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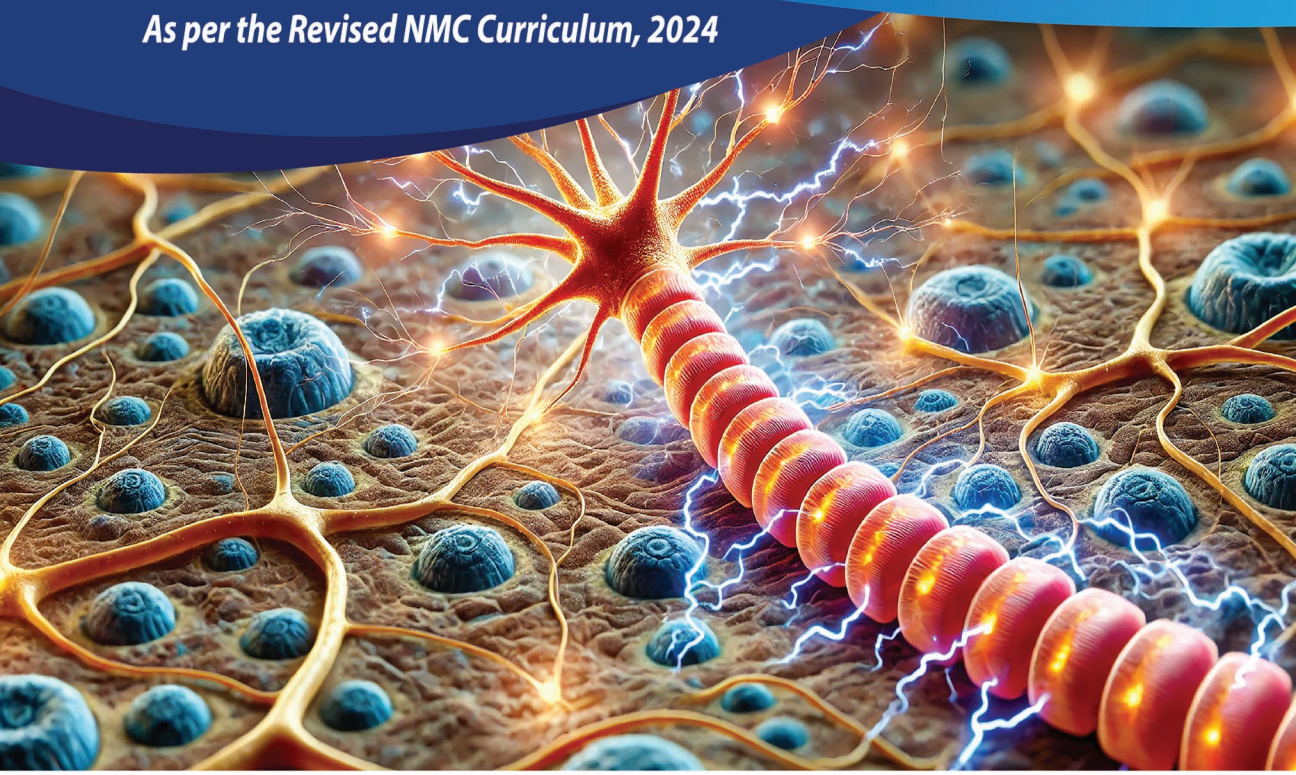
Whys and Hows of Physiology

As per the Revised NMC Curriculum, 2024



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Foreword
Neelam Vaney

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CHAPTER

1

General Physiology

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Q1. Why is cholesterol known as the 'fluidity buffer' of cell membranes?

Ans. Cholesterol acts as a "fluidity buffer" as it keeps the fluidity of the acyl chain region of the phospholipid bilayer in an intermediate range in the presence of agents, such as alcohols, that would otherwise make the biological membranes more fluid.

Q2. Why is blistering of skin common in defective intermediate filaments?

Ans. Intermediate filaments resist external pressure by forming a flexible scaffolding for the cell. If intermediate filaments are absent or abnormal, cells rupture easily and often manifest as skin blisters.

Q3. How does the anticancer drug Paclitaxel (Taxol) act on microtubules to prevent cell proliferation?

Ans. The microtubules form the spindle, which moves the chromosomes in mitosis. The drug binds to microtubules, making them so stable that the mitotic spindles cannot form, and the cells die.

Q4. Why are lysosomes called suicidal bags?

Ans. Lysosomes contain hydrolytic enzymes ribonuclease, deoxyribonuclease, phosphatase, collagenase, etc., that cause autolysis of the cell remnants when it dies.

Q5. Why are mitochondria said to have a maternal inheritance?

Ans. Sperm contributes no mitochondria to the zygote, so all mitochondria are derived from the ovum hence their inheritance is maternal. This maternal inheritance has been used as a tool to track evolutionary descent.

Q6. Why is water molecule (H_2O) an ideal solvent for physiological reactions?

Ans. H_2O has a dipole moment where oxygen slightly pulls away electrons from the hydrogen atoms creating a charge separation that makes the molecule polar, allowing it to dissolve a variety of charged atoms and molecules. It also allows the H_2O molecule to interact with other H_2O molecules via hydrogen bonding that gives water a high surface tension, high heat of vaporization and heat capacity, and a high dielectric constant. These properties make water an ideal solvent for physiological reactions.

Q7. How is the ECF and ICF volume altered on loss of 1 L of water (hypotonic solution) from the human body?

Ans. Loss of hypotonic fluid will decrease ECF volume but increase its osmolality. This will shift water from ICF to ECF, thus decreasing the volume of ICF as well. Hence loss of 1 L of water will decrease ECF and ICF volume by 667 mL and 333 mL respectively.

Q8. Why is there no change in ICF volume on loss of 1 L of isotonic solution from the body?

Ans. No change in osmolality is observed if there is a loss of isotonic solution. Since there is no fluid shift from ICF to ECF, hence ICF volume remains the same.

Q9. Why would the hematocrit increase if a man loses 3 liters of sweat and drinks 3 liters of water while running a marathon on a summer day?

Ans. Approximately 3 liters of sweat replaced by 3 liters of water makes total body water loss zero, but a net loss of NaCl decreases the osmolarity of ECF and plasma, making it hypotonic. The RBCs in hypotonic plasma will imbibe water and swell, increasing the MCV. This will in turn increase the hematocrit.

Q10. Why is there no change in ICF volume if a healthy man eats a bag of chips containing 900 mOsmol of NaCl and drinks 3 liters of water? (Assume that none of the NaCl or H_2O is excreted).

Ans. Osmolarity = Total moles of solute (mOsmol)/Volume of solution (L)

So, Osmolarity = 900 mOsmol/3 L = 300 mOsmol/L

This osmolarity matches that of normal extracellular fluid (ECF), which is also around 300 mOsmol/L. Therefore, the solution ingested is isosmotic with the body's extracellular fluid. No osmotic pressure exists to pull water into or out of the ICF. As a result, the ICF volume remains unchanged while only the ECF volume increases.

Q11. How does Na^+K^+-ATPase maintain the resting membrane potential?

Ans. Na^+K^+-ATPase is an electrogenic pump with a coupling ratio of 3:2. It catalyzes the hydrolysis of ATP to adenosine diphosphate (ADP) and uses the energy to extrude three Na^+ from the cell and takes two K^+ into the cell for each molecule of ATP hydrolyzed, thus, there is a net loss of one positive ion intracellularly.

Q12. How is blocking of Na^+K^+-ATPase by cardiac glycoside (digoxin) useful in cardiac failure?

Ans. The Na^+Ca^{2+} exchanger present in cardiac muscles extrudes Ca^{2+} in exchange for Na^+, thus decreasing intracellular calcium. If more Na^+ is inside, more Ca^{2+} is extruded. Inhibition of Na^+K^+ pump by digoxin decreases intracellular Na^+, hence less Ca^+ is extruded out in exchange of Na^+. This increases intracellular Ca^{2+}, thus increasing the force of contraction in cardiac failure.

Q13. How is osmolarity different from tonicity?

Ans. Osmolarity is concentration expressed in units of solute/volume. It can be measured on a machine called an osmometer, and it has units, usually osmoles or mOsm/L. Osmolality is expressed as kg of water instead of liters. Tonicity is used to describe the osmolality of a solution relative to plasma. Solutions that have the same osmolality as plasma are said to be isotonic; those with greater osmolality are hypertonic; and those with lesser osmolality are hypotonic. A cell in a hypertonic solution will lose volume and shrink, when placed in a hypotonic solution will gain volume and swell. It cannot be measured on an osmometer, and it has no unit. Tonicity depends on osmolarity and permeability of the solutes.

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Q14. Why 0.9% NaCl (normal saline) is isosmotic as well as isotonic?

Ans. The concentration of 0.9% NaCl on an osmometer is 278 mOsmol/L, so it is isosmotic. It remains isotonic because there is no net movement of the osmotically active particles in the solution into cells and the particles are not metabolized.

Q15. Why is 5% glucose solution initially isosmotic with plasma but the net effect is that of infusing a hypotonic solution?

Ans. The concentration of 5% glucose on an osmometer is 278 mOsmol/L, so it is isosmotic. But glucose is metabolized and its osmolality decreases, so the net effect is that of infusing a hypotonic solution.

Q16. Why is the contribution of plasma proteins to the total osmolar concentration of plasma less?

Ans. Although the concentration of the plasma proteins is large when expressed in grams per liter, they normally contribute <2 mOsm/L because of their very high molecular weights.

Q17. Why does the excitable cell become more excitable in hyperkalemia?

Ans. The concentration gradient for K^+ is established across a membrane secondary to very high intracellular potassium concentrations and a relative paucity of potassium ions in the extracellular space. This concentration gradient is maintained by Na^+ K^+-ATPase on the cellular wall, which actively pumps sodium out of the cell and potassium inward. The potassium gradient across the cellular membrane is the most important factor in establishing the resting membrane potential. If potassium levels increase in the extracellular space, the magnitude of the concentration gradient for potassium across the cell diminishes, and diffusion of K^+ decreases, thus decreasing the resting membrane potential and making the cell more excitable.

Q18. How does an increase and decrease in extracellular sodium affect the membrane potential at rest?

Ans. Hypo- and hypernatremia have negligible effects on RMP as Na^+ is least permeable in resting conditions.

Q19. Why are biological membranes known as permeability barriers?

Ans. Water soluble molecules are poorly soluble in the nonpolar environment in the interior of the lipid bilayer of biological membranes. Consequently, biological membranes pose a formidable barrier to the diffusion of most water-soluble molecules. For many substances, this barrier allows the maintenance of large concentration differences between the cytoplasm and the extracellular fluid.

Q20. How can the Nernst equation be used to predict the direction in which the ions tend to flow?

Ans. If the potential difference measured across a membrane is equal to the potential difference calculated from the Nernst equation for a particular ion (e.g., chloride ions –70 mV), then that ion is in electrochemical equilibrium across the membrane, and no net flow of that ion will occur across the membrane. If the measured electrical potential is of the same sign but larger in magnitude than the calculated value (e.g., K^+ –90 mV),

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then the electrical force is larger than the concentration force, and net movement of that particular ion tends to occur in the direction determined by the electrical force. If the measured electrical potential difference across the membrane is of the opposite sign to that predicted by the Nernst equation for a particular ion (e.g., Na^+ 65 mV), then the electrical and concentration forces are in the same direction. Thus, that ion cannot be in equilibrium, and it tends to flow in the direction determined by both electrical and concentration forces.

Q21. Why are cations more and anions less intracellularly?

Ans. The Gibbs-Donnan equilibrium states that in the presence of nondiffusible ions, the diffusible ions are distributed in such a way that the product of diffusible electrolytes in both compartments are equal, their electrical neutrality is maintained, and the total number of a particular type of ions before and after equilibrium is the same. This explains the presence of more cations and fewer anions in the ICF where nondiffusible proteins are present.

Q22. Why are Na^+ and K^+ ion channels responsible for action potential known as voltage-gated channels?

Ans. These channels are voltage-gated because they open and close at a specific membrane potential. Na^+ channels open when the membrane potential is depolarized by 15 mV (–70 to –55 mV). Closure of Na^+ channels and opening of K^+ channels occur at +35 mV of depolarization.

Q23. How does serum calcium affect the excitability of nerve and muscle?

Ans. A high extracellular Ca^{2+} stabilizes the membrane by decreasing Na^+ ion permeability. Hypocalcemia increases the excitability of nerve and muscle by causing uncontrolled Na^+ influx.

Q24. How is resting membrane potential (RMP) produced?

Ans. Resting membrane potential (RMP) is due to the varying permeability of the ions across the cell membrane, primarily K^+ ion. The concentration gradient for K^+ facilitates its movement out of the cell via K^+ channels, but its electrical gradient is in the opposite (inward) direction. Consequently, an equilibrium is reached in which the tendency of K^+ to move out of the cell is balanced by its tendency to move into the cell, and at that equilibrium there is a slight excess of cations on the outside and anions on the inside. This condition is maintained by Na^+K^+-ATPase as it moves three Na^+ out of the cell for every two K^+ moved in (3:2), maintaining negativity inside hence it is termed an electrogenic pump.

Q25. How does a change in ionic permeability affect the membrane potential?

Ans. When an ion becomes more permeable, the membrane potential moves toward the Nernst potential of that ion. For example, if the permeability of Na^+ ion increases (Nernst potential +60 mV), the potential of the nerve (–70 mV) will try to become positive, i.e., it will depolarize. Similarly, if K^+ permeability (Nernst potential –90 mV) increases, the potential will try to become more negative (hyperpolarized).

Q26. How is all or none law applicable to an action potential (AP)?

Ans. Each action potential has a fixed amplitude of around 110 mV (–70 to +40 mV). If a subthreshold stimulus is given, AP is not produced. On threshold stimulus, the

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response is produced. On further increasing the strength, the magnitude of the AP remains the same, there is no graded increase in the magnitude.

Q27. How does temperature affect the action potential?

Ans. When the temperature is raised, the frequency of action potential increases due to rapid depolarization followed by repolarization. This may be attributed to the increase in permeability of these ions.

Q28. Why do the symptoms of multiple sclerosis (MS) get aggravated by increased body temperature or ambient temperature?

Ans. Research has shown that segmental axonal demyelination in MS unmasks an increased density of membrane K^+ channels with a predilection for current leak via K^+ efflux. Additionally, there is the insertion of new Na^+ channels within the axonal membrane as an ion channel adaptation to demyelination. However, these new channels exhibit an altered high sensitivity to temperature-induced pore closure, where even elevation of temperature by 0.2–0.5°C may compromise AP depolarization.

Q29. Why is there an increase in the threshold for an action potential in a nerve fiber during a slowly developing or prolonged depolarization (neuronal accommodation)?

Ans. In parallel with the depolarization and sodium channel activation, the inactivation process of the sodium channels is also driven by depolarization. Since the inactivation is much slower than the activation process, the threshold stimulus fails to open the inactivated Na^+ channels and excite the nerve fiber again. The other reason could be an increase in K^+ conductance in response to a slow cathodal current.

Q30. How is membrane excitability affected by local anesthetics?

Ans. Local anesthetic agents like lidocaine and procainamide decrease membrane excitability and conduction by blocking voltage gated Na^+ channels. However, they have no effect on RMP.

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Whys and Hows of Physiology

The book *Whys and Hows of Physiology* is thoughtfully crafted to simplify the complexities of physiology for Undergraduate and Postgraduate students by addressing two essential questions that drive understanding in physiology: "Why does it happen?" and "How does it happen?" Starting with foundational principles, the book builds up to advanced topics across different organ systems, using this questioning approach to engage readers and promote critical thinking.

With the increasing focus on competency-based medical education, understanding core physiological concepts and their real-world applications is essential. This book serves as a comprehensive yet accessible guide, emphasizing key facts and fundamental concepts, making it an invaluable resource for students seeking clarity and deeper insight into physiology.

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Printed in India

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EMCA House, 23/23-B, Ansari Road,
Daryaganj, New Delhi - 110 002, INDIA
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ISBN 978-93-6616-961-3