EFFECT OF SEGMENTED POLYURETHANE COATING ON THROMBUS REGULATED WITH PULSATILE SHEAR FLOW

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Abstract- The effect of segmented polyurethane coating on thrombus formation was quantitatively studied under shear field *in vitro*. The Couette-type of shear rate was applied to the canine blood between the concave and the convex cones. Variation was made about materials of cones: Polymethyl-methacrylate, polyvinyl chloride, and polyvinyl chloride coated with segmented polyurethane. The study shows that the clotting time extends on the segmented polyurethane especially at the higher shear rates, although the clot ratio is in the same level as that of without coating. This clotting time extension should regulate thrombus formation under pulsatile shear flow.

Key Words- Bio-fluid mechanics, pulsatile shear flow, blood, thrombus, clotting time, polyurethane coating

I. INTRODUCTION

The clot plays an important role to repair ruptured blood vessel walls. It consists of platelets and coagulants. It interrupts, on the other hand, blood flow, when it plugs the blood flow path. Especially, in artificial vessels, clot formation has to be delicately regulated between keeping stable connection to natural vessels and inhibiting formation of plugs. Many factors control the dynamic balance between the formation and removal of clots. Previous studies show that segmented polyurethane coating decreases clot formation to some extent [1]. The mechanism to prevent clot formation is under discussion, because the effect changes with flow condition.

General clot tests *in vitro* are on clotting time in a test tube [2]. Clot formation in flow condition should be tested under quantitatively controlled shear field [3].

In the present study, both the clotting time and the clotting ratio have simultaneously been measured with concave convex Couette flow system *in vitro*.

II. METHODOLOGY

The Couette type of shear rate was applied to the blood between the concave and convex cones. The parts of concave and convex cones are demountable, and the axis of rotation is quickly adjusted with tapered connecting cylinder

(Fig. 1). The apex angle (2B) of convex cone is 115 degree.

Uniform shear rate (G (1/s)) is applied between the concave and convex cones.

$$G = N\, r/L = \{N\, y\, \sin(B)\}/(y\, P) = \{N\, \sin(B)\}/P \quad (1)$$

where N is angular velocity (rad/s) of the concave cone, P is angle (rad) between the concave and convex cones, L is the gap between two circular cones, and y is the distance between the apex and the shearing point. The shear rate is constant regardless of the distance (r) from rotating axes. Shear rate is controlled between 100 and 1000 1/s in proportion to the rotating speed of concave cone.

Variation was made in material of the concave and convex cones; polymethyl-methacrylate, polyvinyl chloride, polyvinyl chloride coated with segmented polyurethane. Combination was selected so that both materials of concave and convex cones are the same. The cones coated with segmented polyurethane were for the single use, because the surface condition might change after exposure to blood.
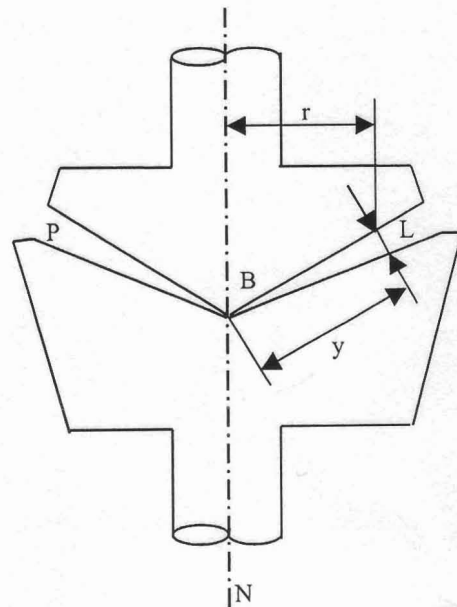

Fig. 1. Concave and convex cones.

One milliliter blood was drained without anticoagulants from the jugular vein of the mongrel dog weighed 15 kg. Immediately after drainage, the blood sample was sheared between the concave and convex cones at 25 degrees C, while the viscous torque between two cones was continuously measured (Fig. 2). The viscous torque increases with clot formation. After several minutes of stable torque tracings, rotation of the concave cone was stopped and clots were macroscopically observed.

III. RESULTS

Fig. 2 exemplifies torque tracings. The viscous torque increases with clot formation from T to T'. The clotting time (t) was measured at torque tracings, and is shown in relation to shear rates in Figs 4, 6, 8. These figures show that the clotting time decreases with the shear rate both on polymethyl-methacrylate and on polyvinyl chloride. The tendency is remarkable on polyvinyl chloride: from six to two minutes (Fig. 6).

The clot ratio (R) was calculated from T and T' (2).

$$R = 1 - T/T' \qquad (2)$$

The clot ratio is zero, when the torque does not increase (T' = T). It becomes 0.5, when the torque increases to doubled value (T' = 2T). It approaches unity, the greater the torque becomes (T' >> T).

Figs. 3, 5, 7 show the clot ratio as a function of the shear rate. The clot ratio decreases with the shear rate, and it becomes smaller than 0.5 at the shear rates higher than 400 l/s (Figs. 3, 5).
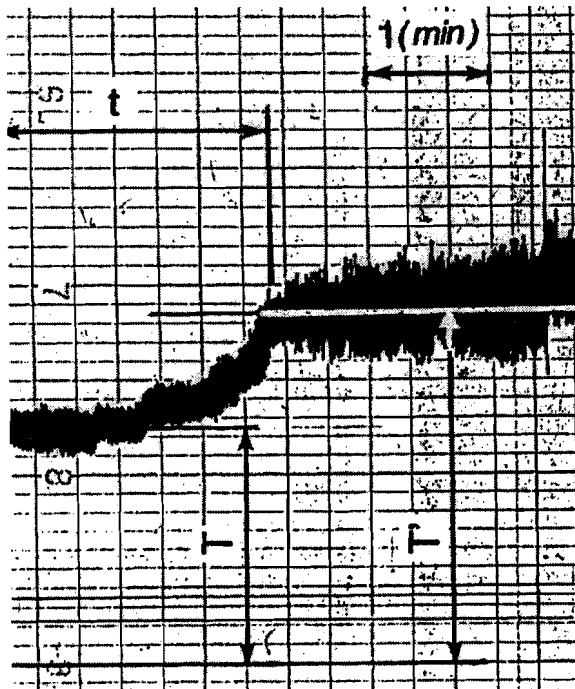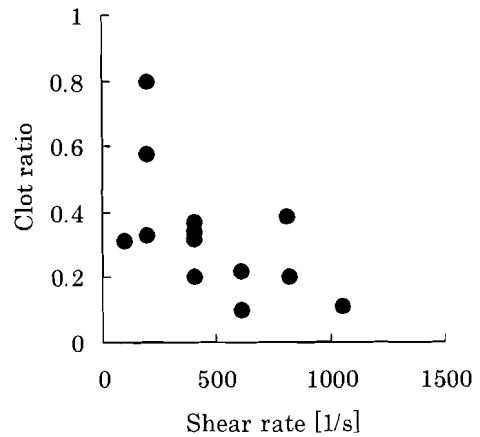

Fig. 2 Torque tracings

Fig. 3 Clot ratio vs. shear rate on polymethylmethacrylate

On polyvinyl chloride coated with segmented polyurethane, on the other hand, the clotting time keeps the same level of six minutes even at higher shear rates (Fig. 8), although the clot ratio decreases with the shear rate (Fig. 7).

IV. DISCUSSION

Segmented polyurethane, which is used in the present study, has been applied to coat the inner surface in blood pumps in artificial hearts. Its effect to prevent clot formation has been reported in previous studies [1]. The morphology of clot formed on the surface, however, depends on blood flow conditions.

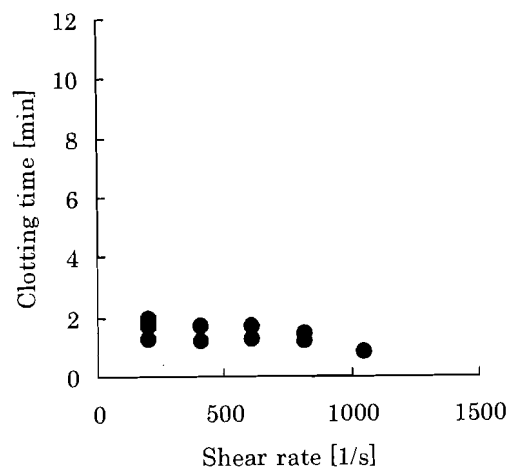The most of test methods for anti-coagulate property of

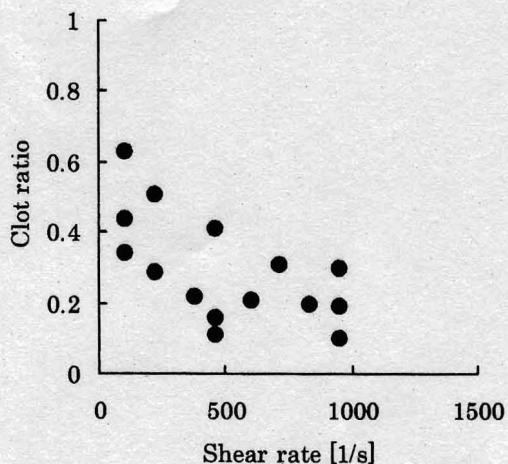Fig. 4 Clotting time vs. shear rate on plymethylmethacrylate

Fig. 5 Clot ratio vs. shear rate on
polyvinyl chloride

materials measure the coagulation time [2]. It has been considered that the extension of clotting time relates directly to anti-coagulation property. The present study, on the other hand, shows that clot ratio does not relate to clotting time in the shear field. At the lower shear rates, the clot ratio increases, while the clotting time extends.

The clotting time extends on segmented polyurethane. Its extension is remarkable at higher shear rates. The clot ratio on polyvinyl chloride coated with segmented polyurethane, on the other hand, is in the same level as that on polyvinyl chloride without coating.

Segmented polyurethane coating should be effective to prevent clot formation especially in pulsatile flow [3], when the blood is washed out periodically before formation of clots in the extended clotting time. In the steady flow, on
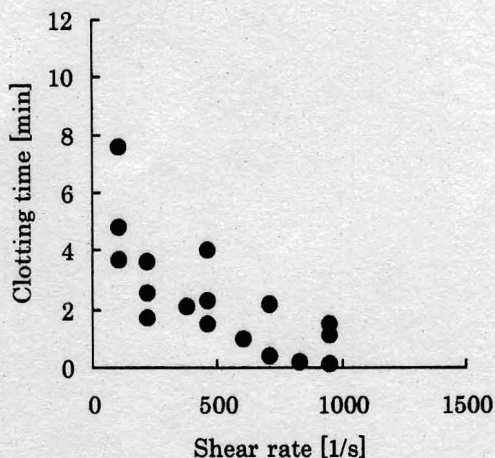

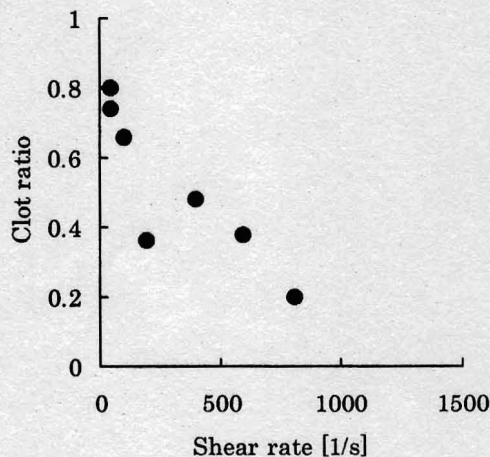Fig. 6 Clotting time vs. shear rate
on polyvinyl chloride

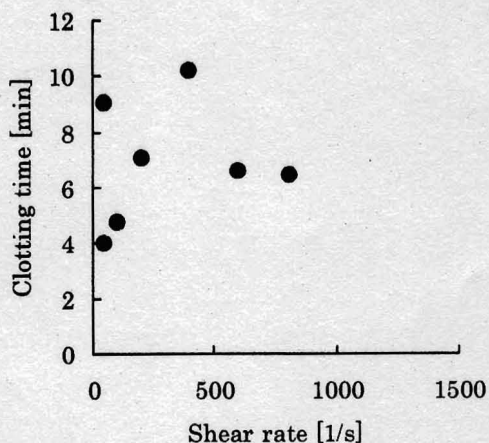Fig. 7 Clot ratio vs. shear rate on
polyurethane

Fig. 8 Clotting time vs. shear rate
on polyurethane

the other hand, segmented polyurethane coating may not have enough effect to prevent clot formation at the lower shear rates. The material, which extends the clotting time, has the considerable effect to prevent thrombus formation in the pulsatile pumps or in the arterial prostheses, but not in the venous prostheses.

V. CONCLUSION

The clotting time was evaluated separately from the clot ratio under shear fields *in vitro*. The study shows that the clotting time extends on the segmented polyurethane coating especially at the higher shear rates, although the clot ratio is in the same level as that of without coating. This clotting time extension regulates thrombus formation under the

pulsatile shear flow.

REFERENCES

[1] E. Nylas, and R. S. Ward, Jr, "Production of biomedical polymers. II. Processing technology/ product property correlations of hemocompatible avcothane elastomers," *Sci. Technol. Polym. Process, Proc. Int. Conf.*, pp. 770-808. 1979.

[2] R. I. Lee, and P. D. White, "A clinical study of the coagulation time of blood," *Am. J. Med. Sci.*, vol. 145, pp. 495-503, 1913.

[3] S. Hashimoto, "Clot growth under periodically fluctuating shear rate," *Biorheology*, vol. 31, pp. 521-532, 1994.