Hyperpolarized Xenon-129 3D SB-CSI at 1.5 and 3 Tesla MRI

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Financial Disclosure

- I do not have any relationships to report with ACCME defined ineligible companies.

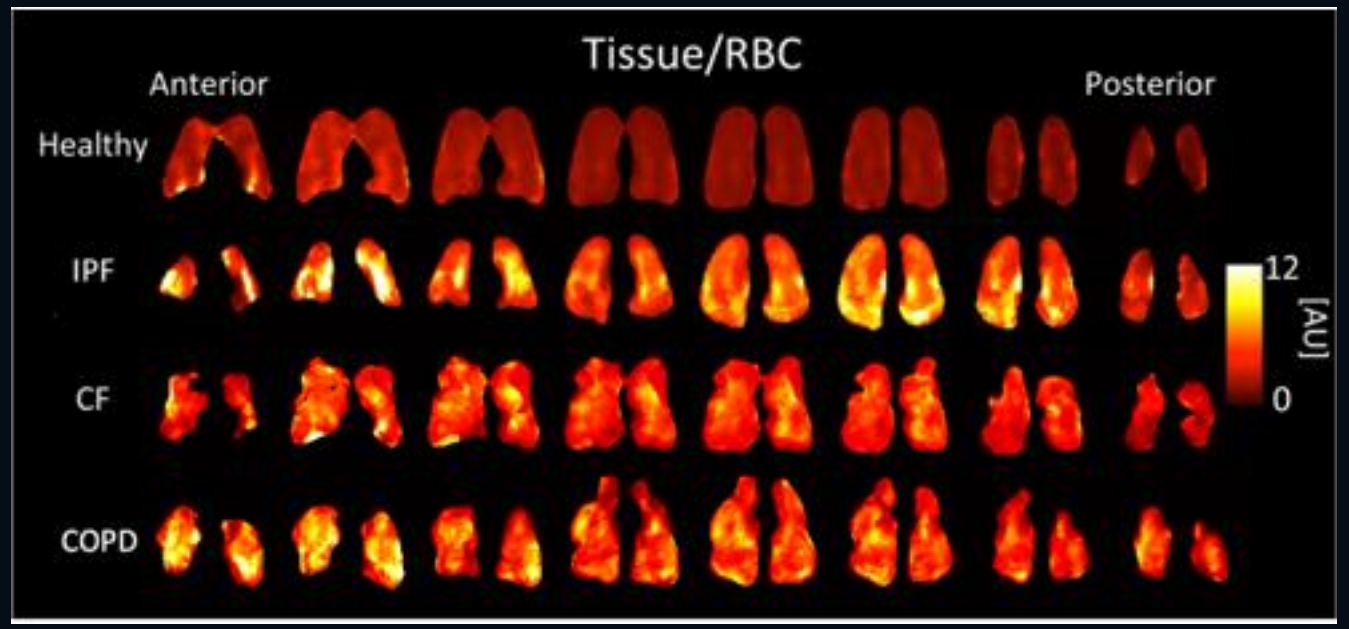
Background

- Traditional assessment of lung function utilizes global measurements such as spirometry/pulmonary function tests.
- However, deficiencies in spirometry arise when subclinical diseases are present, which may not create discernable decreases in global lung function.
- Diseases such as COPD have an indolent progression and early intervention has been shown to improve respiratory rate and decrease mortality rate.
- High-resolution CT is currently the gold-standard for the evaluation of interstitial lung diseases and provides high sensitivity for detecting subclinical interstitial abnormalities.
- However, even low-dose CT exposes participants to ionizing radiation and contributes to increased risk of cancer.

Ebner et al. European J. of Radiology (2017)
Choi et al. J. of Clinical Medicine (2020)
Hatabu et al. The Lancet. Resp. Medicine (2020)
Sodickson et al. Radiology (2009)
Brenner et al. New England J. of Medicine (2007)

Background

- 3D Single-Breath Chemical Shift Imaging (3D SB-CSI) utilizes a combination of MRI with hyperpolarized Xenon-129 (HP Xe-129) gas to generate 3D physiologic maps of the lung.
- Participants inhale a volume of hyperpolarized gas based on 1/3 of their forced vital capacity (FVC), which subsequently diffuses into the lung parenchyma (tissue) and red blood cells (RBCs).
- As a result, ventilation, tissue, and RBC maps can be quantified to locate areas of ventilation defect and abnormalities in tissue diffusion.
- HP Xe-129 gas is non-radioactive and has a low incidence rate of adverse effects.



Tissue/RBC maps generated through 3D Single-Breath Chemical Shift Imaging (3D SB-CSI) of healthy, idiopathic pulmonary fibrosis, cystic fibrosis, and COPD patients at 1.5T MRI.

Guan et al. Tomography (2022)
Driehuys et al. Radiology (2012)
Shukla et al. Academic Radiology (2012)

Background and Rationale

- For the past decade, 3T MRI scanners have become increasingly utilized in diagnostic imaging and research studies.
- As such, it is important to understand the effects that the increased field strength of a 3T MRI has on 3D SB-CSI mapping versus that of a 1.5T MRI.
- This study looked at differences between spectroscopy peaks, mapping, and repeatability between 1.5T vs 3T MRI for 3D SB-CSI imaging.

Subject Cohort

- A total of 17 healthy patients underwent HP Xe-129 3D SB-CSI.
- Each subject underwent spirometry testing and was then imaged in a 1.5T MR and/or 3T MR scanner (Avanto, Siemens Medical Solutions) using a commercial RF coil (Clinical MR Solutions) tuned to the Xe-129 frequency.
- For a direct comparison between 1.5T and 3T, four subjects were imaged on the same day at both field strengths.
- Three patients were imaged twice within 60 minutes using 3T MRI to observe repeatability.

Methods/Statistical Analysis

- Subjects laid supine on the MR table and inhaled a volume of gas mixture equal to 1/3 of their FVC, with a total maximum volume capped at 1000 mL of isotopically enriched (83%) Xe-129 mixed with nitrogen.
- Xe-129 was polarized to ~40% using a commercial polarizer (Polarean, Durham, NC, USA).
- Subjects held their breath for less than 10s during the imaging sequence, during which proton (2D-GRE sequence with spiral trajectories; TA < 2 s) and either 3D-SBCSI (TA ~7 s) or ventilation images (TA ~2.7 s) were acquired.
- 3D SB-CSI images were post-processed in MATLAB (Natick, MA, USA) using a software package developed in-house that analyzes the Xe-129 spectrum for each lung voxel in the 3D SB-CSI image.
- Whole-lung averages were computed for each parameter and results were analyzed in MATLAB using one-way ANOVA and Tukey's test for post hoc analysis.

Results – Tissue Peaks

- Three peaks were found in the HP Xe-129 3D SB-CSI spectrums of subjects: gas (0 ppm), tissue (197 ppm), and RBC (216 PPM).
- The tissue and RBC peaks had a larger 180° phase separation at 3T compared to their 90° phase separation at 1.5T.
- Gas peaks were largely unchanged.

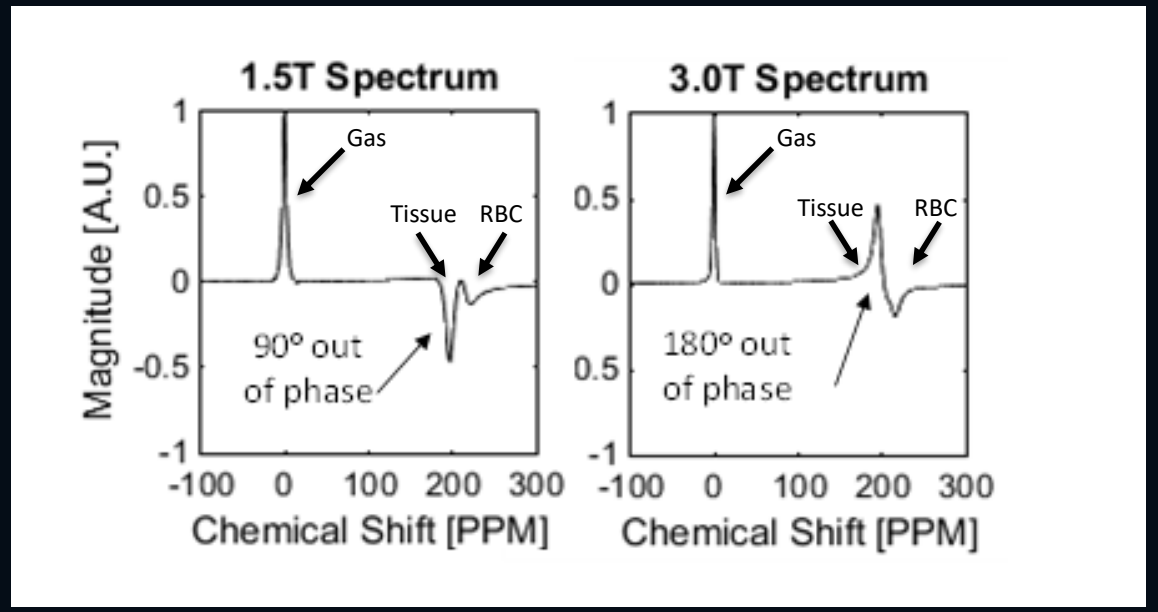


Figure 1: Comparison of the chemical shift [PPM] versus the magnitude [A.U] between 1.5T MRI and 3.0T MRI. Peaks represented either gas (0 ppm), tissue (197 ppm), and RBC (216 PPM).

Results – Tissue/RBC Map Comparison

- In the tissue/RBC maps of subjects, there was a homogenous distribution of ratio values throughout the lungs.
- The mean Tissue/RBC difference between the 1.5T and 3T acquisitions of the same subject was ~7%.
- There was no significant difference calculated between the 1.5T and 3T acquisitions.

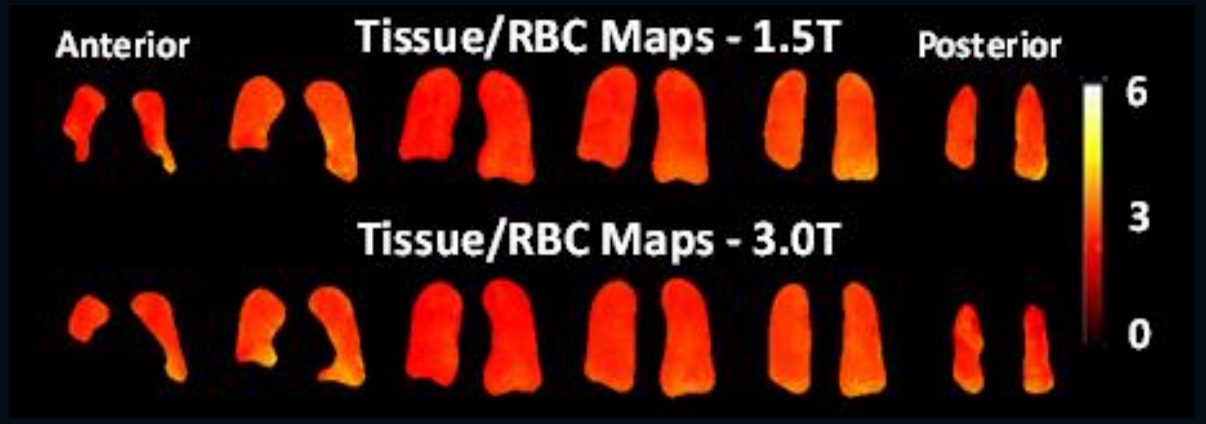


Figure 2: Coronal slices demonstrating spectroscopy maps generated from Tissue/RBC maps generated from 1.5T versus 3T MRI.

Results – Repeatability

- The three patients imaged for repeatability demonstrated no significant differences between their initial 3T MRI scan and the second scan taken 60 minutes later.
- The average difference between the tissue/RBC ratio was 3.63 ± 0.51%.

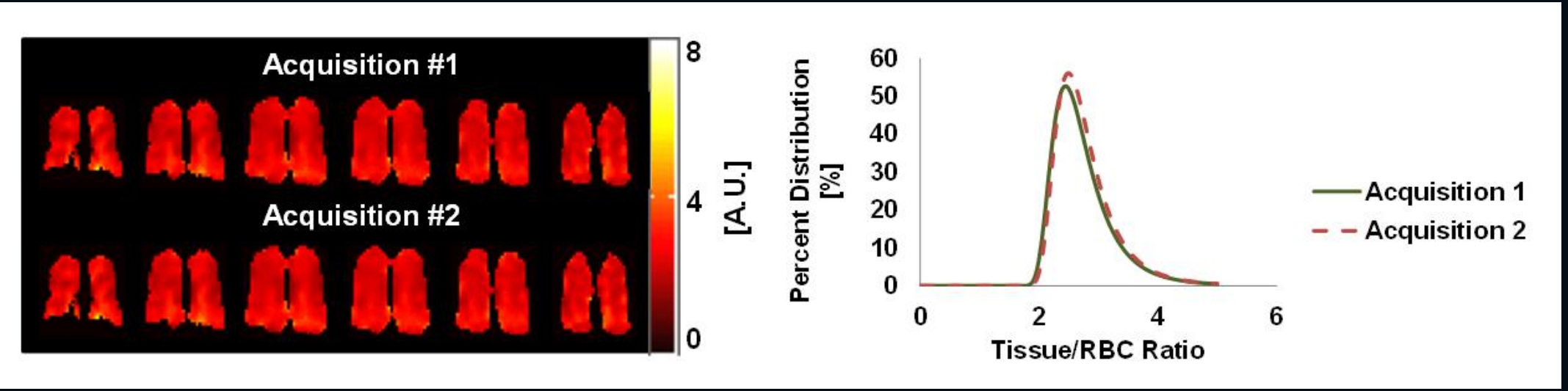


Figure 3: Left: Tissue/RBC ratio maps for two CSI acquisitions on the same healthy subject. Right: Fitted histogram to visualize the tissue/RBC ratio distribution in the two acquisitions.

Discussion

- The results of this study demonstrate that 3T MRI is a valid alternative to 1.5T MRI for the use of HP Xe-129 3D SB-CSI scans.
- As shown, 3T MRI results in a larger 180° phase shift for tissue and RBC peaks, similar spectroscopy mapping, and consistent repeatability between scans.
- Wood et al. 2012 reports that 3T MRI machines have relative equivalence in clinical effectiveness to 1.5T MRI, with advantages in neural imaging such as for multiple sclerosis.
- As scanning techniques and programs improve, 3T MRI 3D-SB-CSI may be able to take advantage of the larger phase separation.

Wood et al. CADTH Tech. Overviews (2012)

Strengths/Limitations

- Pilot study analyzing the feasibility of 1.5T MRI vs 3T MRI with HP Xe-129 gas in human subjects.
- Significant unmet need in diagnostic imaging for chronic lung disease. With recent FDA approval of HP Xe-129 gas for use in pediatric and adult populations >12 years old, the ability to use Xe-129 gas with 3T MRI offers significant flexibility in research and healthcare settings.
- Relatively small cohort
- Unknown how disease pathology would affect the distribution patterns created and whether there is a difference in sensitivity.

Summary

- In this experiment, we demonstrate that HP Xe-129 3D SB-CSI is feasible at 3T MRI and produces similar results to 1.5T MRI.
- As shown, 3T MRI results in a larger 180° phase shift between tissue and RBC peaks, similar spectroscopy mapping, and consistent repeatability between scans.
- The ability to use 3D SB-CSI with both 1.5T and 3T MRI allows for increased flexibility in the various settings it may be used in.

References

1. Ebner, Lukas, Jeff Kammerman, Bastiaan Driehuys, Mark L. Schiebler, Robert V. Cadman, and Sean B. Fain. “The Role of Hyperpolarized 129xenon in MR Imaging of Pulmonary Function.” European Journal of Radiology 86 (January 2017): 343–52. https://doi.org/10.1016/j.ejrad.2016.09.015.
2. Choi, Joon Young, and Chin Kook Rhee. “Diagnosis and Treatment of Early Chronic Obstructive Lung Disease (COPD).” Journal of Clinical Medicine 9, no. 11 (October 26, 2020): E3426. https://doi.org/10.3390/jcm9113426.
3. Hatabu, Hiroto, Gary M. Hunninghake, Luca Richeldi, Kevin K. Brown, Athol U. Wells, Martine Remy-Jardin, Johny Verschakelen, et al. “Interstitial Lung Abnormalities Detected Incidentally on CT: A Position Paper from the Fleischner Society.” The Lancet. Respiratory Medicine 8, no. 7 (July 2020): 726–37. https://doi.org/10.1016/S2213-2600(20)30168-5.
4. Sodickson, Aaron, Pieter F. Baeyens, Katherine P. Andriole, Luciano M. Prevedello, Richard D. Nawfel, Richard Hanson, and Ramin Khorasani. “Recurrent CT, Cumulative Radiation Exposure, and Associated Radiation-Induced Cancer Risks from CT of Adults.” Radiology 251, no. 1 (April 2009): 175–84. https://doi.org/10.1148/radiol.2511081296.
5. Brenner, David J., and Eric J. Hall. “Computed Tomography — An Increasing Source of Radiation Exposure.” New England Journal of Medicine 357, no. 22 (November 29, 2007): 2277–84. https://doi.org/10.1056/NEJMra072149.
6. Guan, Steven, et al. "3D Single-Breath Chemical Shift Imaging Hyperpolarized Xe-129 MRI of Healthy, CF, IPF, and COPD Subjects." Tomography 8.5 (2022): 2574-2587.
7. Driehuys, Bastiaan, Santiago Martinez-Jimenez, Zackary I. Cleveland, Gregory M. Metz, Denise M. Beaver, John C. Nouls, S. Sivaram Kaushik, et al. “Chronic Obstructive Pulmonary Disease: Safety and Tolerability of Hyperpolarized 129Xe MR Imaging in Healthy Volunteers and Patients.” Radiology 262, no. 1 (January 2012): 279–89. https://doi.org/10.1148/radiol.11102172.
8. Shukla, Yajur, Andrew Wheatley, Miranda Kirby, Sarah Svenningsen, Adam Farag, Giles E. Santyr, Nigel A. M. Paterson, David G. McCormack, and Grace Parraga. “Hyperpolarized 129Xe Magnetic Resonance Imaging: Tolerability in Healthy Volunteers and Subjects with Pulmonary Disease.” Academic Radiology 19, no. 8 (August 2012): 941–51. https://doi.org/10.1016/j.acra.2012.03.018.
9. Wood, R., K. Bassett, null Foerster, C. Spry, and L. Tong. “1.5 Tesla Magnetic Resonance Imaging Scanners Compared with 3.0 Tesla Magnetic Resonance Imaging Scanners: Systematic Review of Clinical Effectiveness.” CADTH Technology Overviews 2, no. 2 (2012): e2201.