DEPENDENCE OF BLOOD DRAINAGE FROM THE LONGITUDINAL SINUS ON ITS ANGLE OF BIFURCATION: AN EXPERIMENTAL MODEL

Yu. A. Krasnikov, A. A. Grigoryuk, and S. A. Shakunov

UDC 612.15:611.819.5].001.57

KEY WORDS: longitudinal sinus; angle of bifurcation; hemodynamics.

The principal collector draining venous blood from the cerebral hemispheres is the longitudinal sinus of the dura mater. In the region of the occipital lobes of the brain it divides into right and left transverse sinuses, with an angle of birfurcation that varies in different vertebrates from 60 to 180°. Analysis of variations of this angle has shown that animals leading a quiet and immobile mode of life [7] (guinea pigs, rabbits, domestic pigs, and cats) have an obtuse angle (over 90°) whereas vertebrates with a high level of motor activity (squirrel, Indian marten, roe deer, Steller's sea lion, wild boar, Siberian weasel, mink) have a right angle or close to a right angle, whereas birds which dive and remain for a long time under water (bull-headed shrike, merganser, tufted duck, cormorant, tern) have an acute angle, i.e., under 90° [1, 2, 4]. We know from physical hydrodynamics [12, 13] that the rat of flow of a liquid in branching tubes depends on the angle of bifurcation. In the course of evolution, an appropriate architectonics of the venous division of the cerebrovascular bed has evidently evolved in animals with different levels of mobility and, consequently, with a different volume of their cerebral circulation. However, the relationship between the angle and bifurcation of the cerebral venous system and the characteristics of the blood flow has received little study [9], despite its great importance for an understanding of the principles of cerebral hemodynamics.

The aim of this investigation was to determine the effect of the structure (size) of the angles of bifurcation on the velocity of the flow of fluids of a model system of tubes, making angles of between 60 and 180° with each other, and to obtain an empirical equation describing this relationship.

EXPERIMENTAL METHOD

The construction of the model is illustrated in Fig. 1, in which bifurcation is symmetrical relative to the abscissa; the angle of bifurcation is α. The distance 1 is much less than the main column of fluid H ($l << H$), and for that reason friction in the branched part of the tube can be disregarded. The initial liquid level is A_0 the final level A. The level of liquid falls by an amount H during time t under the action of gravity and is recorded by an electronic seconds timer [3]. The change of level ΔH is much less than the height of the column H ($\Delta H << H$) so that during time t the change in mass of the column of liquid can be disregarded. The radius of the tubes before and after branching is R. The initial experimental data are: ΔH = const = 0.4 mm, the liquid is water, ΔH = const = 0.22 mm, the liquid is glycerin

EXPERIMENTAL RESULTS

The following forces act on the column of liquid of height H: F_{res}) the force of resistance from the bifurcation, directed upward, F_g) the force of gravity, directed vertically downward, F_t) the force of resistance from the walls of the tube, directed vertically upward. Because of the small shift ΔH, $F_t = const_1$ (1°).

Departments of Biophysics and Histology, Vladivostok Medical Institute. (Presented by Academician of the Academy of Medical Sciences of the USSR O. S. Adrianov.) Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 111, No. 6, pp. 595-596, June, 1991. Original article submitted October 10, 1990.

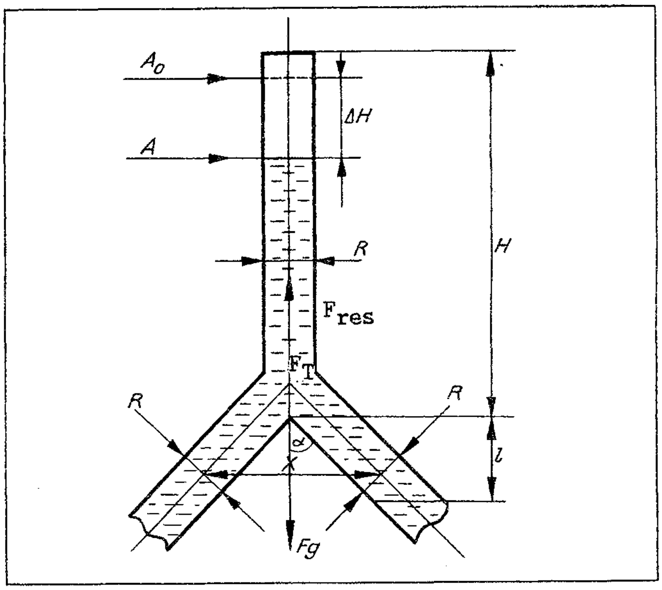

Fig. 1. Model of bifurcation of cylindrical tube (explanation in text).

The force of gravity acting on the liquid, given that ΔH is small, is:

$$F_g = const_2 \ (2°).$$

The force of resistance from bifurcation can be likened to a Stokes' force acting on a sphere of radius x. A certain characteristic size, with dimensionality of length and characterizing the range of branching, is chosen as the value of x (Fig. 1). It is evident that with an increase in the angle α and, consequently, in the value of x, the frontal resistance increases (as a result of an increase in the imaginary radius of the Stokes' sphere) [10], From geometrical considerations the value of x is proportional to the sine of the angle α:

$$x = \varepsilon_1 \cdot \sin(px) \quad (3°),$$

where ε_1 and p are coefficients. Considering the symbols introduced, the force of resistance F_{res} can be represented in the form:

$$F_{res} = 6 \cdot \pi \cdot \eta \cdot x \cdot V = \beta \cdot \sin(px) \quad (4°),$$

where η is the viscosity of the liquid, V the velocity of its movement, and β a coefficient.

Since, with a stabilized flow, and allowing for (1° and 2°):

$$\beta \cdot \sin(px) \cdot v + const_1 + const_2 \equiv 0 \ (5°),$$

when $V = \frac{const_2 - const_1}{\beta \cdot \sin(px)}$ (6°).

It is clear from this equation that with an increase in sin (px) the denominator of the expression (6°) increases, i.e., the rate of flow of fluid decreases. Since within the range of angles from 0 to 90° the sine is a rising function, within this range velocity decreases with an increase in the angle a, and consequently, so also does the flow (outflow) of fluid. For the time of drainage of fluid the relationship will be opposite in character: $t = \gamma \sin(px)$ (7°), where γ is a coefficient. According to mathematical theory, with an increase in the angle α the outflow of fluid should decrease.

It follows from the data in Table 1 that with an increase in the angle the flow rate of fluid decreases and the time of drainage of both water and glycerin increases. Incidentally, in the experiment with glycerin the function of dependence of time on the angle α, other conditions being constant, was chosen empirically: $t = 3.2 \cdot \sin(x/(1.5 + 0.05x))$(8°), in agreement with the conclusions from our mathematical calculations. The value of the angle evidently affects the rate of flow of blood along the longitudinal sinus, and thereby affects its outflow from the brain. In birds which dive and spend long periods under water, and in fast running animals, possessing acute angles of bifurcation, redistribution of the blood takes

TABLE 1. Dependence of Time of Drainage of Fluid on Angle α (M ± m)

Expt. No.	Angle, °	Water	Glycerin
1	180	$0{,}254 \pm 2{,}21 \cdot 10^{-4}$	$1{,}237 \pm 0{,}013$
2	160	$0{,}250 \pm 0{,}27$	$0{,}885 \pm 0{,}08$
3	140	$0{,}243 \pm 2{,}10 \cdot 10^{-4}$	$0{,}795 \pm 4{,}28$
4	120	$0{,}236 \pm 3{,}7$	$0{,}636 \pm 3{,}70$
5	110	$0{,}225 \pm 2{,}7$	$0{,}574 \pm 3{,}39$
6	100	$0{,}220 \pm 2{,}21$	$0{,}536 \pm 9{,}29$
7	90	$0{,}219 \pm 3{,}7$	$0{,}393 \pm 0{,}011$
8	80	$0{,}217 \pm 3{,}65$	$0{,}378 \pm 3{,}9$
9	70	$0{,}214 \pm 2{,}6$	$0{,}290 \pm 0{,}013$
10	60	$0{,}212 \pm 2{,}7$	$0{,}276 \pm 3{,}71$

place so that the amount of it received by the brain remains either unchanged or increased due to occlusion of the blood flow to other organs [8, 11]. During a long stay under water the increased CO_2 concentration leads to a decrease of the cerebrovascular resistance and an increase in the venous outflow [5, 6]. With an obtuse angle of bifurcation, characteristic of less mobile mammals, according to our experimental data the outflow of blood from the brain ought in all probability to be slowed.

Thus the empirical equation we have obtained describes analytically the relationship of the rate of flow of fluid along branching vessels with the magnitude of the angle of bifurcation, and in practice it an be used to assess the characteristics of the cerebral hemodynamics in animals of different species, having different angles of bifurcation of the longitudinal sinus of the dura mater.

LITERATURE CITED

1. Yu. A Krasnikov, Arkh. Anat., **64**, No. 4, 8 (1988).
2. Yu. A. Krasnikov and A. A. Grigoryuk, Proceedings of the Second All-Union Conference of Physiology, Pathophysiology, and Pharmacology of the Cerebral Circulation [in Russian], Tbilisi (1988), p. 93.
3. Yu. A Krasnikov, V. M. Koldaev, and S. A. Shakunov, A Model to Study the Hemodynamic Principles Governing Movement of Blood in Bifurcations of Blood Vessels [in Russian] (1988).
4. Yu. A. Krasnikov, 5th International Theriological Congress, Vol. 2, Rome (1989), p. 1029.
5. P. A. Motavkin, Histophysiology of the Vascular Mechanisms of the Cerebral Circulation [in Russian], Moscow (1980).
6. G. I. Mchedlishvili, Regulation of the Cerebral Circulation [in Russian], Tbilisi (1980).
7. M. F. Nikitenko, Evolution and the Brain [in Russian], Minsk (1969).
8. V. M. Ugryumov, S. I. Teplov, and G. S. Tigilev, Regulation of the Cerebral Circulation [in Russian], Moscow (1984).
9. K. A. Shoshenko, A. S. Golub', V. I. Brod, et al., Architectonics of the Vascular Bed [in Russian], Novosibirsk (1982).
10. C. G. Caro, T. J. Pedley, R. C. Schroter, and W. A. Seed, Mechanics of the Circulation [in Russian], Moscow (1981).
11. D. R. Jones, 28th International Congress of Physiology, Budapest, Oxford (1981), pp. 307-314.
12. C. D. Murray, J. Gen. Physiol., **9**, 835 (1926).
13. M. Zamir, J. Gen. Physiol., **72**, No. 6, 837 (1978).