Blood T2* peaks at an oxygenation level between arterial and venous blood

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Purpose: The T2* of blood has been believed to increase proportionally to the blood oxygenation(1),(2), claiming that the content of the paramagnetic deoxygenated hemoglobin, which distorts the magnetic field, decreases with an increase of the blood oxygenation. However, the distortion of the magnetic field in the blood is caused by the difference of the magnetic susceptibility between the red blood cell (RBC) and the plasma. The magnetic susceptibility of RBC increases proportionally to the blood oxygenation, whereas the magnetic susceptibility of the plasma stays constant(3). When the magnetic susceptibilities of RBC and the plasma are the same, magnetic field in the blood becomes homogeneous(4). This occurs at an oxygenation level between arterial and venous blood(3) and should result in a maximum T2* of the blood. To confirm whether the oxygenation dependency of the blood T2* has a peak, we measured the blood T2* at various blood oxygenation levels from venous one to 99%.

Materials and Methods: A medical doctor drew 10 ml blood from a vein of five healthy male volunteers (23-28 years). To measure the blood T2*, a blood tube (inner diameter 10 mm) was imaged by an incoherent gradient echo sequence SPGR(TR/TE/FA = 250 ms/12, 30 ms/30°) with a 1.5-T scanner (SIGNA Horizon LX, GE). The tube was bathed in a water bath kept at a room temperature (23°C). Shimming was performed carefully by using a manual shim. The values of T2* were calculated from $(30-12)/\ln(S_{12}/S_{30})$ [ms], where S_{12} and S_{30} were the signal intensity of a ROI (170 mm^2) in the tube with a TE of 12 and 30 ms, respectively . To observe changes in blood T2* with an increase in blood oxygenation, a fresh venous blood sample was first imaged and the imaging was repeated 8-11 times. During each imaging, the blood was exposed to the air so as to increase the blood oxygenation. Changes in blood oxygenation were monitored once by sampling a small volume of blood from the tube and by using a blood gas analyzer. The blood oxygenation in each imaging was obtained from the relation between the blood oxygenation and the cumulated time of exposing the blood to the air.

Results and Discussion: The T2* of blood increased with an increase in blood oxygenation and peaked at a blood oxygenation level around 95% (Fig. 1). As the magnetic susceptibility of the deoxygenated hemoglobin is paramagnetic (positive susceptibility), the susceptibility difference between RBC and the plasma is positive for lower blood oxygenation(3) (Fig. 2a). On the other hand, the susceptibility difference between the oxygenated RBC and the plasma is negative(3) (Fig. 2c). When RBC and the plasma have the same susceptibility, RBCs are magnetically transparent in the blood and the external magnetic field is not distorted by the presence of RBCs (Fig. 2b). In this situation, the magnetic field in the blood becomes most homogeneous, giving rise to maximize the blood T2*. These changes of magnetic field homogeneity in the blood due to blood oxygenation has been proved mechanically by observing the blood viscosity in the magnetic field(4). We observed that the T2 of blood also peaked at the same oxygenation to maximize the blood T2*. This is because the influence of the diffusion of the water in the plasma during the echo time increases with an increase of the inhomogeneity of the magnetic field in the blood. As there were few reports measured T2* and T2 of blood at the blood oxygenation levels around 85-95%, the peaking phenomena of T2* and T2 have long been hidden. The contribution of the signal from the blood (intravascular component) is dominant in fMRI at lower magnetic fields (1.5T) and its interpretation has been based on the monotonical relation of T2* and oxygenation of the blood. Therefore, to interpret the results of fMRI, our new findings should be taken into account.

Conclusion: We showed that the T2* of blood peaked at a blood oxygenation level around 95%. This fact lends a revision of the blood T2* dependency on the blood oxygenation. We believe our findings advance the understanding of the MR signal intensity reflecting the blood oxygenation.

References

(1) K. R. Thulborn, et al., *Biochem. Biophys. Acta.* **714**, 265 (1982).
(2) D. Chien, et al., *Magn. Reson. Med.* **32** , 540(1994).
(3) R. M. Weisskoff, S. Kiihne, *Magn. Reson. Med.* **24**, 375(1992).
(4) T. Yamamoto, et al., *Phys.Med.Biol.* **49**, 3267(2004).

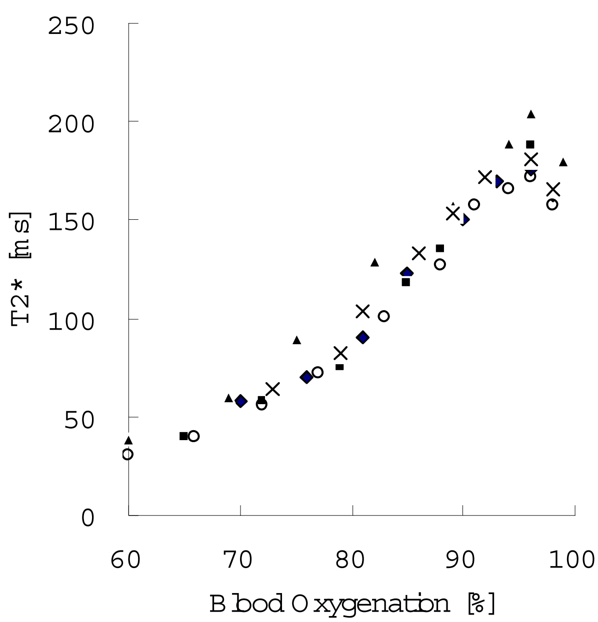

Fig. 1 Oxygenation dependency of the blood T2* at a 1.5-T static magnetic field.

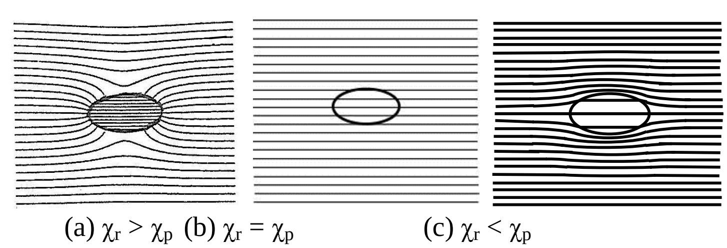

Fig. 2 Models of the magnetic field in the blood. χ_r and χ_p represent the magnetic susceptibility of the red blood cell and the plasma, respectively.