Absolute Quantification of Pulmonary Perfusion Using Intravenous Injection of Hyperpolarized ^{129}Xe

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Introduction: Increasingly, regional perfusion information is desired for effective clinical management of chronic pulmonary disorders. There is a strong need for such imaging techniques to be absolutely quantifiable, particularly for the evaluation of therapeutic drug response. We have recently suggested a novel means of lung perfusion imaging based on intravenous injection of hyperpolarized (HP) ^{129}Xe dissolved in saline (1). In this study we demonstrate that extension to absolute quantification is feasible.

Methods: Animal preparation (5 Fischer 344 rats, 330-425g) according to a Duke approved IACUC protocol included anesthesia (ketamine/diazepam injection), peroral intubation, and ventilation on a constant-volume ventilator (respiration frequency, f_{resp} = 60 bpm, tidal volume, V_T = 2.6mL). HP ^{129}Xe, enriched to 83% was produced in batches of 120 mL at P≈12% using a prototype commercial polarizer (MITI, Durham, NC). ^{129}Xe imaging and spectroscopy used a 23.6MHz linear birdcage coil (L 8cm, ϕ 7cm) in a 2T, horizontal, 15cm clear-bore magnet with shielded gradients (180mT/m) and GE Excite console. HP ^{129}Xe was dissolved in 30-40mL of half-concentrated saline and shaken for 20 s. For imaging, 5 mL of saturated saline was withdrawn and injected over a period of 15 s into the rat's tail or jugular vein while respiration was suspended. GRE images (no slice selection, α 15°, *TR* 250ms, bandwidth 4kHz, matrix 64×64, FOV 7.5cm) were acquired over 16 s starting 5 s after injection. Spectra were acquired for 30 s (α 5-30°, *TR* 125-250ms) to study dynamics of the HP ^{129}Xe resonances.

Modeling of the ^{129}Xe gas signal dynamics (*cf.* Fig. 1 & eqns. below) was based on an adaptation of the Kety-Schmidt theory considering an arterial input function given by the pulmonary perfusion, Q, and the arterial ^{129}Xe magnetization, m_{za}, exchange between bolus and alveolar space, described by partition coefficient, λ_{bolus}, and signal loss due to venous outflow, respiration, and alveolar T_1 relaxation. The combined contributions to this signal loss are described by an apparent relaxation time, T_{1app}. Finally, destruction of magnetization due to RF pulsing was also considered.

Results and Discussion: Examples of fitting results in two rats are given in the Figs. 2 and 3 and in the Table. As expected, the transit time, δ, for the bolus to arrive in the pulmonary capillaries was shorter for the jugular vein than for the tail vein. Assuming total alveolar volumes of V_A=7.6-8.6 mL (2), the obtained estimates of the global perfusion are consistent with literature data (3) for the cardiac output (1.8 mL/s in 320g rats).

$$\frac{dM_{zA}}{dt} = \dot{Q} m_{za} - \frac{M_{zA}}{T_{1app}}; \quad \frac{1}{T_{1app}} = \dot{Q}\frac{\lambda_{bolus}}{V_A} - f_{resp}\frac{V_T}{V_A} - \frac{M_{zA}}{T_{1A}}$$

$$M_{zA}(j) = \dot{Q} m_{za} T_{1app}(1-E_1)\frac{1-(E_1\cos\alpha)^{j-1}}{1-E_1\cos\alpha}; \quad E_1 = e^{-TR/T_{1app}}$$

Rat	V_T [mL]	f_{resp} [bpm]	δ [s]	Q [mL/s]
1 (425g)	3.4±0.4	60.0±0.1	3.1±0.3 (tail) 1.8±0.4 (jug.)	3.0±1.4
2 (380g)	0	0	2.7±0.2 (tail)	2.2±1.8

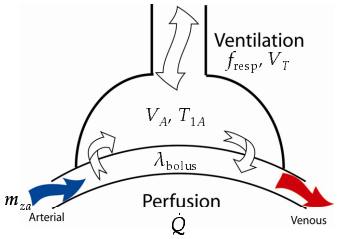

Fig. 1. Schematic of the model described in the text.

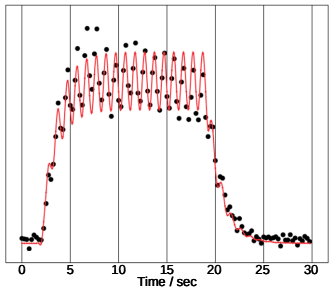

Fig. 2 Gas-phase signal during bolus passage with respiration.

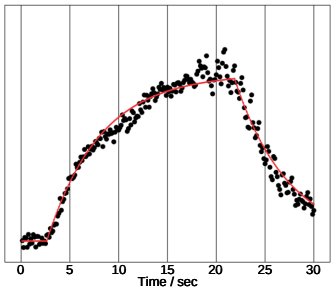

Fig. 3 Gas-phase signal during bolus passage and suspended breathing.

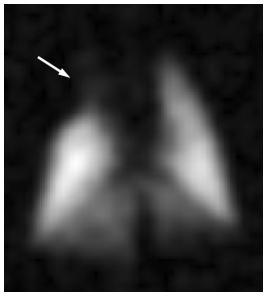

Fig. 4. ^{129}Xe perfusion image.

Conclusions: By selectively imaging gas-phase ^{129}Xe following intravenous injection, qualitative maps pf pulmonary perfusion (Fig. 4) can be obtained whereas analysis of a series of gas-phase spectra permit absolute quantification of global lung perfusion. Combining both informations allows scaling of the image to obtain quantitative regional perfusion information.

References: (1) B Driehuys, Proc ISMRM 15,455,2007; (2) WR Stahl, Adv Biol Med Phys 9,355,1963; (3) MV Andrade, Comp Biochem Physiol C138, 97, 2004.

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