10 years - ANNIVERSARY EDITION ***TRAKIA JOURNAL OF SCIENCES***
Trakia Journal of Sciences, Vol. 10, No 2, pp 36-47 , 2012

ISSN 1313-7050 (print)
ISSN 1313-3551 (online)

Original Contribution

SCALING OF BIOLOGICAL SPACE AND TIME: VOLUME TO SURFACE RATIO IN LIVING ORGANISMS IS PROPORTIONAL TO LIFESPAN

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ABSTRACT

The manuscript presents a relationship between volume to surface ratio and biological time (generation time and lifespan) in 223 organisms (Unicellular organisms, Poikilotherms, Mammals and Aves) with 22 order of magnitude variation between body mass. The study shows that in unicellular and multicellular organisms the volume to surface ratio $V\times S^{-1}$ (m) is proportional to generation time and lifespan T_{ls}(s) as: $V\times S^{-1} = a_{vst}\times T_{ls}^{0.915}$ with correlation coefficient $R^2=0.931$. The coefficient $a_{vst}=8.993\times10^{-11}(m\cdot s^{-1})$ has a dimension of speed and appears relatively constant parameter in comparison to 22 orders of magnitude variation between body mass of organisms. On cellular level a_{vst} has a biological sense of speed of volume/surface ratio change, during growth and multiplication of cells by binary. The equation between volume/surface ratio and lifespan relates to some scientific problems, connecting with body size, form and time in living organisms.

Key words: scaling, organism, mass, volume, surface, space, time

INTRODUCTION

The body mass, the body size (length, volume, surface), the lifespan and generation time are basic physical and physiological characteristics of living organisms. From physical point of view these characteristics as well as the speed of biological processes fall in the scientific area of classical physics [1]. From a small viruses with mass 1.0×10^{-20} kg to big whales with mass 1.0×10^{5} kg the body mass range about 24-25 orders of magnitude [2]. The body sizes range 10 orders of magnitude from viruses (about 1.0×10^{-8} m) to big whales (1.0×10^{2} m) [3]. The lifespan range 6 orders of magnitude from about 20min generation time in bacteria to 3.0×10^{2} years and more lifespan in tortoises [4]. The speed of biological (biochemical and physiological) processes ranges about 14 orders of magnitude-from the linear speed of cell growth ($1.0\times10^{-9} – 1.0\times10^{-12}$ $m\cdot s^{-1}$) [5] to the speed of nerve impulses (1.0×10^{2} $m\cdot s^{-1}$) [3, 6]. The body density of living organisms falls in a very small interval, from about 1070 $kg\cdot m^{-3}$ in animals to 1100-1250 $kg\cdot m^{-3}$ in bacteria and viruses [7]. Because of the mass, size, lifespan, generation time and speed of organism's processes fall in the area of classical physics, this predict the validity of physical equations connecting space and time *via* speed in biological processes. Reasons for this conclusion give us the received from Bonner [8, 9] linear relationship between total length (L_t) and generation time (T_{gt}) across species, ranging in size from bacteria to sequoia tree and whales. Bonner presents this relationship in graphic form only, but in the physical terms this relationship presents the connection between organism's length L_t(m) and generation time T_{gt} (s) *via* speed v($m\cdot s^{-1}$):

$$L_t=v\times T_{gt} \qquad (1)$$

Similarly to body length, the volume to surface ratio ($V\times S^{-1}$) of organisms has a dimension of linear length too. Because of this finding, the volume/surface ratio of organisms can be connect with their generation time *via* given speed (for example 'a_{vst}'), characterizing the life processes. Indeed, from dimensional point

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of view, the ratio between body volume V (m^3) and body surface S(m^2) has a dimension of linear length L(m):

$$L(m)=V(m^3)\times S^{-1}(m^2) \quad (2)$$

If we combined the eqn.1 and eqn.2 we can receive a new equation-between volume to surface ratio and generation time in organisms:

$$V\times S^{-1}=a_{vst}\times T_{gt} \quad (3)$$

where abbreviation 'vst' means 'volume-surface-time'.

From geometrical point of view the main difference between eqn.1 and eqn.2 is that the length L_t correlates with maximum linear length of the body, while the volume to surface ratio correlates with minimum length of the body. Further, the biological sense and the values of the speeds 'v' and 'a_{vst}' are unknown. However, in our case the question about the biological sense and value of the speed a_{vst} arises. In this direction, some previous works of Atanasov [10, 11] have showed that in all living organisms (Prokaryotes, Poikilotherms, Mammals and Aves) the body volume, body surface and lifespan are mutually connected, so that the ratio between volume to surface($V\times S^{-1}$, m) and lifespan (T_{ls}, s) appears relatively constant parameter with dimension of speed (i.e. a_{vst}, $m\cdot s^{-1}$):

$$a_{vst}=V\times(S\cdot T_{ls})^{-1}=1.0\times10^{-9}-1.0\times10^{-11} m\cdot s^{-1} \quad (4)$$

In cited study the calculated parameter a_{vst} changes 2 orders of magnitude and appears a constant in comparison to 22-23 orders of magnitude variation between body mass of studied organisms (from Prokaryotes to Mammals). Accordingly formula (4) between volume to surface ratio and lifespan of organisms the connection from the type (5) must exists:

$$V\times S^{-1}\approx a_{vst}\times T_{ls} \quad (5)$$

For Mammals a similar connection is found by data of Atanasov [11]:

$$V\times S^{-1}=a_{vst}\times T_{ls}^{\,r} \quad (6)$$

with corresponding coefficient $R^2= 0.94$ and the exponent 'r' near to 1.0.

The above equation presents a new mathematical connection between organism's space-time, and allows to scale volume to surface ratio and lifespan (generation time) in terms of the classical physics.

The aim of the study is to calculate the relationship between volume to surface ratio and lifespan in wide range of living organisms (Unicellular, Poikilotherms, Mammals and Aves) with large order of magnitude variation between body mass and lifespan (generation time).

DATA AND METHODS

Database for Poikilotherms, Mammals and Aves

The study involves 223 living organisms. All data for 90 Poikilotherms, 73 Mammals and 60 Aves are given on **Table 1**. The data for body mass M(kg) and lifespan T_{ls} (years, months, days) in Poikilotherms were collected from review paper of Prosser [12], Fujiwara [13-14], Atanasov [15] and Gregory [4]. The data for body mass and lifespan in Mammals were collected from review paper of McNab [16] and paper of Atanasov [17]. The data for body mass and lifespan in Aves were collected from review paper of Sacher [18], Lindsted and Calder [19], Bennett and Harvey [20], Atanasov [21-22] and Gregory [4].

***Table 1**. Data for body mass (M), lifespan (T_{ls}), volume to surface ratio ($V\times S^{-1}$) and volume×(surface·lifespan)$^{-1}$ ratio $V\times(S\cdot T_{ls})^{-1}$ in Poikilotherms, Mammals and Aves. The values of ρ and k are given for every order*

Living organisms	**Mass M (kg)**	**Volume to Surface $V\times S^{-1}$ (m)**	**Lifespan T_{ls} (h, d, y)**	**$V\times(S\cdot T_{ls})^{-1}$ a_{vst} ($m\cdot s^{-1}$)**
POIKILOTHERMS				
Phage (ρ =1200 kg/m^3 , k=0.0542)				
1. *T7 phage*	8.6×10^{-20}	7.85×10^{-9}	0.41h	0.53×10^{-11}
2. *T1 phage*	1.4×10^{-19}	0.917×10^{-8}	0.75h	0.34×10^{-11}
3. *Lambda phage*	2.4×10^{-19}	1.1×10^{-8}	0.753h	0.406×10^{-11}
4. *T4 phage*	3.6×10^{-19}	1.26×10^{-8}	0.38h	0.92×10^{-11}

5. *T2 phage*	4.6×10^{-19}	1.36×10^{-8}	0.75h	0.505×10^{-11}
Prokaryotes (ρ =1100 kg/m^3 , k=0.0542)				
6.*Hemophilus*	1.0×10^{-17}	4.12×10^{-8}	20min	3.43×10^{-11}
7.*Rickettsii*	2.0×10^{-17}	5.175×10^{-8}	20min	4.31×10^{-11}
8.*Haemobatonella muris*	2.0×10^{-17}	5.175×10^{-8}	20min	4.31×10^{-11}
9.*Chlamydii*	3.0×10^{-17}	5.91×10^{-8}	20min	4.92×10^{-11}
10.*Mycoplasma arthritidis*	4.0×10^{-17}	6.5×10^{-8}	20 min	5.42×10^{-11}
11.*Bdellovibrio bacteriovorus*	5.0×10^{-17}	7.0×10^{-8}	20min	5.83×10^{-11}
12.*Wolbachia melophagi*	6.0×10^{-17}	7.44×10^{-8}	20min	6.2×10^{-11}
13.*Mycroccoci*	1.0×10^{-16}	8.8×10^{-8}	20min	7.33×10^{-11}
14.*Ehrlichia canis*	2.0×10^{-16}	1.1×10^{-7}	20min	9.1×10^{-11}
15. *Diplococcus*	3.8×10^{-16}	1.37×10^{-7}	0.422 h	9.01×10^{-11}
16. *Escherichia*	3.9×10^{-16}	1.38×10^{-7}	0.33h	11.6×10^{-11}
17.*Nitrobacter*	5.0×10^{-16}	1.5×10^{-7}	1h	4.17×10^{-11}
18.*Nitrosomonas*	5.0×10^{-16}	1.5×10^{-7}	0.5h	8.33×10^{-11}
19.*Thiobacillus thioparus*	5.0×10^{-16}	1.7×10^{-7}	40min	7.08×10^{-11}
20.*Shigella*	7.1×10^{-16}	1.68×10^{-7}	0.39h	12×10^{-11}
21.*Staphylococcus aureus*	7.8×10^{-16}	3.7×10^{-7}	1h	10×10^{-11}
22.*Azotobacter chroococcum*	2.0×10^{-15}	2.365×10^{-7}	1h	6.57×10^{-11}
23. *Bacillus*	4.3×10^{-15}	3.05×10^{-7}	0.585h	14.48×10^{-11}
Eukaryotes (ρ =1100 kg/m^3 , k=0.0542)				
24.*Saccharomyces cereviseae*	2.0×10^{-14}	5.05×10^{-7}	12h	1.17×10^{-11}
25.*Flagellata and Mastogophora*	1.0×10^{-13}	8.6×10^{-7}	12h	2.0×10^{-11}
26. *Euglena*	8.0×10^{-12}	3.65×10^{-6}	12h	8.45×10^{-11}
27.*Chlamidomonas*	4.0×10^{-12}	2.9×10^{-6}	16h	5.03×10^{-11}
28.*Tetrahymena*	2.0×10^{-11}	4.94×10^{-6}	20h	6.86×10^{-11}
29.*Paramecium caudatus*	4.0×10^{-10}	1.33×10^{-5}	1d	15.4×10^{-11}
30.*Pelomyxa*	1.0×10^{-9}	1.8×10^{-5}	2d	10.4×10^{-11}
31. *Amoeba proteus*	2.0×10^{-8}	4.83×10^{-5}	3d	18.6×10^{-11}
32.*Stentor*	8.0×10^{-8}	7.6×10^{-5}	3d	29.2×10^{-11}
Nematoda (ρ =1070 kg/m^3 , k=0.125)				
33.Soil warm	1.0×10^{-5}	1.67×10^{-4}	5y	0.106×10^{-11}
34.*Ascaris lumbricoides*	7.76×10^{-3}	3.13×10^{-3}	3y	3.3×10^{-11}
Mollusca (ρ =1070 kg/m^3, k=0.06)				
35.*Lymmnaea stagnalis*	2.0×10^{-5}	4.38×10^{-4}	8y	0.1738×10^{-11}
36.*Brachidontes demissus*	2.2×10^{-4}	9.67×10^{-4}	10y	0.307×10^{-11}
37.*Mulinia lateralis*	3.5×10^{-6}	2.47×10^{-4}	7y	0.111×10^{-11}
38.*Mytilus edulis*	0.2×10^{-3}	9.34×10^{-4}	10y	0.296×10^{-11}
Asteroidae (ρ =1070 kg/m^3, k=0.048)				
39.*Asterias rubens*	1.0×10^{-2}	4.26×10^{-3}	7y	1.93×10^{-11}
Arthropoda Arachnoidae (ρ =1070 kg/m^3, k=0.125)				
40. *Phidiphor*	3.37×10^{-4}	5.34×10^{-4}	6y	0.282×10^{-11}
41. *Phidippus audax*	5.68×10^{-4}	6.35×10^{-4}	10y	0.201×10^{-11}
42.*Geolycosa godeffroyi*	3.0×10^{-6}	1.12×10^{-4}	3.5y	0.1015×10^{-11}
Arthropoda (Insecta) (ρ =1070 kg/m^3, k=0.125)				
43. *Lepisma saccharina*	1.25×10^{-6}	8.43×10^{-5}	24d	3.9×10^{-11}
45. *Drozofila melanogaster*	1.2×10^{-6}	8.31×10^{-5}	48d	2.0×10^{-11}
46. *Apis mellifera*	3.1×10^{-5}	2.43×10^{-4}	0.4y	1.928×10^{-11}
47. *Lasius niger*	1.1×10^{-5}	1.73×10^{-4}	0.4y	1.37×10^{-11}
48. *Gryllus domesticus*	2.43×10^{-4}	4.79×10^{-4}	0.4y	3.08×10^{-11}
49.*Blaberus discoidalis*	3.0×10^{-5}	2.4×10^{-4}	0.8y	1.904×10^{-11}
Arthropoda and Isopoda (Crustacea) (ρ =1070 kg/m^3, k=0.125)				
50. *Porcellio scaber*	0.82×10^{-4}	3.35×10^{-4}	10y	0.106×10^{-11}
51. *Orcomella*	2.4×10^{-3}	1.02×10^{-3}	10y	0.32×10^{-11}
52.*Asellus aquaticus*	0.4×10^{-6}	5.78×10^{-5}	2y	0.0917×10^{-11}
53.*Balanus tintinnabulum*	8.1×10^{-5}	3.33×10^{-4}	2y	0.528×10^{-11}

54.*Armadillidium vulgare*	1.44×10^{-4}	4.04×10^{-4}	4y	0.32×10^{-11}
55.*Cirolana imposita*	1.5×10^{-5}	1.91×10^{-4}	2y	0.303×10^{-11}
Osteichthytes (Pisces) (ρ =1070 kg/m^3, k=0.06)				
56. *Neogobius melanostomus*	0.075	6.62×10^{-3}	4y	5.25×10^{-11}
57.*Mugil cephalus*	0.149	8.3×10^{-3}	18y	1.46×10^{-11}
58.*Bagarius bagarius*	0.147	8.25×10^{-3}	25y	1.04×10^{-11}
59.*Salvelinus alpinus*	0.112	7.56×10^{-3}	12y	2.0×10^{-11}
60.*Amiurus nebulosus*	0.127	7.88×10^{-3}	28y	0.89×10^{-11}
61.*Chaenocephalus aceratus*	0.2	9.158×10^{-3}	24y	1.211×10^{-11}
62. *Homarus americanus*	20	41.86×10^{-3}	100y	1.329×10^{-11}
63. *Anguilla anguilla*	1.5	17.8×10^{-3}	88y	0.64×10^{-11}
64. *Acipenser sturio*	15	38.07×10^{-3}	100y	1.208×10^{-11}
65.*Acipenser fulvescens*	20	41.86×10^{-3}	152y	0.874×10^{-11}
Amphibia (ρ =1070 kg/m^3, k=0.06)				
66. *Rana*	32×10^{-3}	5.0×10^{-3}	36y	0.44×10^{-11}
67. *Acris*	30×10^{-3}	4.89×10^{-3}	25y	0.62×10^{-11}
68.*Salamandra atra*	13.4×10^{-3}	3.75×10^{-3}	20y	0.595×10^{-11}
69. *Bufo bufo*	0.1	7.28×10^{-3}	40y	0.58×10^{-11}
70. *Salamandra salamandra*	25×10^{-3}	4.61×10^{-3}	18y	0.813×10^{-11}
Reptilia (ρ =1070 kg/m^3, k=0.06)				
71.*Amphibolurus*	373×10^{-3}	11.25×10^{-3}	10y	3.57×10^{-11}
72.*Dipsosaurus*	64×10^{-3}	6.28×10^{-3}	10y	1.99×10^{-11}
73.*Anolis*	5.0×10^{-3}	2.71×10^{-3}	10y	0.86×10^{-11}
74.*Lasepta*	6.3×10^{-3}	2.926×10^{-3}	10y	0.929×10^{-11}
75. *Chrysemys*	0.2	9.158×10^{-3}	30y	0.969×10^{-11}
76. *Pseudemys*	0.25	9.86×10^{-3}	30y	1.043×10^{-11}
77. *Testudo elephantopus*	100	71.2×10^{-3}	150y	1.5×10^{-11}
78. *Iguana*	0.785	14.38×10^{-3}	20y	2.28×10^{-11}
79. *Varanus komodoensis*	150	81.4×10^{-3}	25y	10.33×10^{-11}
80.*Crocodylus niloticus*	49	56.26×10^{-3}	40y	4.465×10^{-11}
81.*Alligator mississippiensis*	150	81.4×10^{-3}	73.1y	3.536×10^{-11}
82. *Alligator sinensis*	150	81.4×10^{-3}	60.7y	4.257×10^{-11}
Reptilia(Snakes) (ρ =1070 kg/m^3, k=0.125)				
83.*Boidae*	1.0	7.48×10^{-3}	25y	0.949×10^{-11}
84.Boa	10	15.98×10^{-3}	25y	2.029×10^{-11}
85.*Colubridae*	0.080	3.25×10^{-3}	14y	0.739×10^{-11}
86.Piton	5.0	12.7×10^{-3}	25y	1.61×10^{-11}
87. *Eunectes*	11.3	16.64×10^{-3}	30y	1.76×10^{-11}
88.Natrix	0.084	3.3×10^{-3}	14y	0.748×10^{-11}
89.Grass-snake	3.27	11.05×10^{-3}	30y	1.17×10^{-11}
90. *Naja naja*	2.0	9.4×10^{-3}	30y	0.994×10^{-11}
MAMMALS (ρ =1070 kg/m^3, k=0.0993)				
Monotremata				
1. *Tachiglossus aculeatus*	2.5	1.266×10^{-2}	10y	4.019×10^{-11}
2. *Zaglossus* bruijni	10.3	2.016×10^{-2}	19y	3.368×10^{-11}
3. *Ornithorhynchus anatinus*	1.3	1.02×10^{-2}	8y	4.04×10^{-11}
Didelphoidea				
4. *Lutreolina crassicaudata*	0.812	0.87×10^{-2}	7y	3.94×10^{-11}
5. *Didelphis marsupialis*	1.329	1.033×10^{-2}	8y	4.09×10^{-11}
Dasyurida				
6.*Antechinus macdonnellensis*	14.1×10^{-3}	1.968×10^{-3}	2y	3.12×10^{-11}
7. *Antechinus stuartii*	$36,5\times10^{-3}$	3.132×10^{-3}	3y	3.314×10^{-11}
8. *Antechinomus* laniger	8.5×10^{-3}	1.938×10^{-3}	2y	3.076×10^{-11}
9. *Dasyuroides byrnei*	89×10^{-3}	4.206×10^{-3}	3y	4.45×10^{-11}
10.*Isodon macroourus*	1.0	9.342×10^{-3}	6y	4.94×10^{-11}
11. *Perameles nasuta*	0.645	8.088×10^{-3}	5.5y	4.668×10^{-11}

12. *Sminthopsis crassicaudata*	15×10^{-3}	2.337×10^{-3}	2y	3.7×10^{-11}
13. *Planigale maculate*	14.1×10^{-3}	2.29×10^{-3}	2y	3.6×10^{-11}
14.*Sacrophilus harrisii*	5.05	15.95×10^{-3}	10y	5.06×10^{-11}
Syndactyla				
15. *Trichosurus vulpecula*	1.982	11.712×10^{-3}	8y	4.647×10^{-11}
16. *Macropus robustus*	4.69	15.564×10^{-3}	10y	4.94×10^{-11}
17. *Macropus rufus*	40	31.572×10^{-3}	13y	7.71×10^{-11}
18. *Macropus eugenii*	4.796	15.678×10^{-3}	9y	5.53×10^{-11}
Xenarthra				
19. *Bradypus variegates*	3.4	13.992×10^{-3}	15y	2.96×10^{-11}
20. *Dasypus novemcinctus*	3.32	13.88×10^{-3}	12y	3.67×10^{-11}
Pholidota				
21.*Manis tricuspis*	2.73	13.11×10^{-3}	10y	4.16×10^{-11}
Soricomorpha				
22.*Blarina brevicauda*	$21x10^{-3}$	2.63×10^{-3}	2y	4.17×10^{-11}
Rodentia				
23. *Cricetus cricetus*	0.362	6.684×10^{-3}	3y	7.068×10^{-11}
24. *Liomys salvini*	43.8×10^{-3}	3.33×10^{-3}	2.5y	4.228×10^{-11}
25. *Liomys irroratus*	48.1×10^{-3}	3.43×10^{-3}	2.5y	4.355×10^{-11}
26. *Microtus minutus*	9.8×10^{-3}	2.031×10^{-3}	0.75y	8.597×10^{-11}
27. *Sorex* araneus	5.0×10^{-3}	1.626×10^{-3}	450d	4.18×10^{-11}
28. *Sorex caecutiens*	3.6×10^{-3}	1.458×10^{-3}	0.5y	9.257×10^{-11}
29. *Mus musculus*	0.021	2.61×10^{-3}	1.75y	4.735×10^{-11}
30. *Neotoma cirenea*	0.321	6.42×10^{-3}	3y	6.79×10^{-11}
31. *Ondatra zibethicus*	0.842	8.832×10^{-3}	3y	9.34×10^{-11}
32. *Perognathus longimembris*	11.5×10^{-3}	2.142×10^{-3}	1y	6.8×10^{-11}
33. *Chinchilla laniger*	0.494	7.404×10^{-3}	8y	2.936×10^{-11}
34. *Lagostomus maximus*	6.784	1.758×10^{-3}	12y	4.61×10^{-11}
35. *Cavia porcellus*	0.728	8.418×10^{-3}	6y	4.45×10^{-11}
Lagomorpha				
36. *Lepus europaeus*	2.5	1.273×10^{-2}	12y	3.35×10^{-11}
37. *Lepus americanus*	1.581	1.086×10^{-2}	8y	4.31×10^{-11}
38. *Lepus timidus*	3.004	1.344×10^{-2}	8y	5.33×10^{-11}
Artiodactyla				
39. *Antilopa Americana*	32	29.32×10^{-3}	15y	6.207×10^{-11}
40. *Camelus dromedaries*	407	67.88×10^{-3}	30y	7.18×10^{-11}
41. *Elephas maximum*	$3.0x10^{3}$	131.238×10^{-3}	60y	6.94×10^{-11}
42. *Capreolus capreolus*	19	24.69×10^{-3}	12y	6.53×10^{-11}
43. *Cervus elaphus*	58	35.688×10^{-3}	18.4y	6.156×10^{-11}
44. *Equus cabalus*	400	67.5×10^{-3}	40y	5.357×10^{-11}
45. *Ovis aries*	49	33.756×10^{-3}	18y	5.953×10^{-11}
46. *Ovis canadensis*	65	37.056×10^{-3}	15y	7.84×10^{-11}
47. *Bubalus caffer*	420	68.59×10^{-3}	35y	6.22×10^{-11}
48. *Rupicapra rupicapra*	40	31.57×10^{-3}	20y	5.0114×10^{-11}
49. *Sus scrofa*	140	47.73×10^{-3}	20y	7.576×10^{-11}
50. *Tayassu tajacu*	20.2	25.2×10^{-3}	15y	5.333×10^{-11}
Carnivora				
51. *Lutra lutra*	10	19.98×10^{-3}	15y	4.228×10^{-11}
52. *Vulpes vulpes*	5.01	15.906×10^{-3}	12y	4.208×10^{-11}
53. *Canis latrans*	10	19.98×10^{-3}	15y	4.228×10^{-11}
54. *Canis familiaris*	14	22.326×10^{-3}	18y	3.93×10^{-11}
55. *Panthera onca*	18	24.258×10^{-3}	22y	3.5×10^{-11}
56. *Felis silvestris*	3.0	13.428×10^{-3}	11y	3.875×10^{-11}
57. *Mustela vison*	0.660	8.148×10^{-3}	8y	3.233×10^{-11}
Pinnipedia				
58. *Phoca vitulina*	26	27.384×10^{-3}	15y	5.795×10^{-11}
59. *Delphinapterus leucas*	170	50.892×10^{-3}	15y	10.77×10^{-11}

60. *Hyperoodon ampullatus*	1000	91.326×10^{-3}	45y	6.44×10^{-11}
Chiroptera				
61. *Desmodus rotundus*	0.029	2.904×10^{-3}	6y	1.536×10^{-11}
62. *Vampyrops lineatus*	0.022	2.652×10^{-3}	8y	1.05×10^{-11}
63. *Macroderma gigas*	0.148	4.974×10^{-3}	12y	1.315×10^{-11}
64. *Eumops perotis*	0.057	3.63×10^{-3}	10y	1.152×10^{-11}
Primates				
65. *Tree shrew*	0.172	5.26×10^{-3}	5y	3.33×10^{-11}
66. *Marmoset*	0.361	6.72×10^{-3}	15y	1.58×10^{-11}
67. *Owl monkey*	0.925	9.17×10^{-3}	20y	1.45×10^{-11}
68. *Macaca mulatta*	5.0	15.9×10^{-3}	25y	2.019×10^{-11}
69. *Hylobater lar*	8.0	18.564×10^{-3}	30y	1.964×10^{-11}
70. *Pan troglodytes*	45	32.82×10^{-3}	39y	2.671×10^{-11}
71. *Homo sapiens*	65	37.3×10^{-3}	75y	1.568×10^{-11}
72. *Pongo pygmaeus*	150	48.84×10^{-3}	45y	3.455×10^{-11}
73. *Gorilla gorilla*	250	57.798×10^{-3}	50y	3.85×10^{-11}
AVES (ρ =1070 kg/m^3, k=0.1022)				
Nonpasseriformes				
1.*Struthio camelus*	100	4.183×10^{-2}	45y	2.95×10^{-11}
2.*Rhea Americana*	21.7	2.524×10^{-2}	50y	1.6×10^{-11}
3.*Casuarius casuarius*	20.0	2.458×10^{-2}	50y	1.56×10^{-11}
4.*Dromiceus novaehollandiae*	38.3	3.0456×10^{-2}	45y	2.148×10^{-11}
5.*Apteryx australis*	2.38	1.217×10^{-2}	28y	1.38×10^{-11}
6.Apteryx owenii	1.095	0.94×10^{-2}	24y	1.243×10^{-11}
7.*Pygoscelis papua*	6.29	1.678×10^{-2}	35y	1.52×10^{-11}
8. *Eudyptes pachyrhynchus*	2.6	1.255×10^{-2}	28y	1.42×10^{-11}
9.*Macronectes giganteus*	3.63	1.4×10^{-2}	30y	1.48×10^{-11}
10.*Pterodroma hypoleuca*	0.18	0.517×10^{-2}	15y	1.094×10^{-11}
11.*Pelecanus occidentalis*	3.038	1.321×10^{-2}	35y	1.198×10^{-11}
12.*Sula sula*	1.017	0.921×10^{-2}	28y	1.044×10^{-11}
13.*Leptoptilos javanicus*	5.71	1.626×10^{-2}	39y	1.32×10^{-11}
14.*Mycteria americana*	2.5	1.236×10^{-2}	33y	1.189×10^{-11}
15. *Ardea herodias*	1.87	1.123×10^{-2}	31y	1.15×10^{-11}
16. *Cygnus buccinator*	8.88	1.88×10^{-2}	32.5y	1.836×10^{-11}
17.*Anser anser*	5.0	1.556×10^{-2}	35y	1.411×10^{-11}
18.*Aix sponsa*	0.485	0.719×10^{-2}	24y	0.951×10^{-11}
19.*Tringa ochropus*	0.09	4.131×10^{-3}	10y	1.311×10^{-11}
20.*Larus occidentalis*	0.761	0.836×10^{-2}	20y	1.327×10^{-11}
21.*Viltur gryphus*	10.32	1.974×10^{-2}	40y	1.566×10^{-11}
22. *Falco sparverius*	0.117	4.507×10^{-3}	15y	0.954×10^{-11}
23.*Gypaetus barbatus*	5.07	1.551×10^{-2}	30y	1.641×10^{-11}
24.*Gallus gallus*	2.43	1.226×10^{-2}	16y	2.434×10^{-11}
25.*Lagopus lagopus*	0.524	0.738×10^{-2}	18y	1.30×10^{-11}
26.*Callipepla gambelii*	0.126	4.62×10^{-3}	10y	1.467×10^{-11}
27.*Grus canadensis*	3.89	1.433×10^{-2}	31.2y	1.458×10^{-11}
28.*Crex crex*	0.096	4.22×10^{-3}	15y	0.893×10^{-11}
29.*Calypte anna*	0.0054	1.631×10^{-3}	8.5y	0.609×10^{-11}
30.*Calypte costae*	0.0032	1.372×10^{-3}	6y	0.726×10^{-11}
31.*Eugenes fulgens*	0.0066	1.744×10^{-3}	9.2y	0.602×10^{-11}
32.*Patagona gigas*	0.0191	2.477×10^{-3}	13y	0.605×10^{-11}
33.*Colius striatus*	0.0512	3.431×10^{-3}	12y	0.907×10^{-11}
34.*Urocolius macrourus*	0.0485	3.37×10^{-3}	12y	0.891×10^{-11}
35.*Trogon rufus*	0.053	3.468×10^{-3}	12y	0.917×10^{-11}
36.*Alcedo atthis*	0.0343	3.008×10^{-3}	21y	0.455×10^{-11}
37.*Merops apiaster*	0.0338	2.994×10^{-3}	6y	1.584×10^{-11}
38.*Upupa epops*	0.067	3.75×10^{-3}	12y	0.992×10^{-11}

Passeriformes				
39.*Corvus corax*	1.208	0.973×10^{-2}	69y	0.447×10^{-11}
40.*Corvus corone*	0.518	7.365×10^{-3}	19y	1.23×10^{-11}
41.*Corvus caurinus*	0.306	6.19×10^{-3}	16.7y	1.176×10^{-11}
42.*Corvus monedula*	0.215	5.499×10^{-3}	19.9y	0.877×10^{-11}
43.*Cyanocytta crystata*	0.0808	3.99×10^{-3}	26.2y	0.483×10^{-11}
44.*Pipilo alberti*	0.0466	3.323×10^{-3}	8.6y	1.226×10^{-11}
45.*Troglodytes troglodytes*	0.009	1.932×10^{-3}	7.3y	0.84×10^{-11}
46.*Parula americana*	0.007	$1.776x\times10^{-3}$	6.87y	0.821×10^{-11}
47. *Regulus regulus*	0.0055	1.645×10^{-3}	6.56y	0.796×10^{-11}
48.*Riparia riparia*	0.0136	2.214×10^{-3}	10y	0.703×10^{-11}
49. *Parus major*	0.0185	2.453×10^{-3}	15.4y	0.505×10^{-11}
50. *Parula americana*	0.007	1.776×10^{-3}	7y	0.806×10^{-11}
51. *Passer domesticus*	0.0273	2.787×10^{-3}	23y	0.385×10^{-11}
52. *Passer montanus*	0.022	2.594×10^{-3}	13.1y	0.629×10^{-11}
53. *Sylvia communis*	0.0208	2.547×10^{-3}	8.7y	0.93×10^{-11}
54. *Pica pica*	0.202	5.395×10^{-3}	21.7y	0.789×10^{-11}
55.*Pica nuttalli*	0.152	4.911×10^{-3}	10y	1.559×10^{-11}
56.*Oriolus oriolus*	0.0649	3.713×10^{-3}	14.8y	0.796×10^{-11}
57. *Sitta canadensis*	0.0112	2.077×10^{-3}	7.5y	0.879×10^{-11}
58.*Junco hyemalis*	0.018	2.43×10^{-3}	11.3y	0.682×10^{-11}
59. *Sturnus vulgaris*	0.075	3.891×10^{-3}	22.9y	0.539×10^{-11}
60.*Tyrannus tyrannus*	0.0357	3.045×10^{-3}	11.1y	0.871×10^{-11}

Calculation of volume to surface ratio in studied organisms.

In all equations the data were recalculated in SI metrical system (kg, m, s).The body volume V(m^3) of given organism was calculated by formula:

$$V=M\times\rho^{-1} \qquad (7)$$

where ρ is the body density of organisms (1200 $kg\cdot m^{-3}$ for phage, 1100 $kg\cdot m^{-3}$ for Bacteria and 1070 $kg\cdot m^{-3}$ for all multicellular Poikilotherms, Mammals and Aves).

The body surface of studied organism was calculated by formula of Meeh [23], given by data of Schmidt-Nielsen [2]:

$$S=k\times M^{0.67} \qquad (8)$$

where the coefficient k depends on body geometry and varies from 0.04836 to 0.13. In formula (8) the body mass M is in kg and the body surface S is in m^2. The later studies of Rübner [24], Benedict [25] and Gűnter [7] about formula (8) showed that the coefficient 'k' don't change more than 20% between Poikilotherms, Mammals and Aves, despite of their form, size and complexity. The Poikilotherms with spherical shape have coefficient k=0.04836 accordingly data by Meeh [23], Benedict [25], Glaser [3] and Schmidt-Nielsen [2]. The Poikilotherms with cubic and cylinder shape have k=0.06 (mean k=0.0542) and with very long form have k=0.125. The Mammals have the value of coefficient k=0.0993 according to data by Gűnter [7] and Meeh [23]. The Aves have the values of coefficient k between 0.1 and 0.1045 (mean 0.1022) according to data by Meeh [23] and Schmidt-Nielsen [2].

The ratio between equation (7) and (8) gives the formula for calculation of volume to surface ratio:

$$V\times S^{-1}=(M\times\rho^{-1})/(k\times M^{0.67})=M^{0.33}\times(\rho\cdot k)^{-1} \qquad (9)$$

In formula (9) the body mass (M) is in 'kg' and the volume to surface ratio ($V\times S^{-1}$) is in 'm'. On **Table 1** are given the values of body density (ρ) and coefficient (k), necessary for calculation of volume to surface ratio using equation (9).

Statistical methods

A least-square regression analyses were performed using program STATISTICA (www.statsoft.com). The logarithm of volume to surface ratio ($V\times S^{-1}$, m) in organisms was regressed against logarithm of their lifespan (T_{ls}, s) or generation time (T_{gt}, s).

RESULTS AND DISCUSSION

In data set for Poikilotherms (from phage to alligator) the body mass M, the lifespan T_{ls} and the volume to surface ratio $V\times S^{-1}$ varies in the intervals of 6.0×10^{-17}- 49 kg, 20min - 40years and 8.0×10^{-9}- 8.0×10^{-2} m.

In data set for Mammals (from *Antechinomus laniger* to *Elephas maximum*) M, T_{ls} and $V\times S^{-1}$ varies in the intervals of 0.0085-3000 kg, 2year-54 years and 1.0×10^{-3}- 1.0×10^{-1} m.

In data set for Aves (from *Calypte costae* to *Struthio camelus*) M, T_{ls} and $V\times S^{-1}$ varies in the intervals of 0.0032-100 kg, 4years-45 years and 1.0×10^{-3}- 1.0×10^{-2} m.

Thus, the body mass vary 3.0×10^{21} times between studied 223 individuals, the lifespan vary 1.0×10^{6} times and the volume to surface ratio vary 1.0×10^{7} times.

Calculation of relationships between volume to surface ratio and lifespan in organisms

An allometric analysis has shown that a near to linear relationship between the volume to surface ratio ($V\times S^{-1}$, m) and lifespan (Tls, s) in all 223 individuals (Poikilotherms n=90, Mammals n=73 and Aves n=60) in log-log plot holds:

$$V\times S^{-1}=a_{vst}\times T_{ls}^{0.915} \qquad (10)$$

with corresponding coefficient $R^2=0.931$ and coefficient $a_{vst}=8.933\times10^{-11}$ m·s^{-1}. The high correlation coefficient means that the correlation is not random. The relationship (10) graphically is shown on **Figure 1**. The all possible relationships between Poikilotherms, Mammals and Aves (separately and in combination) are given on **Table 2**. The high correlation coefficients R^2 in all equations mean that the correlations are not random. The exponent 'r' in relationships on Table 2 varies around 1.0 from 0.874 in Poikilotherms (eqn.d) to 1.218 in Aves (eqn.g). The mean point of this interval (equal to 1.046) is very near to 1.0. The coefficient a_{vst} in relationships (a, b, c, d, e, f, g) vary 1.0×10^{3} fold, from 23×10^{-11} m·s^{-1} in Mammals (eqn. f) to 1.25×10^{-13} m·s^{-1} in Aves (eqn.g) and has a mean value near to $a_{vst}=8.933\times10^{-11}$ m·s^{-1}. Good linearity it is observed in multicellular Poikilotherms only (eqn. e).

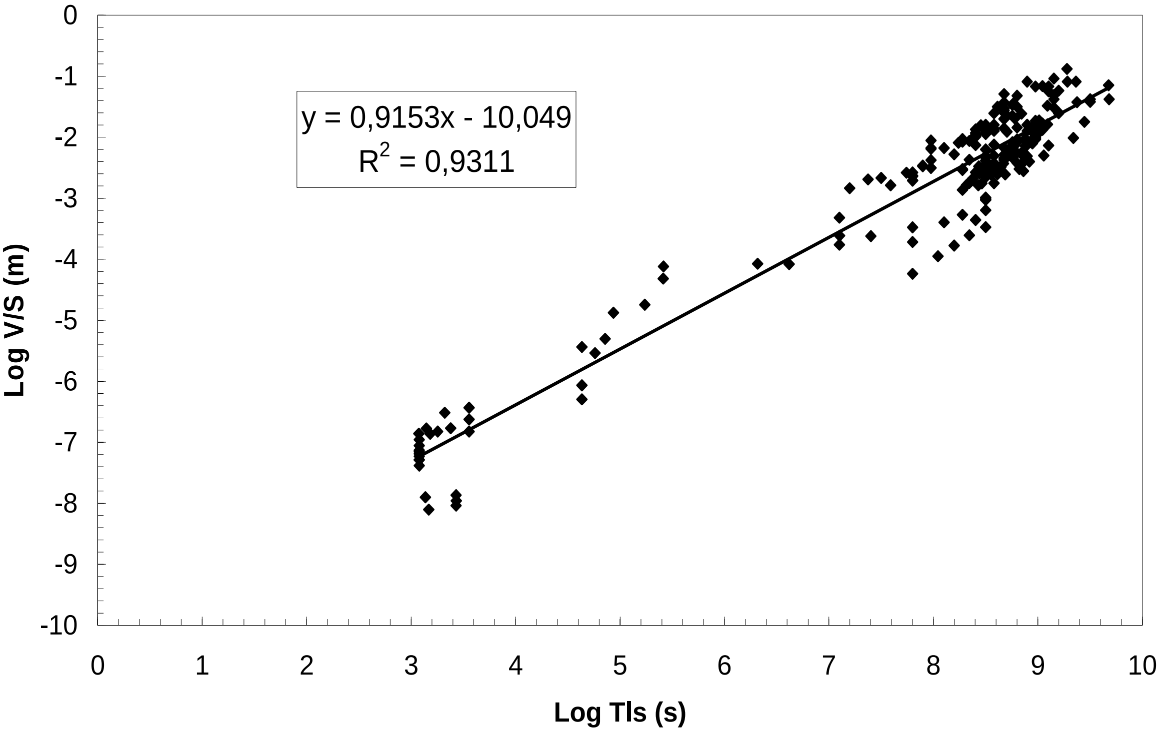

Figure 1. The relationship between volume to surface ratio ($V\times S^{-1}$, m) and lifespan (T_{ls}, s) in 223 individuals (Poikilotherms, Mammals and Aves) from type $V\times S^{-1} = a_{vst}\times T_{ls}^{0.915}$ with $R^2=0.931$ and coefficient $a_{vst}=8.933\times10^{-11}$ m·s^{-1}

Table 2. *The combined relationships between $V\times S^{-1}$ ratio and lifespan T_{ls} in living organisms*

Item	**Class**	$\mathbf{V\times S^{-1} = a_{vst}\times T_{ls}^{\ r}}$	$\mathbf{R^2}$
a)	All (Poikilotherms, Mammals and Aves)(n=223)	$V\times S^{-1} = 8.933\times10^{-11}T_{ls}^{\ 0.915}$	0.931
b)	All without Protozoa (n=191)	$V\times S^{-1} = 9.683\times10^{-11}T_{ls}^{\ 0.9107}$	0.542
c)	Protozoa (n=32)	$V\times S^{-1} = 1.104\times10^{-11}T_{ls}^{\ 1.168}$	0.796
d)	All Poikilotherms (n=90)	$V\times S^{-1} = 11.72\times10^{-11}\ T_{ls}^{\ 0.874}$	0.947
e)	Multicellular Poikilotherms (n=58)	$V\times S^{-1} = 0.58\times10^{-11}\ T_{ls}^{\ 1.023}$	0.703
f)	Mammals (n=73)	$V\times S^{-1} = 23\times10^{-11}\ T_{ls}^{\ 0.91}$	0.756
g)	Aves (n=60)	$V\times S^{-1} = 1.25\times10^{-13}\ T_{ls}^{\ 1.218}$	0.772

The biological sense of coefficient a_{vst}

On cellular level the coefficient a_{vst} ($m\cdot s^{-1}$) has a sense of speed of change of volume/surface ratio, during growth and doubling of cells by binary **(Figure 2)**. For phage, prokaryotic and eukaryotic cells the coefficient a_{vst} could be expressed by generation time of cells (T_{gt}, s):

$$a_{vst}=V\times(S\cdot T_{gt})^{-1},\ m\cdot s^{-1} \qquad (11)$$

In the case of multicellular animals (Poikilotherms, Mammals and Aves) the coefficient a_{vst} could be expressed by lifespan (T_{ls}, s) of animals by the equation:

$$a_{vst}=V\times(S\cdot T_{ls})^{-1},\ m\cdot s^{-1} \qquad (12)$$

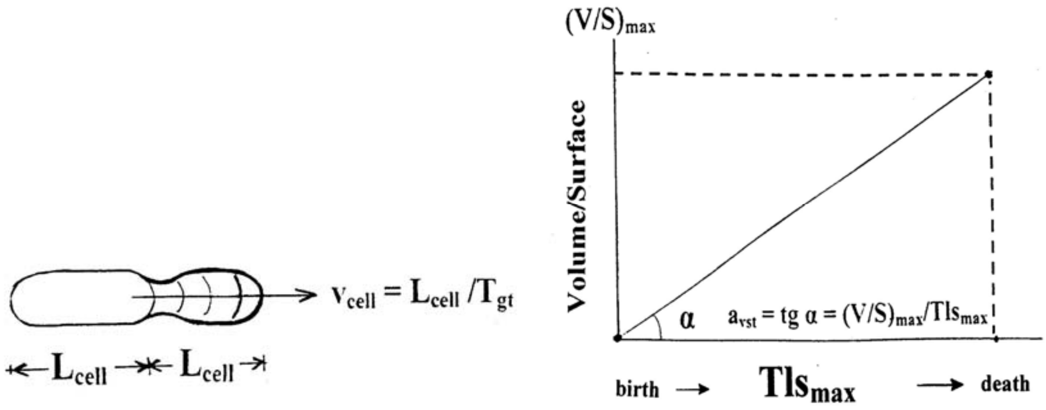

Figure 2.Speed of change of cells size (speed $a_{vst} \approx v_{cell}$) during growth and doubling of cells by binary (left figure) and a scheme that explains the biological sense of coefficient a_{vst} in animals (right figure)

Because in SI metrical system the volume to surface ratio ($V\times S^{-1}$) has a dimension of linear length, a biological sense of $V\times S^{-1}$ ratio can regard as 'characteristic length' (L_{ch}, m) of organisms:

$$L_{ch}=V\times S^{-1}=a_{vst}\times T_{gt}=a_{vst}\times T_{ls} \qquad (13)$$

In **Table 3** are given literature data for the cell mass, cell length, generation time and the calculated data for the linear speed of growth in some Prokaryotes. In data set on **Table 3** the cell mass falls in the range of 5.0×10^{-16}- 2.0×10^{-17} kg, the cell length falls in the range of 0.1×10^{-6}- 2.0×10^{-6} m, and the generation time falls in the range of 20 min-10hours. These values are typical for small *Mycoplasmatales*, *Rickettsiales* and *Chlamydae* [26-29].

The calculated linear speed (a_{vst}) of growth falls in diapason of 1.0×10^{-9} -1.0×10^{-11} $m\cdot s^{-1}$ and overlaps with diapason of a_{vst} (1.0×10^{-10} – 1.0×10^{-13} $m\cdot s^{-1}$) given from the equations 'a, b, c, d, e, f, g' on **Table 2**.

For multicellular organisms (animals) the coefficient a_{vst} has an abstract sense (**Figure 2**). If a given animal grows with speed a_{vst}, than the maximum body mass, maximum body volume and maximum volume/surface ratio will be reached for time equal to the maximum lifespan T_{ls} of animal. Because of the maximum mass, volume and surface in animals are connected with their maturity, possibly between volume to surface ratio and time for maturity the relationship from type (10) could be existed.

Table 3. *Data for cell mass, size, generation time and calculated data for linear speed of growth of some Prokaryotes [26-29] (bold data give all diapason)*

Organism	**Cell mass** **M(kg)**	**Linear size** **L(m)**	**Generation time** **T_{gt} (min, h)**	**Speed of growth** **$a_{vst} \approx L_{ch}/T_{gt}$ ($m \cdot s^{-1}$)**
MYCOPLASMATALES	**2×10^{-17}- 2.0×10^{-16}**	**0.1 - 0.6**	**20min-2.5h**	**1.1×10^{-11}-5×10^{-10}**
1. *Mycoplasma arthritidis*	4×10^{-17} -2.0×10^{-16}	0.2- 0.5	20min-2.5h	2.2×10^{-11}-4.1×10^{-10}
2. *Mycoplasma mycoides*	5×10^{-17}- 2.0×10^{-16}	0.25-0.33	20min-2.5h	2.8×10^{-11}-2.75×10^{-10}
3. *Mycoplasma pneumoniae*	2×10^{-17}- 2.0×10^{-16}	0.1-0.33	20min-2.5h	1.1×10^{-11}-2.75×10^{-10}
RICKETTSIALES AND CHLAMYDIAE	**2×10^{-17}-1.0×10^{-15}**	**0.1-2.0**	**20min-2.5h**	**1.1×10^{-11}-2.75×10^{-10}**
4. *Rickettsii* (Brucella)	(0.2-1.0) $\times10^{-16}$	0.1-0.4	20min-1.0h	2.8×10^{-11}-3.3×10^{-10}
5. Small *Chlamydii*	3.0×10^{-17}	0.2-0.5	20min-2.0h	2.6×10^{-11}-4.1×10^{-10}
6. *Haemobatonella muris,*	(0.2-2) $\times10^{-16}$	0.1×0.3-0.7	20min-5.0h	3.3×10^{-11}-5.8×10^{-10}
7.*Bdellovibrio bacteriovorus*	(0.5-5) $\times10^{-16}$	0.3× 1.0	20min- 10h	3.3×10^{-11}-8.3×10^{-10}
8. *Wolbachia melophagi*	(0.6-1.0) $\times10^{-16}$	0.3× 0.6	30min-2.5h	3.3×10^{-11}-3.3×10^{-10}

Table 4. *The mean values of coefficient a_{vst} for Poikilotherms, Mammals and Aves*

No Order(n)	**a_{vst} ($m \cdot s^{-1}$)**	**No Order (n)**	**a_{vst} ($m \cdot s^{-1}$)**
POIKILOTHERMS			
1. Phage (n=5)	$(0.54 \pm 0.065)\times10^{-11}$	2. Prokaryotes (n=18)	$(7.45 \pm 0.728)\times10^{-11}$
3. Eukaryotes(n=9)	$(10.8 \pm 3.0)\times10^{-11}$	4. Nematoda(n=2)	$(1.703\pm 1.597)\times10^{-11}$
5.Mollusca(n=4)	$(0.2187 \pm 0.05)\times10^{-11}$	6 .Asteroidae(n=1)	1.93×10^{-11}
7.Arachnoidae(n=3)	$(0.195 \pm 0.052)\times10^{-11}$	8. Insecta (n=6)	$(2.36\pm 0.38)\times10^{-11}$
9.Crustacea (n=6)	$(1.791\pm 0.67)\times10^{-11}$	10. Osteichthytes (n=10)	$(1.59\pm 0.42)\times10^{-11}$
11.Amphibia (n=5)	$(0.61\pm 0.059)\times10^{-11}$	12. Reptilia (n=12)	$(2.99\pm 0.756)\times10^{-11}$
13. Snakes(n=8)	$(1.24\pm 0.172)\times10^{-11}$		
MAMMALS			
1.Monotremata (n=3)	$(3.809 \pm 0.22)\times10^{-11}$	2.Didelphoidea(n=2)	$(4.01\pm 0.075)\times10^{-11}$
3.Dasyurida (n=9)	$(3.992\pm 0.263)\times10^{-11}$	4. Syndactyla(n=4)	$(5.706\pm 0.69)\times10^{-11}$
5.Xenarthra (n=2)	$(3.315\pm 0.355)\times10^{-11}$	6. Pholidota(n=1)	4.16×10^{-11}
7.Soricomorpha (n=1)	4.17×10^{-11}	8. Rodentia (n=13)	$(5.95\pm 0.59)\times10^{-11}$
9.Lagomorpha(n=3)	$(4.33\pm 0.57)\times10^{-11}$	10.Artiodactyla(n=12	$(6.358\pm 0.26)\times10^{-11}$
11.Carnivora (n=7)	$(3.885\pm 0.147)\times10^{-11}$	12 Pinnipedia (n=3)	$(7.67\pm 1.56)\times10^{-11}$
13. Chiroptera (n=4)	$(1.262\pm 0.335)\times10^{-11}$	14. Primates (n=9)	$(2.431 \pm 0.306)\times10^{-11}$
AVES			
1.Passeriformes (n=22)	$(0.816\pm 0.61)\times10^{-11}$	2. Nonpasseriformes(n=38)	$(1.21\pm 0.82)\times10^{-11}$

On **Table 4** are presented the mean values of coefficient a_{vst} for all studied orders of Poikilotherms, Mammals and Aves (have calculated by data on **Table 1**).

From **Table 4** you can see that the mean values of coefficient a_{vst} for all animal's orders vary 100 fold only (from 0.1×10^{-11} $m \cdot s^{-1}$ to 11.0×10^{-11} $m \cdot s^{-1}$) in comparison to 22 orders of magnitude variation between body mass, 6-7 orders of magnitude variation between volume/surface ratio and lifespan of studied organisms. This shows that coefficient a_{vst} can regards as a relatively constant parameter.

Application of relationship between volume to surface ratio and lifespan

The equation between volume to surface ratio and lifespan relate to many scientific problems, connecting body size and lifespan of living organisms. This equation must have a direct practical application in many experimental conditions too. In particularly, the basic equation (10) shows that the lifespan (and generation time) depends on $V\times S^{-1}$ ratio (geometrical parameter) and on speed of growth a_{vst}. These dependences can explain some experiments about effect of manipulation of cell size and form on cellular functions.

First example- on cellular level, the study of Ingber [30] has showed that the change of cells shape can switch different gene programs- from apoptosis to cell differentiation and growth. The author and co-workers have showed that cell shape is the most critical determination of cell function, at least in the present of optimal growth factors and high extracellular matrix binding. Thus, cell shape *per se* appears to govern how individual cells will respond to chemical signals in their microenvironment, as first proposed by Folkman and Moscona [31]. What is the mechanism by which cell shape exerts its effect on cell function? Clearly, the full answer is unknown. Our study (exactly, eqn.10) shows that the manipulation of cell shape leads to manipulation of cell volume/surface ratio and this acts on cell function, switching different gene programs -from apoptosis to cell differentiation and growth.

Second example-the previous analysis of Atanasov [5, 10] showed that the volume×(surface·lifespan)$^{-1}$ ratio (a_{vst}, $m{\cdot}s^{-1}$) and integral cells parameters in Prokaryotes (body mass, length, generation time and density) are connected with gravitational constant (G) and Planck's constant (h). In theoretical physics Max Planck and other physicists [1, 32] have calculated the fundamental physical quantum for mass $M=(h{\cdot}c\times G^{-1})^{1/2}=2.176\times10^{-8}$ (kg), length $L=(h{\cdot}G\times c^{-3})^{1/2}=1.616\times10^{-35}$(m), time $T=(h{\cdot}G\times c^{-5})^{1/2}=5.389\times10^{-44}$(s), and density $\rho=M\times L^{-3}\approx1.0\times10^{97}$ ($kg{\cdot}m^{-3}$), using combinations between gravitational constant $G=6.673\times10^{-11}$($Nm^2{\cdot}kg^{-2}$), Planck's constant $h=6.6262\times10^{-34}$ ($J{\cdot}s$) and speed of light $c=2.9979\times10^{8}$ ($m{\cdot}s^{-1}$) . If in these ratios we replace the speed of light 'c' with speed equal to 'a_{vst}', exactly with $a_{vst}=(8\pm0.16)\times10^{-11} m{\cdot}s^{-1}$, we received the modified ratios for mass (14), length (15), time (16) and density (17) in smallest living unicellular organisms (bacteria):

$$M=(h{\cdot}a_{vst}\times G^{-1})^{1/2}, kg \qquad (14)$$

$$L=(h{\cdot}G\times a_{vst}^{-3})^{1/2}, m \qquad (15)$$

$$T=(h{\cdot}G\times a_{vst}^{-5})^{1/2}, s \qquad (16)$$

$$\rho=M\times L^{-3}, kg{\cdot}m^{-3} \qquad (17)$$

From ratios (14-17) we can calculate the minimum mass $\sim1.0\times10^{-17}$kg, minimum size $\sim1.0\times10^{-7}$m, minimum generation time $\sim1.0\times10^{3}$s and density $\sim1.1\times10^{3}$ $kg{\cdot}m^{-3}$ typical for smallest Prokaryotes.

In conclusion, the scaling of biological space and time can help us to answers of many scientific problems, relating to connection between size, form and time in living organisms.

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