RF instrumentation for same-breath triple-nuclear lung MR imaging of ^{1}H and hyperpolarized ^{3}He and ^{129}Xe at 1.5T

Madhwesha Rao[1], Juan Parra-Robles[1], Helen Marshall[1], Neil Stewart[1], Guilhem Collier[1], and Jim Wild[1]
[1]*University of Sheffield, Sheffield, South Yorkshire, United Kingdom*

Target audience: Lung function and Imaging. Hyperpolarized noble gas community.

Purpose: The hyperpolarized gases, ^{3}He and ^{129}Xe have distinct properties, and provide unique and complementary functional information from the lungs[1-3]. A double/triple-nuclear same-breath imaging exam of the lungs with ^{1}H, ^{3}He and ^{129}Xe can therefore provide exclusive functional information from each of the gas images and complementary co-registered structural information from ^{1}H images in the same physiological time frame[4-6]. This study describes the development of a RF instrumentation for same-breath triple-nuclear (^{3}He-^{129}Xe-^{1}H) MR imaging. Application to same-breath ventilation (^{3}He-^{129}Xe-^{1}H) imaging and same-breath ^{3}He-^{129}Xe diffusion imaging are demonstrated.

Method: This work was performed on a GE signa HDx 1.5T. A flexible dual-tuned (17.65MHz and 48.62MHz) dual-Helmholtz quadrature transmit-receive (TR) coil was built in-house as shown in Figure 1(a). The TR coil has 2 traps on each of the Helmholtz pair, one-trap (47.8 MHz) to dual tune the coil at ^{129}Xe-^{3}He frequencies and the other-trap (63.8 MHz) to enable ^{1}H imaging. Images for each of the nucleus were acquired sequentially within a single breath-hold. To switch between the ^{3}He and ^{129}Xe transceiver, a mechanically operated 2kW RF switch (CX-SW2PL, Watson) was incorporated. Both gases were hyperpolarized with spin-exchange-optical-pumping[7]. The gases were delivered in separate Tedlar bags and mixed at the mouth piece during inhalation as shown in Figure 1(b). ^{3}He had polarization of 25%. ^{129}Xe had polarization of ~50%. Pulse sequence parameters were as follows. **^{3}He Ventilation:** SPGR, TE=1.1ms, TR=3.6ms, FOV = 40cm, slice thickness = 15mm, matrix = 104(phase) x 80, flip angle = 8°. **^{129}Xe Ventilation:** SPGR, TE=3.6ms, TR=18.9ms, FOV = 40cm, slice thickness = 15mm, matrix = 78(phase) x 64, flip angle = 9°. **^{1}H bright-blood:** bSSFP, TE = 0.9ms, TR = 2.9ms, FOV = 40cm, slice thickness = 15mm, matrix = 192(phase) x 256, flip-angle = 50°. Gas mixture for triple-nuclear ventilation-structure imaging was 350ml ^{3}He, 500 ml ^{129}Xe and 150ml N_2. **^{3}He ADC:** SPGR, TE = 4.8ms, TR = 10ms, Bandwidth = 31.25kHz, FOV = 44cm, slice thickness = 15mm, matrix = 64 x 48(phase), flip angle = 9°, b value = 1.6. **^{129}Xe ADC:** SPGR, TE = 12.5ms, TR = 27ms, bandwidth = 2kHz, FOV = 44cm, slice thickens = 15mm, matrix = 64 x 48(phase), flip angle = 11.2°, b value = 8. Gas mixture for the same-breath ADC was 300ml ^{3}He, 500ml ^{129}Xe and 200ml N_2. All subjects tolerated ^{129}Xe well and vital statistics were monitored throughout the scan.

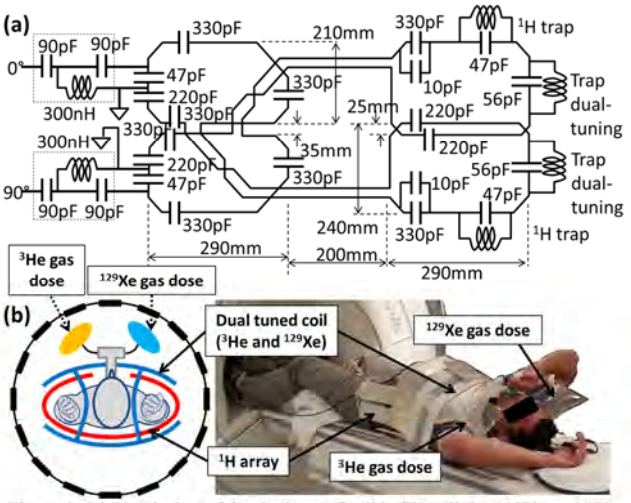

Figure 1: (a) The design of the dual tune flexible TR coil for 129Xe and 3He. (b) Illustration of coils nested and picture of the setup on the scanner .

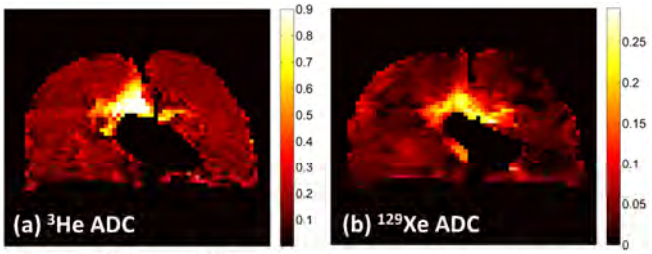

Figure 2: ADC map of ^{3}He and ^{129}Xe, obtained in at the same-slice and same-breath, with gas mixture of ^{3}He, ^{129}Xe and N_2. (a) ^{3}He ADC. (b) ^{129}Xe ADC. (The colour bar indicates the respective ADC values).

Results: The ratio of Q-unloaded to Q-loaded of the dual-tuned TR coil was 3.5 at 17.6 MHz (^{129}Xe Larmor frequency) and 4.5 at 48.6 MHz (^{3}He Larmor frequency). The ADC maps obtained in same-breath ^{3}He-^{129}Xe are shown in Figure 2(a) for ^{3}He and Figure 2(b) for ^{129}Xe. Same-breath triple-nuclear (^{3}He-^{129}Xe-^{1}H) ventilation images are as shown in Figure 3. The ^{1}H images in Figure 3(a), ^{3}He images in Figure 3(b) and ^{129}Xe images in Figure 3(c) acquired in the same-breath, are co-registered as shown in superimposed images in Figure 3(d) and Figure 3(e).

Discussion: The ability to visualize and quantify lung ventilation with the two gases at the same time will allow important questions related to the position of the diffusion – convection front in the lungs. Similarly the capability to measure the diffusivity of both gases in the same lung inflation level provides added information for measuring and modeling lung micro-structure based on their respective measured ADCs[8]. The switching time between the nuclei is 4~6s, (60% of total breath-hold) this because the RF switch is operated manually and the spectrometer limits the number of multi-nuclear transceivers simultaneously connected to the MR system. Electrically operated switches and appropriate spectrometer software engineering are being developed to reduce this time overhead.

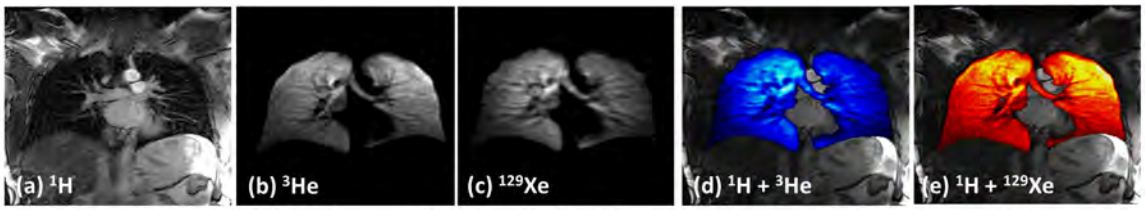

Figure 3: Co-registered ventilation and structured imaging with ^{3}He, ^{129}Xe and ^{1}H in the same-breath same-slice. (a) ^{1}H images from lungs. (b) ^{3}He images from lung. (c) ^{129}Xe images from the lungs. (d) ^{3}He images superimposed over ^{1}H images. (e) ^{129}Xe images superimposed over ^{1}H images

Conclusion: With a custom dual tuned ^{3}He and ^{129}Xe TR coil and a nested ^{1}H array and RF switches we have demonstrated high quality lung images from all three nuclei in the same breath.

Reference: **1.** Kauczor HU, et al. Euro Radiology 1998;8(5):820-827. **2.** Möller HE, et al. MRM 2002;47(6):1029-1051. **3.** Fain SB, et al. JMRI 2007;25(5):910-923 **4.** Wild JM, et al. NMR in Biomedicine 2011;24(2):130-134. **5.** Wild JM, et al. Radiology 2013;267(1):251-255. **6.** Rao, M., et al, MRM, 2014: 10.1002/mrm.25384. **7.** G. Norquay, et al., Journal of Applied Physics, 113 (2013). **8.** Parra-Robles J, et al. JMR 2012. 225(0):102-113.