THE INDEPENDENCE OF MECHANISMS REGULATING THE DIAMETER OF REGIONAL ARTERIES OF THE BRAIN (INTERNAL CAROTID AND VERTEBRAL) AND OF THE PIAL ARTERIES

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Our studies of the function of the regional arteries of the brain (internal carotid and vertebral arteries) under conditions such that the flow of blood out of the brain is disturbed, in traumatic brain edema, and in terminal conditions have shown that these vessels are of great importance in compensating for disorders of cerebral circulation.

It has subsequently proved necessary to determine whether the regional arteries of the brain participate in the development of those changes in cerebral circulation which result from a change in the diameter of the pial arteries, and are connected, in particular, with the functioning of the brain. The answer to this question is very difficult to obtain. It has been shown [10] that in natural sleep the total blood flow to the brain (method of Kety and Schmidt) is not reduced, but even increases; and on the other hand, during intense brain activity (solving problems in arithmetic) the blood supply to the brain does not increase, although there are electroencephalographic changes typical of intensified cortical activity.

In the present investigation, we studied the state of the regional arteries of the brain in those cases where considerable dilatation of the pial arteries supplying the cerebral cortex occurs.

In this case the number of functioning capillaries increases, and dilatation of these capillaries takes place [4]– i.e., the circulation in the brain is unquestionably enhanced. Similar changes in brain circulation occur, on the one hand, during temporary occlusion of the trachea, and on the other, after local application of strychnine to the cerebral cortex. If we record the condition of regional arteries of the brain and that of the pial vessels simultaneously, we will be able to demonstrate the functional connection between the mechanisms that determine the blood flow to the brain as a whole and those that determine the blood supply to small regions of the brain.

METHODS

Experiments were carried out on 16 mature rabbits, anesthetized in some instances with chloral hydrate (0.4 g/kg). After the operation the animals were given heparin (0.3-0.4 ml/kg). The brain circulation was altered either by temporary occlusion of the trachetomy tube or by local application of 0.5-1% strychnine, made isotonic by adding NaCl, to the surface of the brain.

The state of the regional arteries of the brain was determined on the basis of simultaneous recording of arterial pressure in the aorta and the circle of Willis, which allowed us to judge the magnitude of the resistance in the internal carotids and the vertebrals. In some experiments a systemic arterial pressure compensator was employed [3].

The condition of the pial vessels was recorded by serial microphotography at intervals of five or ten seconds, with the time of each photography being indicated on the same kymograph record as the record of arterial pressure. In each frame of the film, the diameter of these vessels was measured with the ocular micrometer of a microscope. When these diameters were subsequently plotted on the kymograph record, it was then possible to obtain an idea both of the state of the regional arteries of the brain and of the time course of changes in the diameter of the pial vessels.

RESULTS

The dilatation of the pial vessels that accompanies occlusion of the trachea is usually regarded as the result of an increase in the carbon dioxide concentration in the blood. Most authors [2, 7] believe that CO_2 is the principal regulator of the cerebral circulation since, by accumulating in the brain tissue when the blood supply is inadequate and producing dilatation of the vessels, it quickly restores the correspondence between the "needs" of the neuronal elements of the brain for an increased blood flow and the magnitude of the flow itself.

The effect of increasing the CO_2 content of the blood (hypercapnia) on the pial arteries has been shown by many authors [2, 8], but the state of the internal carotids and vertebrals under these circumstances has not been determined. Simultaneous recording of the arterial pressure at both ends of the regional arteries of the brain, enabling us to judge the conditions of the lumen of these vessels,

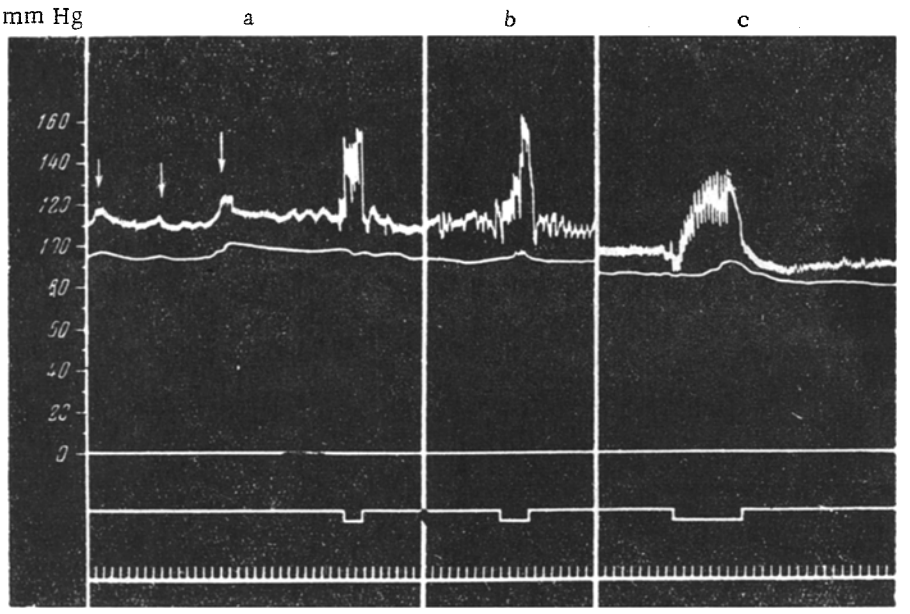

Fig. 1. Changes in arterial pressure in the aorta and in the circle of Willis upon occlusion of the tracheotomy tube at various times. The difference between the indicated pressures gives an expression of the magnitude of the resistance in the regional arteries of the brain (internal carotids and vertebrals). Tracings (top to bottom): arterial pressure in aorta; arterial pressure in circle of Willis; base line; clamping of tracheotomy tube; time (5 sec). Arrows designate times when animal moved, with simultaneous alteration of pressure. a) trachea clamped for 12 seconds; b) trachea clamped for 18 seconds; c) trachea clamped for 45 seconds.

showed that during temporary occlusion of the trachea they behave differently from the pial arteries (Fig. 1). Thus, when the animal moves, even an insignificant elevation of systemic arterial pressure is accompanied by a corresponding change in the pressure in the circle of Willis; whereas when the trachea is clamped, despite a sharp elevation of systemic arterial pressure (the well-known reflex from the chemoreceptors), the blood pressure in the circle of Willis actually falls a little (Fig. 1a). The same thing happens when the tracheotomy tube is clamped for a longer period (Fig. 1b); when the trachea was clamped for 45 seconds the arterial pressure in the circle of Willis rose a relatively small amount, and the rise was delayed (Fig. 1c). From this we may assume that when the trachea is clamped, and during the subsequent hypercapnia and hypoxemia, the regional arteries of the brain not only do not dilate, but actually constrict at the same time as the systematic arterial pressure is elevated. Apparently the internal carotid and vertebral arteries, unlike the cerebral vessels lying peripheral to them, participate in the regulation of systemic arterial pressure.

It is well known that even a slight amount of hypercapnia produces a sharp dilatation of the pial arteries. To determine the diameter of these vessels at the same time as the state of the regional arteries of the brain, we recorded the diameter of pial vessels on photographic film. An example of such an experiment is shown in Fig. 2. Because a systematic arterial pressure compensator was being used, the level of arterial pressure began to oscillate while the trachea was clamped (for approximately 45 sec), but hardly rose at all, while the arterial pressure in the circle of Willis remained constant. At the same time, the pial arteries dilated markedly. Thus, while the trachea is clamped and during the resulting hypercapnia the pial arteries dilate, while the internal carotids and vertebrals actually constrict or keep the same diameter.

In another series of experiments we examined the effect of strychnine on the circulation in a small region of the brain. When this substance is applied locally to the cerebral cortex, convulsive discharges appear in the electrocardiogram, indicating that the activity of cortical neurons is intensified; and dilatation of pial vessels occurs simultaneously [8]. Our studies together with A. I. Roitbak have shown that these changes in the circulation to a small region of the cortex are caused, not by a direct action of strychnine on the wall of the arteries, but by an effect exerted on the arteries by the nerve elements whose activity is markedly increased.

We found (Fig. 3) that local application of strychnine to the cerebral cortex is followed by a considerable dilatation of the pial arteries, whereas the level of arterial pressure in the aorta and the circle of Willis remains unchanged—provided, of course, the strychnine is not applied to the motor cortex and the animal does not become convulsive.

Thus, our data, obtained during tracheal occlusion and during the local action of strychnine on the cortex, provide evidence that the mechanisms whereby the systemic arterial pressure and the diameter of regional arteries of

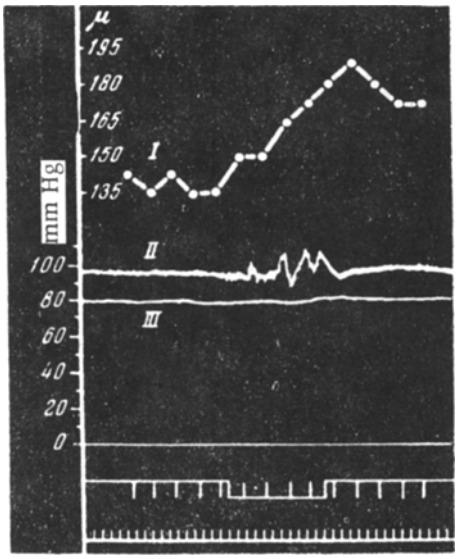

Fig. 2. Changes in the diameter of the pial arteries and in arterial pressure in the aorta and the circle of Willis during temporary occlusion of the tracheotomy tube. Aortic pressure was compensated. I) diameter of pial artery; II) arterial pressure in aorta; III) arterial pressure in circle of Willis. Marker indicates time when trachea was clamped, as well as times when microphotographs of pial vessels were taken; time marker, 5 sec.

the brain are regulated do not participate in the dilatation of cerebral arteries, and therefore can not participate in increasing the local circulation in various regions of the brain; under physiological conditions this local circulation is usually connected with the activity of the nerve elements and with their "need" for a supply of blood.

The peripheral (or local) circulation in all organs possesses a regulatory mechanism that is relatively independent of the central (or systemic) circulation [6]. The mechanisms that regulate the cerebral circulation also show this independence–i.e., the circulation of the blood in the brain can change even when the central circulation, specifically the systemic arterial pressure, remains unchanged [1, 2, and our own studies]. On the other hand, changes in the central circulation may have no effect on the cerebral circulation, since it is common knowledge [9] that when arterial pressure is elevated in hypertension, or lowered in diabetic coma, the cerebral blood flow may not change.

Our studies have shown that in the regulation of cerebral circulation the regional arteries of the brain (internal carotids and vertebrals) are very important, since they compensate for certain disorders of cerebral circulation. It has been established that when the outflow of blood from a region of the brain is disturbed, constriction of the regional arteries of the brain occurs, and this prevents the development of stasis in the brain during the period before the collaterals begin to ensure the outflow of venous blood from the brain. When cerebral edema develops, the regional

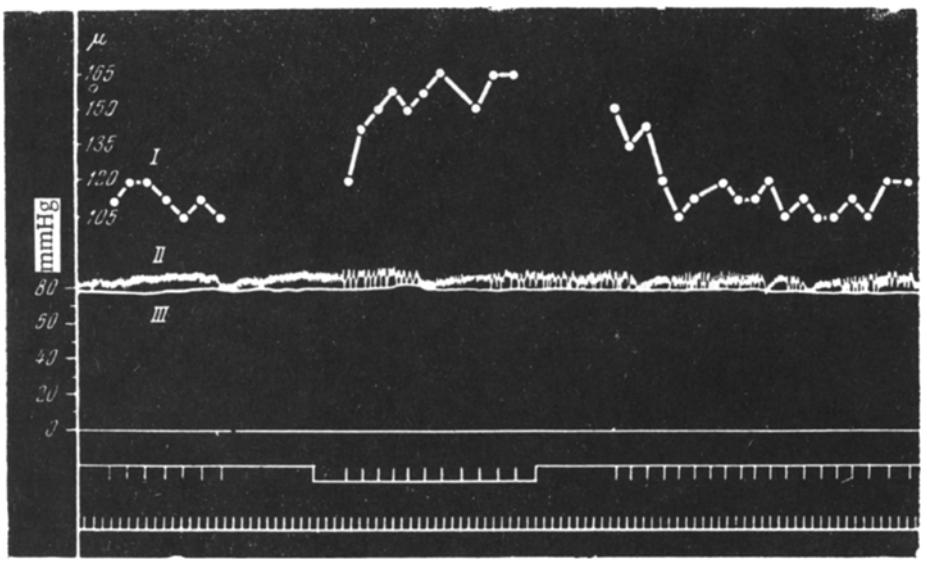

Fig. 3. Changes in the diameter of pial arteries, and in arterial pressure in the aorta and circle of Willis following local application of 0.5% strychnine to the cortex. I) diameter of pial artery; II) arterial pressure in aorta; III) arterial pressure in circle of Willis. Marker indicates time of application of strychnine, as well as times when microphotographs of pial vessels were taken. Time marker, 5 sec.

arteries of the brain constrict, causing a drop in pressure in the brain capillaries, so that the transudation of fluid into the tissue is reduced and the development of edema is retarded. In terminal conditions the regional arteries completely isolate the arterial system of the brain from the other arteries of the organism, so that when the systemic arterial pressure falls to zero, blood continues in the cortex for several minutes.

Under conditions where disorders of the cerebral circulation are compensated, we have in several instances observed a completely coordinated response of the regional arteries of the brain and the pial arteries. Thus, when the outflow of blood from the cranial cavity is disturbed, or in traumatic edema of the brain, when increased flow of blood to the capillaries of the brain may be injurious, the pial arteries constrict along with the regional arteries. In terminal states, after a marked constriction of the regional arteries of the brain, a slow peristaltic wave of contraction develops in the pial arteries, causing blood to flow in the right direction in the brain capillaries after it has stopped in other organs. But in other cases—e.g., when the vital functions of the organism are restored after the animal has passed through the agonal state and clinical death—when brain edema develops and the pial arteries are markedly dilated, the regional arteries of the brain constrict strongly, compensating for the changes mentioned, which would damage the brain.

The experiments described in this paper have shown that the local enhancement of cerebral circulation, caused by an increase in the content of CO_2 in the blood or by intensified functional activity of the cortical neurons, may be brought about through the agency of the pial and other small cerebral arteries without the participation of the internal carotids or the vertebrals.

All of this indicates that two independent mechanisms exist for the regulation of the cerebral circulation. On the one hand, we have the mechanism of the regional arteries of the brain, which determines the intensity of the blood flow to the cerebrum as a whole, and takes an active part in the compensation of certain disorders of cerebral circulation. On the other hand, we have the mechanism of the smaller arteries located on the surface of the brain or inside it, which determine the blood flow to relatively small regions of the central nervous system. The second mechanism is apparently of great importance in those changes of cerebral circulation which are connected with the level of the functional activity of neuronal elements of the brain. We reported on this as far back as 1957 [5].

SUMMARY

The author estimated the resistance in the internal carotid and vertebral arteries from measurements of arterial blood pressure in the aorta and the circle of Willis. These arteries become constricted when the tracheotomy tube is temporarily occluded. Under these conditions the pial arteries may dilate independently of the regional arteries of the brain, while the arterial pressure in the aorta and the circle of Willis remains unchanged. The same changes occur in response to local application of strychnine to the surface of the brain. Thus, the mechanism controlling the diameters of the pial arteries are independent of the mechanism regulating the state of the regional arteries of the brain (internal carotids and vertebrals).

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