Observance of the Optimality Principle in the Microcirculatory Bed of Rat Brain

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An intravital microscopic study of pial microvasculature in the rat cerebral cortex showed that, both in the resting state and when the vessels are dilated as a result of ischemia, the principle of minimal energy expenditure is one of the factors regulating the ratio of arteriolar diameters in arteriolar ramifications.

Key Words: *biomicroscopy; pial microvessels; optimality principle*

Optimality in terms of a particular criterion is one of the basic principles observed in the structure of various biological objects [4]. It has been substantiated theoretically that in the circulatory system this principle may be realized according to the criterion of the least hydraulic resistance offered by the vascular network to the flowing blood [5]. Verification of this thesis using pial vessels of rabbit cerebral cortex showed that for the microcirculatory bed (arterioles less than 100 μ in diameter) it is valid only under conditions of postischemic hyperemia [3]. In that study, however, vessel diameters were measured on morphological specimens, which could skew the results. The present intravital study has shown that, provided the vascular tone is normal, the principle of optimality is observed for cerebral cortical microvessels both in the resting state and when the vessels are dilated.

MATERIALS AND METHODS

The study was conducted in the fall and winter on 60 random-bred white male rats (body weight 250-300 g) under chloral hydrate anesthesia. Their cerebral microvessels were examined (in the area supplied by the middle cerebral artery) as described previously [2] under an ML-2 microscope using an LK-10 contact object lens which enabled these vessels to be viewed through the intact dura mater (at a total magnification of 50). The internal diameters of vessels (widths of erythrocyte flow) were measured on photographs with a graduated grid. The common carotid arteries were occluded bilaterally by applying surgical clips to dissected-off vessels.

The optimality of the ramifications of pial arterioles was evaluated by the following relationship, derived by Rosen [5]:

$$D_0^3 = D_1^3 + D_2^3,$$

where D_0 is the diameter of the main trunk and D_1 and D_2 are the diameters of its ramifications.

The bifurcation for which the above equality was satisfied was considered optimal, i.e., offering minimal hydraulic resistance.

RESULTS

We examined 271 arteriolar bifurcations (the diameter of the main trunk ranged from 20 to 80 μ) and 203 venular bifurcations (diameter of main trunk 30 to 140 μ) under resting conditions and

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TABLE 1. Evaluation of Pial Microvessels in Terms of the Optimality Parameter in the Resting State

	Arterioles					
Bifurcations grouped by diameter of main trunk, μ	21−30	31−40	41−50	51−60	61−70	71−80
Number of bifurcations studied	54	60	65	34	41	17
Cubed diameter of main trunk, μ×10⁴	1.152±0.052*	3.406±0.112	7.469±0.162	13.344±0.288	23.746±0.447	37.533±0.972
Sum of cubed diameters of ramifications, μ×10⁴	1.396±0.106*	3.302±0.238	7.565±0.36	13.021±0.817	22.051±0.919	36.494±2.575
p	<0.05	>0.05	>0.05	>0.05	>0.05	>0.05
	Venules					
Bifurcations grouped by diameter of main trunk, μ	21−40	41−60	61−80	81−100	101−120	121−140
Number of bifurcations studied	36	70	52	26	10	9
Cubed diameter of main trunk, μ×10⁴	2.225±0.237	10.144±0.439*	29.752±0.97*	62.44±2.153	115.29±6.76*	180.51±5.49*
Sum of cubed diameters of ramifications, μ×10⁴	1.946±0.252	7.457±0.46*	23.709±1.15*	53.469±4.612	88.9±18.17	115.11±8.43*
p	>0.05	<0.01	<0.01	>0.05	>0.05	<0.01

Note. Asterisks indicate significant differences.

52 arteriolar bifurcations under conditions of dilatation produced by occlusion of the common carotid arteries.

Preliminarily, when the cubed diameters of the main trunks were compared with the sums of the cubed diameters of their ramifications, the distribution histograms obtained for vessels of both categories showed that their distribution was normal, so that the histograms could be statistically treated by Student's t test.

The arteriolar bifurcations were classified into six groups in order of increasing diameter, in steps of 10 μ (Table 1).

A paired comparison was then undertaken of the cubed diameters of the main trunks with the sums of the cubed diameters of the ramifications in each of the six groups in the resting state. A significant difference by Student's t test was obtained only for group 1 ($p<0.05$). In the other five groups the values did not differ significantly, which indicates that most of the arteriolar bifurcations studied obeyed Rosen's optimality principle in the state of normal vascular tone.

When both carotid arteries were occluded, a pronounced dilatation of the arterioles was observed during the first 5 min after the onset of occlu-

TABLE 2. Evaluation of Pial Arterioles in Terms of the Optimality Parameter before and after Bilateral Occlusion of the Common Carotid Arteries

	Before occlusion			
Bifurcations grouped by diameter of main trunk, μ	21−30	31−40	41−50	51−60
Number of bifurcations studied	5	11	11	25
Cubed diameter of main trunk, μ×10⁴	1.796±0.27	4.955±0.399	9.459±0.38	17.581±0.939
Sum of cubed diameters of ramifications, μ×10⁴	1.651±0.27	4.279±0.385	8.341±0.773	17.429±1.744
p	>0.05	>0.05	>0.05	>0.05
	After occlusion			
Cubed diameter of main trunk, μ×10⁴	7.586±0.266	13.112±1.257	26.233±2.323	40.626±3.01
Sum of cubed diameters of ramifications, μ×10⁴	8.373±0.227	11.049±1.215	24.789±2.613	39.863±3.388
p	>0.05	>0.01	>0.01	>0.05

sion. Although the increments in vessel diameters were potentially large enough (35 to 63%) for the ratios of diameters to exceed the limits of the optimal proportions, estimates of the ratios of cubed diameters of arterioles and bifurcations showed that the optimality principle was still satisfied (Table 2).

These findings indicate that optimality is a regulated rather than a passive parameter. This conclusion is supported by the results obtained for the venules, which are known to be incapable of changing their lumens [6].

The venular bifurcations were also classified into six groups in order of increasing diameter, in steps of 20 m. Here, too, a paired comparison of the cubed diameters of the main trunks with the sums of the cubed diameters of the ramifications was carried out for each group. Significant differences were obtained for groups 2, 3, and 6, but not for the other three (Table 1). Thus, in contrast to the arterioles, only a proportion of the venular bifurcations obeyed Rosen's optimality principle.

Taken together, the results of this study suggest the existence of a mechanism which, while regulating vascular tone, also minimizes the hydraulic resistance of the arteriolar bed [1].

REFERENCES

1. V. V. Aleksandrin and P. N. Aleksandrov, in: *Experimental and Applied Physiology. Physiology of Visceral Systems* [in Russian], Vol. 3, St. Petersburg (1992), pp. 67-73.
2. V. V. Aleksandrin, P. N. Aleksandrov, and V. K. Khugaeva, in: *Itogi Nauki i Tekhniki. Seriya Farmakologiya Khimioterapevticheskikh Sredstv* [in Russian], Vol. 26, Moscow (1991), pp. 105-111.
3. V. A. Mamisashvili, M. K. Babunashvili, and G. I. Mchedlishvili, *Fiziol. Zh. SSSR*, **61**, № 10, 1501-1506 (1975).
4. I. F. Obraztsov and M. A. Khanin, *Optimal Biomechanical Systems* [in Russian], Moscow (1989).
5. R. Rosen, *Optimality Principles in Biology*, Plenum Press (1967).
6. B. I. Tkachenko, *The Venous Circulation* [in Russian], Leningrad (1979).