In Vivo Measurement of Velocity Profiles in Arterioles

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Measurements of velocity profiles in arterial microvessels (20-103 μ in diameter) of rat mesentery and *m. creamaster* showed that bloodflow regimen under natural conditions can be similar to that of Newton fluid or pseudoplastic laminar stream, which indicates significant fluctuations in blood viscosity.

Key Words: *microcirculation; rheology; flow regimen; bloodflow velocity; vascular diameter*

The development of methods for adequate evaluation of blood rheology acquired special significance in studies of the effects of surface-active substances on blood supply intensity under critical conditions caused by acute blood loss (hemorrhagic shock) [2,5-7]. Attempts at explaining the mechanism of this effect by changes in blood rheology were not confirmed in experiments on viscosimeters [5-7], because numerous specific factors of functioning of a living microcirculatory bed (MCB) forming blood rheology could not be reproduced simultaneously [2]. The curve of velocity profiles reflects real value of shear rate in the stream, while its changes in the vessel indicate transformation of the bloodflow regimen and hence, qualitative changes in blood rheology.

We studied the velocity profiles in arterioles of different diameters *in vivo* under real conditions of a living MCB functioning.

MATERIALS AND METHODS

Experiments were carried out on 42 mesenteric arterioles (13-40 μ in diameter) and of *m. creamaster* arterioles (42-103 μ in diameter) in 18 laboratory rats of both sexes (200-300 g). The rats were narcotized with Nembutal (6 mg/100 g, intramuscularly). The respiratory function was provided for by tracheotomy. One or both (depending on the tasks of the experiment) internal carotid arteries, femoral artery, and jugular vein were catheterized. The circulatory system of animal was connected to a Stadtham pickup (Elema-Shonander) for blood pressure recording via a catheter inserted into the femoral artery (in some cases into the carotid artery). The diameter of the vessel and linear velocity of individual strata of the blood stream were measured. Bloodflow velocity in arterioles and distribution of velocities of individual flow lines were recorded in parallel with arterial pressure.

For subsequent biomicroscopy, the abdominal cavity was opened sagittally and a mesenteric loop or *m. creamaster* was isolated, after which the animal was placed on a thermostat table washed with saline in order to prevent drying of the studied object. The visual field was illuminated with a lightguide in order to prevent thermal exposure of the studied object (blood vessel).

Life-time recording of linear velocities of individual layers of the blood stream was carried out on an MPV-Compact Vel. device [4] installed on a microscope phototube perpendicularly to the plane of the mesenteric loop. A vessel for measurements of the velocity profiles was to meet the following requirements: the vessel axis was to be as straight as possible; the diameter of vascular lumen was to

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be about the same in the entire visual field; visually seen flow lines were to be parallel in the entire visual field, parallel to the lattice opening field, and perpendicular to its sides. Linear velocities of the bloodflow (bloodflow lines) were fixed along the transverse section of the vessel. The animal was moved on the scanning table of the microscope preparation guide in the plane perpendicular to the bloodflow direction in the studied organ, so that the bloodflow velocity lines could be recorded at a preset step starting from the layer immediately at the vascular wall towards the contralateral wall. Linear velocity registration (*Vr*) was carried out on an MPV Compact Vel. device in parallel with measurements of the distance between the point in which the velocity was measured and the vascular wall and the inner diameter of the vessel (*2R*). The distance to the vascular wall was then conversed to the distance from the vascular axis (*r*). These distances and bloodflow linear velocities at the vessel axis (*Vax*) were repeatedly controlled during registration of the linear velocities of the bloodflow lines, as the inner diameter of the vessel and *Vax* could change during the measurements. The *Vr*/*Vax* at the vascular wall was taken for the 0, at the axis for 1. The resultant values reflected shear rate in individual layers of erythrocyte flow (velocity profile in the studied MCB vessels).

RESULTS

The velocity profile in large (more than 46 μ in diameter) rat MCB arterioles was stable and did not depend on the arteriolar diameter and linear axial velocity of the bloodflow. The profile shape in a 46-μ vessel virtually did not differ from that in a vessel with a several-fold greater diameter (Fig. 1). The *Vax* value was inessential for the profile curve: its shape for a flow with *Vax*=8.14 mm/sec virtually did not differ from that with *Vax*=16 mm/sec.

The picture in vessels with diameters less than 40-46 μ was qualitatively different. The profile shape could differ in arterioles of approximately the same diameter, indicating a different (from a rheological viewpoint) bloodflow regimen. Flow regimens characteristic of Newton (in a 30-μ vessel) and non-Newton fluid (in a 32-μ vessel) can be seen in MCB arterioles (Fig. 2). Experimental data on velocity profiles in a 30-μ vessel are approximated by a curve reflecting laminar flow of the Newton fluid and are described by an equation: $y=1-x^2$ (approximation reliability coefficient $R^2=0.97$). This fact indicates that under natural conditions the blood in some MCB arterioles can flow with the viscous characteristics of the Newton fluid. In vessels smaller than 46-40 μ, in which the vascular/erythrocyte diameter is much less than 10 and the concentration of erythrocytes is significantly different, *Vax* and *2R* values are obviously not the factors determining the bloodflow regimen. The profile shape in them reflects the integral resultant of the shear and inertial forces, caused by orientation behavior and interactions between erythrocytes. In a 32-μ vessel with *Vax* about 2-fold more (4.5 mm/sec) the flow regimen corresponds to the flow of caisson (viscous plastic, pseudoplastic) fluids. In this case the velocity profile curve is approximated by equation: $y=1-x^5$ with the approximation reliability coefficient $R^2=0.97$. On the other hand, the difference in the bloodflow

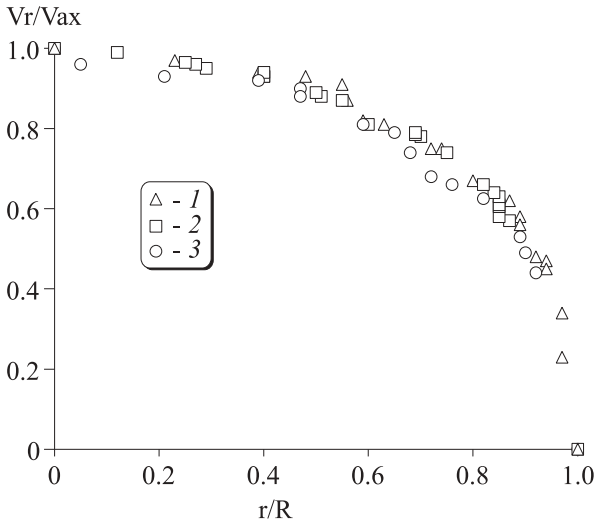

Fig. 1. Velocity profile in the rat m. creamaster arterioles of 46 (*1*), 80 (*2*), 84-102 (*3*) μ in diameter. *Vax*=15-16 mm/sec (*1*), 8.14 mm/sec (*2*), and 11.75-16 mm/sec (*3*).

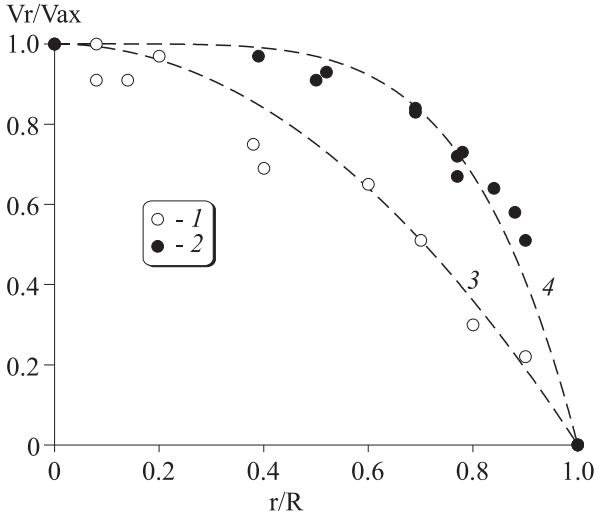

Fig. 2. Velocity profiles in the rat mesenteric arterioles of 30 (*1*) and 32 (*2*) μ in diameter at axial velocities of 2.3 and 4.5 mm/sec, respectively. Interrupted line shows the theoretical curves approximated by equations $y=1-x^2$ (*3*) and $y=1-x^5$ (*4*).

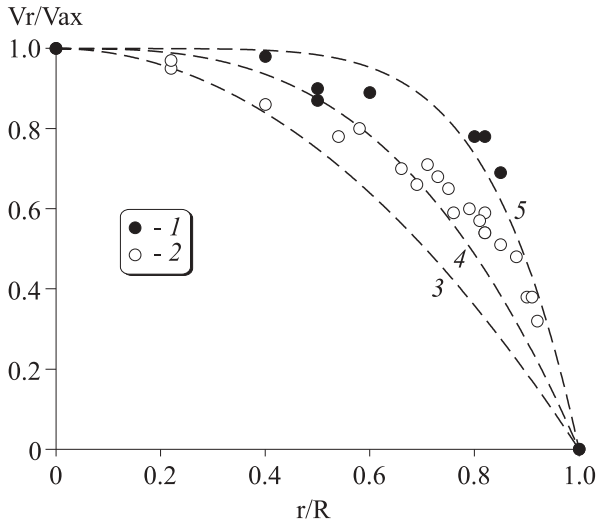

Fig. 3. Velocity profiles of the rat mesenteric arterioles of 20 μ in diameter at axial velocities of 2 (*1*) and 8.75-9.25 mm/sec (*2*). Interrupted line shows the theoretical curves approximated by equations for Poiseuille flow of the Newton fluid: $y=1-x^3$ (*4*) and $y=1-x^6$ (*5*).

velocity significantly affects the profile shape (Fig. 3). In a 20-μ vessel at *Vax* of about 9 mm/sec the profile approximates the profile of the Newton fluid laminar flow, while at a velocity of 2 mm/sec the profile is flat, similarly to the flow profile of the caisson fluid. It is remarkable that both profiles are situated between the curves described by equation $y=1-x^2$ for Poiseuille flow of the Newton fluid and equation $y=1-x^6$ (Fig. 3) characteristic of fluids with a clear-cut flow nucleus, *i.e.* caisson fluids (pseudoplastic, nonlinear viscous). These data prove that under natural conditions (without exogenous effects) the flow regimens are qualitatively different in arterioles smaller than 40 μ in diameter, which indicates significant variability of factors forming the blood rheology. These regimens reflect different friction between layers of the bloodflow — the internal friction coefficient, or the actual viscosity of the blood flowing in arterioles of a living microcirculatory system. Hence, registration of the velocity profile shape by the method described in this paper provides objective data for *in vivo* evaluation of bloodflow regimen and its changes in MCB vessels, directly reflecting the qualitative changes in viscous characteristics of the blood.

REFERENCES

1. V. A. Mamisashvili, N. T. Mchedlishvili, E. T. Chachanidze, and K. N. Urotadze, *Izv. Akad. Nauk Gruz. SSR*, Ser. Biology, **30**, No. 2, 371-380 (2004).
2. V. A. Mamisashvili, N. T. Mchedlishvili, E. T. Chachanidze, and K. N. Urotadze, *Georgian Med. News*, **116**, No. 11, 25-32 (2004).
3. V. A. Mamisashvili, N. T. Mchedlishvili, E. T. Chachanidze, and K. N. Urotadze, *Ibid.*, **116**, No. 2, 68-70 (2005).
4. V. S. Shinkarenko and S. E. Morozov, *Byull. Eksp. Biol. Med.*, **97**, No. 1, 104-106 (1984).
5. G. Gutierrez and S. P. Fuller, *Crit. Care*, **8**, No. 6, 406-407 (2004).
6. M. V. Kameneva, Z. J. Wu, A. Uryash, *et al.*, *Biorheology*, **41**, No. 1, 53-64 (2004).
7. C. A. Macias, M. V. Kameneva, J. J. Tenhuner, *et al.*, *Shock*, **22**, No. 2, 151-156 (2004).