AXIAL SHIFT OF ERYTHROCYTES IN ARTERIES SUPPLYING BLOOD TO THE CEREBRAL CORTEX

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There is now no doubt that the number of erythrocytes in the microvessels and their behavior constitute a highly important factor determining the rheologic properties of the blood in the microcirculatory system. Brain microvessels are particularly interesting from this point of view because of the high sensitivity of brain tissue elements to hypoxia, as well as the importance of the brain for the organism as a whole.

Biomicroscopic studies of the blood flow in small arteries and veins of transparent organs have always revealed axial displacement of erythrocytes and a juxtamural leyer of plasma in the lumen of the vessels [1, 2]. However, the quantitative characteristics of this phenomenon, as also its importance, still remain insufficiently explained. The investigation described below was carried out to study this problem, and the pia mater, through which blood is supplied to the cerebral cortex, proved to be a very convenient object with which to study this problem because of the simultaneous accessibility of the whole system of small pial arteriese from about 200 to 15 μ in diameter, i.e., until they actually entered the cerebral cortex, for investigation.

EXPERIMENTAL METHOD

Acute experiments were conducted on mature rabbits of both sexes weighing 2.5-3 kg, anesthetized with urethane (1 g/kg, intravenously). Through a skin incision along the sagittal line in the neck a tracheotomy tube was inserted, and a wide catheter introduced into the left common carotid artery and connected through a three-way cock both with a pressurized reservoir (to monitor the fall in the level of the general arterial pressure during fixation of the pial arteries), and also with a manometer, to monitor the blood pressure. The skull was widely trephined in the parietal region and the dura mater subsequently removed. The pial arteries were investigated in the control experiments and also in a state of functional dilatation, induced by application of a 0.5% isotonic solution of strychnine to the surface of the brain [3].

Intravital fixation of the pial vessels and brain tissue was carried out in vivo by application of cotton wool, generously soaked in a 20% solution of neutral formalin in 96° alcohol and heated to 50°C, to the brain surface. Meanwhile the right carotid artery was clamped (to prevent the flow of blood along it into the system of the pial vessels), and at the same time the blood pressure was lowered with the aid of the pressurized reservoir to 70 mm Hg, and was maintained for some time at this level, after which it was lowered even more (to prevent a contralateral flow of blood into the brain along the vertebral and other arteries). About 3-5 min later the parietal cortex was quickly excised and placed for 2 h in fixing solution of the same composition, after which it was rinsed in running water, and with the aid of anatomical forceps, the pia mater was carefully removed from the surface of the cortex under a binocular microscope. It was treated as follows: with 10% formalin in 3% potassium bichromate for 1 day, with 3% potassium bichromate for 3-5 days, washing in tap water for 2-3 days and immersion in 70° alcohol (in darkness) for 1 day, staining with hematoxylin (followed by differential staining), staining with an alcoholic solution of eosin (in 60° alcohol) for 1 day, differentiation in 60° alcohol, dehydration, clearing, and mounting in balsam.

The whole vascular system of the pial vessels could be clearly demonstrated in total microscopic preparations of the rabbit pia mater thus obtained, and within the vascular lumen the intravitally fixed axial flow of erythrocytes and the juxtamural layer of plasma were clearly visible. Investigation of total microscopic preparations was carried out under an "Orthoplan" micro-

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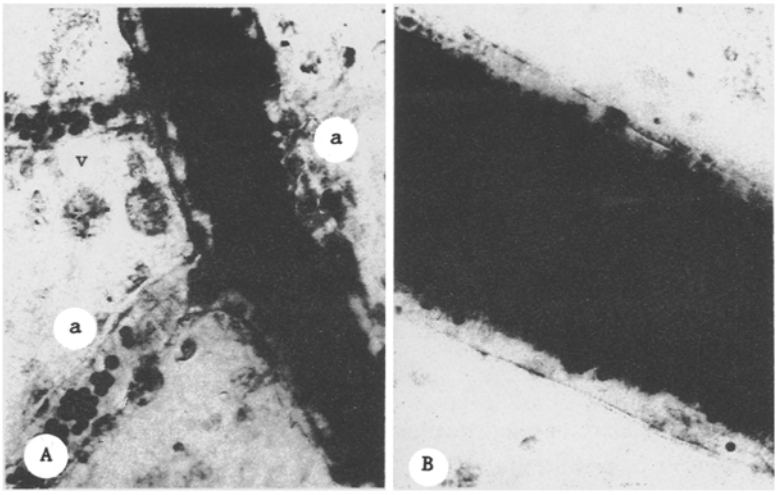

Fig. 1. Intravitally fixed pial arteries of smaller (35 μ) and larger (120 μ) diameter in parietal cortex of rabbit brain. Photomicrograph of total preparations stained with hematoxylin and eosin. 400×. A) Small artery, B) large artery; a) artery, v) vein.

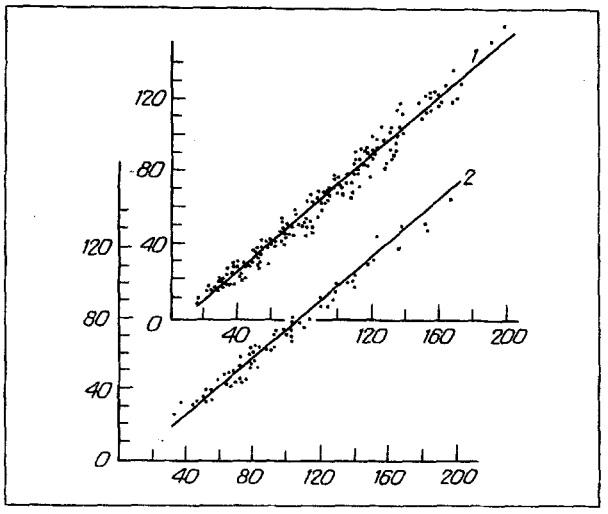

Fig. 2. Linear dependence of width of axial flow of erythrocytes (ordinate, μ) on diameter of lumen of vessel (abscissa, μ) under control conditions (1) and in arterial hyperemia (2) in rabbit parietal cortex.

scope equipped with a special device for measuring length (from "Leitz," West Germany). During measurement of the diameters of the lumen of the pial arteries and the axial flow of erythrocytes, a random sampling method was used. Measurements were made in regions between two branches, where the flow of erythrocytes was undamaged, and where a juxtamural layer of plasma was present. The results were subjected to regression analysis at the computer center of the Institute by M. L. Itkis, to whom the authors are grateful.

EXPERIMENTAL RESULTS

The axial flow of erythrocytes and the juxtamural layer of plasma were clearly visible in the microscopic preparations. Although the boundary between them at different points along the vessel was not completely clear (Fig. 1), this did not prevent determination of its mean value on the microscopic preparations. A strictly linear relationship was found between the width of the flow of erythrocytes and the diameter of the lumen of the vessel, both in control experiments and in the presence of dilata-

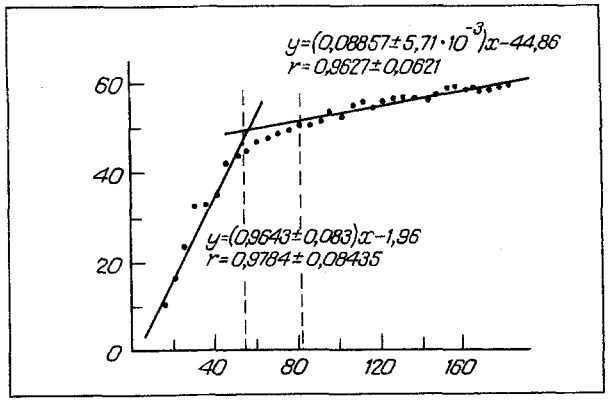

Fig. 3. Dependence of relative volume of axial flow of erythrocytes (per cent) on diameter of pial arteries of rabbit parietal cortex (μ, data for control and arterial hyperemia). r) coefficient of correlation.

tion of the arteries (Fig. 2). This is evidence that the width of the juxtamural layer of plasma is related to the diameter of the vessels and decreases in proportion to the actual diameter of the vascular lumen. Since the relative viscosity of whole blood is more than twice that of its plasma [4], the presence of a relatively wide layer of plasma near the walls of the vessels undoubtedly creates favorable conditinns for the blood flow in the small arteries from the standpoint of the rheologic properties of the blood.

Calculation of the volume of axial flow of the erythrocytes in vessels of different diameters showed that the relationship between them and the diameter of the lumen of the arteries is not linear and can be satisfactorily approximated by two straight lines (Fig. 3). Regression analysis of data by computer showed that the arteries studied can be divided from this point of view into two groups: those with diameters greater and less than 50 μ. In the group of smaller arteries, with a decrease in diameter of the vascular lumen the axial flow volume of the erythrocytes fell more sharply than in the large arteries. The comparatively larger volume of the juxtamural layer of paasma in the smallest arterial branches is undoubtedly one cause of the decrease in the erythrocyte concentration, described elsewhere [5, 6], and the corresponding gradual reduction of the dynamic hematocrit in the direction toward the capillaries. It can be postulated on the basis of these findings that when small arterial branches leave larger arterial trunks approximately at a right angle, blood should drain into their lumen mainly from the layer of the mother vessel close to its walls, i.e., blood containing more plasma and fewer erythrocytes.

On the other hand, the strictly linear relationship found in these experiments between the width of the erythrocyte flow and the juxtamural layer of plasma indicates that in intravital studies of microvessels in objects in which the vessel walls cannot be seen (in the conjunctiva of the eye, the pia mater of the brain, etc.), the data obtained allow the width of the vascular diameter and changes in it to be estimated. Under these circumstances, however, it must be recalled that the principle described above is valid only for a normal intact blood flow in the lumen of the vessel and the absence of stasis, for when this is present, the aggregated erythrocytes usually fill the whole lumen of the vessel and the juxtamural layer of plasma is absent.

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