Blood Longitudinal (T1) and Transverse (T2) Relaxation Times at 11.7 Tesla

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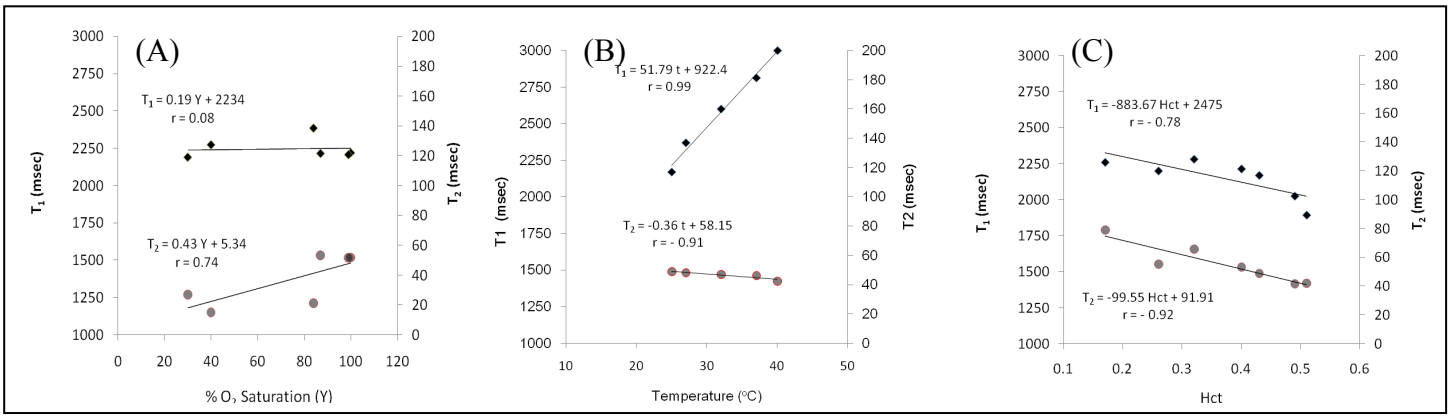
Introduction: The longitudinal relaxation time (T_1) and transverse relaxation time (T_2) of blood are two important MRI parameters. For example, blood T_1 is pivotal for quantifying cerebral blood flow (CBF) using arterial spin labeling (ASL) techniques (1) and for cerebral blood volume (CBV) determination using vascular space occupancy (VASO) method (2). Blood T_2 is important to differentiate vascular contribution to blood oxygenation level dependent (BOLD) signal (3,4). As high field MRI (> 7T) is rapidly getting involved in functional studies with animal models, it is crucial to determine animal blood T_1 and T_2 for these systems. The purpose of the study was to report T_1 and T_2 values as a function of oxygenation level (Y), temperature, and hematocrit fraction (Hct) of rat blood at 11.7T.

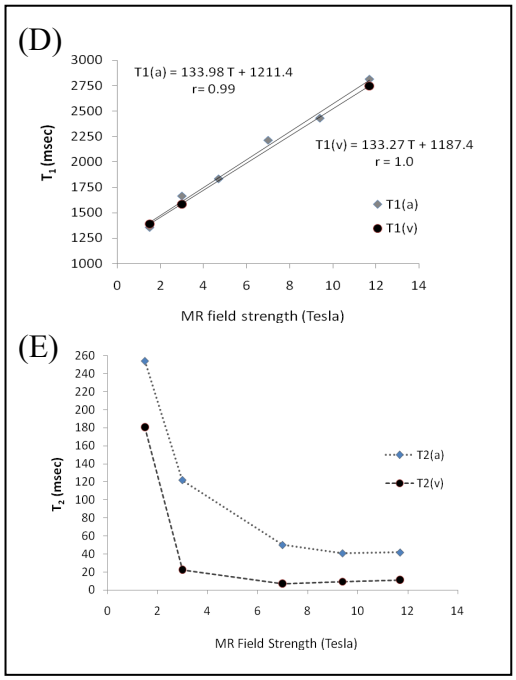
Material and Methods: Fresh blood was withdrawn from 3 normal rats and used within an hour. Blood gases, Y, total hemoglobin and temperature were measured with a blood gas analyzer. Vials were then sealed. Experiments were performed on a 11.7T BioSpec MR scanner (Bruker, Billerica, MA, USA). A quadrature volume coil was used for both RF transmission and reception. T_1 and T_2 were simultaneously measured using a rapid acquisition with relaxation enhancement (RARE) sequence. Six TR (208.4, 400, 800, 1500, 3000 and 3500 ms) and five TE (14.01, 42.03, 70.05, 98.07, 126.05 ms) were used. A single slice centered on the blood sample was chosen. Field-of-view (FOV) = 40 x 40 mm^2, slice thickness =1.0 mm, matrix = 128 x 128 and rare factor = 4. Samples taken from both venous and arterial blood (Y= 30-100%) were sent to measure T_1 and T_2 as a function of Y at room temperature (25°C). To determine the T_1 and T_2 as a function of temperature, an arterial blood sample (Hct = 0.43 and Y = 98-99%) and a thermometer were placed in the center of an acrylic tube (20 mm in diameter and 92 mm long). Water was circulated around the acrylic tube by a water bath. The temperature was adjusted from 25-40°C and monitored in real time by a temperature controller. Finally, the venous blood sample of each rat was putting into an Eppendorf centrifuge for 3 min. The pipette-off plasma and erythrocytes were added to the two arterial blood samples, respectively, to vary the Hct. The 0.1 c.c. blood sample of each arterial blood was taken by a micro-hematocrit tube (with heparin), which was then putted in a micro-hematocrit centrifuge for 3 min. Hct fraction was determined by measuring the ratio between the erythrocytes and the plasma. The resulting range of Hct was 0.17-0.51 with Y = 99% and Temp = 25°C. T_1 was calculated by fitting $M(t) = M_o [1-c*\exp(-TR/T_1)]$ and T_2 was calculated by by fitting $M(t) = M_o \exp(-TE/T_2)$.



Results and Discussion: Figure A shows the plot of T_1 and T_2 versus Y with a normal hematocrit level at room temperature (Hct =0.43, Temp = 25°C). T_1 was insensitive to the changes of the Y (r = 0.08, P > 0.5). In contrast, a linear correlation between T_2 and Y was observed (T_2 = 0.43 Y + 5.34, r = 0.81, P < 0.05). Figure B demonstrates the results of T_1 and T_2 as a function of temperature (Hct = 0.43 and Y = 99%). A significantly linear relationship between T_1 and temperature was observed (T_1 (ms) = 51.79 t (°C) + 922, r = 0.99, P < 0.001). T_2 was also significantly related to temperature, but with negative correlation (T_2 (ms) = -0.36 t (°C) + 58, r = - 0.91, P < 0.05). Arterial blood T_1 and T_2 (Y = 99% and Temp = 25°C) as a function of Hct are shown in Figure C. A negatively linear dependency of T_1 on Hct was seen (T_1 (ms) = -883 Hct + 2475, r = - 0.78, P < 0.05). Similar result was also observed for T_2 versus Hct (T_2 (ms) = -99.55 Hct + 92, r = -0.92, P < 0.005).

Finally, we compared our T_1 and T_2 results at 11.7T to those obtained at other MR field strengths (B_o) in literature. It shows that both arterial and venous T_1($T_{1(a)}$ and $T_{1(v)}$, respectively) are linearly dependent on B_o (Figure D). $T_{2(a)}$ and $T_{2(v)}$ are exponentially dependent on field strength (Figure E).

In conclusion, this study report T_1 and T_2 values as a function of oxygenation level, temperature, and hematocrit of blood at 11.7T and compared with published data at different field strengths. A key finding is that blood T2 did not decrease significantly with increasing B_o at high fields. These results have implications in BOLD modeling, high spatial specificity BOLD fMRI, CBF MRI using arterial spin labeling, and CBV MRI using VASO techniques. These data may prove useful for a wide range of MRI studies.



References: (1) Wang et al., (2003) MRM 49:796–802; (2) Lu et al., (2003) MRM 50:263–274; (3) Ogawa et al., (1993) Biophys. J. 64:803-812; (4) van Zijl et al., (1998) Nat Med 4:159-167.