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A COMPUTERIZED MODEL OF THE CIRCLE OF WILLIS

Note I: Simulation of the autoregulation of cerebral blood flow

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The regulation of cerebral blood flow (CBF) may be understood as a complex mechanism ensuring, on the one hand, the permanent maintenance of an adequate supply of oxygen and glucose, and on the other hand an efficacious removal of carbon dioxide and other waste products of the cerebral metabolism. For its multiple aspects, some of them being proved others having given rise to much controversy or being only presumed, CBF regulation should be considered as a unitary functional system, in which its components act either at the same level of the cerebral vascular tree (synergic or of opposite direction) or at various levels, making use of multiple mechanisms (autoregulation, metabolic and nervous regulation).

The autoregulation of CBF is a phenomenon which can be defined by the intrinsic capacity of the vascular network of the brain in order to maintain a quasi-constant blood flow in spite of the variations of blood pressure (BP). Multiple studies, in which various techniques of BP modification and CBF determination were used, both in human beings and animals, have demonstrated the existence of an extremely efficient autoregulation of CBF (1—7).

The autoregulation ensures that moderate and slow variations of BP might induce but slight modifications of CBF. Notwithstanding, CBF autoregulation has certain limits, yielding to rapid and massive BP changes, and to its extreme values as well. Thus, CBF obviously decreases if mean BP reaches 60 mm Hg or increases dramatically if mean BP is over 150 mm Hg. The inferior limit of the autoregulation is of utmost importance as it represents the measure of functional capacity of cerebral arteries. In this connection it should be mentioned that CBF autoregulation in patients with arterial hypertension begins to yild at higher values of BP than in normal individuals. Also, both anaesthetics and higher values of arterial pressure of carbon dioxide ($PaCO_2$) raised the inferior limit of CBF autoregulation. The phenomenon of exhaustion of CBF autoregulation by exceeding its superior limit was found in patients with hypertensive encephalopathy. CBF autoregulation may be diminished or even disappear in cerebral ischemia and hypoxia, cerebral tumors, cranio-cerebral traumatisms, subarachnoid haemorrhages etc. (8—20).

The autoregulation is carried out by three mechanisms: myogenic, metabolic and neurogenic. The *myogenic mechanism* is based on "Bayliss

effect", according to which: a) BP increase leads to the rise of intravascular pressure, and this starts vasconstriction with the prevention of CBF exacerbation; b) BP decrease induces the diminution of intravascular pressure and the occurrence of vasodilatation with the prevention of CBF collapse. This mechanism acts at all the levels of the cerebral arterial tree. The *metabolic mechanism* occurs at the intracerebral level of thue arterial tree, so that local $PaCO_2$, increase and pH decrease produced by increase of cerebral metabolism determines vasodilatation, while local $PaCO_2$ decrease and pH increase induced by decrease of cerebral metabolism determines vasoconstrsiction. At tehese levels of the arterial system, where there is an autonomous nerve supply, *neurogenic mechanism* also occurs. so that the sympathetic (adrenergic) system determines vasoconstriction, whereas the parasympathetic (cholinergic) system mediates vasodilatation during CBF autoregulation (21-35).

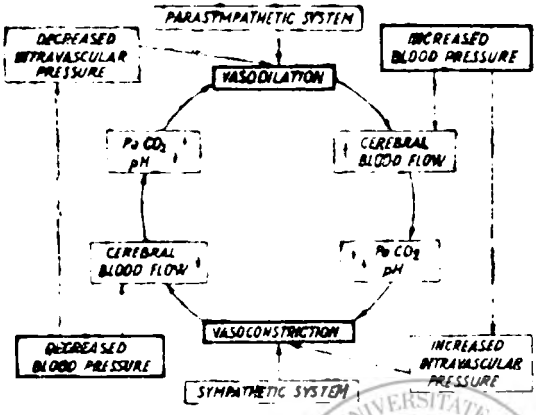

Fig. nr. 1: The scheme of the autoregulation of cerebral blood flow.

SAMPLES	ARTERIAL BLOOD PRESSURE (mm Hg)			CEREBRAL BLOOD FLOW		
	SYSTOLIC/DIASTOLE	MEAN	%	ml/'	ml/100g/'	%
1	20/0	6 7	7 2	82 60	5 90	10 9
2	40/0	13 3	14 3	165 71	11 80	21 7
3	50/20	30 0	32 2	396 52	28 32	52 2
4	60/30	40 0	42 9	550 72	39 34	72 5
5	70/40	50 0	53 6	660 86	47 20	86 9
6	80/50	60 0	64 3	721 44	51 53	94 9
7	100/60	73 3	78 6	737 97	52 71	97 1
8	120/80	93 3	100	760 00	54 28	100
9	140/90	106 7	114 4	776 52	55 46	102 2
10	160/90	113 3	121 4	787 53	56 25	103 6
11	180/100	126 7	135 8	804 05	57 43	105 8
12	200/110	140 0	150 1	820 57	58 61	108 0
13	220/120	153 3	164 3	963 76	68 84	126 8
14	240/130	166 7	178 7	1170 28	83 59	154 0
15	260/140	180 0	192 9	1376 81	98 34	181 2

Table: The absolute values of cerebral blood flow coresponding to each arterial blood pressure.

The important role that autoregulation has in normal and pathological cerebral circulation, made it necesary to test it on the computerized model of the circle of Willis (CW) created in 1987 (36). The program of the model is conceived in such a manner that it calculates standard CBF (54.28 ml/100 g/minute) at a systolic BP of 120 mm Hg and diastolic BP of 80 mm Hg for a brain of 1400 g. With a view to compare the results and to establish the relationships between BP and CBF, mean arterial BP (MA B P) value was also calcu-

lated according to formula: MABP = 1/3 (systoslic BP diastoslic BP) + diastolic PB.

Introducing in the program several systolic and diastolic BP values, from o/o mm Hg to 260/140 mm Hg, CBF values corresponding to each BP were calculated. In the following table 15 samples out of 30 determinations were included.

Within the limits in which autoregulation maintains quasi-constant CBF, it is remarked that a MA BP decrease by 33,7 $^{0}_{0}$ (up to 60 mm Hg) determines a CBF reduction only by 5,1 $^{0}_{0}$, while a MABP increase by 50,1$^{0}_{0}$ (up to to 140 mm Hg) induces a CBF increase only by 8$^{0}_{0}$. Besides the limits of autoregulation, CBF is reduced or increased almost parallel with the MABP values. Thus, at 92.8$^{0}_{0}$ decrease of MABP, CBF reaches a value lower by 89.1 $^{0}_{0}$, whereas at 92.9 $^{0}_{0}$ increase of MABP, CBF rises by 81.2 $^{0}_{0}$ (all percentages are related to the standard values).

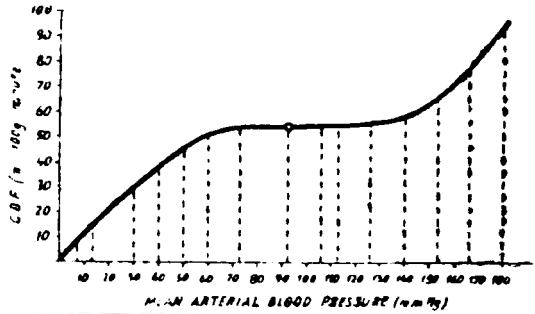

Fig. nr. 2: The relationship between absolute values of mean arterial blood presure and of cerebral blood flow.

Including the absolute MABP values in a diagram reveals a curvve of CBF similar to those obtainned "in vivo" in healthy persons or in experimental animals (1, 3, 5, 19). In figure 2, the inferior and superior limits of CBF regulation in CW are accurately observed.

The relationship between the percental decrease and increase of MABP, on the one hand, and the percental decrease and increase of CBF on the other hand, can be seen in figure 3. It has been pointed out that from extremities till the moment of the occurrenc autoregulation the curve of CBF follows almost parallelly that of

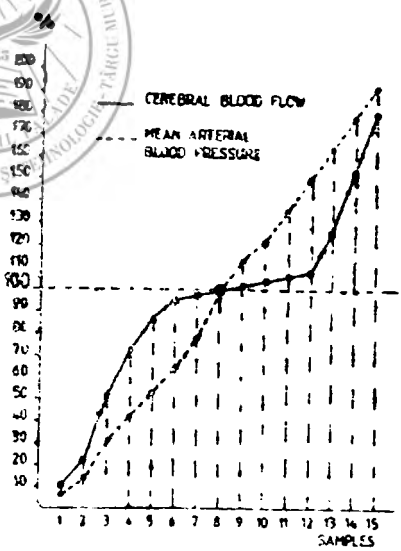

Fig. nr. 3: The relationship between percental values of mean arterial blood pressure and of cerebral blood flow.

MABP. Within the limits of autoregulation the curve of CBF becomes almost horizontal, though the curve of MABP remains aslant.

The possibility of an accurate determination of CBF autoregulation by a computerized model of CW and the similitude with that obtained "in vivo" in man and experimental animals attests the reliability of the model and permits the simulation of most various situatiosns in the circulation through CW.

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