Regional Cardiopulmonary Dynamics with Hyperpolarized ^{129}Xe and Radial Keyhole Image Reconstruction

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Spatially heterogeneous chemical and transport dynamics are of intrinsic interest in phenomena ranging from heterogeneous catalysis to pulmonary medicine, and MRI provides a unique means to quantify these dynamics regionally without perturbing the systems of interest. However, the available signal intensity can limit the utility of MRI in these systems—particularly when low concentration nuclei are studied or high temporal and spatial resolution are required. Thus, hyperpolarized (HP) media are often needed to achieve sufficient experimental SNR. Unfortunately, the use of hyperpolarization complicates the quantification of dynamic processes, because longitudinal magnetization decays dynamically due to spatially varying RF depletion and T_1 relaxation. To address this limitation, we recently demonstrated that HP decay dynamics can be mapped—without additional data collection—using 3D radial MRI and post-acquisition, keyhole reconstruction [1].

Here we extend our earlier results and use radial keyhole to correct magnetization decay in HP ^{129}Xe lung ventilation imaging. This straight-forward correction substantially improves image quantification (Fig.1). Specifically, radial keyhole correction reveals that T_1-induced relaxation is reduced in regions of low O_2 partial pressure (e.g., highly perfused central lung regions in healthy subjects. Reduced magnetization decay also occurs in poorly ventilated, low O_2 regions within the lungs of cystic fibrosis patients, causing disease severity to be underestimated.

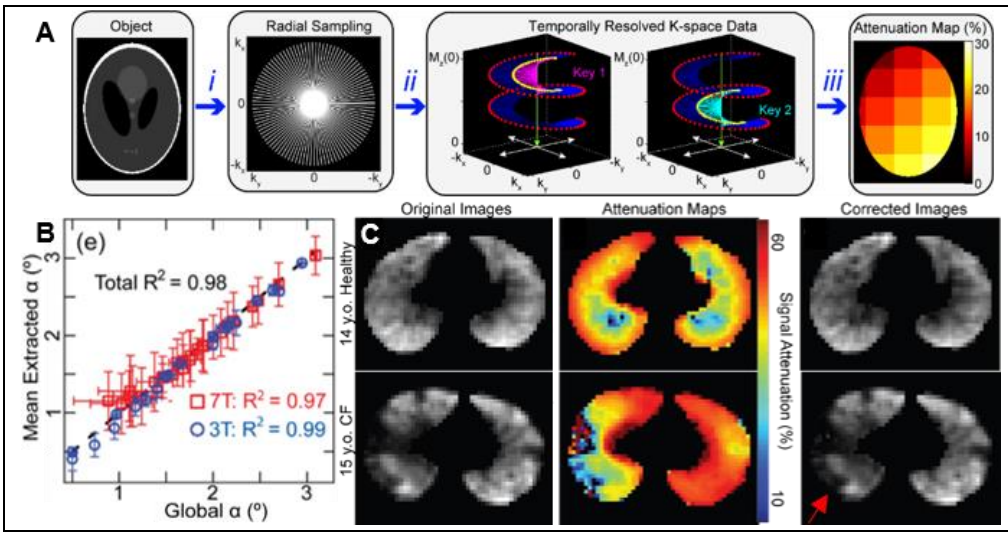

Fig. 1: *Magnetization (**Mz**) decay correction **A:** (**i**) K-space data are radially sampled, while (**ii**) HP magnetization decays due to RF and T_1 (green arrows). K-space is divided into high- and low-frequency components and recombined to generate temporally resolved images. (**iii**) Finally, attenuation maps are calculated from a Bloch equation-based model and the "keyhole" images **B:** Correlation between keyhole-generated mean and prescribed flip angles in phantoms, showing excellent agreement. **C:** HP ^{129}Xe ventilation and attenuation maps. Post-correction, ventilation is more homogeneous in the healthy subject, but defects are more pronounced in the cystic fibrosis patient (red arrow) after attenuation correction.*

Beyond image correction, radial keyhole enables regional dynamics to be visualized with HP media. For example, Bier *et al.,* showed HP ^{129}Xe spectroscopy can detect cardiogenic oscillations in the pulmonary capillaries and the magnitude of these global oscillations, is sensitive to disease state (e.g., lung fibrosis) [2]. To map these oscillations regionally, we combined radial keyhole with 1-point Dixon MRI (Fig. 2). When ^{129}Xe dissolves in lung tissue, unique resonances appear corresponding to ^{129}Xe in red blood cells (RBCs) and adjacent "barrier tissues" (plasma and parenchyma). After excitation, dissolved ^{129}Xe transverse magnetization is allowed to evolve until a 90° phase separation accumulates between resonances, at which time RBC and barrier signals are divided into real and imaginary components, respectively.

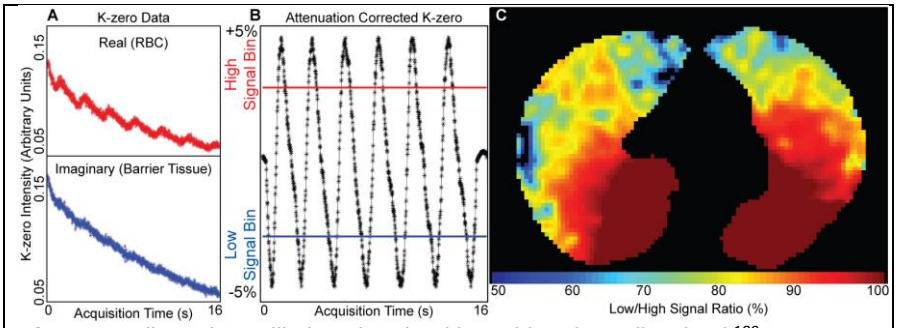

Fig. 2: *Cardiogenic oscillations in a healthy subject from dissolved ^{129}Xe MRI. **A:** Low-frequency k-zero data from a radial acquisition. Large oscillations are seen only in real, RBC signal—consistent with spectroscopy [2]. **B:** K-space data are corrected for HP decay and binned into high and low intensity portions of k-zero oscillations [5]. **C:** Keyhole reconstruction is used to improve image sampling and high-to-low signal ratio maps are generated from the keyhole images.*

Ratio maps of the low/high signal, dissolved ^{129}Xe keyhole images show spatially varying oscillations in the RBC signal. No signal fluctuation is seen in the gravitationally dependent, posterior lung, where pulmonary artery pressure exceeds gas pressure in the alveolar airspaces. In contrast, fluctuations of ~40% are seen in the anterior lung, where alveolar pressure is higher. Thus, dynamic lung physiology can be observed regionally using dissolved ^{129}Xe MRI with keyhole reconstruction, and this information will provide valuable insights in diseases including lung fibrosis and pulmonary hypertension. As a final note, radial keyhole is a general approach and can be used to quantify regional dynamics in a range of HP experiments.

References: **[1]** P Niedbalski, et al., 59th ENC 2018; Poster 097. **[2]** EA Bier et al., NMR Biomed. 2019; 32:e4029. **[3]** ZI Cleveland, et al. NMR Biomed. 2014; 27(12):1502-1514. **[4]** JM Wang et al., Thorax. 2017; 73(1):21-28. [5] NS Higano, et al., MRM, 2017, 77:1284.