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Using Mammal Study Skins to Investigate the Relationship between Surface Area to Volume Ratio and Mass of Two Size Classes of Mammals

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In many biological investigations, measurement data are often collected to determine if there is a relationship between two or more variables. In this exercise students estimate the surface area and volume of small and medium sized Nebraska mammals. From these data the students determine if there is a relationship between the surface area to volume ratio (SA/V) and size (mass) of the mammal. The surface area and volume measurements of the mammals are estimated using the geometric formulas for cones (head) and cylinders (trunk). The wet weight (mass) of each mammal was recorded on the original specimen tag. The data collected from this exercise also can be used to initiate discussions of a variety of concepts including: correlation vs. cause and effect, why cells are small, the importance of mitochondrial cristae, metabolic rates, hibernation, and torpor. This lab exercise has been used in both majors and non-majors introductory biology courses employing both traditional and investigative approaches.

Introduction

In many biological investigations, measurement data are often collected to determine if there is a relationship between two or more variables. For example, a biologist may want to determine if there is a relationship between the mass of adult rats and the amount of fat in their diet. Although the biologist may find a positive relationship between the two variables (i.e. increased fat in the diet is related to increased mass), such data do not prove that increased fat in the diet is the cause of the increased weight. In this exercise you will estimate the surface area and volume of a small, and medium sized mammal. From these data, the students will calculate the surface area to volume ratio and determine if there is a relationship between this ratio and the size (mass) of the mammals.

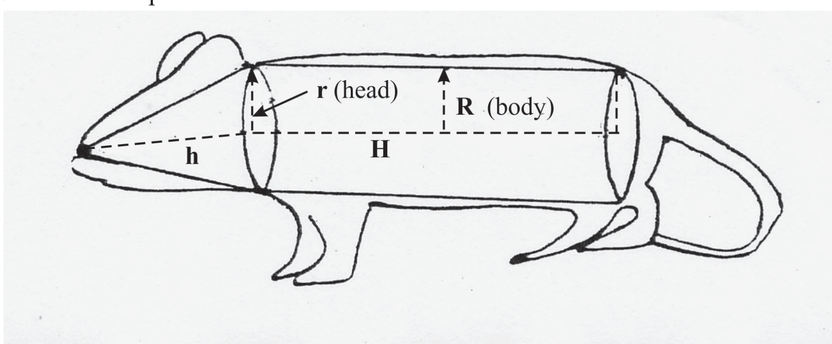
Student Outline

Estimation of Surface Area and Volume of Mammals

Procedure

1. Each pair of students selects either a small mammal or a medium to large sized mammal to measure. Record the common name, scientific name, and mass (in grams) of the animal. **This information is on the tag attached to the animal.** Some of the specimens being used in this exercise are museum quality study skins. **Many of these specimens are fragile so please handle them with extreme care!** When you have finished taking the measurements, return the animal to its designated tray. These study skins have been treated with insecticide so **wash your hands after handling. There are a limited number of study skins available so please share them and complete your measurements as quickly as possible.**
2. In order to estimate the surface area and volume of the mammals, it is assumed that the head of the mammal approximates the shape of a cone and the body the shape of a cylinder (see diagram below). The surface area and volume of the appendages and tail will be ignored in the calculations since their contribution to the total surface area and volume of the mammal is relatively small.

Figure 1. Geometric shapes used to estimate surface area and volume of mammals



3. Head Measurements

   a. *Calculation of the Circumference of the Head*

   To determine the surface area and volume of the cone (head), you must first determine its circumference c = distance around a circle. The circumference of the head is determined by wrapping a piece of string around the head just in back of the ears and then measuring the length of the string required to encircle the head. The radius of the cone (head) is then calculated by dividing the circumference c by 2π (= 6.28).

   b. Record the values for the circumference (c), radius (r) and length (h) of the head of either the small or medium sized mammal in Table 1.

Table 1. Head measurements from study mammal.

Specimen	Circumference (c) of head (cone)	Radius of head cone r = c/6.28	Length (h) of head (cone)
Small mammal	cm	cm	cm
Medium mammal	cm	cm	cm

4. Calculation of Surface Area and Volume of Head (cone)

   Using the head measurements recorded in Table 1 and the equations in the table below calculate the surface area and volume of the head of the small or medium sized mammal and record the values in Table 2.

Table 2. Calculation of surface and head volume.

Specimen	Surface Area of Head	Volume of Head
Formula	$\pi r\left(r+\sqrt{r^2+h^2}\right)=$ $3.14\, r\left(r+\sqrt{r^2+h^2}\right)$	
Small mammal	cm^2	$\frac{1}{3}\Pi\, r^2 h = 1.05\, r^2 h$ cm^2
Medium mammal	cm^2	cm^2

5. Body Measurements

   a. *Calculation of the Circumference of the Body Torso*

   To determine the surface area and volume of the cylinder (body torso), you must first determine its **circumference c** = distance around a circle. The circumference of the body is determined by wrapping a piece of string around the middle of the body and then measuring the length of the string required to encircle it. The radius of the cylinder (body torso) is then calculated by dividing the circumference c by 2π (=6.28)

   b. Record values for the circumference (c), the radius (R), and the length (H) of the body in Table 3.

Table 3. Body measurements from study mammal.

Specimen	Circumference (c) of body (cylinder)	Radius (R) of body (cylinder)	Length (H) of body (cylinder)
Small mammal	cm	cm	cm
Medium mammal	cm	cm	cm

6. *Calculation of Surface Area and Volume of Body (cylinder)*

   Using the body measurements recorded in Table 3 and the equations in Table 4, calculate the surface area and volume of the body of the small or medium sized mammal and record the values Table 4.

Table 4. Calculation of surface and body volume.

Specimen	Surface area of body = 2π RH = 6.28 RH	Volume of body = $\pi R^2H = 3.14 R^2H$
Small mammal	cm^2	cm^3
Medium mammal	cm^2	cm^3

7. *Calculation of Total Surface Area of Whole Mammal*

Fill in Table 5 with your calculations using the equation shown.

Table 5. Total surface area of mammal.

	Surface Area of head +	Surface Area of body =	Total Surface Area
Small mammal	cm^2	cm^2	cm^2
Medium mammal	cm^2	cm^2	cm^2

8. *Calculation of Total Volume of Mammal*

Fill in Table 6 with your calculations using the equation shown.

Table 6. Calculation of total volume of mammal.

	Volume of head +	Volume of body =	Total Volume
Small mammal	cm^3	cm^3	cm^3
Medium mammal	cm^3	cm^3	cm^3

9. *Calculation of Surface Area to Volume Ratio of Mammal*

Use data from Tables 5 and 6 to calculate the surface/volume ratio. Enter in Table 7.

Table 7. Surface to volume ratio.

Specimen	$\dfrac{\textbf{Total Surface Area (cm}^2\textbf{)}}{\textbf{Total Volume (cm}^3\textbf{)}}$
Small mammal	
Medium mammal	

Note: Although the units for the surface area to volume ratio should be cm^{-1} the ratio is expressed without units.

Questions

1. In the class data table on the blackboard, record the common name, scientific name, mass (in **grams**), and the calculated surface/area to volume ratio (S/V) for your small and medium sized mammal. The common name, scientific name, and mass of each mammal is listed on the square museum tag attached to each animal.
2. Fill in summary Table 8 for the class data. Be sure to list the masses (in **grams**) of the mammals in order **from smallest to greatest** mass.

Table 8. Surface area to volume ratio vs. mass of mammals.

Common Name	Scientific Name	Mass (g)	S/V

3. Using the reference books provided, list the geographic distribution, habitat (where an organism lives and its surroundings), and primary food source for the mammals you measured.
4. As a cell or organism enlarges, which variable increases more rapidly, surface area or volume? Hint: Volume increases with the cube of the diameter but surface area increases only with the square of the diameter.
5. For each of the three mammals listed above, calculate the number of days (or fraction of a day) required for the mammal to eat its own body mass in food.

Table 9. Mass of food eaten by representative mammals.

Mammal	Mean mass of mammal	Mass of food eaten/day
Pygmy Shrew *(Microsorex hovi)*	4 g	12 g
Blue Whale *(Balaenoptera musculus)*	9.0×10^4 kg	9.0×10^2 kg
Human *(Homo sapiens)*	68 kg	2 kg

a. If a human having a mass of 68 kg (150 lb.) consumed food at the same rate (kilograms food consumed/day/unit body mass) as that of a shrew, how many kilograms of food would the person consume per day if he/she had the metabolic rate (kilograms food consumed/day/unit body mass) of a shrew? If a typical hamburger has a mass of 0.2 kg, how many hamburgers would a person consume per day if he/she had the metabolic rate (kilograms food consumed/day/unit body mass) of a shrew?

b. What can you conclude about the relationship between the size (mass) of a mammal and the amount of food eaten per day per unit body mass?

6. Mammals and birds are called **endotherms**, i.e., they derive the majority of their body heat from their own metabolism. **Metabolism** is the total of all of the chemical activities of a living organism. It can be shown that the normal metabolic rate of mammals is inversely related to body size, i.e., **the smaller the mammal the higher the metabolic rate. Aerobic respiration** is the primary metabolic process occurring within the cells of birds and mammals which produces heat energy as a by-product. During the process of aerobic respiration, food is oxidized ("burned") in the presence of oxygen; resulting in the formation of (1) the chemical compound ATP which is the primary energy source for all cells and (2) large amounts of heat energy. This heat energy is used by birds and mammals to maintain a **constant** body temperature at a level generally higher than that of their environment. This heat energy is constantly being lost to the environment from all the animal's surfaces.

   a. Which of the mammals you measured would be expected to have the greatest relative heat loss to the environment per unit time? Why? HINT: Which animal had the greatest surface area to volume ratio?

   b. As shown above, the Pygmy Shrew (the smallest living mammal) eats nearly three times its own mass in food everyday and can starve to death in a few hours if deprived of food. Based on your knowledge of the relationship between the surface area to volume ratio and mammal size, what is one possible explanation why a Pygmy Shrew must consume three times its own weight in food daily?

   c. All mammals possess some type of hair. How does hair help prevent heat loss from mammals?

   d. Certain mammals such as bats and certain species of rodents (e.g. mice, ground squirrels, gophers, etc.) hibernate in the winter months. What occurs during the process of hibernation and how does hibernation enable these animals to withstand long periods of cold temperature and decreased food supplies?

Notes for the Instructor

Introduction

This lab is designed for students to discover the relationship between two variables, i.e., the relationship between the surface area to volume ratio and the mass of two size classes of mammals. Therefore, it is important that the instructor leads them through the data collection and a discussion of the data. Also, it is important to stress that although there may be a positive relationship (correlation) between two variables this does not prove that there is any cause and effect relationship between these two variables

Procedure

1. Stress that the study skins are extremely fragile and irreplaceable. Students will have to share specimens! Make sure students do not remove the tags from the animals.
2. Describe how study skins are prepared and their importance in taxonomic studies. The skulls are generally kept with specimens for taxonomic purposes.
3. **Show** students how to obtain the circumference of the head and body.
4. Using the diagram of the mammal in the lab outline and one of the larger mammals, show the students what measurements to take. Make sure to point out that "h" and "H" stand for length instead of height.
5. Remind students that the "fresh" weight of each mammal is listed on the square" white tag attached to the animal, not on the museum tag.
6. Students should NOT be required to memorize the geometric equations for calculating surface area to volume ratios.
7. After the class data table has been completed, have students construct a table which gives the mass of each animal and its corresponding surface area to volume ratio (Table #1). List the mammals from low to high mass. Hopefully, you should have data which shows a trend for decreased s/v ratio with increased body weight. ***With class input, construct a line graph of the vs. mammal mass (x-axis) vs. S/V (y-axis)***
8. In endothermic animals, metabolic rate is inversely related to body size. One explanation for this relationship is that smaller animals have a greater surface area-to-volume ratio, and consequently a larger relative heat loss to the environment per unit time. To maintain a constant high body temperature despite rapid heat loss across its body surface, a small animal must oxidize food at a very high rate. Because the relative amount of food consumed and the pace of digestion, respiration, and so on must rise with decreasing size, there is a lower limit on the size of endotherms. The smallest living mammals are shrews, weighing only about 4 grams. They must eat nearly their own body weight (or more, depending on the species) of food every day, and can starve to death in a few hours if deprived of food.
9. Discuss the implication of metabolic rate and body size in endotherms during the cold season. The relationship between metabolic rate and body size in endotherms has serious implications for small animals during the cold seasons of the year. Not only does the rate of heat loss rise at such times, but the food supply is generally low. Small mammals belonging to three groups - the insectivores, bats, and rodents- have evolved a mechanism that enables them partly to evade this problem. When winter comes, they hibernate: their body temperature falls far below its normal level, and their metabolism, heart rate, respiration, etc., are greatly depressed. The animals pass the winter in this dormant state, using up their energy reserves very slowly. Bats are of particular interest, because they not only hibernate in winter in cold climates, but go into a similar dormant state during the daylight hours every day, thus conserving the energy derived from the food they eat during the night. Large mammals like bears are good heat conservers and have relatively low metabolic rate. Though they do not hibernate during the winter, they become relatively inactive and spend much of their time sleeping, while using up their extensive fat reserves; but their body temperature decreases by only a few degrees and they are not truly dormant.
10. Some of the questions at the end of the outline are difficult, especially for students with little biology background. Therefore, you may have to ask some leading questions to get students on the right track.

    a. Use question #5 in developing the concept that the larger the organism the lower the **relative** metabolic rate - that is, the lower the metabolic rate **per gram of body tissue**? Make sure you understand this question and have done all of the calculations so that you know the correct answer.

    b. Note that question #6 includes a brief discussion of the concepts of endothermy, hibernation, metabolism, and aerobic respiration. Read over the supplementary handout on thermoregulation so that you have a good understanding of this concept how it relates to terrestrial mammals and the concept of surface area/volume ratio. Students are only expected to understand the material presented in the question.

Table 1. Student Data Set

Mammal	Mass (g)	S/V
Shrew (*Blarina* sp.)	3.0	2.9
Prairie Vole (*Microtus ochrogaster*)	18.6	1.7
House Mouse (*Mus musculus*)	28.2	1.6
Fox Squirrel (*Sciurus niger*)	581.5	0.75
Badger (*Taxidea taxus*)	7,000.0	0.30
Beaver (*Castor canadensis*)	25,000.0	0.25

References

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About the Author

Bill Glider earned his B.S. degree in Secondary Education from Cornell University, his M.S. degree in Botany from the University of Maine and his Ph.D. in Biological Sciences from the University of Nebraska-Lincoln in 1985. He is currently a Senior Lecturer in the School of Biological Sciences at UNL. In 2002, he received the Distinguished Teaching Award from the College of Arts and Sciences. He has spent over 20 years designing laboratory curriculum for the General Biology Program at UNL and lecturing in General Biology. In addition, to General Biology he has taught Botany, Organismal Biology, and field courses at the UNL Cedar Point Biological Station. Currently, he devotes the majority of his time to teaching large lecture sections of General Biology and pursuing a number of collaborative research projects focused on methods of increasing student learning in the biological sciences and designing methods of teaching students with disabilities in both lab and lecture.

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