Redistribution of Fractional Ventilation after Circumscribed Primary Lung Injury and Atelectasis

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TARGET AUDIENCE: Hyperpolarized noble gas MRI researchers, pulmonary physiologists, clinicians.

PURPOSE: Mechanical stress caused by the ventilator is a major contributor to the genesis of acute respiratory distress syndrome (ARDS) after an initial insult to the lungs. However, it is not clear how tidal volume (VT) damages healthy lung tissue when the primary injury is limited and inspiratory stress is moderate. Atelectasis in the setting of mild primary injury could regionally augment ventilatory stress in functional airspaces. Using hyperpolarized (HP) ^{3}He MRI, we explored the effects of circumscribed lung injury and atelectasis on maps of regional fractional ventilation (r), an established measure of peripheral airspace dynamics during tidal breathing. We hypothesized that: a) poor lung recruitment (i.e. reopening of atelectasis) augments the effects of moderate VT on healthy parenchyma, and b) circumscribed lung lesions redistribute ventilation to aerated airspaces, thus increasing inspiratory stress.

METHODS: Ten supine anesthetized and intubated rats were randomly split into two cohorts. Six rats were ventilated with low VT (6ml/kg) and zero positive end-expiratory pressure (PEEP) for two hours to create atelectasis. HP MRI was performed every hour and after a recruitment maneuver (PEEP 9 cmH_2O applied for one minute). Four rats received circumscribed lung injury by selective endobronchial hydrochloric acid (HCl) injection (pH 1.25, 0.4 ml/kg via wedged micro-catheter). HCl was labeled with evans blue to confirm the site of injection during necropsy. All rats were ventilated with VT 10 ml/kg during the whole experiment. HP MRI was performed at healthy baseline (at zero PEEP), after HCl (at both zero and 9 cmH_2O PEEP), and twice during a 30-minute period of ventilation at zero PEEP. In both groups, r maps were obtained from series of HP MRI images acquired during inspiration of six HP ^{3}He breaths using the centric gradient echo sequence [1]. Two coronal (anterior and posterior) 10mm thick slices were studied.

RESULTS: Prolonged low-VT ventilation in healthy rats increased mean r **(Figure 1)**, while the recruitment maneuver partially restored lower values of r. Changes of r were more evident in the dorsal slice, likely due to larger buildup of atelectasis in dependent lung regions. Local HCl injection involved a small portion of lung tissue, as shown in **Figure 2** (insert photograph). After injury, HP ^{3}He MRI showed areas of heterogeneous over-ventilation, likely resulting from the loss of functional airspaces in the injured region. Imaging at PEEP 9 cmH_2O showed more homogeneous distribution of r, although residual over-ventilation persisted near the injury. This improved distribution of ventilation was not maintained once PEEP was returned to zero; r and its distribution heterogeneity further increased during subsequent ventilation.

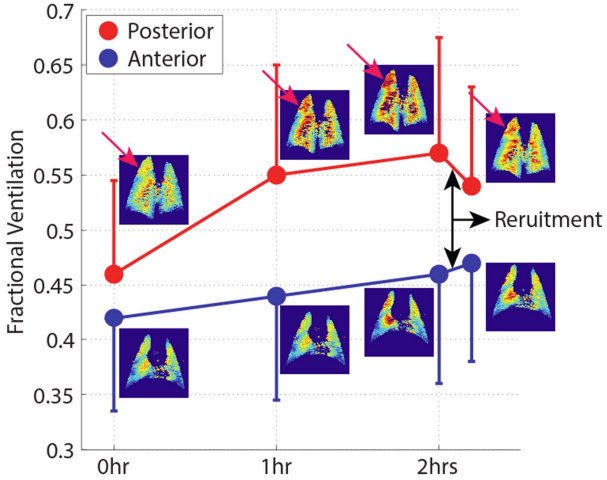

Figure 1. Representative r maps of prolonged low VT ventilation.

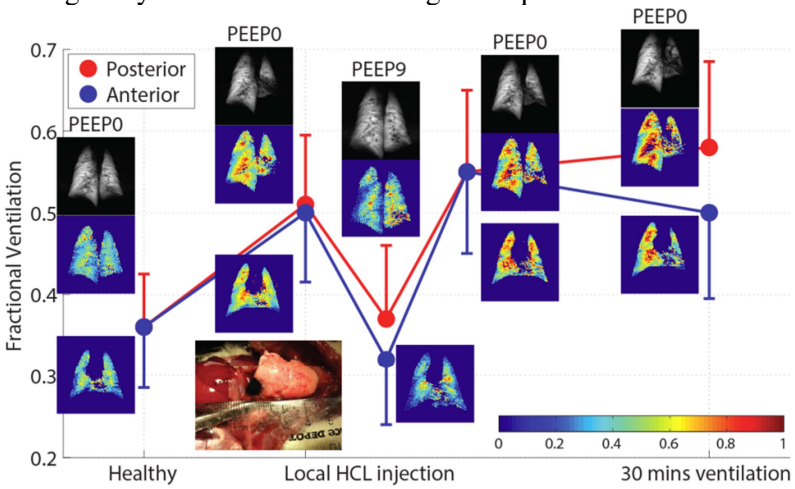

Figure 2. Representative r maps of before and after the local HCl injection

CONCLUSION: Atelectasis and circumscribed lung injury caused redistribution of inspired gas to residual ventilated airspaces, resulting in their over-ventilation and potentially harmful ventilatory stress. PEEP and recruitment attenuated the maldistribution of ventilation in both healthy and injured rats, although the effect of recruitment was not sustained in the rats with HCl injury. This was likely because of higher alveolar instability in injured vs. normal rats. Regional over-ventilation and stretch could have a role in explaining the harmful effects of moderate VT on the evolution of circumscribed injury after a mild primary insult to the lungs.

REFERENCE: [1] Emami K, *et. al.* Magnetic resonance in medicine. 2010;63(1):137-50.