An oxygen-enhanced lung T1 model

T. Wang[1], E. D. Pracht[1], J. F. Arnold[1], P. M. Jakob[1]
[1]Department of Experimental Physics 5, University of Wuerzburg, Wuerzburg, Bavaria, Germany

Introduction: In blood, physically dissolved oxygen is weakly paramagnetic and has been used via inhalation of molecular oxygen as a T_1-shortening contrast agent in the functional ^1H MRI of the human lung [1,2]. The purpose of this work is to develop the corresponding theoretical oxygen-enhanced lung T_1 model that depicts the dependence of lung T_1 on the inspired oxygen concentration.

Theory: According to the fast-exchange two-compartment model, the observed lung T_1 can be described by

$$1/T_1 = P_f/T_{1f} + P_b/T_{1b} \quad (1)$$

where P_f is the free-water fraction with T_{1f} and P_b (= 1 - P_f) the bound-water fraction with T_{1b} in the lung. T_{1f} can be described by [3]

$$T_{1f} = (T_{1a} + T_{1v})/2 \quad (2)$$

where T_{1a} is pulmonary arterial and T_{1v} venous blood T_1. In the blood with 100% oxygen saturation, T_{1a} can be described by [4–6]

$$1/T_{1a} = A + B\cdot pO2 \quad (3)$$

where A, B are constant and pO2 is the oxygen partial pressure in the pulmonary arterial blood. pO2 can be described by [7]

$$pO2 = (pB - 47)\cdot F_{IO2} - (V_{O2}/V_A)\cdot 863 \quad (4)$$

where pB is the current barometric pressure, F_{IO2} the inspired oxygen concentration, V_{O2} the oxygen uptake of the blood and V_A the alveolar ventilation. Combing Eq. 1–4, lung $1/T_1$ can be described by a function of the inspired oxygen concentration F_{IO2}. With parameters of a healthy adult as an example: $A \approx 0.60$ 1/s, $B \approx 4.11\cdot10^{-4}$ 1/s/mmHg and $1/T_{1v} \approx 0.64$ 1/s [4,5], $V_{O2} \approx 0.28$ L/min, $V_A \approx 5$ L/min and pB ≈ 760 mmHg [7], $P_f \approx 0.9$ and $T_{1b} \approx 0.7$ s according to the estimation, the resulting function is plotted in Fig. 1.

Results: Fig. 1 depicts a line with a slope of approximately 0.12 1/s and a $1/T_1$ axis intercept of approximately 0.69 1/s which are consistent with experimental results from seven volunteers in Tab. 1 using the method of [2], implying that our oxygen-enhanced lung T_1 model can describe the dependence of healthy lung T_1 on the inspired oxygen concentration.

Discussion: A theoretical oxygen-enhanced healthy lung T_1 model has been successfully derived from respiratory physiology and T_1 relaxation mechanisms in the lung. The model can be used to interpret in vivo healthy lung T_1 data in case of experiments with oxygen inhalation and to further optimize oxygen-enhanced ^1H MRI of the human lung. However, Eq. 3 and thus the model do not hold for the situations where hemoglobin in arterial blood is not fully saturated by oxygen under physiological conditions. Deoxygenated hemoglobin is moderately paramagnetic and provides a relaxation pathway in addition to physically dissolved oxygen.

References: [1] Edelman RR, et al. Nat Med 1996;2:1236–1239. [2] Jakob PM, et al. MRM 2004;51:1009–1016. [3] Belle V, et al. JMRI 1998;8:1240–1245. [4] Hueckel P, et al. ISMRM 2000. p 1586. [5] Silvennoinen MJ, et al. MRM 2003;49:568–571. [6] Lu H, et al. MRM 2004;52:679–682. [7] Thews G, et al. In: Human physiology. Berlin: Springer; 1989. p 544–577.

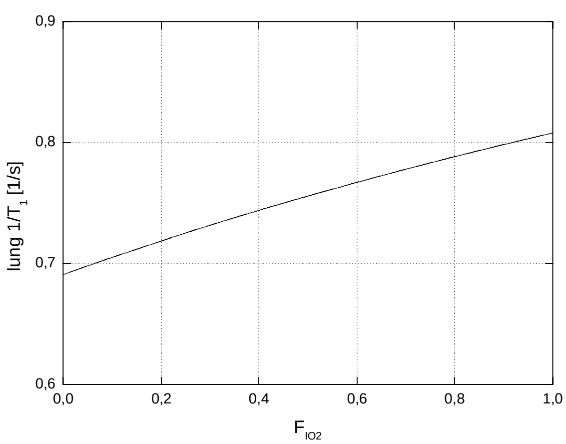

Fig. 1. Theoretical dependence of healthy lung $1/T_1$ on inspired oxygen concentration F_{IO2} with a slope of approximately 0.12 1/s and a $1/T_1$ axis intercept of 0.69 1/s.

volunteer	age/sex	slope [1/s]	$1/T_1$ axis intercept [1/s]
1	30/F	0.12 ± 0.00	0.69 ± 0.00
2	26/F	0.11 ± 0.02	0.72 ± 0.01
3	22/M	0.14 ± 0.01	0.77 ± 0.01
4	22/M	0.13 ± 0.01	0.75 ± 0.01
5	35/M	0.10 ± 0.01	0.81 ± 0.01
6	20/F	0.11 ± 0.01	0.75 ± 0.01
7	22/M	0.10 ± 0.01	0.75 ± 0.01

Tab. 1. Slopes and $1/T_1$ axis intercepts (mean ± standard error) of measured dependence of lung $1/T_1$ on inspired oxygen concentration F_{IO2} from seven volunteers using the method of [2].