

Chapter 6: Interactions Between Cells and the Extracellular Environment

6.1 Extracellular Environment

Body Fluids

- The **intracellular compartment** contains 67% total body water; the **extracellular compartment** contains the remaining 33% total body water
 - **Blood plasma** is composed of about 20% of this extracellular fluid contained in the cardiovascular system
- **Blood** transports:
 - Oxygen from lungs to body cells and carbon dioxide from body cells to lungs
 - Nutrients from food to body cells, other nutrients between organs
 - Metabolic wastes to the kidneys and liver for elimination
 - Hormones from endocrine glands to target organs
- **Interstitial fluid** (extracellular tissue fluid) is composed of remaining 80% of this extracellular fluid, and contained in the extracellular matrix
 - Oxygen, nutrients and regulatory molecules in blood must pass through interstitial fluid to reach body cells, and waste products and hormone secretions must pass through interstitial fluid to reach blood plasma

Extracellular Matrix

- The **extracellular matrix** consists of collagen and elastin (provide structural strength to connective tissues), and gel-like ground substance (composed of glycoproteins and proteoglycans)
 - Example: The basal lamina is a collagen that bonds the epithelium to its underlying connective tissues
- **Integrins** are glycoproteins in the cell that extend from the cytoskeleton through the plasma membrane into the extracellular matrix, and serve as an adhesion molecules which bind intracellular and extracellular compartments
 - The actions of integrins help impart polarity to the cell, affect cell adhesion in a tissue, motility, and the ability of cells to proliferate in their tissues

Categories of Transport Across the Plasma Membrane

- The plasma membrane exhibits **selective permeability** to certain molecules
 - It is not generally permeable to large molecules like proteins, nucleic acids and other molecules needed for structure and function
 - It is generally permeable to molecules that facilitate nutrient and waste movement for metabolism, and ions used for production of impulses (in nerve/muscle cells)
- **Carrier-mediated transport** requires membrane protein carriers; **non-carrier mediated transport** allows free diffusion through the membrane
 - **Passive transport** is the net movement of molecules and ions across a membrane from higher to lower concentration
 - **Active transport** is the net movement of molecules and ions across a membrane from lower to higher concentration (requires ATP energy input)
 - ATP powers **pumps**, or specific carrier proteins

6.2 Diffusion and Osmosis

- **Diffusion** is the random motion of molecules that eliminates concentration differences between two regions of a solution separated by a permeable membrane
- **Net diffusion** is the movement of molecules from the region of higher to lower concentrations until equilibrium is established
- Mean diffusion time increases with square distance the molecules must travel

Diffusion Through the Plasma Membrane

- Nonpolar (lipid soluble) or uncharged molecules pass easily through the membrane

- Gas exchange occurs by diffusion between cells and their extracellular environments, because there is a low concentration of O₂ inside the cell and high concentration of CO₂ produced inside the cell; the concentration gradient for O₂ produces net diffusion from air to blood, and the concentration gradient for CO₂ produces net diffusion from blood to air
- Despite not being lipid-soluble, water molecules are small and lack charge, so they may pass through the plasma membrane to a limited extent (but is aided by water channels called **aquaporins** in most membranes)
- **Ion channels** permit passage of ions like Na⁺ and K⁺ through the membrane; some are always open for ongoing diffusion, while others are gated (such as specific channels for passage of Na⁺ and K⁺, which respond to changes in voltage)

Rate of Diffusion

- The speed of diffusion depends on the magnitude of the concentration gradient, permeability of the membrane, temperature of solution and membrane surface area
 - The plasma membrane is ~20 times more permeable to K⁺ than Na⁺, therefore K⁺ diffuses much more rapidly; however, changes in protein structure of membrane channels may change this rate (i.e. during production of a nerve impulse, which stimulates faster Na⁺ diffusion)
 - In body areas specialized for rapid diffusion, the surface area of membranes may be increased by folds or microvilli may aid molecule transport

Osmosis

- **Osmosis** is the net diffusion of water across a selectively permeable membrane which separates different solute concentrations
 - **Osmotically active** solutes are those that cannot pass through the membrane and promote movement
 - There is net movement from higher to lower water concentration
- **Osmotic Pressure** is the pressure needed to stop osmosis
 - The greater the concentration of a solute, the greater its osmotic pressure

Molarity and Molality

- A **mole** always contains 6.02×10^{23} molecules
- A **one-molar solution** is composed of 1 mole solute dissolved in water to make 1 liter of solution
- **Molality**: in a 1-molal solution, 1 mole of solute is dissolved in 1 kilogram water

Osmolality

- **Osmolality (Osm)** expresses the total molality of a solution
 - Osmotic pressure does not depend on the chemical nature of the solute, but ratio of solute to solvent; for example, a solution of 1.0 m glucose and 1.0 m fructose has an osmolality (total molality) of 2.0 osmol/L (=2.0 Osm)
 - A 1.0 m solution of NaCl has a total concentration of 2.0 Osm

Measurement of Osmolality

- Freezing-point depression is a good measure of osmolality since it depends on total concentration of the solution, and not on chemical nature of the solute
- One mole of solute per liter depresses the freezing point of water by -1.86°C
 - A 1.0 m glucose solution freezes at -1.86°C, and a 1.0 m NaCl solution freezes at $2 \times (-1.86) = -3.72^\circ\text{C}$

Tonicity

- **Tonicity** describes the effect of a solution on the osmotic movement of water
 - **Isotonic** solutions contain the same amount of dissolved substance
 - **Hypo-osmotic/hypertonic** solutions have lower concentrations relative to solvent; **hypertonic** solutions have higher concentrations relative to solvent
 - **Crenation** will occur when water moves out of the cell into a region of higher solute concentration

Regulation of Blood Osmolality

- A fairly constant osmolality of extracellular fluid must be maintained in order to prevent swelling or shrinkage of the brain
 - When dehydration occurs blood conc. increases and volume reduces:
 - Increased plasma osmolality and osmotic pressure stimulate **osmoreceptors** (neurons located in the **hypothalamus**)
 - Water leaves osmoreceptors, causing them to shrink and increase production of nerve impulses (which stimulates thirst)
 - The posterior pituitary releases **antidiuretic hormones (ADH)** into the blood, which acts on the kidneys to promote water retention so that a lower volume of more concentrated urine is excreted
 - Salt deprivation, on the contrary, lowers plasma osmolality:
 - Osmoreceptors become less stimulated, and the posterior pituitary releases less ADH (so that more water is excreted in the urine to restore appropriate plasma concentration)

6.3 Carrier-Mediated Transport

- Common characteristics of enzymes and carrier proteins are specificity, competition, and saturation
- As the concentration of a transported molecule increases, its rate of transport will increase until it reaches a **transport maximum (T_m)**, at which point the carrier transport is said to be **saturated**

Facilitated Diffusion

- Facilitated diffusion is illustrated by the transport of glucose from the blood across the plasma membrane
- Facilitated diffusion is powered by thermal energy of diffusing molecules (does not require ATP), and involves net transport from higher to lower concentration
- Unlike simple diffusion, diffusion of glucose through the plasma membrane exhibits properties of carrier-mediated transport
 - The carrier protein has a site which binds specifically to glucose, causing a conformational change so a pathway is formed through the membrane and glucose can diffuse down its concentration gradient

Active Transport

- In certain cases, glucose is transported against its gradient by a different carrier, dependent on simultaneous transport of ions (i.e. epithelial cells of kidney tubules and small intestine)
- **Active transport** is the movement of molecules and ions against their concentration gradients, from lower to higher concentrations
 - Active transport requires expenditure of metabolic energy from ATP
 - “Pumps” are primary active transport carriers
- **Primary active transport** occurs when hydrolysis of ATP is responsible for carrier (proteins that span the membrane) functions
 - Pumping action is controlled by addition/removal of ATP phosphate groups

The Ca²⁺ Pump

- Ca²⁺ pumps are located on the plasma membranes of all cells and striated muscle endoplasmic reticulum membranes
 - Active transport by Ca²⁺ pump moves Ca²⁺ from cytoplasm into the extracellular fluid or ER cisternae, creating a gradient that signals the release of neurotransmitters from axon terminals and muscle contractions
 - The Ca²⁺ pump is activated by phosphorylation, using Pi derived from ATP:
 - Binding of cytoplasmic Ca²⁺ to an amino acid site (on pump) activates ATPase, causing hydrolysis of ATP to ADP and Pi (bound to pump)
 - Both the exits for Ca²⁺ are now temporarily blocked