33.1D: Limiting Effects of Diffusion on Size and Development

Less efficient diffusion in larger cells led to multicellular organisms with specialized tissues that supply nutrients and remove waste.

Learning Objectives

- Describe how diffusion limits cell size and development

Key Points

- Diffusion is effective over a specific distance, so it’s more efficient in small, single-celled microorganisms.
- Diffusion becomes less efficient as the surface-to-volume ratio decreases, so diffusion is less effective in larger animals.
- To overcome the limitations of diffusion, multicellular organisms have developed specialized tissues and systems that are responsible for completing a limited number of nutrient and waste tasks.

Key Terms

- **surface-to-volume ratio**: the amount of surface area per unit volume of an object or collection of objects; decreases as volume increases
Limiting Effects of Diffusion on Size and Development

The exchange of nutrients and wastes between a cell and its watery environment occurs through the process of diffusion. All living cells are bathed in liquid, whether they are in a single-celled organism or a multicellular one. Diffusion is effective over a specific distance and limits the size that an individual cell can attain. If a cell is a single-celled microorganism, such as an amoeba, it can satisfy all of its nutrient and waste needs through diffusion. If the cell is too large, then diffusion is ineffective at completing all of these tasks. The center of the cell does not receive adequate nutrients nor is it able to effectively dispel its waste.

An important concept in understanding the efficiency of diffusion as a transportation mechanism is the surface-to-volume ratio. Recall that any three-dimensional object has a surface area and volume; the ratio of these two quantities is the surface-to-volume ratio. Consider a cell shaped like a perfect sphere: it has a surface area of $4\pi r^2$, and a volume of $(4/3)\pi r^3$. The surface-to-volume ratio of a sphere is $3/r$; as the cell gets bigger, its surface-to-volume ratio decreases, making diffusion less efficient. The larger the size of the sphere, or animal, the less surface area for diffusion it possesses.

Figure (PageIndex{1}): Surface-to-volume ratio: The image illustrates the comparison of spheres of one to one thousand volume units. The surface-to-volume ratio of a sphere decreases as the sphere gets bigger. The surface area of a sphere is $4\pi r^2$ and it has a volume of $(4/3)\pi r^3$ which makes the surface-to-volume ratio $3/r$. This has an effect on diffusion because it relies on the surface area of a cell: as a cell gets bigger, diffusion becomes less efficient.

The solution to producing larger organisms is for them to become multicellular. Specialization occurs in complex organisms, allowing cells to become less efficient at completing all tasks since they are now more efficient at doing fewer tasks. For example, circulatory systems bring nutrients and remove waste, while respiratory systems provide oxygen for the cells and remove carbon dioxide from them. Other organ systems have developed further specialization of cells and tissues and efficiently control body functions. Surface-to-volume ratio also applies to other areas of animal development, such as the relationship between muscle mass and cross-sectional surface area in supporting skeletons or in the relationship between muscle mass and the generation of dissipation of heat.