Imaging Ventilator-Induced Alveolar Overdistension with Hyperpolarized Xenon Diffusion MRI

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

PURPOSE: Atelectasis during mechanical ventilation and anesthesia redistributes inspired gas to residual ventilated airspaces, causing overdistension and excessive mechanical stress of the alveolar walls. This can result in dissemination of ventilator-induced lung injury without proper treatment. Using hyperpolarized (HP) ^{3}He diffusion MRI in rats, we previously showed that recruitment of atelectasis with positive end-expiratory pressure (PEEP) attenuates airspace overdistension at the acinar level [1]. The aim of this study was to examine the effects of atelectasis and recruitment on airspace dimensions in a large animal model using a more widely available HP gas: ^{129}Xe.

METHODS: Five Yorkshire pigs (20-25 kg) were anesthetized, intubated, and mechanically ventilated at zero PEEP (ZEEP) with constant tidal volume of 10 ml/kg at 18 bpm. Four pigs were ventilated in the supine position (two pigs with ~60%Xe/15%N_2/25%O_2, one pig with ~45%Xe/30%^{4}He/25%O_2, one pig with ~75%Xe/25%O_2). One additional pig was ventilated (~60%Xe/15%N_2/25%O_2) in the prone position. After one hour of ventilation at ZEEP (to induce atelectasis), maps of the apparent diffusion coefficient (ADC) were obtained in all pigs, followed by recruitment of atelectasis (applying PEEP 9 cmH_2O for one minute). ADC acquisitions were then repeated shortly after recruitment. ADC was measured by diffusion-weighted imaging using interleaved gradient-echo sequences with b values 0 and 10 s/cm^2 applied during a 7-sec inspiratory holds after breathing the HP enriched ^{129}Xe gas mixture. Three coronal ADC maps were acquired along the anterior (A)-posterior (P) axis.

RESULTS: Representative ADC maps show that regional ADC values were decreased by recruitment in the supine position **(Figure 1)**. Individual ADC values are shown in **Figure 2**. In the supine animals, the effect of recruitment was larger in the dependent lung – i.e., the posterior regions. Peak inspiratory pressure decreased from ~15 to ~12 cmH_2O after the recruitment maneuver, confirming reopening of atelectasis. Recruitment also slightly decreased ADC in the prone position **(Figures 1 and 2),** but the vertical gradients of ADC and the effects of recruitment were attenuated compared with the supine position. The Xe/^{4}He/O_2 gas combination resulted in high ADC values due to facilitation of Xe diffusivity by the smaller ^{4}He atom mass as compared with N_2 or O_2.

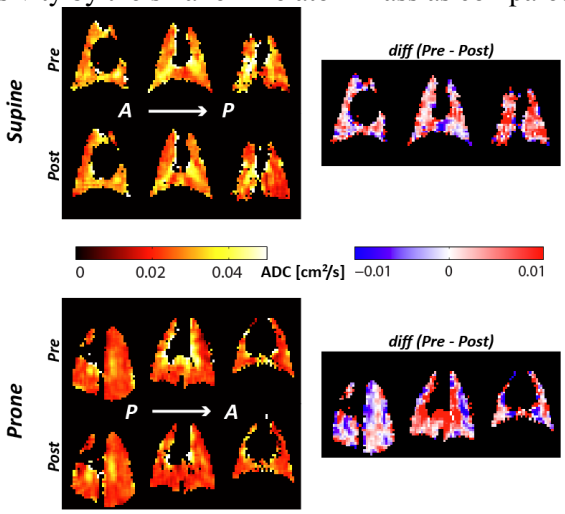

Figure 1. Representative ADC images obtained pre- and post-recruitment in the supine and in the prone posture. The coronal images were acquired along the anterior (A)-posterior (P) axis. The change of ADC due to recruitment is shown on the right for all image levels.

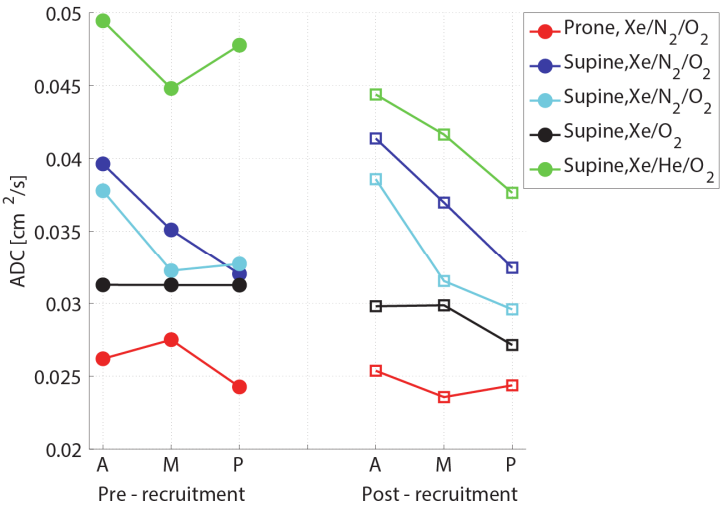

Figure 2. The average ADC of anterior (A), middle (M) and posterior (P) of the lung of pre- and post- recruitment maneuver.

CONCLUSION: Alveolar recruitment maneuvers caused ADC to decrease, a finding that was likely due to redistribution of inspired gas to a larger number of newly reopened airspaces. Vertical distribution of atelectasis justifies the larger effects of recruitment on ADC in the dependent lung regions in the supine animals. The more homogeneous gas distribution characteristic of the prone position explains the smaller effect of recruitment in the prone animal. These results in an atelectasis-prone large animal model support the use of HP xenon MRI to investigate the responses of lung microstructure to mechanical ventilation in realistic models of human disease.

REFERENCES: [1] Cereda M, et.al. *Journal of applied physiology*. 2011;110(2):499-511.