Preliminary Lung Density Measurements with a Portable Low-Filed System

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Purpose: Acute Lung Injury (ALI), which includes acute respiratory distress syndrome (ARDS), is a relatively common clinical condition characterized by sudden respiratory failure. It has an unacceptably high mortality rate of 38.5% making it a major problem to be addressed in the ICU [1]. ARDS/ALI is accompanied by flooding of the alveoli with fluid, protein, and cellular debris. By applying positive pressure, mechanical ventilation is used to open these lung regions. Too much pressure can result in damage to the delicate septal tissue by over distension whereas too little pressure allows alveolar units to remain closed or only partially open. Either scenario leads to further inflammation. Currently ventilator settings are adjusted based on global pressure-volume measurements. What is needed is a device to measure regional lung mechanics in the ICU. Thus, a portable device capable of measuring localized lung density would assist clinicians in determining optimal ventilator pressures to safely maintain lung patency without causing barotrauma. We have previously described a prototype of such a system, "Lung Density Monitor" (LDM), built in our lab [2,3]. The system utilizes a monohedral permanent magnet assembly of modest dimensions and low field strength (0.008T). The surface of the magnet is placed on the posterior portion of the chest allowing the remote homogeneous field region to be located inside the lung. The signal thus obtained provides regional information about (i) lung density when detecting ^{1}H (LDM) or (ii) ventilation, when detecting hyperpolarized gas signal. Though RF shielding is currently used in our laboratory, using active noise cancellation [4] we expect to eventually obviate its need.

Methods: For details of the construction and field characteristics of the LDM, refer to [2,3]. All human experiments followed a protocol approved by the local IRB. Local lung density was measured in a human subject *in vivo*. A Carr-Purcell-Meiboom-Gill sequence was used with TE=4ms, 50 echoes in the echo train, and 60 repetitions per breath-hold. Measurements were performed during breath-holds at RV, FRC and TLC, with at least 10 repeats at each lung volume to measure reproducibility. The echoes were combined in a weighted average to improve SNR. We also measured T_1 and T_2 at this field. Additionally we performed initial hyperpolarized Xe tests: the gas has been polarized using XeNA polarizer [5] and then transported to the LDM lab in a transport box (HPXe T_1 in the transport box is 20min).

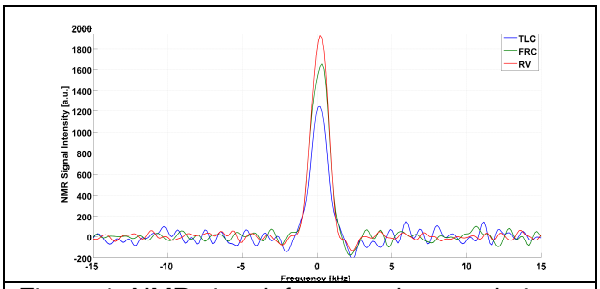

Figure 1. NMR signal from a volunteer during a breath-hold at TLC, FRC and RV.

Results: The measured *in vivo* relaxation times are as follows: in the lungs T_1=135ms, T_2=81ms; in the muscle (leg) T_1=113ms, T_2=60ms. The lung volume dependence of the in vivo lung parenchyma data is presented in Figure 1. As expected, the observed signal increases as the lung volume decreases. We performed 10 repeats at each lung volume and estimated the reproducibility of 9%, 10% and 12% at RV, FRC and TLC, respectively. The SNR of a single acquisition at the highest lung volume (lowest signal), was calculated as the ratio of the phased signal to the standard deviation of the noise, to be 118. Data from our HPXe test, which is a single CPMG train, is shown in Figure 2. The second acquisition shows significantly reduced signal because of the depletion of the hyperpolarization after the first excitation.

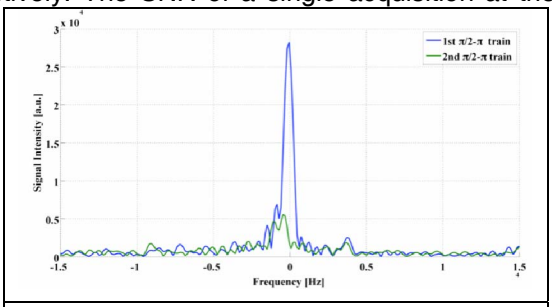

Figure 2. HPXe signal obtained using LDM.

Discussion: We report initial in vivo lung density measurements as well as hyperpolarized phantom Xe measurements using LDM [2,3]. The device measures the NMR signal from a remote region ~8 cm from the LDM surface. The size of the region is determined by the signal bandwidth and, for the results reported here, was ~16cm^3. By placing a small cylindrical (diam=55cm, h=2cm) phantom at different distances from the surface we observed the signal peak at the saddle point and the profile of the response function agreed well with the numerical model. The measurements at 3 lung volumes demonstrate the LDM's capability to assess the differences in the lung densities at TLC, FRC and RV with high reproducibility. In the future we will calibrate LDM so absolute density can be obtained directly and regional values of lung density plotted vs inhaled air volume. Additionally, in order to avoid lengthy breath-holds, we will acquire data during free breathing and use the correspondence between the synchronously acquired relative volume data from the ventilator and the NMR data from the LDM. Active Noise Cancellation (ANC) will be implemented to eliminate the need in bulky RF shielding. The ANC algorithm considers random, and spurious components of the noise acquired by an independent coil before subtracting them from the signal in the main channel. This can take place offline, thus relaxing computational speed requirements necessary for real-time audio noise elimination.

References: 1. Rubenfeld et al. *New Engl J Med* 2005;353:1685-93. 2. M. Dabaghyan et al. Proc. ISMRM 2013, 2762. 3. Patz et al. Proc ISMRM 2013. 4. M. Hrovat, M. Dabaghyan, Proc. ENC 2013, #412. 5. Nikolaou et al. PNAS 2013; 110(35): 14150–5.