TOPIC II: CELL PHYSIOLOGY I

Learning Outcomes: Upon completion of Topic II (2), you should be able to:

a) Describe the phospholipid bilayer of the cell membrane and explain its function in controlling permeability.
b) Describe the function of, and where applicable, give examples of, the following cell membrane proteins: channels, carrier proteins, receptor proteins, enzymes, joining proteins and identifying proteins.
c) Describe the structure and function of membrane carbohydrates.
d) Compare and contrast simple diffusion, facilitated diffusion and facilitated transport in respect to their mechanisms, the type of material being moved, and the energy source for the movement.
e) Define osmosis and explain how it differs from simple diffusion.
f) Define osmotic pressure.
g) Compare and contrast osmolarity (osmotic pressure) and tonicity of solutions.
h) Describe the effects of hypotonic, isotonic and hypertonic solutions on cells.
i) Compare and contrast facilitated transport, primary active transport and secondary active transport in respect to their mechanisms, the type of material being moved, and the energy source for the movement.
j) Compare and contrast exocytosis, endocytosis, pinocytosis and phagocytosis in respect to their mechanisms, the direction of movement, the type of material being moved, and the energy source for that movement.

A) The Cell Membrane

1) Phospholipid Bilayer
- continuous layer around cell
- barrier to water soluble substances – **NOT** to small molecules and/or lipid soluble molecules (e.g. O_2 & CO_2)

2) Membrane Proteins
a) transport proteins
i) channels
- form pore in membrane
- selectively permit channel-mediated facilitated diffusion of specific ions
- can be:
① gated: can open or close – in response to stimuli
② non-gated (= leakage channels): always open

ii) carrier proteins

- bind solute + carry it across membrane
- allow protein carrier-mediated <u>facilitated transport</u> OR <u>active transport</u>
- e.g. glucose transporters

b) receptor proteins
- can bind specific extracellular molecules (= ligands) e.g. hormones, neurotransmitters (nt)
- e.g. glucose uptake:
  i) insulin binds to receptor on skel. muscle or adipose tissue
  ii) triggers movement of more glucose transporters to cell membrane
  iii) ↑ glucose movement from blood into cells

c) enzymes
- control chemical reactions on outer or inner surface
- e.g. 1: acetylcholinesterase
- e.g. 2: Na^+/K^+- ATPase - all cells have this

d) joining (linker) proteins
- anchor cell membrane to cytoskeleton or an adjacent cell
  i) junctional proteins between cells forming:
    - desmosomes, tight junctions, gap junctions
  ii) extracellular fibres (usually glycoproteins)

e) <u>identifying proteins</u>
- e.g. Major Histocompatibility Complex (MHC) proteins
  - on surface of all cells except rbc
  - identify cell as "self" (part of the body) - not foreign

3) Membrane Carbohydrates
- glycoproteins and glycolipids
- differ for every cell type - allow cells to recognize type e.g. sperm recognizes egg

B) <u>Membrane Transport</u>
- movement of material between the intra- and extracellular fluids
- terms:
  - solute – substance dissolved in a solution
  - solvent – substance solute is dissolved in e.g. water
- types of transport:
  1) Passive Transport

- no energy required (no ATP)
- movement from a high to low concentration (i.e. down its concentration gradient)
- the greater the difference in concentration = the more & faster the molecules will move
- types:
    a) Simple diffusion (solute movement)
        - solute crosses through cell membrane bilayer ∴ small, lipid soluble (O_2, CO_2, etc)
    b) Facilitated diffusion (solute movement)
        - ions diffuse through membrane via protein channels
    c) Facilitated transport (solute movement)
        - large, charged or water-soluble molecules
        - move across membrane using a specific carrier protein
            - must bind to protein to be transported
        - e.g. glucose into liver or skel. muscle cells
    d) Osmosis (solvent movement)
        - movement of H_2O across a semipermeable membrane (permeable to H_2O) due to [H_2O] difference (H_2O moves down its concentration gradient) via pores (channels) or across the membrane bilayer
        - note:
            - high [H_2O] = low [solute]- dilute solution
            - low [H_2O] = high [solute] – concentrated solution
            - [solute] depends on the number of ions or molecules, not the type
        - Osmotic Pressure (OP)
            - pressure that must be applied to prevent movement of H_2O from pure H_2O solution (S1) across a semipermeable membrane into another solution (S2)

            i) if S2 has high [salt] (low [H_2O]) then H_2O will move into it → requires pressure to stop it moving into S2
            ∴ the greater [salt] in S2, the greater the OP and lower [H_2O] → more water will move in (down its gradient) → more P needed to stop it moving

            ii) if S2 also = pure H_2O, → no P required to prevent H_2O movement (no gradient) ∴ S2 OP = 0

- OP is used as a measure of the [solute] in a solution
  - high OP = high [solute] (low [H_2O]) + vice versa

- Tonicity
  - response of a cell immersed in a solution
  - depends on [solute] (and permeability of cell membrane to the solute)
  - classifications:
    - i) Isotonic solution
      - cell neither swells nor shrinks
      - ECF and ICF have equal OP
      - rbc - [all solutes] in ICF = 0.9% saline (NaCl) solution (= normal saline)
    - ii) Hypotonic solution
      - cell swells (takes in water)
      - ECF has higher [H_2O] (lower OP) than ICF (cytosol)
      - <0.9% NaCl e.g. 0.1%
      - swelling can rupture cell = lysis
        - if a red blood cell → hemolysis
    - iii) Hypertonic solution
      - cell shrinks (loses H_2O)
      - ECF has lower [H_2O] (higher OP) than ICF (cytosol)
      - >0.9% NaCl e.g. 1.5%
  - uses:
    - injecting 10% sucrose solution (hypertonic) will draw water into blood from tissues
    - e.g. use to ↓ brain edema (swelling)

- Osmosis role in <u>regulation of [solute]:</u>
  - Concentration of solutes in body fluids must be maintained within narrow limits or cells will die
    - Major body fluids:
      - i) extracellular fluids (ECFs):
        - blood plasma

- interstitial fluid (ISF)
ii) intracellular fluid (ICF)

- e.g. if body loses H_2O (e.g. sweat) ⇒ [blood] ↑
∴ blood OP ↑ → fluid moves from tissues into blood
- response = thirst and ↓ renal H_2O loss which leads to ↓ urine production

e) Bulk Flow
- movement of fluid (+ solutes) due to a pressure gradient (high pressure to low pressure)
- hydrostatic pressure = P of a fluid pressing against a surface e.g. cell membrane, blood vessel wall (= blood pressure)
e.g. capillary
– if blood has higher pressure than ISF, fluid flows out of capillary (= filtration)
- if ISF has higher pressure than blood, fluid flows from ISF into capillary (= absorption)

2) Active Processes
- require energy (ATP)
- types:
a) Active Transport
- substances move against conc. gradient (low to high)
- always protein carrier-mediated
- types:
i) Primary (1^o) Active Transport
- molecular pumps - ATP breakdown is a direct part of transport process i.e. one protein breaks down ATP and transports the solute(s)
- e.g. Na^+/K^+-ATPase – 3 Na^+ out of cell and 2 K^+ in per ATP
ii) Secondary (2^o) Active Transport
- cotransport (2 proteins involved & use of ATP is indirect) i.e. one protein breaks down ATP (creating a Na^+ gradient = stored energy) and another protein transport the solute(s)
- e.g. glucose entry at small intestine - 2 steps:
① Na^+ gradient established by Na^+/K^+-ATPase (= ATP-use step)

② glucose & Na^+ both must bind to carrier and are cotransported into the cell → Na^+ moving down its concentration gradient drives in glucose against glucose concentration gradient (= transport step) ∴ <u>glucose</u> transport is active

b) Vesicular Transport

- substance is surrounded by a membrane within a cell (a vesicle)
- types:
  - i) endocytosis - movement into a cell
    - ① phagocytosis
      - large items into cell (e.g. bacteria) = "cell eating"
    - ② pinocytosis (bulk phase endocytosis)
      - fluids (+ dissolved substances) = "cell drinking"
  - ii) exocytosis - movement out of cell
    - vesicles containing hormone, enzymes, neurotransmitter etc
    - fuse with cell membrane, releasing contents into ECF (triggered by a rise in cytosolic Ca^{++})