Regional Ventilation Differences at Large Lung Volumes Assessed Using Hyperpolarized ^{3}He MRI

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Introduction

It is widely believed that pulmonary expansion in the healthy mammalian lung is very close to being completely homogenous near total lung capacity, defined as that state of expansion at 30cm H_2O transpulmonary pressure. This has been supported by numerous studies in many species, in which morphometric analysis of parenchymal architecture at these large volumes show a remarkable degree of isotropy and homogeneity over different lung regions. Using hyperpolarized ^{3}He MR imaging, we were able to visualize regional ventilation differences at large lung volumes in healthy adults, which were not reported on previously.

Methods

^{3}He MR images were acquired using a Signa 1.5T MRI scanner with an FOV of 46cm, a 256×128 matrix, a Fast GRE pulse sequence, and a 14° flip angle. Static ventilation scans were performed for two different breathing protocols on six subjects in the supine position. During these scans, subjects were instructed to inhale a ^{3}He/N_2 gas mixture (consisting of 330ml of hyperpolarized ^{3}He, and 670ml of nitrogen) from a 1-liter Tedlar bag as quickly as possible, then hold their breath. Scanning began immediately upon breath hold and lasted 10 seconds. The two breathing protocols consisted of static ventilations at functional residual capacity (FRC) and at total lung capacity (TLC). In the former, the subjects' lungs were at FRC before they inhaled the 1-liter ^{3}He gas mixture. In the static ventilation at TLC, the subjects were first instructed to inhale to TLC. They then exhaled 1 liter of air into an empty 1L Tedlar bag, and subsequently inhaled the 1-liter ^{3}He gas mixture from an identical Tedlar bag and held their breath while the scanning was in progress. The images were comprised of 13 slices, each approximately 13cm thick.

Results

Figure 1 depicts mid-coronal slices of ^{3}He multi-slice images of a healthy adult's lungs. The top row shows the static ventilation images of the lungs after inhalation of the ^{3}He gas mixture from FRC. The bottom row shows the images of the same subject's lungs after inhaling the gas at TLC. Note the pronounced difference in signal intensity in the pericardial region of the lungs: at FRC, the signal intensity is relatively homogenous, while at TLC the pericardial region of the lower left lung is characterized by a very high signal intensity with a small amount of hyperintensity in the lower region of the right lung. The same observations were made in all six subjects.

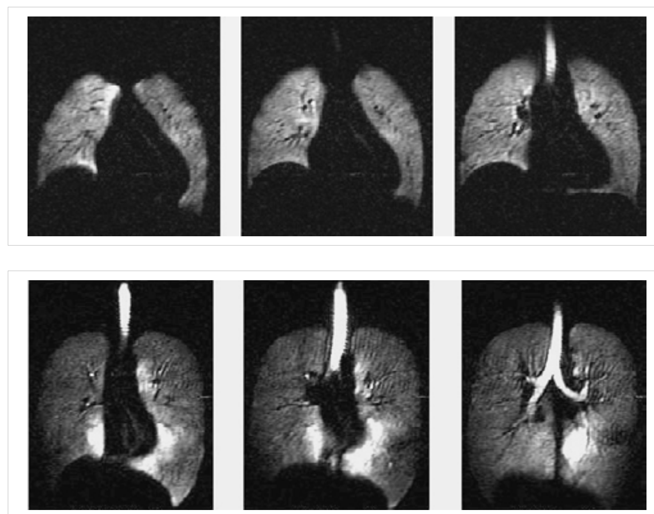

Figure 1: Images from a mid-coronal slice during static breathhold at FRC (top row) and TLC (bottom row).

Discussion

These results show that some regions of the lung (specifically the pericardial region of the left lung), which were ventilated homogeneously during normal breathing near FRC, receive a larger fraction of gas during inhalations near TLC. The high signal intensity in the pericardial region of the left lung that was seen at TLC and absent at FRC is representative of a sharp increase in the ventilatory volume of this region. We are currently in the process of quantifying the volume of gas seen in this high intensity region. Although lung compliance drops at large lung volumes, regional differences in compliance will cause the gas to distribute itself disproportionately, with more volume going into regions of higher compliance. Thus, even small variations in the absolute values of the low compliances that exist throughout the lung near TLC can exhibit large variations in their ratios, and hence the distribution of the final portion of the gas inspirate. Furthermore, the anatomical features of the pericardial region might offer an explanation as to why lung compliance increases specifically in the area seen in the images: The pericardial pleural surfaces are concave, and the pericardial surface in the left hemi-thorax displays the sharpest curvature. Due to the concave nature of this region, any local expansion of the subjacent parenchyma will result in a release of strain and tension, therefore making these regions more compliant and causing a large fraction of the inspirate to expand the pericardial region of the lung.

Conclusion

Using hyperpolarized ^{3}He MRI, we were able to visualize regional ventilation differences at large lung volumes. We found that a large fraction of the inspired gas goes to the pericardial region of the lower left lung, possibly due to its concave nature and believe that the above arguments are consistent with our observations, and in particular, point to a specific anatomic reason for the particular location that we have identified as the site of preferential filling of the last portion of an inspirate.