RBC Aggregation and Blood Flow Resistance Under Vibration

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1. Introduction

It has been known that blood flow resistance is an important parameter involved in various cardiovascular diseases. In fact, numerous in-vitro studies of human blood with varying experimental conditions have been reported that RBC aggregation is largely responsible for its significant non-linear rheological properties. However, the effect of RBC aggregation on flow resistance has been a controversial issue. In vitro studies in a rotational viscometer have reported that viscosity of human blood shows an inverse relation to shear rate and this relation is due to primarily to RBC aggregation[1-3]. In contrast, experimental studies in vertical glass tube have been reported that increased RBC aggregation at low shear rates (< 15 s^{-1}) promoted the formation of a cell-free plasma layer near tube wall, which, in turn, caused an apparent viscosity to be nearly independent of flow rate[4-6]. Using by visualising analysis of the flow pattern in the tubes, it became apparent that as flow rate decreased, aggregates formed as expected but the aggregates migrated to the center of the flow stream. As a consequence the aggregates were localized to the low shear central region of the flow stream, which in turn foams a cell-free layer near tube wall.

Meanwhile, there have been interesting researches concerning the flow behavior of non-Newtonian fluids subjected to a mechanical vibration or oscillation. It has been reported that mechanical vibration causes flow enhancement in shear-thinning fluids, whereas it causes flow retardation in shear-thickening fluids. It is worthy to note that the applied vibrations and oscillations had a longitudinal direction to the flow. Deshpande and Barigou[7] investigated the effects of vibration on flow characteristics by comparing experiments and numerical calculations. In addition, Shin and Lee[8] investigated the effect of traversal vibration on apparent viscosity of suspension: They reported that the suspension viscosity was significantly reduced with increasing either frequency or amplitude of vibration.

After reviewing previous researches, a question arises whether blood flow resistance can be decreased with traversal vibration. As indicated earlier, RBC aggregation may be a main governing factor of flow resistance. Therefore, the objective of the present study is to investigate the effect of traversal vibration on the flow resistance of normal blood over a range of flow rates. To achieve this goal, we measured flow resistance of flowing blood under transversal vibration.

2. Materials and Methods

Samples of venous blood were drawn from the antecubital vein and collected into EDTA containing Vacutainers (BD, Franklin Lakes, NJ). In order to demonstrate the validity of this pressure-scanning capillary viscometer, the viscosity data were compared with data obtained from a rotating viscometer viscometer (Physica model UDS-200, Parr Physica, Inc., Glen Allen, VA).

In order to measure either viscosity or flow resistance of blood with vibration, one needs to repeat the measurement over a range of flow rates by varying driving pressure for fixed vibration parameters such as frequency and amplitude and then by varying the vibration frequency or amplitude for a fixed flow rate, which is a time-consuming process. Therefore, it is necessary to develop a new method to measure flow resistance of shear-thinning fluids over a range of flow rates with vibration. Recently, Shin *et al*[9] introduced a new pressure-scanning capillary viscometer (PSCV). The PSCV enabled the measurement of non-Newtonian viscosity continuously over a range of shear rates at a time. In addition, there was neither difficulty in applying vibration to the instrument nor accuracy decrease in accuracy due to the vibration. Using the PSCV with slight modification, it is possible to measure both the flow resistance and viscosity of blood over a range of flow rates with vibration. Thus, the present study used the modified PSCV for measuring flow resistance.

3. Results and Discussion

Figure 1 shows microscopic examination of RBCs in an adulterated blood with varying vibration frequency from 0 Hz to 100 Hz for 3 min. Blood without applying vibration ($f = 0$ Hz) shows aggregates of red blood cells. As frequency increases, the degree of red blood cell aggregates is significantly deceases. There was no significant RBC aggregation at $f = 100$ *Hz*.

Figure 2 shows the flow resistance of an adulterated blood at 37°C measured with the PSCV with varying vibration frequency. In this experiment, vibration was

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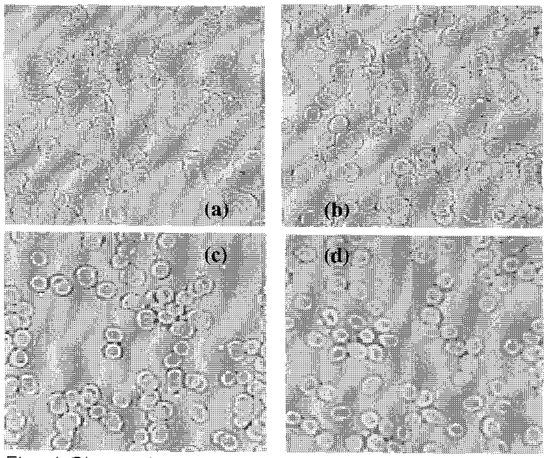

Fig. 1 Photomicrograph of RBC aggregation in adulterated blood (X400) for various frequencies (a) f= 0Hz (b) f= 30Hz (c) f= 50Hz (d) f= 100Hz

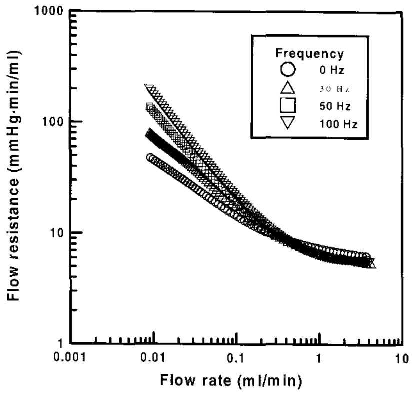

Fig. 2 Flow resistance vs. flow rate for various frequencies for whole blood

applied during viscosity measurement with PSCV. The flow resistance of blood is greatly affected by the frequency of vibration over a wide range of flow rates. As vibration frequency increases, the flow resistance increases at shear rates lower than $0.2s^{-1}$. At high shear rates, there was slight decrease of flow resistance in vibrated cases. Meanwhile, it is worth noting that the vibration should be characterized by both frequency and amplitude. When the vibration frequency varies, the amplitude of vibration should be constant. In Figure 2, the amplitude was fixed as Δ = 0.3 mm while the frequency varies. In addition, this phenomenon of flow resistance reduction can be interpreted by introducing a concept of particle-free layer near wall induced by vibration. In other words, particles having higher inertia than liquid which were forced to move into central layer by vibrated wall could not follow the speed of the vibrated wall moving outward. In turn, particles are concentrated in the central region, which resulted in the particle-free layer near the wall.

4. Conclusion

The present study investigated the effect of transversal vibration on the flow resistance of an adulterated blood using a newly designed pressure-scanning capillary viscometer. Frequency of vibration was found to be a main parameter causing flow resistance increase in the blood flow. Flow resistance increase due to vibration was greater at the lower flow rate than at the higher rate. The present study confirms that this phenomenon should be interpreted by adopting cell migrations associated with traversal vibration. In other words, the higher frequency applies, the lesser aggregate becomes and the lesser cell migration occurs. Thus, blood flow with high frequency shows relatively large flow resistance.

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