Comparison of 129Xe pulmonary gas exchange measured by two techniques: XTC and CSSR

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Introduction: Two independent methods were used to investigate the mean gas exchange in human lungs as a function of diffusion time: a spectroscopic counterpart of the Single-Breath Xenon Transfer Contrast technique (XTC) [1], an optimized version of XTC developed by Ruppert et.al. [2], and Chemical Shift Saturation Recovery (CSSR) technique, developed by Butler et.al. [3], and which was validated on a porous medium. The data obtained from these two very different methods are compared. In single-breath XTC spectroscopy, 3 simple FID signals (S_1, S_2, S_3) are acquired for each exchange time with multiple spectrally selective 180° pulses applied at -205ppm between S_1 and S_2 at +205ppm between S_2 and S_3. Then fractional gas transport $F(t_{exch}) = 1 - \sqrt[N]{(S_3/S_2)(S_1/S_2)}$ is calculated, where ratio (S_1/S_2) accounts for the signal decay due to T_1 and RF depletion, and N is number of 180°'s. XTC is an indirect measurement of the amount of the xenon that diffused into the lung parenchyma. By varying the delay between applied inversion pulses, the dependence of the gas exchange on exchange time is studied.

The CSSR method, on the other hand, provides a direct measurement of the signal from xenon dissolved into the septal tissue. Since the dissolved phase frequency f_{Diss} of Xe is ~205ppm away from the gas phase frequency, applying a selective 90° RF pulse at f_{Diss}, followed by a spoiling gradient, destroys the dissolved state magnetization, thereby creating an initial condition with the dissolved phase signal, $S_{diss}=0$, and uniform magnetization in the gas state. The dissolved state signal is then measured as a function of the time allowed for diffusion, t_{exch}. Butler et. al (3) showed that for a 1D semi-infinite two-phase system the fractional gas transport, defined as the ratio of the dissolved state signal (S_{diss}) at time t_{exch} to that of the gas state (S_{gas}) at t=0, S_{diss}/S_{gas} in an ideal semi-infinite medium increases as $F(t_{exch}) = b(S/V)\sqrt{(4/\pi)Dt_{exch}}$, where b is the partition coefficient, S is the surface area available for the gas transport, V is the gas volume, and D is the diffusion coefficient. However, in reality the parenchymal thickness is finite and the ratio will eventually reach saturation (if $\mathbf{t_{exch}}$ is long).

Methods: All experiments were performed on a GE Signa Profile IV MRI magnet (0.2T) interfaced with a broadband Tecmag Apollo (Houston, TX) research console. A Mirtech, Inc (Brockton, MA) whole body transmit/receive coil (Q=300) was used for all studies. ^{129}Xe was hyperpolarized on site using a polarizer developed and built at the UNH [4]. All experiments were in compliance with local IRB and FDA IND approved protocols which stipulates that the inhaled gas mixture must contain no less than 21% oxygen and no more than 70% xenon, and that the mixture must not exceed 35% Xe in the lungs during a 40s breath hold. All experiments were done at nearly the same lung volume (~54% of TLC).

Results: Figure 1 shows a sample set of data from CSSR experiment. Here we plot the mean fractional gas transport, F(t) ~ S_{diss}/S_{gas}. The data were fit with F(t)=a+b√t, which is shown as a solid purple line in Fig.1. As evident from the graph, the data fit the model of 1D semi-infinite medium for the short exchange times. As exchange time is increased, F(t) reaches a plateau. Two repetitions are presented in the graph showing the reproducibility of the technique. Figure 2 shows the same fractional gas transport measured using a different technique - XTC. Since XTC uses inversion pulses at dissolved state frequency to attenuate the gas signal, one expects to measure at most twice the gas transport as CSSR per pulse. Fig.2 shows F(t) for XTC at short times. Blue solid line is a √t fit to the XTC data and fits the data remarkably well.

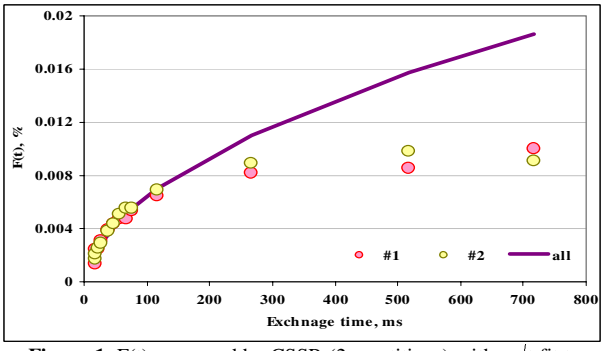

Figure 1. F(t) measured by CSSR (2 repetitions) with a √t fit to the data. There is a great agreement for short times (<120ms) after which data deviates from √t behavior and infinite medium approximation is not valid anymore.

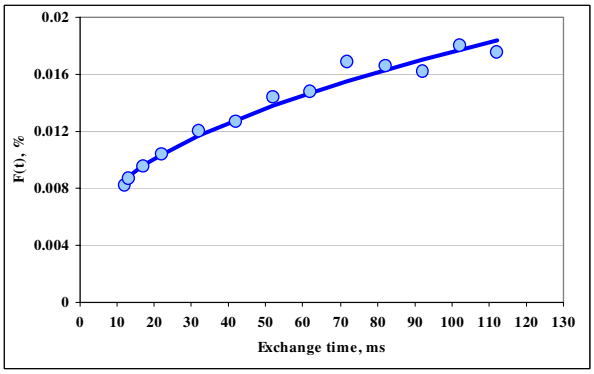

Figure 2. F(t) measured by CSSR (2 repetitions) with a √t fit to the data. There is a great agreement between data and the infinite medium model for the exchange times measured (up to 120ms).

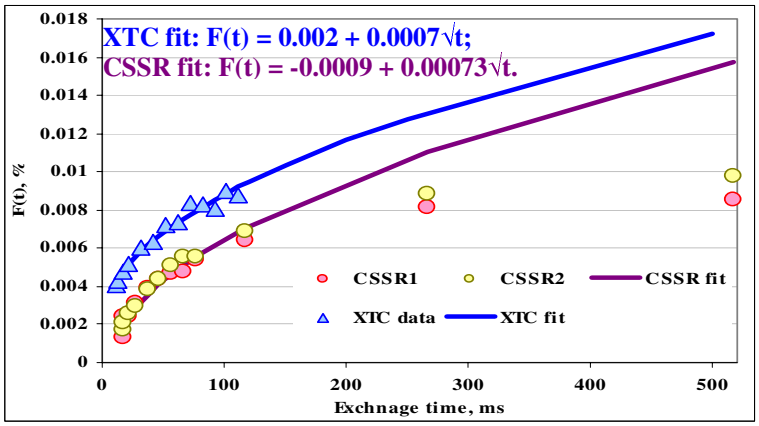

Figure 3. Comparison of mean F(t) dependence on exchange time measured using CSSR and XTC methods. Both methods provide the same functional form for the short times.

In figure 3 we compare the two methods. Here we plot both the CSSR and XTC F(t) data on the same graph. As seen from the two fits, the slopes are very close to each other, whereas there seems to be an offset in XTC data compared to CSSR data.

Discussion and Conclusions: Two independent methods were used to investigate the dependence of the mean fractional gas transport of ^{129}Xe in the lungs. The data acquired using both techniques were fit to the same model. The data show identical functional behavior with t_{exch}. The constant offset between two data sets might be due to a build up of the effects of imperfect inversion pulses repeated multiple times in XTC experiment. Also, Ruppert et.al. [2] reported exchange times of less than 50ms in rabbits when the plateau in F(t) is reached, whereas in humans we observe much longer exchange times following the semi-finite medium model (up to 120ms by both techniques).

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References: [1] Patz et.al.,14th Annual ISMRM, Seattle,p.192(2006); [2] Ruppert etal.,MRM 51:676-687(2004); [3] Butler et.al. J.Phys:Condens.Matter2002;14:L297–L304; [4] Ruset et.al,Phys.Rev.Lett.96,053002(2006).