DEVELOPMENT AND SPREAD OF THE PULSE WAVE IN THE CRANIAL CAVITY

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The problem of the nature of the blood flow in the vascular system is of great importance in hemodynamics.

Great attention has been paid to the pulsation of the blood stream in the cerebral vessels. The results obtained by B. N. Klosovskii [3] and others [9, 10, 13] showed that the cerebral vessels did not pulsate when the skull remained hermetically sealed; the contrary claim has also been made [1, 2, 5, 16] that the blood flow in all the vessels, both arteries and veins, is pulsatile. However, much remains to be found out about the mechanism of transmission of the pulse waves within the cranial cavity.

We have shown previously in dogs [1], when studying the spread of the pulse wave from the heart to its entry into the sinuses, and following it as far as a more remote point in the superior longitudinal sinus, that despite the variation in distance from the heart, the time of spread of the pulse wave to these points was the same, having a value of 61-63 milliseconds.

Following up this result, we have studied the rate of spread of the pulse wave within the cranial cavity.

METHOD

The experiments were carried out on 23 adult dogs weighing 20-30 kg; morphine-urethane anesthesia was used, and heparin injected. The pulse rate was recorded using a piezomanometer, and cathode ray and string oscillographs (writing speed 60-250 mm/second).

In the first set of experiments the pulse rate was recorded simultaneously at the confluence of the sinuses and at the origin of the superior longitudinal sinus at a distance of 3-4 cm from the confluence. In the second set of experiments, recordings were made from the four points in the cerebral circulation as illustrated in Fig. 1.

RESULTS

If it is supposed that the pulse wave spreads in the vessels with a certain velocity in the direction of the blood flow, then from the direction of flow in the superior longitudinal sinus (toward the confluence of the sinuses) it would be expected that at the confluence the wave would develop somewhat later than at the origin of the superior longitudinal sinus. However, as can be seen from Fig. 2, the pulse wave in the superior longitudinal sinus and that at the confluence arise simultaneously.

In the second set of experiments, simultaneous recordings were made first of the pulse in the left and then of that in the right cerebral hemisphere, each being recorded together with the pulse in the superior longitudinal sinus; the pulse at the confluence was then recorded in turn simultaneously with that in the left and right hemispheres, and finally the pulse in both hemispheres was recorded (Fig. 3).

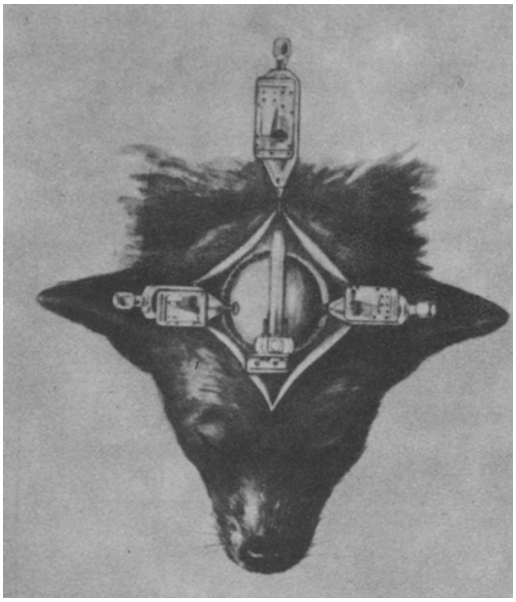

Fig. 1. Diagram showing the arrangement of the piezomanometers used for recording pulsations at 4 points (at the confluence of the sinuses, in the superior longitudinal sinus, and at two points in the cerebral hemispheres).

Accoring to published results the cerebral pulse is derived from the pulsation of the cerebral arteries through the spread of the pulse wave along the blood stream, and if this is so it ought to occur somewhat before the sinus pulse. However, in our experiments there was no consistent time interval between the pulse waves at the points described. Thus, the time of spread of the pulse wave from the heart to the superior longitudinal sinus was 61 mseconds, from the heart to the left cerebral hemisphere 57 mseconds, to the right hemisphere 57 mseconds, and to the sinus confluence 63 mseconds. The differences in the above figures are within the limits of experimental error. Consequently, the pulse wave at all points in the blood stream develops practically instantaneously. Such a result is only possible if, due to the hermetically sealed skull, the increase in cerebral arterial pressure induced by cardiac systole is spread through the fluid medium and the incompressible mass of the brain in all directions equally and almost instantaneously; such a wave will travel with the velocity of sound in water, and will be compensated by transference of a sufficient amount of venous blood into the cerebral veins and of cerebrospinal fluid (CSF) into the spinal canal [2, 4, 5].

Thus, the CSF transmits the pulse wave from the arteries to the veins and cerebral sinuses. However, its hemodynamic function is not confined to a simple transmission of the pulse wave.

It has been known for a long time that the amplitude of the pulse wave becomes considerably reduced in the cranial cavity. Thus, the oscillations in intracranial pressure in the dog under morphine anesthesia are 4-5 mm of water [12]; the variation in intravenous pressure under the same conditions is 1-2 mm of mercury [16]. We have found that in a dog under morphine-urethane anesthesia, when the pulse wave is generalized, the pressure variation at the confluence of the sinuses is 20 mm of water inspiration, and 30 mm at expiration.

a

b

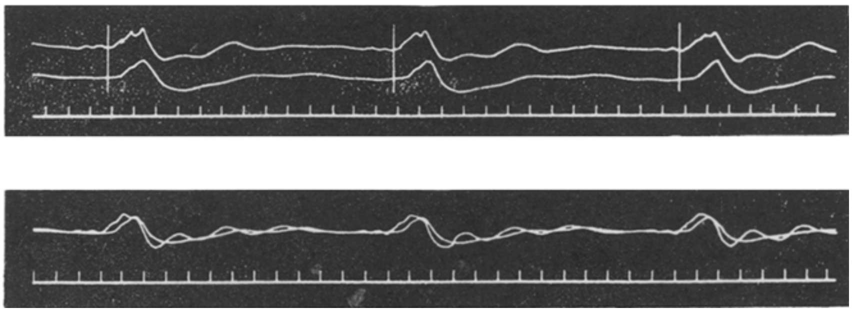

Fig. 2. Coincidence of pulse in the superior longitudinal sinus and at the confluence of the sinuses.
a) Upper curve – pulse at the confluence, lower curve – pulse in the superior longitudinal sinus; b) ditto with the traces superimposed. Writing speed 250 mm/second.

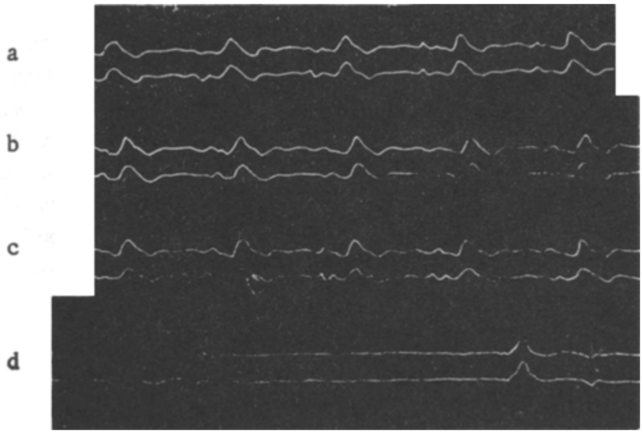

Fig. 3. Simultaneous occurrence of the pulse at 4 points in the blood stream. a) Upper curve – pulse in superior longitudinal sinus, lower curve – brain pulsation; b) upper curve – pulse at sinus confluence, lower curve – brain pulsation; c) upper curve – pulse at sinus confluence, lower curve – pulse in superior longitudinal sinus; d) upper curve – brain pulsation in right hemisphere, lower curve – brain pulsation in left hemisphere.

TABLE

Pressure in the Arteries of the Circle of Willis (in mm mercury)

Pressure in the internal carotid artery in neck	Pressure in brain	
	internal carotid artery	medial meningeal artery
114/78	104/72	—
74/40	84/64	—
96/72	—	92/66
96/60	—	96/56
94/56	—	90/54
—	—	130/82
		134/84
		130/80

It has been suggested [3, 9, 10, 13] that the pulsations of the blood cease on entering the skull so that the flow becomes steady on account of the skull being hermetically sealed, and because of the special structure of the cerebral arteries (the siphons of the internal carotid and vertebral arteries, the well-developed elastic layer in the wall of the cerebral arteries, the reticular arrangement of the arteries of the pia mater). However, direct measurements of the pressure in the cerebral arteries has shown that both the average and pulse pressure are reduced very little. Thus, according to Best and Taylor [7], in the large cerebral arteries the systolic pressure is 100 mm mercury, and the diastolic 65 mm. In measuring the pressure in all the arteries of the circle of Willis during operations [8, 14, 15], the following figures were obtained (see Table).

From these results it can be seen that the increase in pulse pressure in the cerebral arteries is of the order of several tens of millimeters of mercury, while the pulsatile variation in the CSF and sinuses is measured in millimeters of water. Thus, although the pulse pressure does not disappear, it becomes enormously reduced. However, this reduction does not occur principally in the cerebral arteries, where the pressure remains equal to that in the peripheral arteries of corresponding caliber, but in the transmission of the wave to the CSF, veins, and sinuses. Direct experimental evidence has been obtained which shows that when there is disturbance of the normal CSF circulation, the fluid becomes less able to act as a shock absorber and take up the pulse wave. Thus V. P. Osipov [6] found that hemorrhage through perforations in the brain was reduced by reducing the volume of CSF. Evidently, when the fluid is removed, the pulse pressure is increased, so causing further damage to the cerebral vessels. When CSF is withdrawn from the spinal canal, a considerable increase in the brain pulse is observed [11].

It appears probable, therefore, that the CSF is chiefly responsible for absorbing and transmitting the pulse wave; it accounts for the particular hemodynamic features of the brain. It maintains the high level of the arterial pressure necessary for the maintenance of an optimal blood flow, and greatly reduces the transmitted pulse pressure.

SUMMARY

Experiments were carried out on 23 anesthetized dogs, and heparin was injected. The pulse wave was recorded simultaneously at various points of the cerebral vascular system. It was shown that the pulse wave appeared at all points simultaneously, 57-63 milliseconds after the blood entered the aorta. This result confirms the idea that the cerebrospinal fluid plays a definite part in acting as a shock absorber and in transmitting the pulse wave through the cranial cavity.

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