MICROVASCULAR BLOOD FLOW: FUNCTIONAL RELATION TO VESSEL SIZE

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INTRODUCTION Under appropriate conditions blood flow, Q, in an isolated blood vessel is proportional to the fourth power of the vessel diameter D. The applicability of this relationship to a vessel within the microvasculature of a living animal is questionable since flow will be determined both by its own diameter and the distribution of hemodynamic resistance throughout the microvascular bed. Data from a variety of microvascular preparations show that arterial diameters progressively diminish as the capillaries are approached. This observation is consistent with the teleological notion that there is a relationship between the diameter of a vessel and the amount of tissue supplied by it. However the specific relationship linking flow and diameter under *in vivo* conditions has yet to be established. Arguing that economy of operation is a paramount factor in the evolution, growth, and development of the vascular system, Murray[1] attacked the flow-diameter question on a purely theoretical basis. By simultaneously mini-minimizing the energy equivalent cost of blood flow and volume he concluded that optimal economy of circulation is realized if Q is everywhere proportional to D^3 ($Q=kD^3$). Though this prediction has far reaching implications, no systematic test of its *in vivo* applicability has been reported. Specifically to address this issue, data obtained from 160 paired simultaneous measurements of blood flow and diameter in the rat cremaster microvasculature were used in this study to assess the parameters and *in vivo* applicability of the relationship $Q = kD^m$.

METHODS: EXPERIMENTAL Eight male wistar Kyoto (WKY) and 8 spontaneously hypertensive rats (SHR) of the Okamoto and Soki strain were prepared for microscopic observation of the cremaster microvasculature. In each animal a consistent arterial pathway from first through 5th order was defined and simultaneous measurements of blood velocity (on-line cross correlation technique) and inside vessel diameter were made in each consecutive branch. Blood flow was calculated from these quantities. Following the control measurements the microvasculature was dilated by the topical application of adenosine, a potent vasodilator and the sequence of measurements repeated. The set of these 160 D-Q pairs constituted the data base applicable to the cremaster muscle microvasculature. Supplementary data was obtained from the literature pertinent to other microvascular beds and used to assess the generality of the results obtained.

METHODS: ANALYTICAL All cremasteric data was logrhythmically transformed and subjected to least squares regression analysis from which the value of the exponent m and constant k were determined. Average microvessel blood flow and diameters for branching orders roughly corresponding to those studied in the cremaster were obtained from the literature (cat mesentery[2], tenuissimus muscle[3] and rabbit omentum[2]) and used as a comparison data base with similarly determined values for the cremaster. Finally, an estimate of the value of k was made from first pricinples by minimizing the per unit vessel length cost of the sum of hydraulic power and vascular volume taking into account energy consumption of blood (WBC and RBC) and vessel wall.

RESULTS: Table 1 summarizes the main results of the study.

TABLE 1. Parameters of $Q=kD^m$ and coefficient of correlation (r).

	m	k	r
From all cremaster paired D-Q values	3.10	780	0.983
From average D-Q values of corresp. branching orders			
Cremaster	2.99	519	0.995
Mesentery	2.88	77	0.999
Omentum	2.90	54	0.999
Tenuissimus	2.90	81	0.993
From optimality analysis and energy cost of blood & wall	3.00	69	----

DISCUSSION: The value of 3.10 for the exponent m determined from the composite of all cremaster data strongly supports the optimality concept underlying the theoretical value of 3.00. This finding is the first direct demonstration of the *in vivo* applicability of an approximate third power dependence of blood flow on vessel diameter. Evidence for the generality of this relationship is embodied in the indicated uniformity of m determined from four different microvascular beds. The values of k determined for tissues other than the cremaster muscle microvasculature are reasonably close in value and similar to the value determined by applying optimality concepts and utilizing known energy consumption values of blood and vascular wall. The reason for the large difference between the value of k determined for the cremaster and all of the other k values is unknown, but probably reflects the presence of organ specific parameters. Independent of this difference, the hemodynamic implications of the present results are quite numerous. One of these predicts a pressure drop across the microvascular bed which is linearly related to the ratio of vessel length (L) to diameter, a concept significantly divergent from the L/D^4 dependence classically espoused.

1. Murray C.D. The Physiological Principle of Minimum Work Proc. N.A.S. 12:207-213, 1926
2. Zweifach B.W. & Lipowsky H.H. Quantitative Studies of Microcirculatory Structure and Function III Circ. Res. 41: 380-390, 1977
3. Fronek K & Zweifach B.W. Microvascular Blood Flow in Cat Tenuissiumus Muscle Microvascular Research 14: 181-189, 1977

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