Blood T_1 Measurements at High Magnetic Field Strengths

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Introduction

Longitudinal relaxation time constant (T_1) of blood is a critical parameter in optimizing and analyzing blood flow measurements based on spin tagging techniques and in blood vessel imaging utilizing time-of-flight methods. Previously, T_1 of bovine blood has been measured at 1.5 (1) and 3 (2) Tesla. In this study, we extend these studies to magnetic fields up to 9.4 Tesla, covering the range often used in an experimental setting for both animal and human studies. Together with previously reported data and measured data, the results allow the prediction of blood T_1 at any magnetic field used currently for *in vivo* studies.

Methods

Fresh bovine blood containing 0.25 mL heparin sodium (0.5% by volume) was centrifuged before the experiment to determine hematocrit content. A circulation system was designed that required ~180 mL of blood. The circulation system consisted of Tygon tubing, a commercial pediatric blood oxygenator (MiniMax Plus, Medtronic), a glass tube surrounded by the coil, and a commercial rotary pump. Constant temperature (~37.0ºC) was maintained by warm water circulation. The temperature of the blood was measured via a probe placed 10 cm downstream from the measurement area. Blood oxygenation was manipulated using mixtures of N_2 and O_2 with 5% CO_2 and room air. Blood samples (~0.2 mL) were drawn at regular intervals to determine the pH and oxygenation using a blood gas analyzer (Radiometer AB, Copenhagen). The blood oxygenation was calculated as the average of the oxygenation before and after each measurement. To prevent erythrocyte sedimentation and minimize temperature drifts, the blood was circulated at all times except during the time commencing with the first RF pulse and ending with the recording of the FID.

An inversion recovery sequence followed by slice selection based on LASER (3) was used (Figure 1). Square pulses were used for the inversion (π = 170 μs) and the subsequent excitation ($\pi/2$ = 85 μs) pulses, and two AFP were used to localize a slice perpendicular to the long axis of measurement tube positioned vertically in the horizontal bore magnets. Seventeen time points with variable delay d2 (Figure 1) were acquired for each oxygenation level. The data was obtained at 4.7 T (40 cm horizontal bore), 7 T (90 cm horizontal bore), 9.4 T (31 cm horizontal bore) magnets equipped with Varian INOVA consoles. A single sheet solenoid coil was used in transmit and receive mode. The integration of the data was performed in VNMR, and fitting and analysis were carried out in Origin.

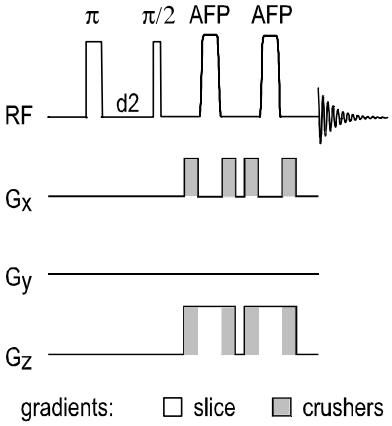

Figure 1. A modified LASER sequence where d2 is a variable delay.

Results and Discussion

Table 1 gives the field strength and corresponding blood T_1 obtained in our study for hematocrit content 47 ± 6 and oxygenation level 63 ± 25. For lower hematocrit content (~30%), the increase of the blood T_1 was observed which was expected given the higher proportion of water. No significant T_1 dependence on blood oxygenation level was obtained which was consistent with previous studies of T_1 and blood oxygenation. Figure 2 illustrates these data together with previous literature values measured at 1.5 and 3 Tesla and calculated for 4.7 Tesla. The linear relationship between T_1 of blood and the strength of the magnetic field is observed using reported data and data obtained in this study. The results obtained in this study are consistent with previous predictions (1).

In conclusion, a modified LASER sequence was used to measure the T_1 of bovine blood at 4.7, 7 and 9.4 Tesla magnetic fields. The results showed that T_1 relaxation increases linearly with the magnetic field strength described by the equation $T_1 = 0.134B_0 + 1.226$.

Magnetic field (T)	T_1 (s)	S.D.
4.7	1.921	0.008
7.0	2.20	0.02
9.4	2.44	0.02

Table 1 . Magnetic field strength dependence of T_1. The last column presents standard deviation of measurements.

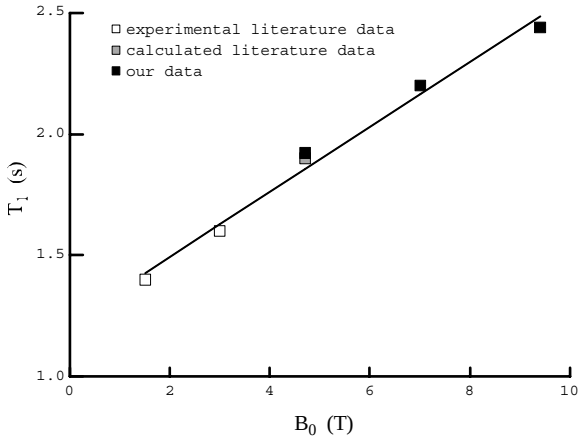

Figure 2. T_1 values as a function of magnetic field strength.

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