What is the longitudinal relaxation time (T1) of blood at 3.0 Tesla?

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ABSTRACT: The longitudinal relaxation time (T1) of blood was measured at 3.0 T under physiological conditions in a blood perfusion system. At physiological temperature of ~37°C, blood T1 values ranged from 1504ms to 1684ms, depending on hematocrit (Hct: 0.46-0.38). Temperature significantly affected T1: a 10°C decrease corresponded to a 130ms reduction in T1. In contrast to the influence of Hct and temperature, blood oxygenation effects were small. In our perfusion setup at 3.0 T, effects of radiation damping caused a drop of ~20ms in measured T1 values.

INTRODUCTION: Recently, 3.0 T has become available as the new common field strength for human MR research. To date, T1 of blood has not been reported for this field strength. Blood T1 values are of critical importance in many MR experiments, such as perfusion estimation using arterial spin labeling (1), black blood imaging in vascular stenosis studies (2), and Vascular-Space-Occupancy (VASO) dependent fMRI (3). In this study, we measured T1 of arterial and venous blood at 3.0 T and its dependence on temperature at two common hematocrits. The effect of radiation damping on the inversion recovery T1 measurement was also assessed.

METHODS: Experiments were conducted on a 3.0 T whole body scanner (Philips Medical System, Best, the Netherlands). Bovine blood (Hct=0.38-0.46), which is known to have physiological and MRI properties comparable to human blood, was studied in a circulating system. Slow sample flow (~3.1ml/min) was maintained to avoid coagulation. Sample conditions were monitored using a blood analyzer (Radiometer America Inc., Westlake, OH): MetHemoglobin fraction < 1.5%, pH=7.0-7.4. The blood temperature was controlled using a water bath and water circulation around the blood tubes, and monitored by an MR compatible fiber optic thermo-sensor (FISO Technologies, Quebec, Canada). Inversion recovery imaging was used for T1 mapping: TIs (10, 50, 100, 250, 500, 1000, 2000, 3000, 5000, 10000 ms), recovery time 9 s, non-slice-selective sinc RF inversion pulse. Unless otherwise mentioned, a small dephasing gradient (2 mT/m) was applied throughout the inversion time to remove any radiation damping effects. Three-parameter fitting of the absolute signals was applied to determine T1 values.

RESULTS and DISCUSSION: At hematocrit of 0.46 and temperature 37.2°C, the T1 values of arterial (Y=0.97) and venous blood (Y=0.66) were 1526 ms and 1504 ms, respectively (Fig. 1). It can be seen that blood oxygenation has small effects on longitudinal relaxation time, which is probably due to the highly sequestered paramagnetism of deoxyHb (4). In contrast, temperature has a greater effect on blood T1 (Fig. 2, R1 = 1/T1) and shows the well-known inverse relationship. Note that a 10°C temperature decrease corresponds to ~130 ms of T1 reduction, demonstrating the importance of precise temperature control during in vitro T1 measurements.

It was previously shown that radiation damping may have a significant effect in inversion recovery experiments (5). This effect originates from the reaction of receiving coil with the large transverse magnetization of the sample, resulting in a more rapid longitudinal recovery. Radiation damping increases with improved coil quality (Q) and higher static field (B0). To assess the significance of such effects on a clinical 3.0 T scanner using a commercial quadrature coil, we compared blood (T=37.2°C, Hct=0.38) T1 values measured with (Fig. 3, left) and without (Fig. 3, right, small gradient applied during TI) radiation damping effects. It can be seen that radiation damping has a small but significant (paired *t*-test, $p<0.001$) effect under our experimental setup. Thus caution has to be taken when using quantitative parameter determination with inversion recovery sequences at high field (e.g. 4 T, 7 T). Note that T1 values in Fig. 3 are greater than that in Fig. 1, due to the dependence of T1 on Hct (0.38 vs 0.46).

REFERENCES:

1) Detre et al. MRM 23: 37-45 1992;
2) Chien et al. JMRI 2: 437-441 1992;
3) Lu et al. Proc. ISMRM 2003;
4) Brooks et al. Med. Phys. 14: 903-913 1987;
5) Zhou et al. MRM 40: 712-719 1999.

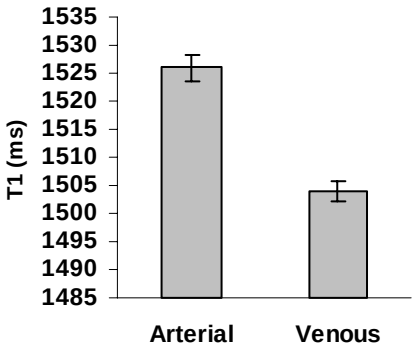

Fig. 1: T1 of blood (pH = 7.2, T = 37.2±0.5°C, Hct=0.46)

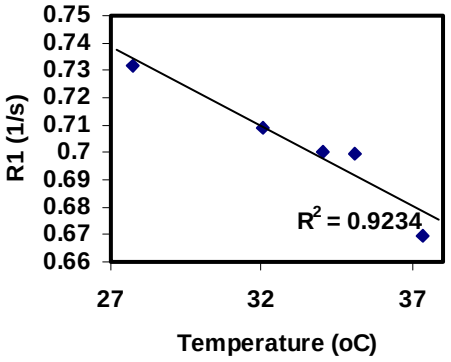

Fig. 2: Temperature dependence of blood T1 values (pH=7.2, Hct=0.46, Y=0.68)

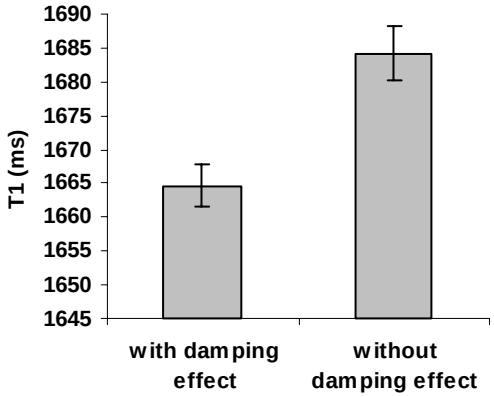

Fig. 3: Effects of radiation damping on inversion recovery T1 measurements (pH=7.1, Hct=0.38, T=37.2±0.5°C, Y=0.30)