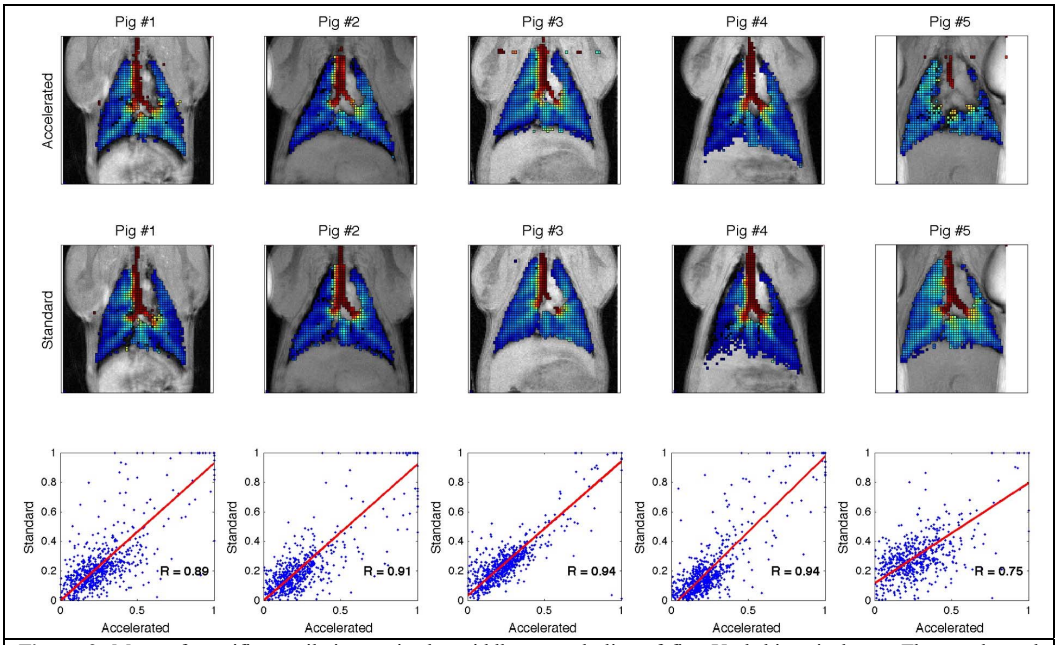

Figure 2. Maps of specific ventilation, r, in the middle coronal slice of five Yorkshire pig lungs. The accelerated ventilation imaging technique (top row) underestimates the r value by approximately 13% compared to the standard technique (middle row). The measurements nevertheless correlate well on a regional basis (bottom row). Hot red color represents regions with near-unity ventilation, i.e. conductive airways.

CONCLUSIONS: The accelerated acquisition scheme for imaging specific ventilation effectively reduced the total imaging time by a factor of two as implemented in mechanically ventilated Yorkshire pigs. In addition to retaining the breathing pattern closer to normal conditions, this technique is less sensitive to the accumulative RF effect, as well as O2-induced depolarization of ^{3}He, which collectively improve the accuracy of r measurements, and encourages transition to voluntarily breathing human subjects.

REFERENCES: [1] Emami K, *et al.*, Magn Reson Med. 2010 Jan; 63(1):137-50. [2] Griswold MA, *et al.*, Magn Reson Med. 2002 Jun;47(6):1202-10.