LUNG VOLUME AND BODY SIZE

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Abstract:

Lungs are often highly folded to maximize their surface area for gas exchange. A ventilation mechanism is often used to move air convectively into and out of the lung. Vital capacity (VC) does vary according to males and females (in humans) and to their body size (BS). Females have a more significant relation between BS and VC than males. However a relation between the same two variables is significant when evaluating the subjects BS in relation to its VC independently of sex.

Nevertheless, the method used (spirometry) has a few disadvantages and problems that makes unable to quantify the residual volume (RV), functional residual capacity (FRC) or the total lung capacity (TLC).

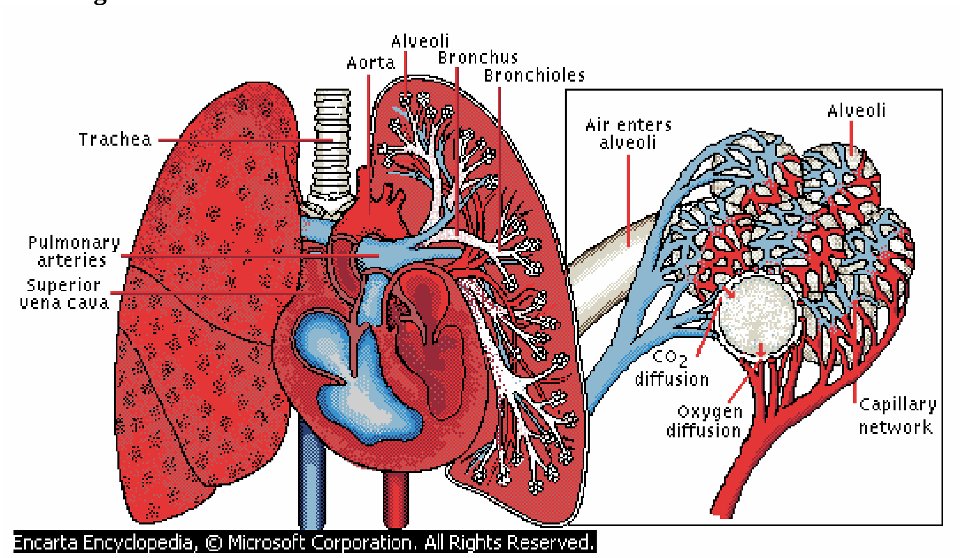
Smaller animals have more energy expenditures towards their metabolism and temperature maintenance than larger animals, for this reason they also have proportionally larger lungs to overcome the need to produce more energy per unit of time.

Because in water the supply of oxygen is not so readily prepared for intake as on dry land fishes have larger gas exchange surface area (gills) than mammals in the order of 54.4 times. Tuna however has "smaller" gills than other species of fishes, but in contrast has a much more energetic life than most of them; so to ventilate their gills they use their way of living to take as much oxygen as possible from water by constantly provide the gills with "fresh" water (because they move very fast) permitting a greater O_2 supply by a counter-current effect.

Introduction:

As well as many other factors we couldn't live without lungs! Lungs are paired organs in the chest that carry on respiration. In the adult human, each lung is 25 to 30 cm (10 to 12 in) long and roughly conical. The two lungs are separated by a structure called the mediastinum, which contains the heart, trachea, oesophagus, and blood vessels. They are covered by a protective membrane called the pulmonary pleura, which is separated from the parietal pleura – a similar membrane on the chest wall – by a lubricating fluid. Inhaled air passes through the trachea, which divides into two tubes called bronchi; each bronchus leads to one lung. Within the lungs the bronchi subdivide into bronchioles, which give rise to alveolar ducts; these end in sacs called alveoli (Hildebrand, 1995).

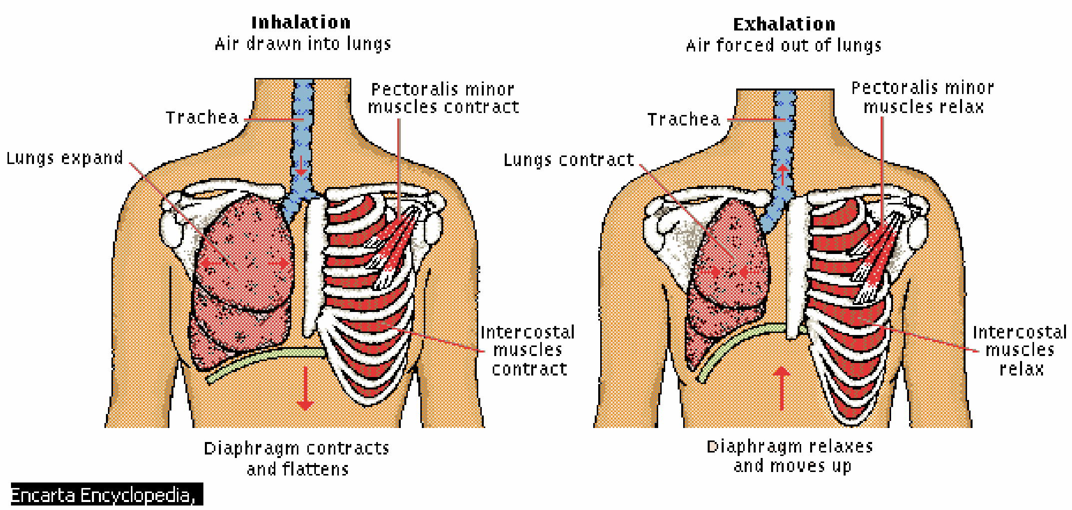
Figure 1.0 – Lungs structure.



The right lung has three lobes, the left lung, with a cleft to accommodate the heart, has only two. The two branches of the trachea, called bronchi, subdivide within the lobes into smaller and smaller air vessels. They terminate in alveoli, tiny air sacs surrounded by capillaries. When the alveoli inflate with inhaled air, oxygen diffuses into the blood in the capillaries to be pumped by the heart to the tissues of the body, and carbon dioxide diffuses out of the blood into the lungs, where it is exhaled (Romer & Parsons, 1986).

In this life-supporting process, oxygen from incoming air enters the blood and carbon dioxide, a waste gas from the metabolism of food, is exhaled into the atmosphere. The exchange of gases takes place when air reaches the alveoli. These small sacs are only one cell thick, and they are surrounded by blood capillaries that are also only one cell thick. Air diffuses through these cells into the capillary blood, which carries the oxygen-rich air to the heart to be distributed throughout the body. In the alveoli, at the same time, gaseous carbon dioxide diffuses from the blood into the lung and is expired (Hildebrand, 1995; Pough, 2002).

Figure 1.1 – Lung expansion and contraction mechanism.



Air enters the lungs when the diaphragm, a strong muscle under the lungs, forcibly lowers and enlarges the chest cavity in which the lungs are suspended. As the diaphragm contracts and moves downwards, the pectoralis minor and intercostal muscles pull the rib cage outwards. The chest cavity expands, and air rushes into the lungs through the trachea to fill the resulting vacuum. This causes the lungs to expand, and the air to fill the enlarged lungs. When the diaphragm relaxes, upwardly curving position, the lungs contract and the air is forced out. In times of greater oxygen need, the rib cage can also expand, further enlarging the chest cavity for greater air intake. A healthy adult can draw in about 3.3 to 4.9 litres (200 to 300 cu in) of air at a single breath, but at rest only about 5 per cent of this volume is used. The lungs also excrete water as gas; store glycogen, a complex carbohydrate; and filter out incoming organisms and dangerous particles via hairs called cilia (Withers, 1992).

Nevertheless, behind the inhale and exhale mechanism many terms can be related with the lung volume and air capacity of a human: total lung capacity (TLC) – refers to the total amount of gas which can be held within the lungs; residual volume (RV) – part of the air in the lung which cannot be exhaled; it represents the remaining volume of lung when forced exhalation of the lung has occurred; tidal volume (TV) – the normal amount of air inhaled and exhaled at rest; vital capacity (VC) - the maximum volume that an individual can expire after a single maximal inspiration; inspiratory capacity (IC) - the tidal volume plus the inspiratory residual volume (it is therefore the amount that can be inspired from normal expiration); inspiratory reserve volume (IRV) – amount of air that can be forcibly inspired at the end of normal inspiration; it is the amount of air which can be inspired on top of the tidal volume; expiratory reserve volume (ERV) – amount of air that can be forcibly expired at the end of normal expiration. It is the amount of air that can be exhaled on top of the tidal volume; and functional residual capacity (FRV) – amount of air left in the lungs at the end of a normal - not forced – expiration (GPnotebook, 2004).

Spirometry is the classic pulmonary function test for measuring lung volumes and capacities as a function of time. It can monitor quiet breathing and thereby measure TV, and also trace deep inspirations and expirations to give information about VC. A 'Harvard Student Spirometer' can be used to measure these variables. It a fairly simple machine composed by a chamber isolated with water and two lateral tubes connected to a mouthpiece; the chamber can has a regulator in the opening so it can be modified, and is also connected to a moving chart by a pen. As the subject exhales into a mouthpiece, there is an increase pressure of oxygen in the chamber and the oxygen bell rises, causing the pen to move upwards on the moving chart recorder, and when the subject inhales the oxygen bell moves downwards, causing the pen to move downwards on the moving chart (Johnson, 2004).

Method:

Since the temperature and pressure of the spirometer are different from those of the body, the volume the air occupies in the spirometer was subject to changes in ambient (room) conditions. To standardise the volumes measured in the spirometer, we multiply these measured volumes by a correction factor known as the BTPS factor (body, temperature, atmospheric pressure, saturated water vapour). Since the BTPS factor is very close to 1.1 atm normal room temperatures we will use this figure in the calculations.

<u>The Vital capacity test:</u>

First we start by calibrating the spirometer and chart recorder. Then the subject started breathing by the mouthpiece and we obtained a record of normal breathing at rest (TV) for approx. 20-30 sec. After this time interval a 'vital capacity test' was performed by asking the subject to inhale as hard as he could at the end of a normal exhalation and then exhale to the fullest extent possible, thus completing the test. After this the chat trace was removed so the calculations could be performed (see appendix 1.1).

Results:

Data collected during the experiment was added to data collected in 1998 and it is displayed in table 1.0. H stands for height measured in meters (m), W is weight and the units used were kilograms (Kg), and VC is vital capacity and it was measured in litres (L).

There are a total of 34 subjects being those 15 males and 19 females. Males make up 44% of the sample while females are 56%.

Data was treated in two different populations looking at 3 different variables. The populations were defined as male and female and the 3 variables as H and W, and VC. Averages were also made for an idea of the mean ratio of the 3 variables.

The average of H between males is 1.75m, W is 76.5Kg, and for VC is 4.63L. For females the average for H is 1.60m, W is 62.0Kg, and VC is 3.28L.

Although, a more in-depth and rigorous analysis can be done by using some other biostatistics tools and concepts. To assay for the relationship and significance of the data some tests were carried out. First to check for linear relationships between the two sexes and Size and then with VC linear regressions were carried out; for size however a ratio weight/height was created to do a projection of the 2 concepts as seen in table 1.0. Charts 1.0 and 1.1

Table 1.0 – Lung Volume Data

Sex	H (m)	W (Kg)	VC (L)	W/H
M	1.67	69	3.8	41.3
M	1.88	85	5.7	45.2
M	1.6	76	3.88	47.5
M	1.93	98	6.1	50.8
M	1.69	81	4.1	47.9
M	1.69	68	4.55	40.2
M	1.75	85	5	48.6
M	1.68	65	3.54	38.7
M	1.61	67	3.49	41.6
M	1.79	88	5.4	49.2
M	1.88	101	6.22	53.7
M	1.77	64	4.4	36.2
M	1.71	59	4.4	34.5
M	1.80	70	4.6	38.9
M	1.82	72	4.2	39.7
F	1.51	49	2.99	32.5
F	1.57	52	2.78	33.1
F	1.5	48	2.68	32
F	1.67	79	4.22	47.3
F	1.56	58	3.75	37.2
F	1.51	59	2.89	39.1
F	1.54	50	2.79	32.5
F	1.62	61	3.65	37.7
F	1.56	59	3.22	37.8
F	1.52	66	4.1	43.4
F	1.61	68	4	42.2
F	1.69	54	2.7	32.0
F	1.68	53	3.3	31.5
F	1.61	48	2.8	29.8
F	1.69	90	3.8	53.3
F	1.62	100	2.8	61.7
F	1.57	62	3	39.5
F	1.58	48	2.9	30.4
F	1.74	72	4	41.4

show the linear regression and the respective equation (y = mx + b). The equations show that there is a significant relation between the two variables.

Chart 1.0 – Linear regression for males relatively to body size and VC

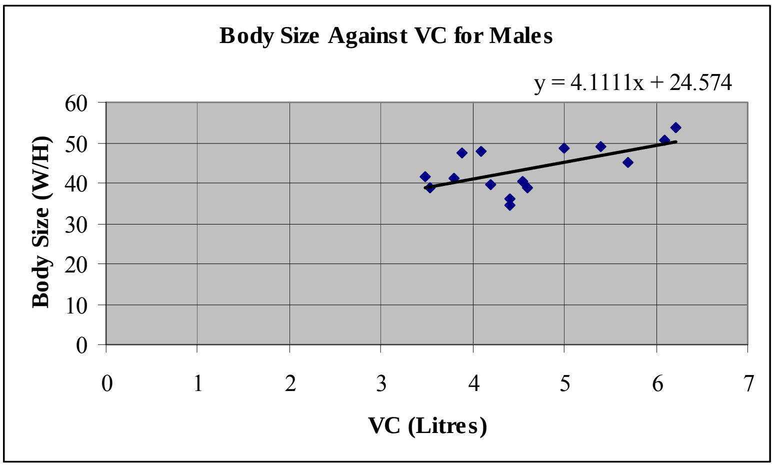
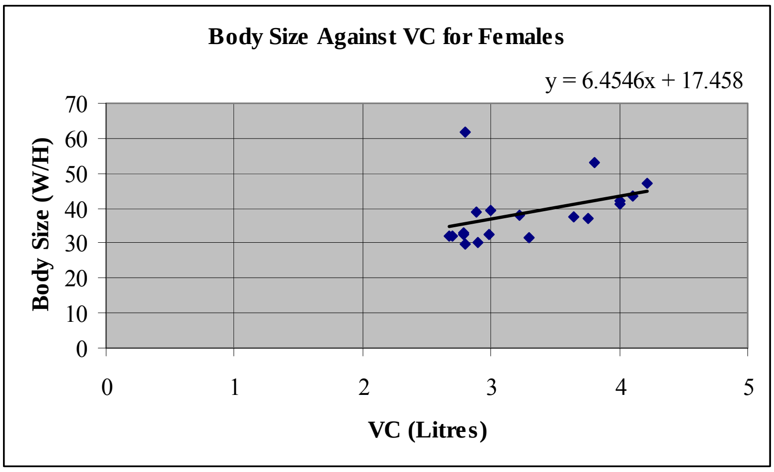


Chart 1.1 - Linear regression for females relatively to body size and VC



To analyse BS and VC independently of sex chart 1.2 was cerated. It is merely an interception between charts 1.0 and 1.1

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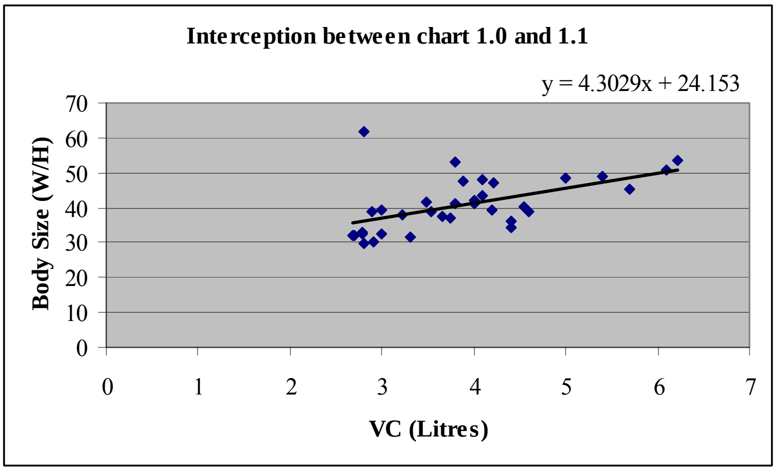
Chart 1.2 – Linear regression for all the subjects relatively to body size and VC



For data integrity a normal distribution test was made with the null hypothesis being that the variables were normally distributed and α 0.05. After carrying out a kolmogorov-smirnov test the significance values for normality was of 0.193 for H and 0.200 for W and VC which is > than 0.05 so we accept the null hypothesis that the data is normally distributed, however, to W and VC this value was a lower bond of the true significance.

Because there are more than 2 variables is question an ANOVA is the appropriate test to carry out. To apply an ANOVA we have to assume that measurement is on a ratio or interval scale, each group is composed of a random sample, the error variances are equal, and the variable is approximately normally distributed. The fact that we want to compare the different variable H, W, VC and sex and then an interaction between sexes a 2-way ANOVA is the more indicate since we have two independent variables, sex and body size. The null hypothesis is that "there is no difference between and within the subjects". After carrying out the test the results for the Mauchly sphericity test is that Sig. = 0.000 which is lower that 0.05 so the data does not have homogeneity of covariance.

The calculation of the TV of one of the subject was also made it being 1.03664L.

Discussion and conclusions:

By just looking at the mean it is possible to draw some conclusions about how males and females differ in their lung capacities. The average of the male VC is 4.63 while females have 3.28. however when looking at the averages of H (1.75 for males and 1.60 for females) and W (76.5 for males and 62.0 for females), the result come to a stable degree because females do have a small average of VC but their H and W are also smaller giving a normally distributed data. Nevertheless, while the points for the male linear regressions are fairly in the same aggregation in females there are 2 point are distinctively out of the aggregation. These two points correspond to subjects whose weight goes way of the average (62Kg), 90Kg and 100Kg respectively. These two points can clearly unbalance the results resulting in a non homogeneity of covariance and so ANOVA doesn't met.

When it concerns to body size related to all the subjects in study independently of sex the picture stays almost the same. By looking at the slopes of the equations we can say that in females the significance of BS (6.4546) is greater than for men (4.1111), and for the interaction between the both the slope is almost as the men (4.3029). However when looking at individual cases more conclusions are possible to be draw. A female with 100Kg has the VC of 2.8L whereas a male of almost the same W has the VC of 6.22L – the difference here is in height; the female is 1.62m and the man 1.81m. When looking at H first instead for W a male with 1.61m has a VC of 3.49L weighting 67Kg and a Female of the same height has a VC of 2.8L; nevertheless another female with the same H but with 68Kg has a VC of 4L. based on this is possible to infer that VC is not directly related with H or W but with a interaction of both. For this reason a ratio was made between W and H to have a better view of how the VC varies according BS, and the regression equation reveal to be positive – leading to the conclusion that people with a bigger ratio of W/H have a higher VC.

Interpretation:

1) **Why can we not calculate RV, FRC or TLC? How are these lung volumes normally measured? How would you go about measuring them in other animals?**
Spirometry cannot, however, access information about absolute lung volumes, because it cannot measure the amount of air in the lung but only the amount entering or leaving. Thus information about functional residual capacity, and lung volumes computed from FRC, such as TLC and RV, must be computed via different means, such as body plethysmography or gas dilution.
In body plethysmography, the patient sits inside an airtight box, inhales or exhales to a particular volume (usually FRC), and then a shutter drops across a breathing tube. The subject makes respiratory efforts against the closed shutter (this looks, and feels, like panting), causing their chest volume to expand and decompressing the air in their lungs. The increase in their chest volume slightly reduces the box volume (the non-person volume of the box) and thus slightly increases the pressure in the box. For the interpretation of plethysmography it is necessary to use the Boyles Law.
Gas dilution is a method of determining those lung volumes that cannot be determined from simple spirometry. These include functional residual capacity, which is computed directly, and RV and total lung capacity, which are computed from FRC. The subject is connected to aspirometer containing a known concentration of helium, or some other inert and insoluble gas. After several minutes of breathing, the helium concentrations in the spirometer and lung become the same. From the law of conservation of matter, we know that the total amount of helium before and after is the same. Therefore we can set the fractional concentration times the volume before equal to the fractional concentration times the volume, because of the conservation law of matter (John Hopkins School of Medicine's, 1995). Spirometry in animals started in 1868 by Bert, the animal in question has to be in enclosure during a certain period in a closed plethysmographic system; the subject is enclosed in a chamber equipped to measure pressure, flow, or volume changes. However this method has several disadvantages (Care, 2001).

2) **Below are data collected from a previous year. Add your own class data to this and comment on the effects of size and sex on lung volume in humans.**
The data below doesn't fill the requirements to answer what is asked because a comparison cannot be done towards the factor sex since it is not referenced. Data from 1998 was supplied with 22 subjects, and this will be added to the one collected and a comment of the effects of size and sex on lung volumes in humans can be evaluated in the <u>*Discussion and conclusions*</u>.

SUBJECT	Body Mass (kg)	Height Height (m)	Tidal Volume (litres)	Vital Capacity (litres)	Expiratory Reserve Volume (litres)	Inspiratory Reserve Volume (litres)
1	64	1.67	0.25	2.92	0.60	1.30
2	48	1.59	0.33	2.69	0.95	1.52
3	60	1.70	0.35	3.80	1.6	2.20
4	53	1.74	0.40	4.04	1.52	2.52
5	87	1.97	0.57	7.13	3.53	3.59
6	87	1.78	0.51	5.49	1.54	3.94
7	72	1.75	1.43	5.07	1.93	1.71
8	48	1.62	1.14	3.90	1.43	0.74
9	95	1.84	0.97	5.99	2.11	2.74

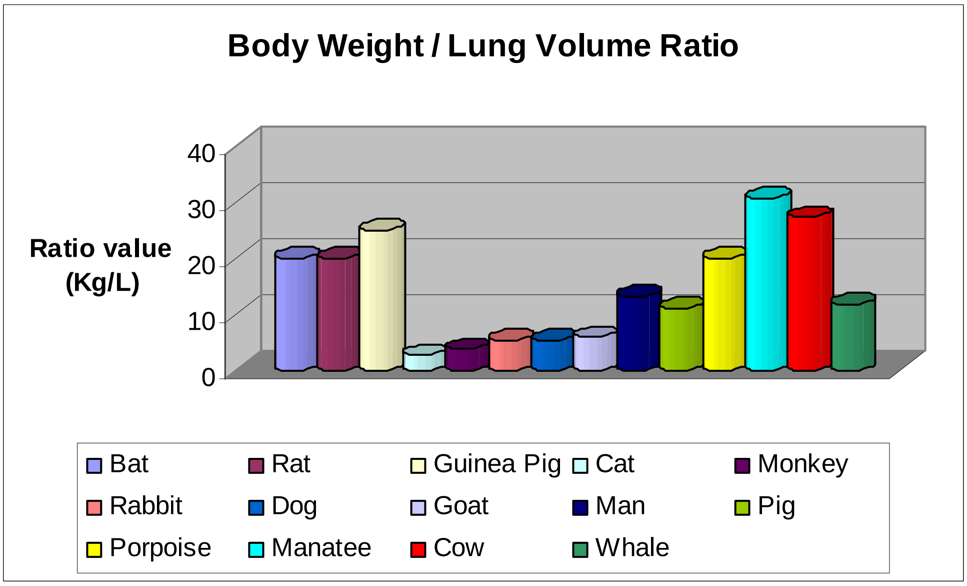
10	57	1.77	0.63	3.76	1.43	2.00
11	49	1.66	0.40	3.30	1.11	1.76
12	52.5	1.70	0.58	3.60	1.46	1.46
13	55	1.69	1.10	3.52	2.20	1.32
14	76	1.98	1.69	4.97	2.04	1.64
15	57	1.70	0.76	3.65	1.36	1.63
16	71	1.78	0.26	4.14	2.46	1.41
17	90	1.88	1.36	5.41	2.33	2.02
18	79	1.80	0.70	4.75	2.20	1.76
19	76	1.80	1.15	5.00	1.4	3.25
20	51	1.66	0.85	3.80	1.45	2.35
21	70	1.89	0.95	5.6	2.90	2.85

Mammalian Lung Volumes:

You should now appreciate that smaller mammals have a higher demand for oxygen.

3) Therefore, to deal with this extra demand do small animals have relatively larger lungs? Answer this question in full (equations and graphs) using the data below.

Chart 2.0 – Histogram showing the BW/LV ratio between the different species



BW – Body Weight / LV - Lung Volume

Species	BW (Kg)	LV (L)	Ratio BW/LV
Bat	0.01	0.0005	20
Rat	0.2	0.01	20
Guinea Pig	0.5	0.02	25
Cat	0.57	0.2	2.85
Monkey	0.58	0.15	3.9

Rabbit	0.6	0.11	5.5
Dog	11	2	5.5
Goat	30	5	6
Man	80	6	13.3
Pig	100	9	11.1
Porpoise	200	10	20
Manatee	400	13	30.7
Cow	600	22	27.3
Whale	2500	210	11.9

It is quite difficult to infer a general view to animals based only on their BW and LV. However is clearly possible to conclude that small animals do have larger demands for metabolic activities (most due to heat lost). All the animals in the table are homeotherms so in this case it is possible to draw a relation between the energetic demands (O_2 is an essential component to improve energy production). For example a bat with BW of 0.01 has the same ratio than a porpoise with 200Kg of BW, and a guinea pig with only 0.5Kg has more than the double of ratio than a whale!

Comparison with aquatic poikilotherms:

Look at the data for lung surface area and body mass in fish and mammals.

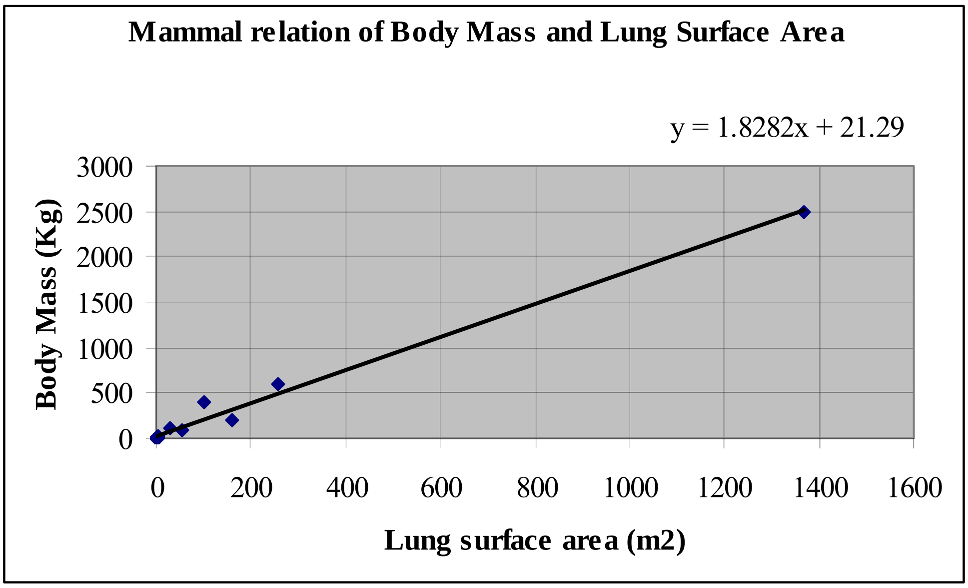
4) **We know that oxygen is present in water in far smaller amounts than it is in air - do fish therefore have a comparatively larger respiratory surface area than mammals? If not, why not? Illustrate your answers with graphs and equations.**
Even though we are not comparing animals with the same body mass (BM) by the regression equations ($y = 1.8282x + 21.29$ for mammals and $y = 122.71x + 0.3763$ for fish) obtained through the charts (see chart 3.0 and 3.1 below) it is possible to see the difference between the gills and lungs surface areas for an animal with the same dimensions. Take as an example an animal with 50Kg; based on the equations it's a mammal of such dimensions would have a lung surface area (LSA) of 12.7m^2 and a fish a gill surface area (GSA) of 6135.9m^2 – 54.4 times larger than the mammal. So yes the fish have comparatively larger respiratory surface area than mammals.

5) **Why and how do the data for tuna differ from the other species of fish? Once again, illustrate your answers with graphs and equations.**
After plotting a chart and a regression equation (see chart 3.2) a conclusion can be made by comparing a tuna and a fish of the same BM. Take as a value 30Kg. A tuna with this BM would have 496.6m^2 and a normal fish 3681.7m^2 of GSA – tuna has a GSA 7.4 times smaller that the other fish species. They depend on swimming for gill ventilation and for his reason their gills don't need to be has bigger/folded as fish that are benthic or don't move very actively because they are constantly being provided with fresh water, and so the counter current mechanism of respiration is fish is much more efficient and tuna are able to pump enough oxygen to withstand their activity even having comparatively smaller GSA than other fish species.

Mammals:

Species	Body Mass (Kg)	Lung surface area (m^2)
Man	80	56
Bat	0.01	0.01
Rat	0.2	0.1
Rabbit	0.6	0.11
Dog	11	5
Whale	2500	1367
Cow	600	257
Porpoise	200	159
Pig	100	31
Guinea Pig	0.5	0.5
Manatee	400	102
Monkey	0.58	0.15
Cat	0.57	0.2
Goat	30	5

Chart 3.0 – Relation between mammal body mass and lung surface area

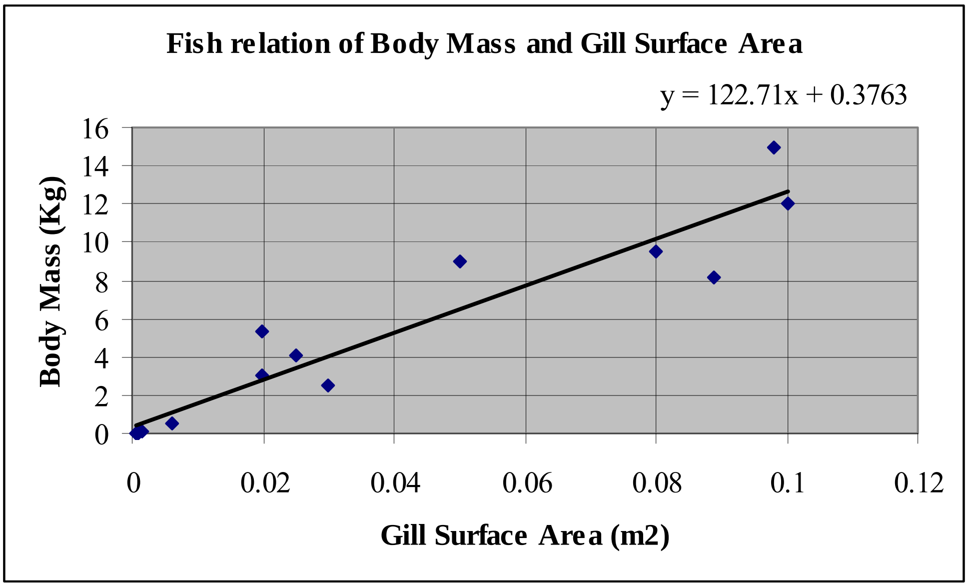


Fish:

Species	Body Mass (Kg)	Gill surface area (m^2)
Sturgeon	12	0.1
Striped bass	9	0.05
Goldfish	0.5	0.006
Carp	2.5	0.03
Stickleback	0.01	0.0005
Minnow	0.09	0.0015
Halibut	9.5	0.08
Salmon	8.2	0.089
Trout	5.3	0.02
Cod	4.1	0.025
Whiting	3	0.02

Goby	0.05	0.001
Blue-fish	15	0.098
Blenny	0.075	0.001

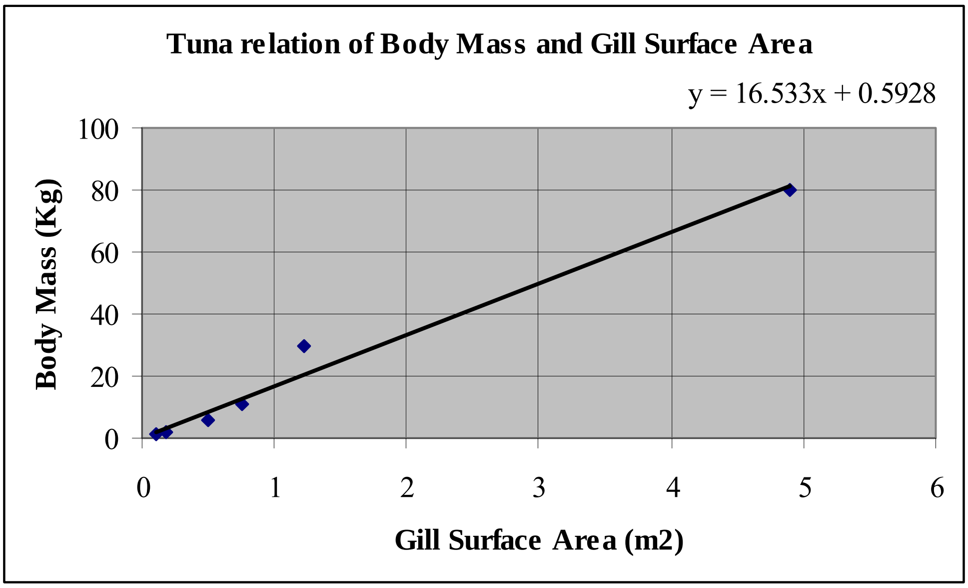
Chart 3.1 – Relation between fish body mass and gill surface area



Tuna:

Body Mass (kg)	Gill Surface Area (m^2)
80	4.9
11	0.75
30	1.23
6	0.5
1	0.1
2.2	0.18

Chart 3.2 - Relation between tuna body mass and gill surface area



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