High-resolution Chemical Shift Imaging of the lungs with Xe-129 during a single 6 second breath-hold: Results from a rabbit model of pulmonary embolism.

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Introduction: Chemical shift imaging (CSI) is an MR technique developed many years ago for acquiring images wherein an NMR spectrum is obtained from each voxel. Previous implementations of CSI of the lung with hyperpolarized xenon-129 (hp Xe-129) required imaging for 8 minutes (1), which is not practical for application in humans. We developed an optimized version of CSI that yields images of hp Xe-129 with high in-plane spatial resolution (2.5 x 2.5mm^2) during a single breath-hold of less than 6 s. Here, we report the preliminary evaluation of this technique using a rabbit model of pulmonary embolism (PE). From the CSI data we directly calculate images reflecting the amount of Xe-129 in the airspaces, and dissolved in the lung tissue and blood, and thus obtain detailed spatial information regarding how Xe-129 is distributed in the different compartments, providing regional information about lung physiology.

Methods and Materials: Six New Zealand rabbits (4.2-5.2 kg) had an angio-catheter with a balloon placed in their left pulmonary artery under fluoroscopic guidance (Fig. 1A). This balloon permitted full occlusion of the left pulmonary artery, cutting the blood supply to the same lung (Fig. 1B). Each animal was scanned during two separate inhalations of 50 cc of hp Xe-129, one prior to occlusion and one 5 minutes post occlusion. This permitted us to assess in-vivo the sensitivity of the breath-hold CSI technique to the volume of blood in the left lung, while using the healthy (right) lung as a control (Fig. 1E-J). It is known from clinical data that in cases of severe PE the amount of pulmonary blood volume can decrease by approximately 50% in the lung or area affected by the occlusion (2).

All animals were anesthetized with a mixture of Ketamine/Xylazine (50/5 mg/Kg) and intubated with an endotracheal tube prior to the angio-catherization and balloon placement. Anesthesia was maintained with a single bolus of the same mixture as needed. All animals were scanned in a 1.5 Tesla clinical system (Sonata, Siemens Medical Solutions) using a transmiter/receiver birdcage RF coil (IGC Medical Advances, Milwaukee, WI) tuned to the Xe-129 frequency. Isotopically enriched (85%) Xe-129 was polarized via the optical-pumping spin-exchange method in an IGI-9600Xe polarizer (MITI, Durham, NC), with final polarization levels between 12-15%. For the CSI acquisition, a matrix of 32 x 32 voxels were positioned over the lungs (Fig. 1D). For each excitation an RF pulse with duration 1280µs and bandwidth 3125 Hz was applied at the frequency of the dissolved-phase Xe-129. This frequency is approximately 200 ppm from that for hp Xe-129 gas in the airspaces (Fig 1C). 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. Subsequently, each peak in the spectrum was fitted with a Gaussian curve and the areas under the peaks were determined (Fig. 1C). CSI maps based on the integrals of the dissolved and gas peaks were calculated separately for each animal based on the data obtained before occlusion (Fig. 1F, 1H) and after occlusion (Fig. 1E, 1G). The ratios of the dissolved- and gas-phase CSI maps were also calculated in order to obtain values that did not depend of the polarization and amount of gas. The histogram, mean, median and standard deviation for the ratio maps were calculated and analyzed statistically. For correlation with the CSI results and to demonstrate the amount of obstruction and position of the balloon (Fig. 1B), each animal was also scanned using a 3D contrast-enhanced MRA sequence (ce-MRA) with 3cc of a gadolinium chelate while the left pulmonary artery was still occluded**.**

Results: The balloon was positioned at essentially the same location in all animals. As a result, among all cases, the ce-MRA (Fig. 1B) and CSI maps (Fig. 1E-J) were very similar. In all cases, the dissolved-phase maps for the left lung (LL) and right lung (RL) were essentially identical before occlusion (Fig. 1F) but clearly different during occlusion (Fig. 1E), while the maps for the gas phase remained unchanged (Fig. 1G, 1H). The maps of the dissolved-phase/gas ratios (Fig. 1I, 1J) also clearly showed the changes that occurred with occlusion; the ratios for the RL and LL were 1.88±0.40 (mean±STD) and 1.95±0.38, respectively, before occlusion, and 1.54±0.28 and 1.09±0.26, respectively, during occlusion. The percentage differences in the ratio between right and left lungs were 5.4±4.5% (median = 8.7%, p = 0.06) before occlusion and 22.1±12.4% (median = 23.3%, p = 0.03) during occlusion.

Discussion: Conventional proton-based CSI is well established and used routinely. This study demonstrated the feasibility of optimizing the CSI technique for hp Xe-129 to obtain data from the lung in a single short breath-hold acquisition. The initial results from this method appear very promising and correlated well with the established ce-MRA method. Further optimization of the pulse sequence and higher gas polarization will permit higher spatial resolution and multiple slices. Additional tests in other animal models are under way.

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References: 1) Swanson SD, Rosen MS, Coulter KP, Welsh RC, Chupp TE. Magn Reson Med 1999; 42:1137-1145. **2)** Ellis J, Steele P. Chest 1976; 69(5):575-581.

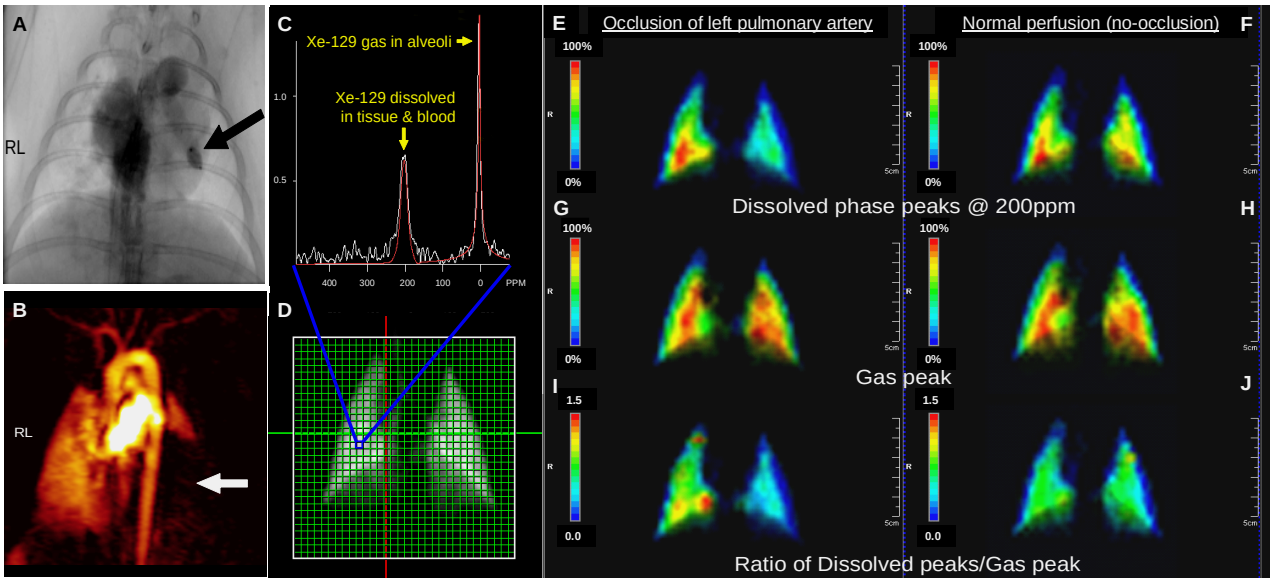

Figure 1 – Rabbit model of PE. All images are from the same animal. **A**: X-ray obtained during balloon (black arrow) occlusion of the left pulmonary artery. **B**: Contrast-enhanced MRA shows the right lung (RL) with normal perfusion while the left lung is not perfused (white arrow). **C**: MR spectrum from a single voxel of a CSI acquisition shows the combined peak for Xe-129 dissolved in tissue and blood (center) and the gas peak (right); Gaussian curve fits are in red. **D**: Overlying a Xe-129 ventilation image, the 32x32 matrix shows the placement of voxels for the CSI acquisition. Images **E**, **G** and **I** were obtained during occlusion and images **F**, **H** and **J** were obtained before occlusion. E and I show left lung with a reduced amount of Xe-129 dissolved in the blood and tissue, while F and J show both lungs with a similar amount of signal. G and H show unchanged ventilation maps for both lungs during and before occlusion.