Form and Function Lab

In this lab you will investigate a few of the many ways in which animal shape affects function. We’ll be focusing on surface area-to-volume ratios, which are abbreviated as “SA/V ratios.”

Part #1: Effects of SIZE on SA/V ratios:

1a) Complete the following table. Each cube is exactly 1 cm per side. The first two rows of the table have been filled in for you to as an example. Please note the units.

<table>
<thead>
<tr>
<th>Width of cubic block (assume each sugar cube is 1 cm wide)</th>
<th>Number of sugar cubes required</th>
<th>Volume (assume each sugar cube is 1 cubic centimeter)</th>
<th>Exposed surface area</th>
<th>SA/V ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 cm</td>
<td>1</td>
<td>1 cm³</td>
<td>6 cm²</td>
<td>6 cm⁻¹</td>
</tr>
<tr>
<td>2 cm</td>
<td>8</td>
<td>8 cm³</td>
<td>24 cm²</td>
<td>3 cm⁻¹</td>
</tr>
<tr>
<td>3 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1b) Do you notice a trend? Use these results to develop a mathematical formula that gives the SA/V ratio for a cube that’s w cubes wide. Show your work, and circle your final formula.

1c) Use your formula to calculate the SA/V ratio for a cube that’s 10x the width of a single cube. (In other words, assume w = 10.)

1d) Use your formula to calculate the SA/V ratio for a cube that’s 100x the width of a single cube.

1e) What happens to the SA/V ratio every time you double the width of the cube?

1f) What do you think would happen to the SA/V ratio of an elephant, octopus, or moth, if you doubled its size (length) without changing its proportions?

1g) How long in inches is a newborn human baby? How tall are you in inches? What has happened to your SA/V ratio during your lifetime? Why might pesticide exposure for a child be worse than that for an adult?
Part #2: Effects of SHAPE on SA/V ratios:

For this part, you will take 64 cubes and arrange them in various ways, keeping track of the shape and the SA/V ratios you get. All 64 cubes must be used in each arrangement; you cannot, for example, split them into two groups of 32 cubes.

2a) What will be the volume of every shape?

2b) Shape #1: A cube. Arrange the 64 sugar cubes into a 4x4x4 cube to represent a stocky animal, such as a toad. What is the exposed surface area of this shape?

2c) Shape #2: A flat square. Arrange the 64 cubes into an 8x8 square to represent a flat animal, such as a flatworm. What is the exposed surface area of this shape?

2d) Shape #3: A long rod. Arrange the 64 cubes into a single row to represent a long, skinny animal, such as a worm. What is the exposed surface area of this shape?

2e) Shape #4: Intestinal villi. Arrange your 64 cubes into 4 groups of 16 cubes each. Use 9 of the 16 cubes in each set to form a 3x3 square on the tabletop. This square represents a patch of intestinal lining. Stack the remaining 7 cubes vertically on top of the center of the 3x3 square to represent a tall villus projecting into the digested food inside the intestine. Do this with all 4 groups of 16 cubes to produce 4 patches of intestinal wall, each with a single villus. Move your four 3x3 squares together to represent a small patch of intestinal lining with 4 villi. Now imagine that this pattern is repeated indefinitely in all directions, and think about the surface area exposed to the food inside the intestine. For exposed surface area, count only the surfaces that would be in contact with that food. What is the exposed surface area?

2f) Shapes #5: Now remove the “villi” from your 6x6 patch of intestinal lining. What now is the exposed surface area that would be in contact with food? Is it more or less? Do villi have a significant affect on the surface area available for absorbing nutrients?

2g) What shape(s) seem to maximize the SA/V ratio?

2h) What shape(s) seem to minimize the SA/V ratio?

2i) What other things did you discover about how shape affects SA/V ratios?

2j) Can you think of some examples from animal structures where the shape of an animal or one of its parts can be explained, at least in part, by the results you have gotten during today’s lab exercise.

Part 3: What is the ideal cell size?
As you have observed, cells are small. Consider your little toe: it is made of about 2-3 billion cells! A newly-made cell will grow, but once it reaches a certain size it will divide to form two new cells rather than growing bigger. Why is this? Why aren’t you made of a few dozen, or a few hundred cells, instead of trillions? Why don’t single-celled organisms like amoebas and paramecia grow as big as a human? In this lab, we will investigate this question using model cells.
1. In this lab, we will investigate the ability of four model cells of different sizes to obtain nutrients from their environment. How do cells obtain the materials they need and get rid of waste products?
2. Hypothesis: Which size cell do you think will be more successful? Explain your reasoning.

<table>
<thead>
<tr>
<th>Test tube #</th>
<th>Cube Size/number</th>
<th>Surface area</th>
<th>Volume</th>
<th>SA/V ratio</th>
<th>Height of H₂O₂ bubbles in cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Cut into 2 pieces (in half)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Cut into 4 pieces (in half twice)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Cut into 8 pieces (in half 3 times)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Label 4 test tubes.
2. Obtain 4 1 cm³ pieces of potato.
3. Cut the potato into the number of equal size pieces as indicated on the chart. Put the potato pieces into the test tubes.
4. Add 10 ml of hydrogen peroxide to each tube. Measure and record the maximum height of bubbles produced by the decomposition of H₂O₂ by catalase.
5. Clean up by pouring out the liquid and throwing the potato pieces into the trash—DO NOT POUR THE POTATO PIECES INTO THE SINK!

Analysis Questions:
1. Geometric formulas for the volume (V) and surface area (SA) of a sphere are given below:
   \[ V_{Sphere} = \frac{4}{3} \pi r^3 \]
   \[ SA_{Sphere} = 4 \pi r^2 \]

   Complete the following table using a sphere instead of a cube. The first row has been filled in for you as an example. You can use it to check your calculation technique.

<table>
<thead>
<tr>
<th>Diameter of sphere (in cm)</th>
<th>Radius of sphere</th>
<th>Volume of sphere</th>
<th>Exposed surface area of sphere</th>
<th>SA/V ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 cm</td>
<td>0.5 cm</td>
<td>0.5236 cm³</td>
<td>3.1416 cm²</td>
<td>6 cm⁻¹</td>
</tr>
<tr>
<td>2 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1a) Use these results to develop a mathematical formula that gives the SA/V ratio for a sphere that's \( d \) cm in diameter.
1b) Use your formula to calculate the SA/V ratio for a sphere that’s 10 cm in diameter.

1c) Use your formula to calculate the SA/V ratio for a sphere that’s 100 cm in diameter.

1d) What happens to the SA/V ratio every time you double the diameter of the sphere?

2. Examine your data. Describe what happens to the surface area and the volume as the cell grows larger.

3. What happens to the ratio between surface area and volume as the cell grows larger?

4. According to your data, which cell would be most successful at receiving needed nutrients and excreting wastes?

5. What can you say about the surface area to volume ratio that will best meet the needs of living cells?

6. Why is surface area significant in this situation?

7. Based on what you have learned in this lab, why do cells divide?

8. In what way may multicellular organisms have an advantage over single-celled ones?