Possibility of Linear Dependence between Vascular Wall Tension and Blood Flow in Precortical Arterioles

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Intravital microscopy was used to determine the diameter and length of pial cortical arterioles in rat brain. Mathematical model yielded a formula showing that regulation of arteriolar wall tension results in autoregulation of the blood flow.

Key Words: *cerebral blood flow; autoregulation; precortical arterioles*

The concept of autoregulation of cerebral blood flow is a corner stone of the theory of cerebral vascular system [5]. However, there are many controversies in this field, in particular, the role of myogenic mechanisms in this autoregulation. According to concept proposed by P. Johnson [5], the phenomenon of autoregulation of regional blood flow can be viewed as the ability of vascular smooth muscle cells to maintain a certain tension. This results in maintenance of a stable regional blood flow. The basic problem not explained by Johnson's theory is whether arterioles responding to only intravascular pressure can maintain stable blood flow? This question arises because arterioles control only the tension of the vascular bed, but not blood flow? This problem can be solved by mathematical modeling of this process and elucidation of the relationships between arteriolar wall tension and regional blood flow.

MATERIALS AND METHODS

The study was carried out on 30 random-bred narcotized and naturally breathign male rats weighing 250-300 g. The animals were placed on a thermocontrolled stand for stabilization of body temperature at 38°C. A 3×5-mm opening was drilled in the right parietal bone. The bone was rinsed with physiological saline to prevent overheating. The dura mater remained intact. The diameter of pial arterioles was measured intravitally using an original setup constructed on the basis of OSL-1 and OI-30 lighters and an MNF-10 microphotographic headpiece (×50) [2]. The internal diameter and the length of arterioles were measured in photographs using a morphometric grid.

The data were analyzed using the following equations.

The blood flow through arteriole (Q) was calculated using Poiseuille formula:

$$Q=\pi(P_1-P_2)r^4/(8L\eta), \quad (1)$$

where r and L are radius and length of the arteriole, η is blood viscosity, P_1 and P_2 — blood pressure in the initial and terminal part of arteriole, respectively. The initial conditions were as follows: r_1=5 μ, P_1=35 mm Hg (4655 Pa), P_2=34 mm Hg (4622 Pa) [4], L=100 μ (10^{-4} m), and $\eta=1.75\times10^{-3}$ N×sec/m^2. The length of arteriole and blood viscosity were constant.

Laplace's law was used in Frank's modification:

$$T=[(P_1+P_2)/2]r/\omega, \quad (2)$$

where T and ω are tension and thickness of vascular wall, respectively.

Liquid incompressibility principle means constancy of vascular wall area (S) after changes in arteriole radius:

$$\omega=(r^2+S/\pi)^{1/2}-r. \quad (3)$$

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TABLE 1. Distribution of Precortical Arterioles in Cerebral Cortex by Their Diameter and Length (Intravital Microscopy Data)

Diameter, μ	Length, μ						
	10-50	60-100	110-150	160-200	210-250	250-300	>300
10-15	20	20	10	11	7	1	
20-25	6	11	6	6	1	1	1
30-35		2	4	2	1	1	2
40-45			1	2			1
50				1			4
M±m	39.7±1.9	89.1±2.6	132.9±3.2	181.2±3.9	232.2±4.0	283.3±12	382.5±41.0

The precortical arterioles are characterized by S=199 μ^2 (10^{-10} m^2) [4].

By transforming and combining equations **(1)** and **(3)** we get:

$$T=(P_1+P_2)/[2((1+S/\pi r^2)^{1/2}-1)]. \quad \textbf{(4)}$$

Formula 4 yields the tension T for different intravascular pressures $(P_1+P_2)/2$ and $(P_{1'}+P_{2'})/2$. The condition of autoregulation of blood flow through arteriole yields $Q_1=Q_2$, where Q_1 is blood flow at (P_1-P_2) pressure gradient across the arteriole of radius r_1, while Q_2 corresponds to $(P_{1'}-P_{2'})$ pressure gradient and radius r_2. By combining this condition with Poiseuille formula **(1)** we get

$$r_2=r_1[(P_{1}-P_2)/(P_{1'}-P_{2'})]^{1/4}. \quad \textbf{(5)}$$

Therefore, to answer the question whether precortical arteriole stabilize the blood flow by controlling constant tension in the vascular wall, one have to solve a set of equations **(4)** and **(5)** relatively to unknown values r_2 and $P_{2'}$, assuming $P_{1'}$ to be a preset variable parameter.

RESULTS

Regulation of regional blood flow was studied using the Koch model which represent vascular network as a single effector vessel. The limitations of such a model are evident. However, intravital microscopy of pial arteries revealed terminal precortical arterioles possessing no branches and anastomoses and transforming into radial arteries diving into the brain perpendicularly to the neocortex surface. We previously showed that changes (%) in the diameter of precortical arterioles during global ischemia surpasses the reaction of all other (larger) cerebral vessels [1]. This observation supports the well-known thesis that precortical arterioles play an important role in the regulation of local cerebral blood supply [3]. The majority of precortical arterioles are 10-25 μ in diameter, while their length is <200 μ (Table 1). One can expect a pressure drop of about 1-2 mm Hg along this vascular segment. We chose the following initial value: arteriole length 100 μ and pressure gradient 1 mm Hg (133 Pa). Taking into account anatomical and physiological peculiarities of these vessels, we analyzed

TABLE 2. Theoretical Efficiency of Autoregulation of Cerebral Circulation at the Level of Precortical Arterioles

Input pressure in arteriole, Pa	Output pressure in arteriole, Pa	Arteriole radius, 10^{-6} m	Vascular wall tension, Pa	Blood flow, 10^{-15} m^3/sec
4123	4024.58	5.3845	5196	185.6
4256	4148.27	5.278	5188	187.6
4389	4273.29	5.175	5193	186.2
4522	4396.98	5.08	5198	186.8
4655	4522	5.00	5218	186.5
4788	4643.03	4.899	5199	187.4
4921	4765.92	4.813	5196	186.9
5054	4887.75	4.732	5199	186.9
5187	5010.11	4.653	5197	186.2
5320	5129.81	4.578	5198	187.4

whether autoregulation of cerebral blood flow can be realized at this level via stabilization of vascular wall tension. Theoretical modeling of the myogenic response of precortical arterioles confirmed that blood flow via the arteriole remains virtually constant after pressure rise from 4123 Pa (31 mm Hg) to 5320 Pa (40 mm Hg) due to a decrease in vessel radius (Table 2). The condition of constant tension is also fulfilled with good accuracy.

Thus, mathematical modeling revealed a relationship between controlled tension of vascular wall and blood flow in non-branching vessels: maintenance of a stabile T means "automatical" maintenance of a stable Q.

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