An Increase in Blood Viscosity in a Static Magnetic Field of a 1.5-T Magnetic Resonance Scanner

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Purpose: To understand the underlying mechanisms of the magnetic influence on blood viscosity, we measured the time for blood to fall through a glass capillary inside and outside a 1.5-T MR scanner.

Materials and Methods: A medical doctor drew 10 ml blood from a vein of healthy male volunteers (20-40 years). The blood was oxygenated by bubbling with oxygen gas for 1 minute, and was deoxygenated by stirring with the deoxidization agent $Na_2S_2O_4 \cdot 2H_2O$. To observe changes in the blood viscosity inside and outside a static magnetic field of 1.5 T, we measured the falling time by using an Ostwald viscometer bathed in a water bath placed at the center of an MR scanner and outside a magnet. The water bath was controlled at 25 ± 0.1 °C with a closed thermo controller. The falling time of oxygenated and deoxygenated blood was measured four times each for inside, then outside and again inside an MR scanner (Fig. 1). To observe changes in the falling time during changes in blood oxygenation, the falling time of four fresh venous blood samples was measured in a magnet. This experiment was repeated eight times for about 35 minutes for each blood sample. Changes in the blood oxygenation were monitored once by sampling a small volume of the blood from the viscometer and by using a blood gas analyzer. The blood oxygenation in Fig. 2 is obtained from the relation between blood oxygenation and time after blood collection. After the measurement in a magnet, the viscometer was quickly moved to the outside of the magnet. The falling time was measured four times outside the magnet, and the measurements were averaged. The shear rate of the flowing blood in the capillary of the viscometer was varied by adjusting an air-cock connected to the top of the reservoir side of the viscometer.

Results and Discussion: The falling time of fully oxygenated and fully deoxygenated blood increased by 1.7 ± 0.4% (P<0.0005) and 3.7 ± 0.1% (P<0.0002), respectively, in a static magnetic field when the shear rate of the blood flow was about 18 s^{-1}. The falling time in a static magnetic field decreased and peaked minimally with an increase of blood oxygenation (Fig. 2). The minimum peak of the regression curve of falling-time changes was at blood oxygenation of 88% and showed the same falling time as outside the magnetic field, implying no magnetic effect. As oxygenated hemoglobin is diamagnetic (negative susceptibility), the susceptibility difference between the oxygenated red blood cell (RBC) and the plasma is negative(1). On the other hand, the susceptibility difference between the deoxygenated RBC and the plasma is positive because of its paramagnetism(1). When RBC and the plasma has no susceptibility difference, RBCs are magnetically transparent in the blood and the external magnetic field does not change by the presence of RBCs. In this situation, the blood viscosity is not influenced by magnetic field; Figure 2 shows this event as the minimum point of the falling time. The percentage change in the falling time in a static magnetic field decreased with an increase in shear rate. The falling time in a static magnetic field increased by 2.6 ± 0.3% (P<0.02) when the shear rate was 50 s^{-1}, which is around a shear rate of large veins having a 5-6 mm diameter. As shear rate decreases with an increase of the diameter of the blood vessel, in vivo blood viscosity increases even at 1.5 T. However, changes in the falling time were negligible (0.3 ± 0.2%) in the presence or absence of a static magnetic field when the shear rate was 130 s^{-1}. The non-Newtonian property of blood viscosity(2) becomes marked with an increase in the shear rate because the long axis of the RBC tends to orient to the flow direction. Thus, the fluid dynamic moment overcomes the magnetic moment of the RBC, reflecting less influence of the magnetic field.

Conclusion: We showed that blood viscosity increases with exposure to the magnetic field of a 1.5-T MR scanner. We also found that an increase in blood viscosity is nonlinearly dependent on blood oxygenation. We believe our findings advance the understanding of the physiological influence of static magnetic fields.

References

(1) R. M. Weisskoff, S. Kiihne, *Magn. Reson. Med.* **24**, 375(1992).
(2) G. B. Thurston, *Biorheology* **31**, 179(1994).

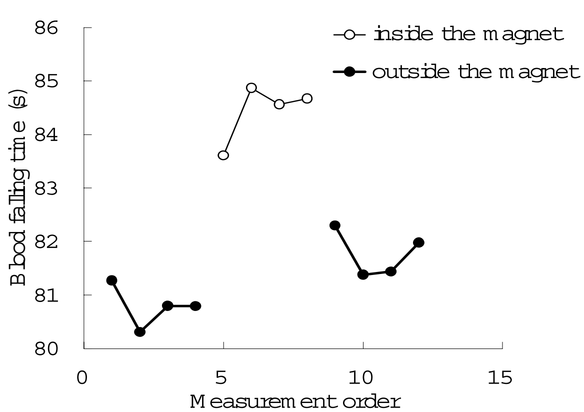

Fig. 1 Falling time changes of a fully deoxygenated blood sample inside and outside a 1.5-T static magnetic field.

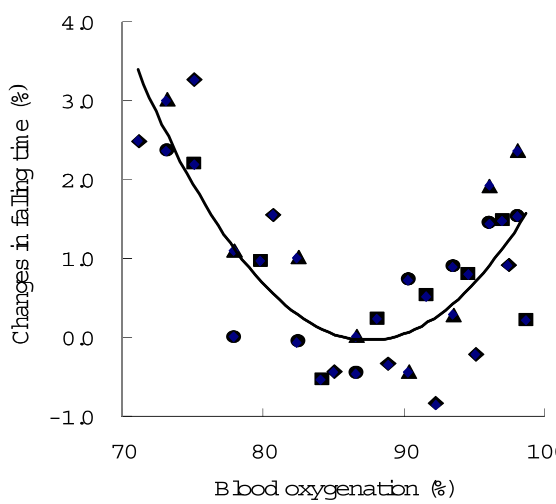

Fig. 2 Percentage changes in falling time of fresh venous blood in a viscometer inside a 1.5-T static magnetic field. Symbols (triangle, diamond, square and circle) represent four blood samples. Percentage changes were based on the average value of data outside a static magnetic field for each sample. The solid curve is a regression curve of all data.