Improved Separation and Quantification of Xe-129 Dissolved-Phase Resonances in the Lung

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Introduction: Both 2D and 3D Chemical Shift Imaging (CSI) of the lung with hyperpolarized xenon-129 (Xe-129) have been previously demonstrated (1). Here, we report the application and evaluation of a potentially more robust statistical post-processing treatment of the CSI data, using principal component analysis (PCA) (2). Preliminary evaluation of its application to Xe-129 CSI data of a rabbit model of lung fibrosis, and comparison with traditional area integration of the dissolved-phase peaks, is presented. From the CSI data, we directly calculate images reflecting the amount of Xe-129 in the airspaces, and dissolved in the lung tissue (parenchyma/plasma), red-blood-cells (RBC), and other compartments, thus obtaining detailed spatial information regarding how Xe-129 is distributed in these compartments and providing regional information about lung physiology.

Methods: New Zealand White rabbits underwent hyperpolarized Xe-129 2D-CSI on four different days: baseline and 1, 2 and 8 weeks after the endotracheal instillation of bleomycin, which induces lung fibrosis; one control animal had no intervention. Animals were anesthetized with a mixture of Ketamine/Xylazine (50/5mg/Kg) and intubated. All scans were done in a 1.5 Tesla clinical system (Avanto, Siemens Medical Solutions) using a transmitter/receiver birdcage RF coil (IGC Medical Advances, Milwaukee, WI) tuned to the Xe-129 frequency. Isotopically enriched (~87%) Xe-129 was polarized to ~35% using a commercial prototype polarizer (Xemed LLC, NH). For each 2D acquisition, a single 40cc volume of gas was administered to the animal, and respiration was suspended for the acquisition. A matrix of 26x26 voxels, interpolated to 32x32 voxels, was positioned over the lungs, with a FOV of 90x90 mm^2, corresponding to an in-plane resolution of 2.8x2.8mm^2. TR was 27 ms and TE was 2.3ms. For each excitation an RF pulse was applied at the frequency of dissolved-phase Xe-129, approximately 200 ppm from that for Xe-129 gas in the airspaces. The protocol was approved by our Institutional Animal Care and Use Committee.

Xe-129 CSI post-processing was performed using the 3DiCSI (Qi Zhao, Columbia University, NY) and MATLAB (MathWorks, Natick, MA) software packages. Two different methods to post-process the CSI data were evaluated: 1) Traditional method: The absolute component of the free-induction decay (FID) corresponding to each voxel was filtered with a Gaussian, zero filled to 2048 points, Fourier transformed and corrected for frequency shifts, and then each peak in the spectrum was fitted with a Gaussian curve and the areas under the peaks were determined. 2) PCA method: The real component of the signal from each voxel was filtered, zero filled and Fourier transformed in an identical fashion to the first method, followed by PCA as previously described (2). Subsequently, Xe-129 CSI maps of the multiple-dissolved peaks and gas peak (Fig. A, top) were calculated separately for each animal and method. The mean, standard deviation and ratios among the different peaks were determined.

Results: Data post-processing using the traditional method yields tissue and RBC maps that appear very similar; high signal is seen in the heart and aorta in the tissue component image (Fig. B), which may, at least in part, be signal contamination from the adjacent, large RBC peak. With the PCA method, and taking advantage of a phase-difference between the RBC and tissue peaks (Fig. A, bottom), the signal from the RBC and tissue peaks can be quantified separately (Fig. C). The signal distributions for the tissue and RBC components are now distinct differently, and appear to reasonably reflect the expected distributions of dissolved-phase Xe-129.

Quantification of the CSI maps from the PCA method for the fibrosis model group (Fig. D) show a statistically significant increase in the normalized tissue peaks (tissue/gas ratio) from baseline to 8-week post, but not a statistically significant difference in the RBC peaks (RBC/gas ratio), following the instillation of bleomycin.

Conclusions: Xe-129 CSI maps post-processed using the real component of the signal and PCA analysis appear to provide superior separation of the tissue and RBC dissolved-phase peaks, potentially providing more accurate anatomical and physiological information. Preliminary analysis of the multiple Xe-129 peaks in a rabbit model of lung fibrosis showed high sensitivity to temporal physiological changes expected in association with this disease, such as an increase in the tissue (tissue/gas ratio) peak.

References: [1] Mata J et al. ISMRM, Stockholm, 2010 (abstract #989). [2] Stoyanova R.et al. JMR 154, 2002.

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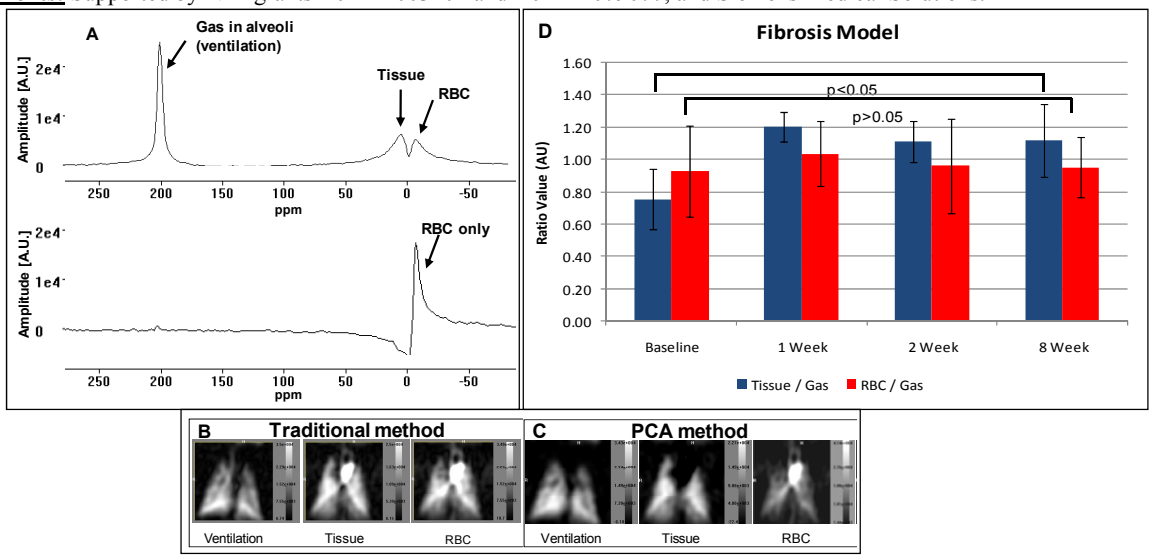

Figures – A, top row: Spectrum of the absolute Xe-129 data from a single voxel located in the lung of a healthy animal, obtained using a 2D-CSI acquisition. Close proximity of the dissolved-phase tissue and RBC peaks results in overlap. **A, bottom row:** Real data spectrum, from a single voxel located in the heart, shows mainly the dissolved-phase RBC component, with a phase shift for the signal tail between 0-50ppm. **B:** 2D-CSI maps for each of the peaks indicated in figure A, using the traditional method. **C:** 2D-CSI maps for each of the peaks indicated in figure A, using the PCA method. Note, on the tissue map, the absence of signal in the heart and aorta regions. **D:** Quantification of the maps for the fibrosis model group show a statistically significant increase in the tissue/gas ratio 8 weeks following the instillation of bleomycin, as expected in fibrosis. RBC/gas ratios did not change significantly.