3.3.1 Surface area to volume ratio

SPECIFICATION

- The relationship between the size of an organism or structure and its surface area to volume ratio.
- Changes to body shape and the development of systems in larger organisms as adaptations that facilitate exchange as this ratio reduces.
- **Students should be able to** appreciate the relationship between surface area to volume ratio and metabolic rate.

Source: AQA Spec

All organisms are capable of exchanging substances and heat with their environment. This exchange of material is very important in the survival of these organisms. Exchange of material occurs across the membranes within and between the cells of an organism. These biological membranes serves to control of internal conditions, for generating electrical potential in living organisms, and for concentrating useful chemicals.

Organisms need to exchange materials with their environment

1. **Oxygen** and **nutrients** are needed to be taken up by cells for metabolism.
2. **Waste products** of metabolism like carbon dioxide and urea need to be excreted from the body.
3. There is a need to maintain the **body temperature** of animals as it is crucial to their survival. Because of this, there is a need for **exchange of heat** between the body and the environment.

For single-celled organisms, exchange of material is easier as the diffusion pathway is short. However, for multi-cellular organisms, the rate of exchange is dependent on a number of considerations. One of which is the **surface area to volume ratio**.

Surface area to volume ratio

Surface area and volume are both important in studying the exchange of materials in an organism. The volume is important to study as it tells you how much of a substance needs exchanging. On the other hand, surface area tells you of how much of a substance can be exchanged.

Surface area refers to the area exposed to the external environment.

Volume refers to the amount of space inside of the object.

Surface Area of Cubic Pig:

6 faces x (5 x 5) = 150

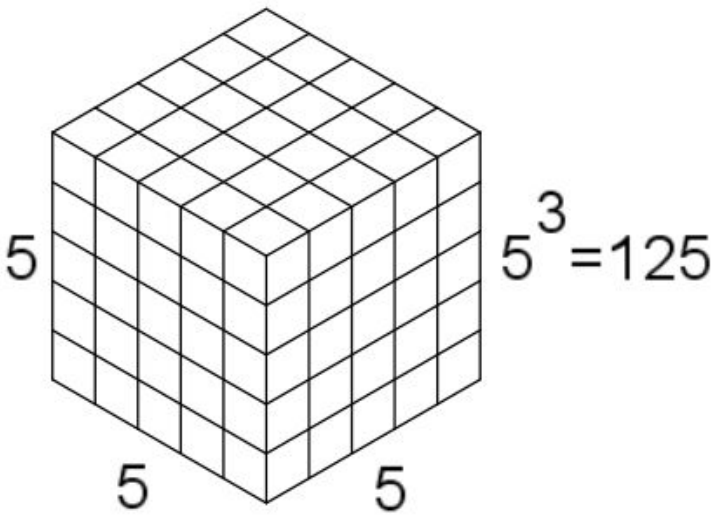
SA:V ratio of Cubic Pig: 150: 125

Let us say a cubic mouse is a 1 x 1 x1 cube:

Volume = 1 x 1 x 1 = 1

SA = 6 x (1 x 1) = 6

SA:V ratio of cubic mouse: 6:1



Cubic Pig

Image source: Wikimedia Commons

As the size of an organism increases, the surface area to volume ratio decreases.

Importance of Surface Area to Volume Ratio

The size of the cell is important when talking about exchange of material. For example, cells generally need to be small because they rely mainly on **diffusion** to get their needed materials, and to expel unwanted materials. As the cells become larger, it will be much harder for material to reach the center of the cell, thus rendering diffusion as less efficient as a mode of transport. Because of that, large cells tend to divide into two smaller cells to again produce cells with higher SA:V ratio.

Ways to Increase SA:V ratio

- **Folding** in the surface of the cell membrane to increase the surface area
- Developing into long, thin, or **elongated shaped cells**
- Presence of **large vacuoles** inside the cell that pushes the other organelles to the side of the cell for easier diffusion of materials.

For Unicellular organisms

Unicellular organisms are generally smaller than multi-cellular organisms. Their small size means a large SA:V ratio. This means it is easier for materials to move into and out of the cell by diffusion and active transport.

Developments in Multicellular Organisms for Material Exchange

Since for multi-cellular organisms, normal diffusion can not be used as the absolute means of materials exchange, these organism develop organs and mass transport systems. These developments provide a more efficient way to exchange material from the external environment into the inside of the body. It is also used to efficiently excrete or remove waste from the cells to avoid cellular damage.

These developments include:

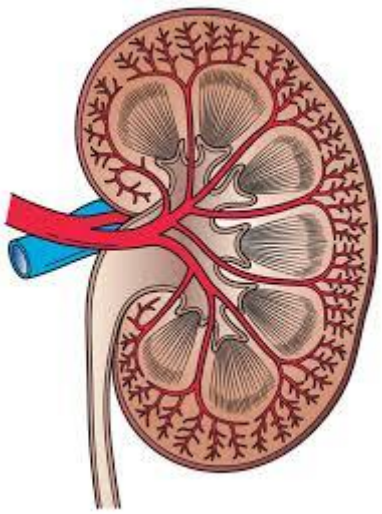
1. **Exchange organs** - Organs in charge of exchanging material from the outside environment to inside of the body. Examples lungs and kidneys.
2. **Mass transport system** - System by which materials can be transported from the exchange organs to the all the cells in the body. The transport system is also the ones used by the body to transport materials to be eliminated from the cells to the exchange organs, eventually to the outside environment. (Examples blood vessels, circulatory system, xylem and phloem in plants)

Heat Exchange

Aside from nutrients and gases to be exchanged, the body of a multicellular organism also need to have a means of exchanging heat as the organism needs to maintain its body temperature at a certain range, regardless of the external temperature. Two main factors influence heat exchange. These are:

1. **Size** - Rate of heat loss is dependent on the surface area of the organism. The larger the volume of the organism, the surface area of that organism will be smaller relative to its size. Because of this, heat loss from the body is harder. On the other hand, a small organism has a smaller volume, and a higher surface area. Since there is a high surface area where heat exchange can happen, these organisms need to have higher metabolic rate to generate more heat for it to stay warm.
2. **Shape -** Differences in shape of the organism, means difference in their surface area, thus affecting the heat loss for the organisms. Animals with more compact shape have small surface area and so need not to have high metabolic rate to minimize heat loss from the body. On the other hand, animals with less compact shape have higher surface area, and so need to have high metabolic rate to produce more heat to maintain body temperature.

Behavioral and Physiological Adaptation to Facilitate Exchange



Kidneys

Elephant Ears

Squirrel and Nuts

Images Source: Wikimedia Commons

Small desert mammals have high SA:V ratio which makes loss of water fast. To control loss of water, they develop **smaller kidneys** to produce less urine. On the other hand, the big SA:V ratio of an elephant is very low which makes them hard to cool down during the hot months. Because of this, they develop to have **large ears** to increase their surface area. In the cold region, small mammals like squirrels tend to **store nuts** as a source of high energy food that they need to support their high metabolic rates.