STUDIES OF CEREBRAL CIRCULATION IN SERIES EXPERIMENTS BY MEANS OF CHANGES IN THE BLOOD PRESSURE GRADIENT IN VESSELS SUPPLYING THE BRAIN

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Regulation of cerebral circulation has, up to now, been studied mainly in short experiments and it is only recently that this problem has begun to be investigated under series conditions.

The present communication presents a brief statement of the principles underlying the method developed by us for the determination of cerebral circulation in series experiments by the gradient of the fall of blood pressure in the vessels supplying the brain.

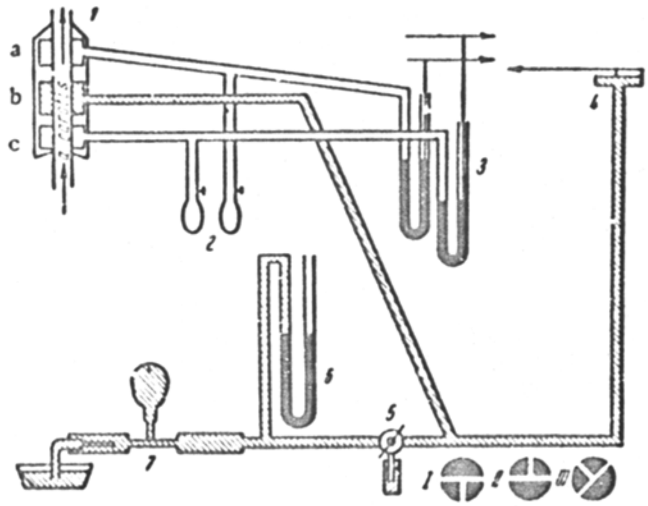


Fig. 1. Diagram of recording apparatus (explanations in text).

The premises for this method are taken from K. Hurthle who suggested investigation of cerebral circulation in short experiments using arterial pressure in the common carotid artery (M) and pressure in the vessels of the circle of Willis (M_1) as indicators. The difference in pressures ($M-M_1$) provides evidence of the rate of blood flow in the common carotid artery and the ratio of pressure in the circle of Willis to that in the aorta $\frac{M_1}{M}$ - of the state of cerebral vessels' lumen. An increase in this ratio indicates constriction, and a decrease in the ratio – dilatation of the cerebral vessels.

Our observations were carried out on dogs with the common carotid artery externalized in a skin flap (of 35 operations 23 were successful). To avoid rupture of the carotid artery, the animals' hind limbs were bound for 10-15 days following operation.

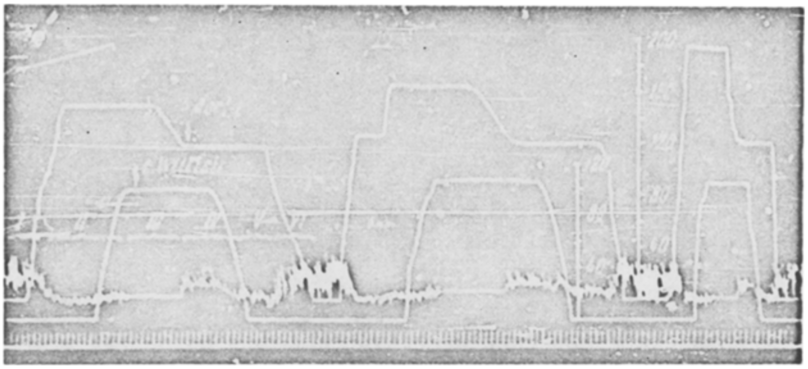


Fig. 2. Three cases of successive measurements of blood pressure in the aorta and the circle of Willis by the three-cuff method. Records from above down: sphygmogram, pressure in "thoracic" cuff, pressure in "head" cuff, time marker (2 seconds). I), II), III), IV), V), VI) phases of sphygmogram changes. First arrow – height of pressure in the circle of Willis, second arrow – pressure in the aorta. Scale for pressure in circle of Willis 0-120 mm Hg, for aorta – 0-200 mm Hg.

Arterial blood pressure was measured by means of the apparatus shown diagramatically in Fig. 1. The recording part consisted of a folding metal capsule (1) 42 cm in length and 21 mm in diameter, in which were placed 3 cuffs: middle recording one (b), and two end ones – occluding, pneumatic ones (a, c). Each of the occluding cuffs was connected by an air system with a mercury manometer (3) and a bulb (2) for pressure production. The recording cuff (b) was connected by a hydraulic system with the recording capsule (4) or a spring manometer, and by means of a three-way tap (5) with a mercury manometer (6) and a water pump (7).

For recording, the three-way tap (5) was put in position I and part of the fluid was thus removed from the system. The capsule with the cuffs was fixed to the carotid artery; the tubes leading from it were tied to the collar. The tap was then placed in position II; pressure of about 60-70 mm of mercury was established in the system, after which the tap was placed in position III and measurements were taken. The whole preparatory procedure took 3-4 minutes.

Changes in pressure in the end cuffs are accompanied with phasic changes in the character of the sphygmogram (Fig. 2).

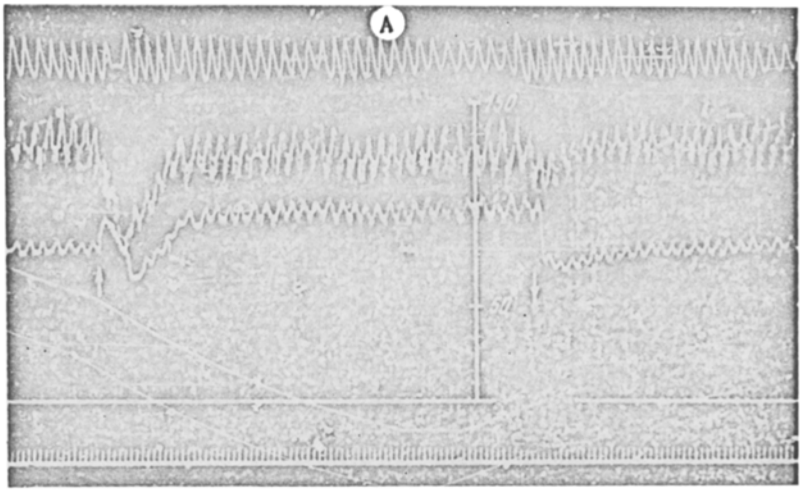
Phase I (background). Initial pulsation in the common carotid artery without limitation of blood flow.

Phase II. Excessive pressure created in the "thoracic" pneumatic cuff (c) led to complete occlusion of the aortal end of the common carotid artery and produced a sharp drop in the amplitude of oscillations, but their complete disappearance was never observed owing to "return" pulsation from the vessels of the circle of Willis.

Phase III. On gradual pumping of air into the "head" pneumatic cuff (a) a moment was attained when pulsation disappeared completely; the manometer reading at that stage corresponded to pressure in the circle of Willis.

Phase IV.. In the course of lowering the excessive pressure in the "thoracic" pneumatic cuff the appearance of the first pulse notch on the curve was noted and the manometer readings at that moment corresponded to maximal pressure in the aorta.

Phase V. Lowering of pressure in the "head" cuff to zero with partial occlusion of the aortic end of the common carotid artery was accompanied by a drop of the sphygmogram and diminution of its amplitude, apparently owing to friction of the blood against the vessel wall on re-establishment of outflow (in phase IV there is no movement of blood in the carotid artery since the "head" cuff completely occludes flow into the circle of Willis).



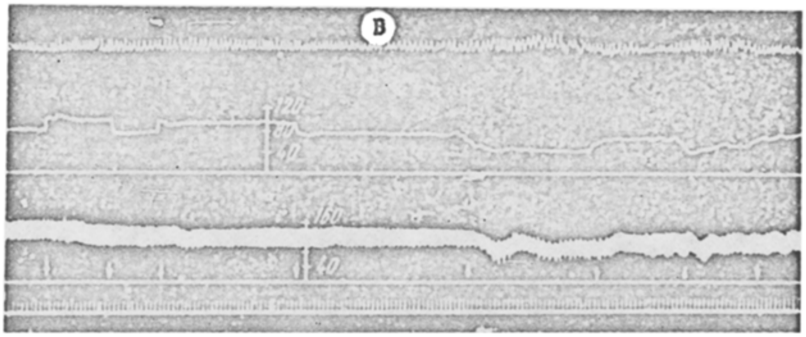


Fig. 3. Changes of blood pressure in short experiment with exclusion of branches of the common carotid artery on the side of recording.
A) Experiment on April 15, 1954; records from above down: respiration, aortal kymogram, cerebral kymogram (mercury manometer record), base line, time marker (1 second), ↑ – simultaneous occlusion of left external carotid and occipital arteries, ↓ – simultaneous removal of clamps.
B) Experiment on May 4, 1954. Records from above down: respiration, cerebral kymogram, base line, aortal kymogram, base line, time marker (1 second). Scale of pressure for circle of Willis 0-120 mm, for aorta 0-160 mm Hg. Sensitivity coefficient for the circle of Willis manometer 4.2; for aortal 6.4; first ↓ – simultaneous occlusion of the external carotid and occipital arteries on the left; second ↓ – removal of clamps; third ↑ – repeat occlusion of the same vessels; fourth ↓ – removal of clamps, fifth and seventh ↑ – clamping of the internal carotid artery on the left sixth and eighth ↓ – removal of clamps.

Phase VI (background). On lowering the pressure in the "thoracic" cuff to zero initial pulsation again appeared in the carotid artery.

In order to check the data obtained by the three-cuff method simultaneous recording of blood pressure by the direct method was carried out (15 dogs). In 11 animals the arteries were externalized into a skin flap at the time of the experiment, while in 4 dogs the vessels were externalized some time before (permanent preparation). In addition to measuring background values of blood pressure records were taken under the influence of various procedures (intravenous injection of adrenalin, infusion and withdrawal of blood). The experiments showed the similarity of results obtained by the direct and three-cuff methods. The only difference consisted of the fact that figures for pressure obtained by the indirect method were 15-20 mm Hg higher than the true value as the result of the elasticity of the skin-vessel flap and the occluding cuff and the pressor reaction from the carotid sinus.

In order to determine on what depends the pressure measured in the cephalad end of the common carotid artery (on blood flow through the circle of Willis or on blood flow along anastomoses of the external carotid and occipital arteries) a series of short experiments on 13 dogs and series experiments on 4 dogs were carried out.

In the short experiments ligatures were placed on the internal carotid, the external carotid and occipital arteries on the side from which recordings were taken. The superior thyroid artery and small vessels branching from the region of the carotid sinus were tied; their exclusion was not reflected either on the aortic or the circle of Willis blood pressure.

After recording initial pressure simultaneous clamping of the external carotid and occipital arteries left only one path for blood flow to the manometer, viz. through the internal carotid artery. The general blood pressure curve (aorta) showed either no change during this procedure or, in cases where the clamp was applied somewhat carelessly, a transient fall of blood pressure (depressor reaction from the carotid sinus) was seen, followed by a return to initial levels. The blood pressure curve for the circle of Willis invariably showed a sharp rise which exceeded the initial level throughout the period of clamping (Fig. 3,A). If the clamp was removed from the external carotid and occipital arteries and placed on the internal carotid artery the curve for the circle of Willis showed a lowering of pressure. On removal of the clamp the pressure, as in the former case, rapidly returned to the initial level (Fig. 3,B).

Measurements of Blood Pressure in the Right and Left Skin Flap

No. of measurements	Left carotid (with tied vessels)				Right carotid (without tied vessels)			
	Circle of Willis	Aorta	$\frac{M_1}{M}$	$M-M$	Circle of Willis	Aorta	$\frac{M_1}{M}$	$M-M_1$
	In mm Hg.				In mm Hg.			
1	96	132	0.73	36	104	140	0.74	36
2	94	132	0.71	38	108	144	0.74	36
1	106	146	0.72	40	112	136	0.83	24
2	112	142	0.79	30	108	140	0.79	32
1	110	134	0.81	24	114	138	0.82	24
2	116	132	0.87	16	108	130	0.83	22

Prior to occlusion of the external carotid and occipital arteries the return blood flow from the circle of Willis thus takes place through the internal carotid artery in the direction of the common carotid artery (towards the recording manometer) as well as the external carotid and occipital arteries.

For complete exclusion of return blood flow along the supposed anastomoses through the system of external carotid and occipital arteries clamps were applied successively first to the external carotid and occipital arteries (with a rise of pressure in the circle of Willis manometer), then to the common carotid artery on the opposite side when the pressure in the aorta rose while that in the vessels of the circle of Willis dropped. The pressure returned to the initial levels immediately upon removal of clamps. On successive occlusion of the internal carotid artery on the recording side and the contralateral common carotid artery a two-fold drop in pressure was observed: the first as the result of exclusion of blood flow along the internal carotid artery, the second as the result of diminished flow of blood to the brain along the common carotid artery on the opposite side. Consequently, when connection with the external carotid and occipital arteries is maintained against the background of exclusion of the internal carotid artery the former are unable to keep arterial pressure at the initial level, since the pressure within them is lower than in the internal carotid artery. It follows from this that the level of pressure in the peripheral segment of the common carotid artery when all the branches are kept open depends on the pressure in the internal carotid artery, and the blood flow along the external carotid and occipital arteries is directed towards the anastomoses and not in the reverse direction.

Comparison of vascular reactions against the background of occlusion of the external carotid and occipital arteries and without such occlusion was then undertaken. Test reactions were provided by the pressor reaction to occlusion of the common carotid artery and constriction of cerebral vessels on stimulation of a specially prepared sympathetic twig of the cephalad end of the vagosympathetic trunk. The pressor reaction on occlusion of the common carotid artery contralateral to recording consisted of a considerable rise of arterial pressure in the aorta and the circle of Willis; the character of this reaction remained unchanged on exclusion of the external carotid and occipital arteries.

Induction current stimulation of the cephalad end of the sympathetic twig caused a sharp rise of blood pressure in the circle of Willis while in the aorta the pressure either remained unchanged or even fell. Narrowing of the lumen on stimulation of this twig was observed both on occlusion of the external carotid and occipital arteries and without it, but quantitatively the reaction was weaker in the former case. This fact confirms literature data concerning similar reaction of cerebral and superficial head vessels to stimulation of vasoconstrictors. The isolated rise of blood pressure in the vessels of the circle of Willis shows that the lumen of cerebral vessels can alter independently of fluctuations in the level of general blood pressure.

The series experiments consisted of the following: the dogs had both their common carotid arteries externalized; on one side the external carotid artery was tied at the same time, while on the other side it remained intact. It was thus possible to compare results of measurements on the two sides. Measurement data are given in the table.

As can be seen from the table, tying of the external and occipital arteries did not affect substantially the pressure in the circle of Willis and in the aorta; therefore observation of cerebral circulation by means of the three-cuff method can be carried out without preliminary tying of these vessels.

SUMMARY

A method of graphic recording of arterial blood pressure in the aorta and the circle of Willis in series experiments on dogs is described. Measurements were taken in the common carotid artery brought out into a skin flap, to which 3 cuffs were attached: medial, recording variations in the pulse, one placed caudad and one cephalad from the medial cuff, occluding correspondingly the blood flow from the aorta and the circle of Willis. The blood pressure in the head occluding collar corresponded to the blood pressure in the circle of Willis, after disappearance of oscillations during complete occlusion of the inflow of blood from the aorta. The aortic blood pressure was determined by the appearance of the first pulse beat in decrease of the pressure in "thoracic" cuff with preserved occlusion of the "head" portion of the common carotid artery. The changes of the gradient of the fall of blood pressure from aorta to the blood vessels of the circle of Willis served as an indication of changes of the lumen of blood vessels of the brain (Hurthle's principle).

LITERATURE CITED

K. Hurthle Pflüger's Arch. fur die gesamte Physiologie des Menschen und der Tiere, 1889, Bd. 44, S. 561.