Xenon Surface Relaxivity: Potential Applications to Probing Lung Disease

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Introduction

Because hyperpolarized ^{129}Xe gas NMR signals can result in four to five orders of magnitude polarization enhancement compared to thermal equilibrium signals even at high fields [1], hyperpolarized ^{129}Xe gas MRI has shown great promise for lung imaging. Scientists have developed many techniques to assess lung properties, such as ADC (apparent diffusion coefficient) [2], XTC (Xenon polarization Transfer Contrast) [3], CSSR (chemical shift saturation recovery) [4], etc, in order to diagnose and evaluate the pulmonary function. Driehuys et al. has determined the thickness of the blood–gas barrier via imaging ^{129}Xe alveolar-capillary gas transfer, and shown the utility of such method in a rat model of pulmonary fibrosis [5]. The effective transverse relaxation (T_2^*) in lung has been investigated by treating the lung as a porous medium [6]. However, a drawback is that for any of these methods to be quantitative, a model of the lung is required. We believe that probing lung diseases by measuring xenon surface relaxivity in alveoli could offer unique advantages towards a model-free characterization. We demonstrated the probing of xenon surface relaxivity in phantoms and discuss potential application towards monitoring physiological changes in the alveoli surface properties.

Materials and Methods

Three cylindrical Pyrex tubes (O.D. 3 mm, 5 mm and 10 mm; I.D. 1.7 mm, 4.14 mm and 8.16 mm) coated with Surfasil were filled with pure natural abundance xenon (26.4% ^{129}Xe) at 79.3 psi, 77.3 psi and 75.7 psi, respectively. Two uncoated ones (O.D. 3 mm and 5 mm) were filled the same pure xenon gas at 62 psi and 65 psi. The T_2 of all phantoms were measured using a short interpulse spacing (τ=5 ms) CPMG train on Varian AS400 Micro-imaging system with VNMRJ 2.2C. The xenon frequency was 110.57MHz. The pressure dependence for $1/T_2$ is similar to that for $1/T_1$ [7], and the only difference originates from the static dephasing, which can be safely neglected in the limit of short interpulse spacings. Therefore, $1/T_2=1/T_{2\_bulk}+1/T_{2\_surface}=Ap+B/a^2p$, here p is the pressure, a is the tube's radius, and A and B are coefficients. This above equation can be fit to our data (at various values of a) in order to obtain $1/T_{2\_surface}$ for different phantoms. According to Brownstein and Tarr's theory of surface relaxation mediated by classical diffusion [8], we have in the case of cylindrical geometry

$$1/T_{2\_surface} = D\eta_n^2 / a^2,$$

where D is the free (bulk) diffusion coefficient, and the η_n are the positive roots of $\eta_n J_1(\eta_n)/J_0(\eta_n) = Ma/D$ expressed in terms of cylindrical Bessel functions. Accordingly, values of M (surface relaxivity) can be derived from the above equations.

Results and Conclusion

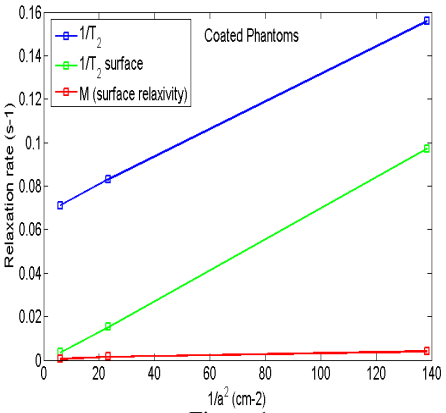

Figure 1.

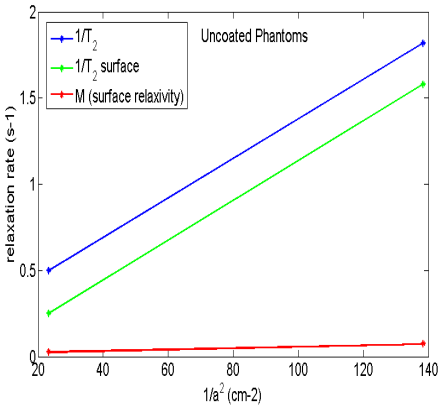

Figure 2.

Figure 1 is a plot of relaxation rates as function of $1/a^2$ the coated phantoms. The blue line reperesents the measured T_2 from the CMPG train. The green line shows the $1/T_{2\_surface}$ of different size tubes. From these curves, the surface relaxivity (M) was measured to be 0.0022 cm/s. Figure 2 shows a similar plot, but for the uncoated phantoms. In this case, the surface relaxivity is calculated to be 0.052 cm/s, more than an order of magnitude higher than for coated glass. We note that the rate $1/T_{2\_surface}$ is dependent of vessel size, i.e., the geometric quantity; while surface relaxivity (M) is independent of vessel size (within 5% experimental error), but depends of material property. The surface relaxivity parameter is an intrinsic characteristic of a surface. For example, it is related to the number of relaxation sinks present per unit area, and scales with the strength of these sinks. In the case of lung, this surface relaxivity can be mediated by exchange with the alveolar tissue, which would be expected to depend on the physiological state of the tissue.

We therefore propose that surface relaxivity be investigated as a possible method to the surface relaxivity of alveoli, which may exhibit some correlation with pulmonary physiology. Our method, which proved to be quite sensitive to changes in surface properties in the present phantom study, should also be readily extended to the study of materials, especially porous media, and their surface properties.

Sponsors

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