Detecting Pulmonary Capillary Blood Pulsations Using Hyperpolarized 129Xe CSSR

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Target Audience: MR scientists and physicians interested in hyperpolarized-gas MRI and the assessment of pulmonary function.

Purpose: Xenon uptake spectroscopy, commonly referred to as "Chemical Shift Saturation Recovery" (CSSR), is a method for monitoring the uptake of hyperpolarized xenon-129 (HXe) by the lung parenchyma (1-5). This is achieved through the acquisition of a free induction decay following a delay time τ after an RF saturation pulse that destroys the signal from all HXe currently residing in the lung tissue ("dissolved phase" HXe). By varying τ the time course of HXe uptake can be quantified, and by fitting the results to a model (1-4) certain aspects of lung physiology can be investigated. However, all existing models assume that the dissolved-phase compartment consists of static tissue and constant blood flow. The purpose of our studies was to demonstrate that, by holding τ fixed, it is feasible to evaluate the pulsation of flowing blood in the pulmonary capillaries in real time. The pulsation dependence on τ and lung inflation was investigated.

Methods: Gaussian RF pulses (2-ms duration) were applied to saturate the tissue/plasma (TP; 198 ppm) and red blood cell (RBC; 218 ppm) dissolved-phase resonances. Following a delay time τ, a 1.2-ms Gaussian RF excitation pulse was used to generate a free induction decay. This sequence was repeated 32 times during a single breath hold. The signal was sampled for 30.72 ms with 1024 sampling points, apodized by a squared cosine function, zero-filled to 2048 points, Fourier transformed and phased. Each of the two dissolved-phase resonances was integrated numerically. To account for T1 and RF-pulse induced magnetization decay, both sets of peak integrals were corrected with an exponential decay function fitted to the TP peak integrals. All MR studies were performed at 1.5T (Avanto; Siemens), using a flexible (Clinical MR Solutions) or rigid (custom built) Xe129 chest RF coil, under a physician's IND for HXe MRI. Informed consent was obtained in all cases and a physician supervised each study. Enriched xenon gas (87% Xe129) was polarized using a prototype commercial system (XeBox-E10, Xemed). The study group included 8 healthy nonsmoking subjects who were asked to inhale 0.5L of HXe starting from residual volume (RV) and either subsequently hold their breath or continue inhalation of room air and hold their breath at total lung capacity (TLC). τ values of 50, 100, 200 or 300 ms were used.

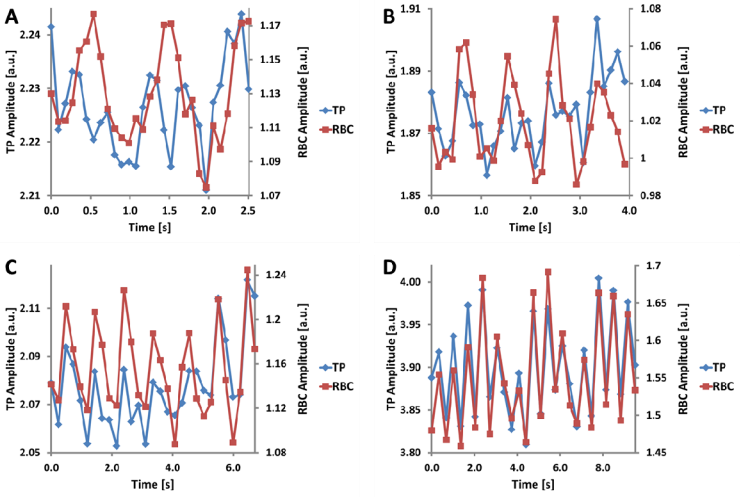

Figure 1. RBC (red) and TP (blue) amplitude pulsations for delay times τ of 50, 100, 200 and 300 ms (A-D), respectively.

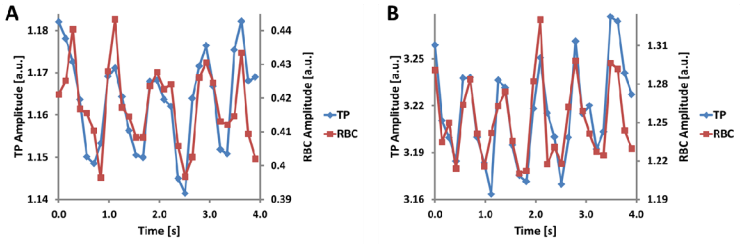

Figure 2. RBC (red) and TP (blue) amplitude pulsations at (A) TLC and (B) RV for a τ value of 100 ms.

Results and Discussion: Figure 1 depicts the pulsations in the RBC and TP dissolved-phase peak integrals over time for four different τ values at RV, reflecting the differences in gas uptake by the tissue/blood plasma and the RBCs throughout the cardiac cycle. The observed oscillations agree qualitatively with those measured by body plethysmography (6). As τ increases, the temporal sampling resolution decreases and the pulsations are less well characterized. However, for longer τ values, the signal strengths, and thus the signal-to-noise ratios, increase for both peaks; the amplitude of the pulsations grows stronger as well. Figure 2 illustrates the differences in the peak pulsation at TLC and RV in the same subject for a τ of 100 ms. Interestingly, based on the average for different subjects, we found the TP amplitude fluctuations to be fairly similar (~2%) at both inflation levels while the RBC amplitude fluctuations were about twice as high at TLC than at RV. We anticipate that certain lung diseases which affect the elastic properties of the capillary bed, such as pulmonary hypertension, would impact the pulsations. Also, coupling these measurements with cardiac triggering might permit an estimation of the time it takes for the pressure wave induced by cardiac contraction to reach the lung, where abnormal values may indicate cardiovascular pathologies. In the future, the use of receiver arrays may permit coarse spatial localization without sacrificing temporal resolution.

Conclusion: We demonstrated that the CSSR technique can be used to characterize the pulsatile flow of pulmonary capillary blood in real time during a breath hold period.

References: **[1]** Butler JP et al. J Phys Condens Matter 2002;14:L297-L304. **[2]** Mansson S et al. MRM 2003;50:1170-1179. **[3]** Abdeen N et al. MRM 2006;56:255-264. **[4]** Patz S et al. Acad Rad 2008;15:713-727. **[5]** Ruppert K et al. NMR Biomed 2000;13:220-228. **[6]** Lee G de J et al. J Clin Invest 1955;34:1380-1390.

Acknowledgements: Supported by NIH grant R01 HL109618 and Siemens Medical Solutions.