The Effect of RBC Deformability on Whole Blood Viscosity

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1. Introduction

The rheological properties of the blood play an important role in the regulation of blood flow in micro and macro vessels. There is a growing body of evidence linking blood rheology to commonly accepted risk factors of atherosclerosis (heart disease and stroke) such as: smoking, cholesterol, diabetes and gender. The anomalous behavior of blood viscosity, that is, its dependence on shear rate, has received the increasing attention of investigators in biomedicine, biophysics and bio-engineering. The shear thinning of blood viscosity can be attributed mainly to the shear- dependent deformation and aggregation of red blood cells[1].

It is well known that the red blood cell consists of a very flexible membrane filled with a concentrated solution of hemoglobin. In large vessels whose diameter is much larger than the diameter of a red blood cell, the red cells are biconcave disks(i.e., indented at the center on both sides) that are 8mm in diameter and 2 μm thick at the outer edge. The thickness of the center portion is approximately 0.5 μm, much thinner than the outer edge. The shape of the red blood cell substantially changes as blood moves through small vessels. When red cells move in a relatively small vessels, they deform so that they are umbrella shaped. As the vessel diameter further reduces below 10mm, the red cell deforms into the shape of a bullet or a slipper, which helps minimize the shear stress due to friction in such a small vessel. This explains why red blood cell deformability plays such a critical role in determining whole blood viscosity. When red cells lose their ability to deform, the frictional resistance and hence the viscosity increase[2].

Chien[3] studied that the viscosity of suspensions of human erythrocytes(normal cells in plasma, normal cells in Ringer's solution containing albumin and hardened cells in Ringer's solution containing albumin) was measured over a wide range of shear rates, and the macro -rheological data were correlated with the micro-rheological behavior of erythrocytes and rigid particles. Furthermore, Baskurt et al.[4] investigated that major cellular determinants of low-shear apparent viscosity related RBC geometry, cell deformability and aggregation.

This study investigates the effects of red blood cell deformability on whole blood viscosity over a wide range shear rates. The deformability of red blood cell measured by laser-diffraction slit rheometer for normal red blood cell suspension and hardened red blood cell suspension. Then it was measured blood viscosity using pressure-sensing capillary viscometer for each suspension with wide range shear rates.

2. Materials and Methods

Venous blood was drawn from the antecubital vein after 12hours fasting with a minimum stasis. In accordance with the Committee on Hemorheology Standardization[5] RBC deformability was determined within the first three hours of sampling to avoid deterioration of this rheological property. Previously, in order to eliminate the leukocytes and platelets the blood anticoagulated with EDTA K3 was centrifuged for 10min at 3000 rpm, thus removing the plasma and buffy coat. 0.05ml of the mean fraction of the RBC package was resuspended in 4.95ml of PVP (Polyvinylpyrrolidone, M.W 360,000, Sigma, St. Rouis MO), yielding an 1% red cell suspension. And in order to loss the RBC deformability, RBC suspension that exposed to 0.005 %, 0.015%, 0.02% Glutaraldehyde and control (no treatments), were measured the viscosity with wide range shear rates.

RBC deformability was determined at fluid shear stresses between 0 and 35 Pa, by laser diffraction analysis using slit rheometer(Laser-diffraction Slit Rheometer). Viscosity of blood suspension was determined in a pressure-sensing capillary viscometer over a shear rate range of 0.7~1300 1/s at room temperature. The feasibility and accuracy of the Pressure-scanning capillary viscometer have been demonstrated for distilled water and adulterated human blood by comparing the results against an established viscosity measur-

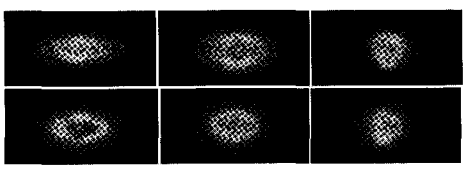

Fig. 1 Laser diffraction pattern (a)control and (b)Harden cell for various shear stresses.

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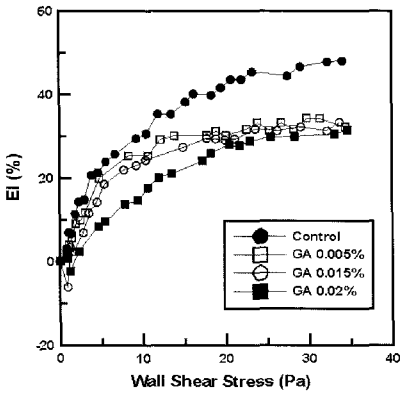

Fig. 2 Elongation index versus wall shear stress for several RBC suspension.

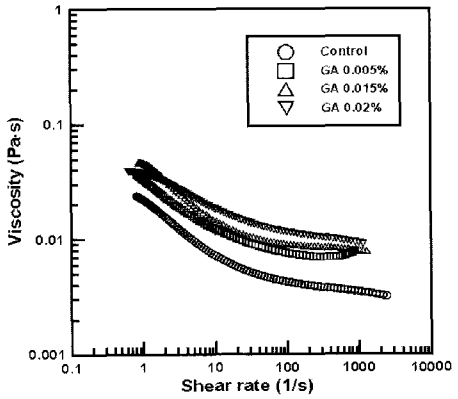

Fig. 3 Viscosity versus shear rates for several RBC suspension.

ement technique with a rotating viscometer. Among the advantages of this viscometer are simplicity (i.e., ease of operation and no moving parts), quick measurement, and the ability to make accurate measurements over a relatively broad shear rate range without using anticoagulants.

3. Result and Discussion

Fig. 1 shows the change in diffraction patterns during fluid flowing at room temperature. As the shear stress decreases, the RBCs change gradually from a prolate ellipsoid towards the circular morphology. It is worthy to note that the diffraction pattern images are oriented perpendicular to the orientation of the elongated cells. This diffraction patterns show the change of deformability of RBC. The hardened cell that exposed to each Glutaraldehyde level had slightly reduced deformability compared to normal cells. The more Glutaraldehyde level, the less the deformability of RBC.

Fig. 2 shows the Elongation Index (*EI*) as a measure of the RBC deformability along shear stress. The *EI* is calculated from an isointensity curve in the diffraction pattern as shown in Fig. 1 using an ellipse-fitting program. The *EI* is defined as (X-Y)/(X+Y), where X and Y are the major and minor axes of the ellipse, respectively. The *EI* is continuously obtained over a range of shear stresses (0~35 Pa). The decrease of shear stress from 35 to 0 Pa results initially in a slow decrease of EI until 10 Pa, followed by a rapid decrease. The EI decrease according to the more Glutaraldehyde level.

In Fig. 3, it shows that with an increase in shear rate, the viscosity decreases for suspensions of normal RBC in control suspension, but not for the hardened RBC relatively. This shear dependent deformation concept also seems relevant to the viscometric behavior Glutaraldehyde treated RBC: increasing Glutaraldehyde level results in RBC whose resting shape is discocytic but whose ability to deform and align is progressively impaired. Thus for such cells with a diminished ability to deform, there would be a smaller decrease of viscosity at high shear.

4. Conclusion

The effects of red blood cell deformability in influencing general fluidity of whole blood is shown Fig. 4. The results indicate that as red cells becomes less deformable (as do deoxygenated sickle cells and diabetic retinopathy) blood will have a viscosity similar to the much higher viscosity of a suspension of hardened cells. Therefore, as measuring the whole blood viscosity, it can explain the alteration of hemorheological property of RBC.

Acknowledgments

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