Alveolar Mechanics During Ventilation

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What happens to the alveoli during ventilation?
Unresolved Mysteries

Intravital Microscopy

J Halter et al. AJRCC 2002; 167:1620-6
Hyperpolarized Gas ($^{3}\text{He}$) MRI
$^3\text{He}$ is polarised

Transported

And inhaled
Maps of Lung Aeration by Hyperpolarized $^3$He Inhalation
A Hybrid Multibreath Wash-in Wash-out Lung Function Quantification Scheme in Human Subjects Using Hyperpolarized $^3$He MRI for Simultaneous Assessment of Specific Ventilation, Alveolar Oxygen Tension, Oxygen Uptake, and Air Trapping

Hooman Hamedani,¹ Stephen Kadlecék,¹ Yi Xin,¹ Sarmad Siddiqui,¹ Heather Gatens,¹ Joseph Naji,¹ Masaru Ishii,¹,² Maurizio Cerda,³ Milton Rossman,⁴ and Rahim Rizi¹*
Apparent Diffusion Coefficient (ADC) as a Metric of Airspace Geometry

- Multiple diffusion sensitizing gradients: ADC
- Signal affected by restricted diffusion of Helium
- ADC estimates the dimensions of ventilated sub-acinar structures

Hyperpolarized gas diffusion MRI of biphasic lung inflation in short- and long-term emphysema models

Yi Xin,1 Maurizio Cereda,2 Stephen Kadlecuk,1 Kiarash Emami,3 Hooman Hamedani,1 Ian Duncan,1 Jennia Rajaie,4 Liam Hughes,1 Natalie Meeder,2 Joseph Naji,1 Harrilla Profka,1 Brian J. Bolognese,5 Joseph P. Foley,5 Patricia L. Podolin,5 and Rahim R. Rizi1
Lung Inflation in ARDS: a Binary Model

Baby Lung

Consolidation/Atelectasis

Bellani et al. CCM 2009

Wellman et al. et al. CCM 2014
Find the ‘Normal’ Lung’
What is the interaction of atelectasis and over-distention?
Quantitative imaging of alveolar recruitment with hyperpolarized gas MRI during mechanical ventilation

Maurizio Cereda,1 Kiarash Emami,2 Stephen Kadlecak,2 Yi Xin,2 Puttisarn Mongkolwisetwarar,2 Harrilla Profka,2 Amy Barulic,2 Stephen Pickup,2 Sven Månsson,3 Per Wollmer,3 Masaru Ishii,4 Clifford S. Deutschman,1 and Rahim R. Rizi2
Imaging the Interaction of Atelectasis and Overdistension in Surfactant-Depleted Lungs*

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Clifford S. Deutschman, MD, FCCM
Rahim R. Rizi, PhD

CT Density

Healthy

Surfactant Depletion

\(^3\)He Density

ADC

[cm\(^2\)/s]

0

0.1

0.2

0.3

0.4

HU

Crit Care Med 2013
Imaging the Interaction of Atelectasis and Overdistension in Surfactant-Depleted Lungs*

Maurizio Cereda, MD; Kiarash Emami, PhD; Yi Xin, MS; Stephen Kadlecek, PhD; Nicholas N. Kuzma, PhD; Puttisarn Mongkolwisetwara, MS; Harrilla Proftka, DVM; Stephen Pickup, PhD; Masaru Ishii MD, PhD; Brian P. Kavanagh, MD, FRCPC; Clifford S. Deutschman, MD, FCCM; Rahim R. Rizi, PhD

![Graph showing PEEP vs Healthy in different time points (0, 3, 6, 9, 12, 15) with images representing (a) and (b).]
Recruitment Reduces Airspace Dimensions

PEEP 0
Recruitment Reduces Airspace Dimensions

PEEP 6
Recruitment Reduces Airspace Dimensions

PEEP 9
Alveolar Interdependence

Healthy

High volume

Low volume

How Much Signal From the Alveolar Ducts?

In-vivo Lung Morphometry

Effects of hysteresis on airspace dimensions

Effects of hysteresis on airspace dimensions
Sub-Voxel Atelectasis

- Schematic representations of light micrographs of healthy rat lungs fixed at 7 cmH2O. Collapsed alveoli are visible as thickened septa (arrows). The dimensions of a CT voxel (100 µm wide) are shown for comparison. 

Redrawn from ref. 30 (Gil J & Weibel. Respiration Physiology 1972; 15: 190-213).
Collateral alveoli?

Example 1

Presssure

Example 2

Mild loss of lung aeration augments stretch in healthy lung regions

Maurizio Cereda, Yi Xin, Hooman Hamedani, Justin Clapp, Stephen Kadlecck, Natalie Meeder, Johnathan Zeng, Harrilla Profka, Brian P. Kavanagh, and Rahim R. Rizi
The Seeds of Lung Injury

Conclusions

• Mystery still unresolved

• Atelectasis increases the size of ventilated airspaces.

• Recruitment attenuates regional airspace distension

• Altered gas distribution at the sub-acinar level may contribute to regional ventilator-induced damage in absence of severe primary injury
# Acknowledgements

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<th>Rahim Rizi</th>
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http://www.med.upenn.edu/fmig/people/
Lung Inflation in ARDS: a Binary Model

Recruit this

“Open up the lung and keep it open”

Consolidation/Atelectasis

Bellani et al. CCM 2009

Wellman et al. et al. CCM 2014
What is the Effect of PEEP on Ventilated Airspaces?

Overview

- Using imaging to measure regional airspace mechanics during mechanical ventilation
- Imaging the effects of atelectasis and recruitment on ventilated lung
Positive End-expiratory Pressure Increments during Anesthesia in Normal Lung Result in Hysteresis and Greater Numbers of Smaller Aerated Airspaces

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Anesthesiology 2013