High-resolution MRI of hyperpolarized propane at 4.7 T and 0.0475 T

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Target Audience: Pulmonologists, Chemists, Physicists

Purpose: Lung imaging by CT and MRI is challenging due to low tissue proton density. Imaging methods using hyperpolarized inert gases, e.g. ^{129}Xe and ^{3}He, and radioactive xenon isotopes are typically used as contrast agents to measure lung function. However, these are relatively expensive agents and require custom imaging software and hardware, i.e. RF-coil, sequences, polarizers, etc. Here, we demonstrate the use of non-toxic hyperpolarized (HP) propane for high resolution imaging of fine gaseous structures.

Methods: Heterogeneous (het) Parahydrogen Induced Polarization (PHIP) was used for preparing ^{1}H hyperpolarized propane gas (1) with ~ 1% nuclear spin polarization P corresponding to the enhancement factor $<\varepsilon>$ of ~650 at 4.7 T, and P = 0.3% with $<\varepsilon>$ ~20,000 at 0.0475 T. >90% parahydrogen was used (2). %P was lower at 0.0475 T due to difference in experimental setup and spin manipulation of propane PHIP. This enhancement of nuclear spin polarization by het-PHIP enabled fast 3D imaging of ~20 mM (corresponding to ~0.5 atm partial pressure) propane gas using gradient echo imaging (GRE). 3D images with up to 6144 (96x64) encoding projections (TR/TE = 3.48/1.76 ms, spectral width (SW) = 40 kHz, RF excitation pulse α = 15°) were acquired in ~22 s corresponding to isotropic spatial resolution of 0.5x0.5x0.5 mm^3 over 48x48x32 mm^3 FOV without compressed sensing. The spiral phantom was made using 3/32 in. ID Tygon tubing. 4.7 MRI images were recorded under continuous flow condition of HP propane.

Low-field MRI utilized frequency optimized RF coils (3) and 0.0475 T small-animal MRI scanner. 2D images were recorded using GRE imaging of HP propane using the following imaging parameters: TE/TR = 7.0/20 ms, acquisition time = 6.4 ms, SW = 5.0 kHz, RF excitation pulse α = 7°, FOV = 30×30 mm^2 using 32×32 imaging matrix with 2 dummy scans. No compressed sensing or image manipulation was used. 0.0475 MRI images were recorded under stopped flow condition of HP propane.

Results: Het-PHIP using Rh/TiO_2 solid phase catalyst enabled relatively high levels of proton nuclear spin polarization of hyperpolarized propane, Fig. 1A. While the level of polarization P was only ~1%, it enabled high-resolution 3D images at 4.7 T and 2D images at 0.0475 T. Imaging of fine structures with 0.5x0.5x0.5 mm^3 was possible, Fig. 1B. ^{1}H relaxation time of propane HP state produced via reaction of molecular addition with parahydrogen in the Earth field was ~0.8±0.1 s at 9.4 T and ~4.7±0.5 s at 0.0475 T.

Discussion: %P of HP propane can be potentially significantly increased from available to us 1%. This would translate to further significant sensitivity improvements of HP propane imaging. Despite low P ~0.3-1 %, high-resolution imaging is feasible, because there are two HP protons per molecule and protons have significantly greater magnetic moment compared to ^{129}Xe used for lung imaging. While low relaxation time of HP propane would likely preclude high field clinical imaging, significantly higher relaxation times measured at 0.0475 T would allow for potential clinical implementation of HP propane gas for lung imaging. There are no significant translational barriers: (i) propane is a non-toxic asphyxiant odorless gas, (ii) HP gas can be produced free from heterogeneous solid Rh catalyst, and (iii) conventional proton imaging hardware and RF pulse sequences can be used for fast MRI.

Conclusion: High-resolution 2D and 3D MRI of HP propane gas was demonstrated for imaging of fine structures. Future work will focus on improving %P of HP propane and low-field MRI 3D pulse sequence development. HP propane gas will likely emerge as a new molecular contrast agent for inexpensive and fast imaging of lung function.

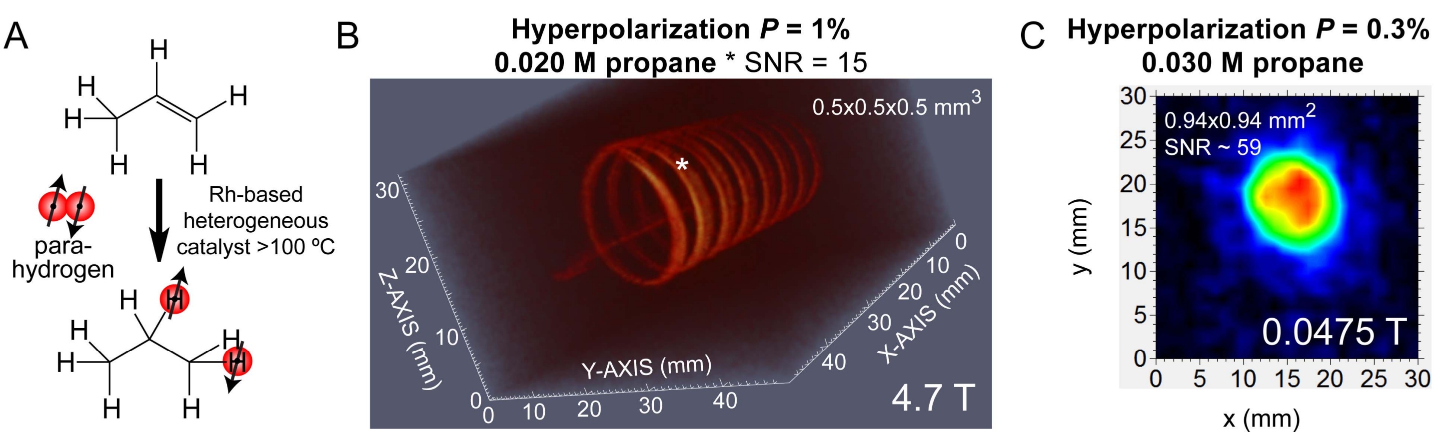

Fig. 1. A) Scheme of heterogeneous molecular addition of parahydrogen to propene resulting in PHIP of propane; B) Rendering of 3D high-resolution imaging of hyperpolarized propane gas flowing through a spiral shaped phantom (tubing ID = 3/32") in 4.7 T small-animal MRI; C) 2D high-resolution imaging of hyperpolarized propane gas stopped in a ~2 mL cylindrical phantom in 0.0475 T small-animal MRI.

References: [1] K. V. Kovtunov, V. V. Zhivonitko, I. V. Skovpin, D. A. Barskiy, I. V. Koptyug, Parahydrogen-Induced Polarization in Heterogeneous Catalytic Processes. *Top. Curr. Chem.*, 2013, 338, 123. [2] B. Feng, A. M. Coffey, R. D. Colon, E. Y. Chekmenev, K. W. Waddell, A pulsed injection parahydrogen generator and techniques for quantifying enrichment. *J Magn Reson.* 2012;214:258-62. [3] A. M. Coffey, M. Truong, E. Y. Chekmenev, Low-field MRI can be more sensitive than high-field MRI. *J Magn Reson*, http://dx.doi.org/10.1016/j.jmr.2013.10.013.