Effects of temperature and haematocrit on the relationships between blood flow velocity and blood flow in a vessel of fixed diameter

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Background. To determine whether temperature and haematocrit (Hct) alter the relationship between blood flow (BF) and blood flow velocity (BFV).

Methods. Using a transcranial Doppler apparatus, we measured the peak velocity of whole blood cells pumped by a cardiopulmonary bypass (CPB) circuit, through a 0.15-cm internal diameter segment of rigid tubing. BF and BFV relationships were obtained at temperatures of 19, 28, and 37°C and at Hct of 0.05, 0.22, 0.39, and 0.54, by altering CPB flow over a range from 10 to 100 cc/min. Linear regression analysis was performed.

Results. The relationship between velocity and flow for the pooled Hct data was $y = (0.43)x + 0.86$, $r^2 = 0.998$ and 95% CI (0.999–1) whereas the association for the temperature data was $y = (0.42)x + 0.02$, $r^2 = 0.9998$ and 95% CI (0.999–0.9997). Changes of blood viscosity had no effect on velocity at a given flow rate. The combined effect of Hct and temperature on velocity for the relationship with flow is expressed by: $y = 1.3 + 2.4x$.

Conclusion. In fixed diameter vessels with laminar flow, the linear relationship between flow and velocity is not affected by changes in temperature and Hct in clinical ranges. These results are explained by the Fahraeus–Lindquist effect. They support the use of transcranial Doppler sonography to estimate cerebral blood flow in infants who may have large variations of Hct and/or temperature during bypass.

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Transcranial Doppler sonography (TCD) is used to measure cerebral perfusion. It is non-invasive, has a high temporal resolution, and allows continuous monitoring. The major limitation is that it measures blood flow velocity (BFV) rather than blood flow (BF). Clinical and animal studies have found a good correlation between changes in BFV in the basal cerebral arteries and BF during physiological changes such as $P_{aCO_2}$ and temperature. Blood temperature and haematocrit (Hct) can influence blood viscosity, and might change the relationship between BF and BFV. This study was designed to determine whether temperature and Hct alter BFV, in a model, simulating a small basal cerebral artery in infants.

Methods and results

A cardiopulmonary bypass (CPB) circuit primed with human whole blood was connected to a 0.15-cm internal diameter segment of rigid tubing. The CPB flow rates were adjusted between 10 and 100 cc min$^{-1}$ with increments of 10 cc min$^{-1}$. Calibration of this system was by timed collection of all effluent blood from the circuit into a graduated
cylinder. Peak velocity through this tubing was determined by TCD using a 4 MHz continuous wave Doppler probe (Medasonics, Fremont, CA, USA). This segment of tubing passed through a glass box containing mock cerebrospinal fluid. The TCD probe was fastened to the box through a hole created on the box side, which was subsequently sealed with epoxy glue (Fig. 1). The TCD probe was 30 mm distant from the tube, allowing for blood velocity recordings. The angle of insonation was set at 5°. Flow-velocity data were obtained at temperatures of 19, 28 and 37°C using outdated human packed red blood cells (PRBC) reconstituted with outdated plasma to give a Hct of 0.39. The velocity was also recorded at Hct of 0.05, 0.22, 0.39, and 0.54 using reconstituted whole blood at a temperature of 37°C. Five velocity values were recorded at each interval and averaged. Linear regression analysis and the coefficient of correlation (r²) were performed and calculated using GraphPad InStat version 3.00 for Windows 95 (GraphPad Software, San Diego, CA, USA). P<0.05 was considered statistically significant.

There was a strong linear relationship between blood flow and blood velocity at each set of conditions (r²>0.99). The velocity varied directly with flows at all Hct (Fig. 2). The relationship between flow and velocity for the pooled Hct data was y=(0.43)x+0.86, r²=0.998 and 95% CI (0.999–1). Similarly, temperatures from 19 to 37°C did not affect the relationships between flow and velocity (y=(0.42)x+0.02, r²=0.9998 and 95% CI (0.999–0.9997)). The combined effect of temperature and Hct changes on velocity was y (BFV)=1.3+2.4x (BF).

**Comments**

We found a linear relationship between blood flow and peak blood flow velocity, in fixed diameter vessels with laminar flow. This relationship is not altered by changes in temperature and haematocrit within clinical ranges. Variations of blood viscosity which are affected by Hct and temperature do not affect the peak velocity in a small fixed diameter vessel, as peak velocity for a given flow rate was similar whatever the temperature or Hct.

In experimental and clinical settings, many physiologic factors affect cerebral blood flow velocity. Among them, Hct and core temperature have been widely studied. In adults, normovolaemic haemodilution with a decrease of Hct from 38 to 30% was associated with an average 16% increase in cerebral blood flow velocity.3 In children, an inverse relationship between cerebral blood flow velocity and Hct has been demonstrated during deep hypothermic cardiopulmonary bypass.4 During deep hypothermia, cerebral blood flow was reduced by 40%.5 The cerebral blood flow velocity was also correlated with cerebral blood flow. In eight children undergoing cardiac surgery with deep hypothermia, the authors demonstrated that cerebral blood flow velocity was reduced to 33% of the control value,
whereas oxygen consumption was decreased to 20% of control.\textsuperscript{1}

The effects of Hct and temperature on cerebral blood flow velocity can be related either to their effect on blood viscosity, on cerebral blood flow adaptation to cerebral metabolic rate for oxygen, or both. Changes in Hct can change blood viscosity. Moderate haemodilution (Hct 22%) decreases blood viscosity by 30–50% at a low blood temperature\textsuperscript{2} whereas an increase in Hct increased blood viscosity and decreased CBF.\textsuperscript{6} Blood viscosity increases when blood temperature decreases; however, the increase in viscosity is observed mostly at temperature below 15°C.\textsuperscript{2} The cerebral blood flow adapts with metabolic demand. It is reduced during hypothermia when oxygen consumption is decreased.\textsuperscript{1} During polycythaemia, there is an increase in arterial oxygen content and a decrease in cerebral blood flow velocity.\textsuperscript{6} In animals, a nitroprusside infusion simulates the diameter of an infant’s mean cerebral artery, decreases blood viscosity and/or an adaptive phenomenon.\textsuperscript{8} When blood temperature decreases; however, the increase in viscosity does not affect blood flow velocity recordings. In conclusion, we found that in a small vessel of fixed diameter, wide variations of temperature, Hct and viscosity did not affect the relationships between blood flow velocity and blood flow. It supports the clinical usefulness of TCD to assess cerebral blood flow in infants who have large changes of Hct or temperature which can occur during cardiopulmonary bypass.

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### References


2. Eckmann D, Bowers S, Stecker M, Cheung A. Hematocrit, volume expander, temperature and shear rate effects on blood viscosity. \textit{Anesth Analg} 2000; \textbf{91}: 539–45


