BLOOD FLOW VELOCITY DISTRIBUTION IN TERMINAL MICROVASCULAR BED OF RAT MESENTERY

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An important role in the study of the principles governing function of the microcirculatory system and also the effects of various physical, chemical, and pharmacologic factors on it is played by the dynamics of changes in the basic physical and morphological parameters along the course of the microcirculatory bed in its various parts. One such parameter characterizing the state of the hemodynamics under normal and pathological conditions is the velocity of the microvascular blood flow (MVBF). However, there have been few systematic attempts to describe the character of changes in MVBF along the course of the microvascular bed [1, 8, 9]. Data in the literature are either averaged for the whole of the vascular bed or they relate to only certain parts of it [2, 3, 5, 6].

The aim of this investigation was to study the dynamics of changes in MVBF in successive parts of the microvascular bed of the mesentery of the rat small intestine, a model widely used to study the microcirculation.

EXPERIMENTAL METHOD

Experiments were carried out on 16 noninbred male albino rats weighing 180-250 g anesthetized with pentobarbital (6 mg/100 g intramuscularly). The animals were prepared for biomicroscopy of the mesenteric vessels in the usual way [6]. An "Orthoplan" research microscope ("Leitz," West Germany) with 6.3 × 0.20 (for observation) and SW 50 × 1.00 saline immersion (for measurement) objectives, together with a special condenser with long working distance (0.46/L20), was used. Measurements of MVBF were made by the microprismatic grating method, using the MPV-Kompakt-Vel instrument ("Leitz") [7], the measuring unit of which is mounted on the photographic tube of the microscope. A semiautomatic RZD-DO linear dimensions meter ("Leitz") with transducer located in the 12.5× ocular was used to record the diameter of the microvessels. The systemic blood pressure was monitored through a catheter introduced proximally into the left common carotid artery. The pressure, transformed by an No. 746 transducer through type 863 amplifier, was recorded on a "Mingograf-82" (Sweden) synchronously with MVBF (through a type 854 amplifier). Photomicrographs of the microvascular bed were taken with the semiautomatic "Orthomat-B" ("Leitz") photographic attachment and a camera of "Polaroid" type. The results were subjected to statistical analysis by Student's t test.

EXPERIMENTAL RESULTS

The experiments were carried out on vascular loops, each comprising a closed hydraulic system with one "entry" (arteriole) and one "exit" (venule), a spatially organized complex of arterioles, capillaries, venules, and anastomoses. Relations between individual parts of the vascular bed are determined by the natural structure of the vascular bed and not by the experimenter's subjective choice. The number of vessels in individual loops varied from 10 to 50. Measurements of MVBF and of the internal diameter of the corresponding microvessels were made consecutively in all the elements of each such loop. The results of determination of these parameters within the same loop (Fig. 1) are given in Table 1.

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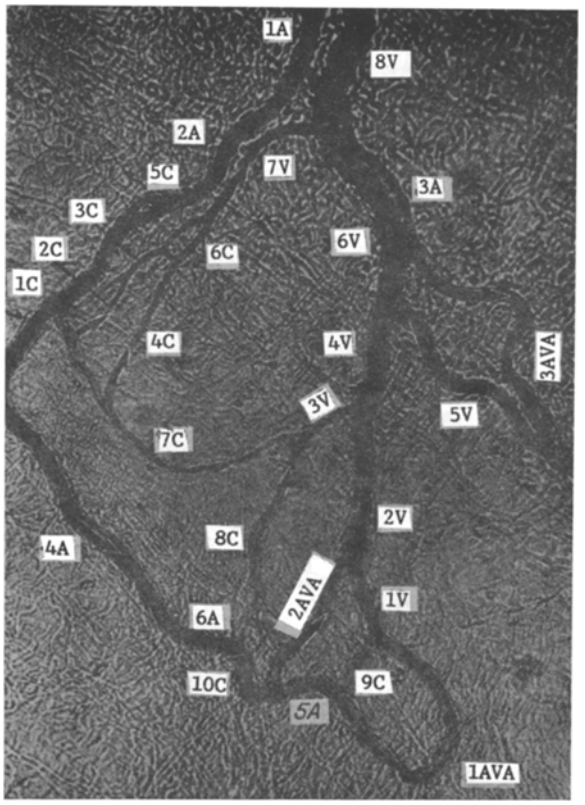

Fig. 1. Microvascular loop of mesentery of rat small intestine. Biomicroscopy. Objective 6.3 × 0.20. Here and in Fig. 2: A) arterioles, V) venules, C) capillaries, AVA) arteriolovenular anastomoses. Arrow indicates direction of blood flow.

TABLE 1. Distribution of Velocities in Microvessels of Loop

No. and type of vessel	Diameter of vessel, μ	Velocity of blood flow, mm/sec
1A	18,6	3,1
2A	17,2	1,9
3A	14,5	2,0
4A	19,8	2,6
5A	18,0	2,4
6A	8,3	1,2
1V	14,8	0,9
2V	20,8	1,5
3V	9,1	1,2
4V	23,3	1,5
5V	16,8	1,8
6V	26,4	1,9
7V	7,4	1,1
8V	25,2	1,5
1C	5,7	0,9
2C	4,8	1,2
3C	6,7	0,9
4C	6,6	0,8
5C	6,4	0,6
6C	8,5	0,9
7C	6,5	0,9
8C	6,5	1,1
9C	5,3	0,4
10C	5,1	0,0
1AVA	12,7	1,0
2AVA	12,9	2,2
3AVA	10,0	1,6

Legend. Here and in Table 2: C) capillaries, A) arterioles, V) venules, AVA) arteriolovenular anastomoses.

TABLE 2. Internal Diameters of Different Components of Microvascular Bed

No. of group	Type of vessels	Number of vessels	Diameter, μ		
			minimal	maximal	mean
1	C	49	4,5	12,0	7,6±0,3
2	A	16	6,9	9,9	8,8±0,2
	V	13	7,2	9,9	8,9±0,2
	AVA	10	5,0	9,9	7,6±0,4
3	A	40	10,0	14,9	12,7±0,2
	V	24	10,3	14,8	13,2±0,2
	AVA	16	10,7	14,5	12,4±0,3
4	A	21	15,2	19,8	17,5±0,3
	V	29	15,4	19,9	17,2±0,3
	AVA	3	15,2	16,5	16,0±0,4
5	A	7	20,4	23,2	21,6±0,9
	V	12	20,2	24,9	22,3±0,5
6	V	6	25,1	28,2	26,6±0,4
2—6	A	84	6,9	23,2	13,9±0,1
	V	84	7,2	28,2	16,2±0,2
	AVA	29	5,0	16,5	11,1±0,2

Altogether 246 vessels of different types with an internal diameter of 4.5-29 μ were studied. Depending on the size of the loops, the number of arterioles varied in them from three to nine, the number of capillaries from one to ten, of venules from three to nine, and of arteriolovenular anastomoses from one to five. All the arterioles, venules, and arteriolovenular anastomoses studied were divided into groups depending on their internal diameter, with a step of 5 μ. Capillaries constituted a separate group. The diameters of vessels of different groups are given in Table 2, and the corresponding values of MVBF are shown in Fig. 2.

Most modern methods of determination of MVBF can measure the velocity of movement not of the blood as a whole, but only of its cells. This is true also of the microprismatic grid method, used in the present investigation. To convert the results of the measurements into values nearer the true values of MVBF, a series of formulas, differing depending on the method of measurement and the concrete experimental condition, is suggested. Since the main aim of this investigation was not so much to analyze the absolute values of MVBF, but rather to study the character of its changes along the course of the microvascular bed, we give below the direct results of measurements of the flow rate which, if necessary, can be corrected in order to obtain real values of linear velocity of blood flow [7].

With a mean systemic blood pressure of 113 ± 3 mm Hg (15 kPa) the values of MVBF in the arterioles studied varied from 0.4 to 4.5 mm/sec, in the capillaries from 0.25 to 1.6 mm/sec, in the venules from 0.3 to 2.7 mm/sec, and in the anastomoses from 0.2 to 4.7 mm/sec. The mean values of MVBF (in mm/sec) were: in the arterioles as a whole 1.9 ± 0.1, in the venules 1.2 ± 0.1, in the capillaries 0.8 ± 0.06, and in the anastomoses 1.7 ± 0.2 mm/sec. Under these circumstances, the differences between the values of MVBF in the arterioles and the venules were quite large ($p < 0.001$); they also differed in the venules and anastomoses ($p < 0.01$). Differences between MVBF in the arterioles and anastomoses were not significant, although between the mean diameters of all three types of blood vessels, the differences were highly significant ($p < 0.001$).

Despite a gradual decrease in the mean values of MVBF with a decrease in diameter of the arterioles, no significant change took place in velocity in this region of the vascular bed. A marked decrease in velocity (by 50%, $p < 0.001$) took place only where arterioles change into capillaries. A similar change in MVBF, although opposite in sign and rather smaller in magnitude (by 40%, $p < 0.05$) took place where the capillaries changed into venules. Throughout the region of the venules studied, no significant increase took place in MVBF.

Since arteriolovenular anastomoses occupy an intermediate position between afferent and efferent blood vessels, values of MVBF in them are reflected on the graph in groups of both arterioles and venules of corresponding diameter (Fig. 2). Although differences in the mean values of velocity for anastomoses of different groups are not significant, nevertheless a tendency can be seen for values of MVBF to rise as the diameter of these vessels falls. The

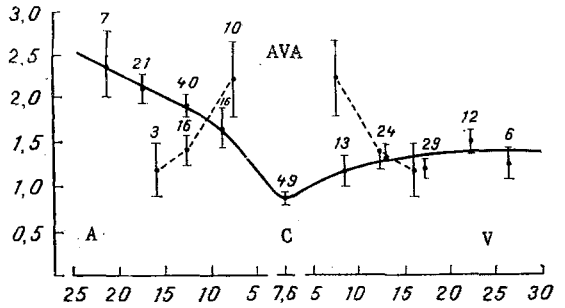

Fig. 2. Graph showing distribution of mean velocity of blood flow (V) in different components of microvascular bed of mesentery of rat small intestine. Broken line represents MVBF in anastomoses. I-VI) Groups of vessels. Numbers above curve indicate number of vessels. Abscissa, internal diameter of microvessels (in μ); ordinate, velocity of blood flow (in mm/sec).

velocity in the large anastomoses, moreover, was appreciably less than in arterioles of the same diameter ($p < 0.05$), and it was virtually identical with values corresponding to venules of this same group. In the smallest anastomoses (group No. 2) the opposite relationship was observed: the velocity of the blood flow in them, while differing from values relating to venules ($p < 0.05$) were very close to values obtained for the smallest arterioles. Meanwhile, in anastomoses closest in size of lumen to capillaries, MVBF differed significantly from that in the capillaries ($p < 0.001$).

An equal number of arterioles and venules will be noted in the population of microvessels studied, although the ratio between them differed in different groups of vessels. In addition, the number of anastomoses was considerable. On the whole the ratio between the numbers of different elements of the vascular bed investigated was A:V:C:ABA = 2.9:2.9:1.7:1.

The subdivision of microvessels into groups depending on their diameter, so that changes in the parameters of the microhemodynamics in different components of the microvascular bed can be subjected to differential analysis, the course adopted in the present and many other investigations, nevertheless does not fully reflect their morphological and functional properties. However, the attempt to classify the vessels studied in another way and, in particular, depending on the orders of branching, was not successful. The reason was both the marked heterogeneity and complex structure of the microvascular networks of the mesentery and also the still unsolved problem of single criteria of evaluation and a single classification of microvessels [4, 5].

The investigation described above showed that changes in MVBF in the terminal vascular bed on the scale of the changes in diameter of the arterioles from 25 to 7 μ and of the venules from 7 to 30 μ are not great. The most significant decrease in MVBF took place in a very limited sector — where the arterioles change into capillaries, and the most significant increase at the junction between the capillary network and the venules.

LITERATURE CITED

1. K. A. Shoshenko, A. S. Golub', V. I. Brod, et al., Architectonics of the Vascular Bed [in Russian], Novosibirsk (1982).
2. C. G. Caro, T. J. Pedley, R. C. Schroter, and W. Seed, Mechanics of the Circulation, Oxford (1978).
3. R. F. Rashmer, Structure and Function of the Cardiovascular System, 2nd edn., Philadelphia (1978).
4. B. I. Tkachenko, Patol. Fiziol., No. 4, 13 (1987).
5. B. Folkow and E. Neil, Circulation, New York (1971).
6. A. M. Chernukh, P. N. Aleksandrov, and O. V. Alekseev, The Microcirculation [in Russian], Moscow (1975).
7. V. S. Shinkarenko and S. E. Morozov, Byull. Éksp. Biol. Med., 97, No. 1, 104 (1984).
8. H. H. Lipowsky and B. W. Zweifach, Microvasc. Res., 7, No. 1, 73 (1974).
9. V. S. Shinkarenko (V. S. Schinkarenko), E. Yu. Kostromina, S. E. Morozov, and I. M. Rodionov, New Methods and Instruments for Microscopy in Biology and Medicine, Moscow and Wetzlar (1987), pp. 170-175.