

Allometric Scaling in Biology

The design of living beings is not only a matter of molecular biology but also of geometry and physics. This was once more demonstrated with a biophysical model by G. B. West *et al.* (*1*) that had been fine-tuned to predict the famous scaling law of metabolism (*2*), namely a 3/4 power relation between body mass and energy consumption. While properties and predictions of the model are remarkable, as N. Williams points out in a related Perspective (*3*), we would like to question the view that fractal geometry is essential for real life. We rather believe that fractal scaling of a branched transport system may not be an unequivocal prerequisite, but merely may simplify calculations. West *et al.* have not evaluated their "fractal geometry" approach against an approach without assumptions about a "fractal" structure. Consequently, their conclusion that "fractal" design is essential for their predictions is not valid because a "control experiment" is lacking.

Our arguments are based on observations during embryonic angiogenesis (*4*), on properties and predictions of a nonfractal blood vessel growth model (*5*), and on the original report (*1*). (i) During embryonic development, blood vessels do not follow a fractal branching pattern, that is, in segmental arteries, capillary plexus, and vascular rings (*4, 5*). (ii) Even in adult life, nonfractal branching is constantly observed, for example in vessels branching off the aorta; moreover, arterial anastomoses, in addition to interconnected venous networks, are common and represent a situation that is not covered by the fractal approach (*4, 5*). (iii) The scaling law of metabolism, and other putative "fractal" properties like flow heterogeneity and so forth, can also be derived with a nonfractal model, as we have discussed recently (*5*). (iv) The West *et al.* model (*1*) is—strictly speaking—not fractal, because of the finite number of bifurcations, and definitely is not self-similar throughout the entire system, because the diameter relations vary from large vessels (where area-preserving branching is assumed) to smaller vessels (where cubic branching is postulated).

We acknowledge West's *et al.* "zeroth order" approach and their cautious interpretation of the model. Nevertheless, in order to assess the influence of a (nearly) fractal as opposed to a nonfractal design, they would have to evaluate the difference. They did not include a (3D) visualization of the simulated system, and the geometric properties were not evaluated. Their model does not appear to comply with real patterns, whose branch length distributions indicate nongeometric increase of the number of small branches (*5*).

Moreover, evolutionary constraints on the design of a vascular system (except in mammals) may come from a developmental bottleneck: eggs are (nearly) closed systems, where parsimony of blood and vessel material, but not of pumping energy, may be required to shape embryonic organs and to maximize fitness (*5*). Finally, comparable approaches (*6*) were inspired by Mandelbrot's famous book (*7*).

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G. B. West *et al.* (*1*) develops some properties of the cardiovascular system of mammals, starting from the assumption that the dimensions of the capillary blood vessels do not vary with mammal size. Their work also assumes that the blood velocity in the capillaries does not vary with mammal size and that the total blood flow through the capillaries varies with mammal weight raised to the 3/4 power. When the scale-invariant assumption on capillary size was combined with these last two conditions, the resulting conclusion was that the number of capillaries in mammals must scale with mammal weight raised to the 3/4 power.

The assumption that the capillary dimensions do not vary with mammal size is, how-

ever, contrary to my earlier work (*2*) and to the basic cardiovascular design and physiological processes of mammals. To illustrate this, we let r_c , l_c , and n_c denote the characteristic (or typical) radius, length, and number of capillary blood vessels, respectively, and we let W denote mammal body weight. The associated scaling laws may then be written (*2*, p. 71) as

$$r_c = W^{\alpha/3}, \quad l_c = W^{\beta/3}, \quad n_c = W^{1-\alpha} \quad (1)$$

where α denotes proportional variation.

These laws refer to changes in dimensions and number of capillary blood vessels accompanying change in mammal size, for example, from the mouse to the human and on to the elephant. The scaling laws were derived by considering basic restrictions associated with similar designs of the cardiovascular system of all mammals. They apply both to the actual beds of capillaries in the individual organs of mammals, as well as to the capillaries in representative single systemic and pulmonary beds. West *et al.* assume that r_c and l_c do not vary with mammal weight and that n_c varies with mammal weight raised to the 3/4 power.

With regard to Eqs. 1 and the basic design of the cardiovascular system, we may consider, for example, the total volume of blood V_c in the systemic or pulmonary capillaries. This volume is proportional to the product of their characteristic number n_c and their characteristic individual volume $\pi r_c^2 l_c$. Thus, we have the proportional relation

$$V_c = n_c r_c^2 l_c \quad (2)$$

With the use of Eqs. 1, we see that this volume is predicted to vary directly with mammal weight, in agreement with experimental measurements of pulmonary capillary volume by Gehr *et al.* (*3*).

With regard to Eqs. 1 and physiological processes, we may consider, for example, the exchange of oxygen between capillaries and surrounding cells. This matter is of fundamental importance in understanding the scaling relations for capillary dimensions and number. Rate of oxygen transfer is determined by a diffusion operation that is, insofar as geometry is concerned, directly proportional to the product of characteristic number n_c and characteristic surface area $2\pi r_c l_c$ of the capillaries and inversely proportional to their characteristic wall thickness, h_c . Oxygen transfer also depends on the driving force, as measured by the oxygen partial pressure. Thus, if ΔP_c denotes difference between oxygen partial pressure inside and outside a capillary vessel, the following proportional relation applies for the oxygen transfer rate Q_c from a representative systemic capillary bed

$$Q_c = n_c \Delta P_c \frac{r_c l_c}{h_c} \quad (3)$$

Scaling In Biology

WJ Hussar



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supporting documentation for agenda items is available for public review in the office of the clerk of the board of supervisors located at 940 w main street suite 209 el centro ca 92243 during regular business hours 8 00 a m to 5 00 p m monday through friday excluding holidays the office is closed from 12 00 to 1 00 pm

mental health executive board meeting county of sonoma - Nov 15 2022

nov 1 2023 mental health executive board meeting date november 01 2023 time 10 30 a m 12 00 p m hybrid in person meeting webinar information sonoma county dhs office santa rosa conference room 1450 neotomas avenue santa

board of supervisors extends american rescue plan act funding - Jan 17 2023

oct 25 2023 matt brown communications specialist publicaffairs sonoma county org 707 565 3040 575 administration drive suite 104a santa rosa ca 95403 the board of supervisors on tuesday extended american rescue plan act funding for community based organizations that have supported thousands of sonoma county residents through programs

agenda for the regular meeting of the board of supervisors - Apr 08 2022

agenda for the regular meeting of the board of supervisors county of los angeles california tuesday march 21 2023 9 30 a m board hearing room 381b kenneth hahn hall of administration 500 west temple street los angeles california 90012 janice hahn chair fourth district hilda l solis supervisor

board meeting agendas la bos - Sep 25 2023

oct 24 2023 board of supervisors county of los angeles board meeting agendas live board meeting to address the board 10 17 23 regular board meeting at 9 30 a m call 877 226 8163 participant code 1336503 to listen by telephone only call 877 873 8017 access code 111111 english 222222 espanol live stream submit public comment

board of supervisors agenda placer county - Jul 23 2023

board of supervisors agenda tuesday may 10 2022 8 30 a m county administrative center 175 fulweiler avenue auburn ca 95603 bonnie gore district 1 todd leopold county executive officer robert weygandt district 2 karin schwab county counsel jim holmes district 3 vice chair megan wood clerk of the board

board of supervisors santa cruz county - Mar 07 2022

contact us 701 ocean street room 500 santa cruz ca 95060 phone 831 454 2200 fax 831 454 3262 to email all five members of the board of supervisors at once please use boardofsupervisors santacruzcountyca gov please note emails sent to this address will be publicly published in the written correspondence packet attached to the

agenda for the regular meeting of the board of supervisors - Mar 19 2023

agenda for the regular meeting of the board of supervisors county of los angeles california tuesday january 24 2023 9 30 a m board hearing room 381b kenneth hahn hall of administration 500 west temple street los angeles california 90012 hilda l solis supervisor first district lindsey p

board of supervisors agenda placer county - Aug 24 2023

board of supervisors agenda tuesday september 26 2023 9 00 a m county administrative center 175 fulweiler avenue auburn ca 95603 bonnie gore district 1 jane christenson county executive officer shanti landon district 2 karin schwab county counsel jim holmes district 3 chair megan wood clerk of the board

board of supervisors meeting calendar for 2022 march - Feb 18 2023

board in session holiday budget hearings begin cancelled march july november board of supervisors meeting calendar for 2022 march december revised 11 1 22 january may september february june october april august december special meeting offsite meetings author millerju created date 11 2 2022 10 13 58 am

board of supervisors agenda placer county - Jun 22 2023

board of supervisors agenda tuesday november 8 2022 9 00 a m county administrative center 175 fulweiler avenue auburn ca 95603 bonnie gore district 1 jane christenson acting county executive officer robert weygandt district 2 karin schwab county counsel jim holmes district 3 vice chair megan wood clerk of the board

agenda for the regular meeting of the board of supervisors - Oct 14 2022

jul 23 2002 agenda for the regular meeting of the board of supervisors county of los angeles california tuesday february 7

2023 9 30 a m board hearing room 381b kenneth hahn hall of administration 500 west temple street los angeles california 90012 janice hahn chair fourth district hilda l

board of supervisors agenda placer county - May 21 2023

board of supervisors agenda tuesday august 23 2022 9 00 a m county administrative center 175 fulweiler avenue auburn ca 95603 bonnie gore district 1 jane christenson acting county executive officer robert weygandt district 2 karin schwab county counsel jim holmes district 3 vice chair megan wood clerk of the board

agenda for the regular meeting of the board of supervisors - May 09 2022

agenda for the regular meeting of the board of supervisors county of los angeles california agenda posted december 1 2022 meeting televised wednesday december 7 2022 at 11 00 p m on klcs assistive listening devices agenda in braille and or alternate formats are available upon request

board of supervisors butte county ca - Sep 13 2022

board of supervisors meetings begin at 9 am generally are held on the 2nd and 4th tuesday of the month due to holidays and other schedule conflicts the board may meet on alternate tuesdays view the board of supervisors 2023 regular meeting calendar pdf for meeting dates 25 county center drive suite 205 board of supervisors chambers