14

BODY WATER, OSMOLARITY AND IONIC COMPOSITION OF BODY FLUIDS

14.1 INTRODUCTION

Water is the solvent of life. It bathes our cells, dissolves and transports compounds in the blood, provides a medium for movement of molecules into and throughout cellular compartments, separates charged molecules, dissipates heat, and participates in chemical reactions. In spite of the variation in the amount of water we ingest each day and produce from metabolism, our body maintains a nearly constant amount of water that is approximately 60% of our body weight.

OBJECTIVES

After reading this lesson, you will be able to:

- describe the fluid component in the body
- explain ionic composition of body fluids
- explain osmolarity and osmolality
- describe the buffer systems of human body

14.2 FLUID COMPARTMENTS IN THE BODY

Total body water is roughly 50 to 60% of body weight in adults and 75% of body weight in children. Because fat has relatively little water associated with it, obese people tend to have a lower percentage of body water than thin people, women tend to have a lower percentage than men, and older people have a lower percentage than younger people.

Total body water is approximately around 42L. Approximately 40% (1/3rd) of the total body water is intracellular fluid (ICF) and 60% (2/3rd) is extracellular fluid (ECF).

ECF : The extracellular fluid includes

(i) *Plasma*: fluid part of blood after the blood cells have been removed. It constitutes about 25% of ECF.

(ii) *Interstitial water*: the fluid in the tissue spaces, lying between cells and also includes lymph. It constitutes about 75 % of ECF..

(iii) *Transcellular water* : a small, specialized portion of extracellular water that includes gastrointestinal secretions, urine, sweat.

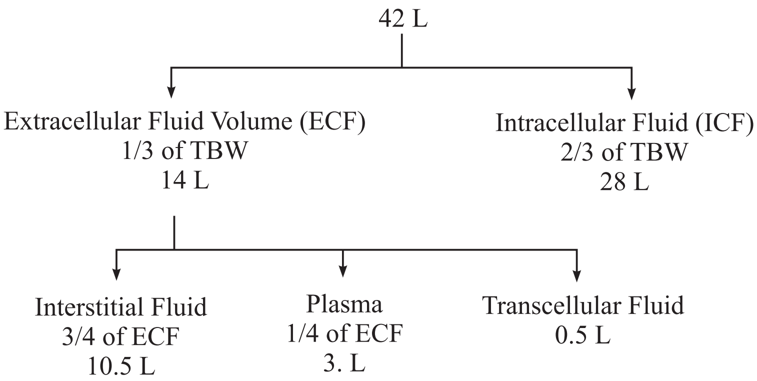

Fig. 14.1: Distribution of body fluid compartments

14.3 IONIC COMPOSITIN OF BODY FLUIDS

The ions are unequally distributed between the ECF and ICF compartments.

ECF

Major cation: Na^+

Major anion: Cl^- and HCO_3^-

ICF

Major cation: K^+

Major anion: Inorganic Phosphates

Table 14.1: Concentration of ions in body fluids

Ions mmol/L	ECF	ICF
Cations		
Na^+	145	12
K^+	4	150
Anions		
Cl^-	105	5
HCO_3^-	25	12
Inorganic Phosphates	2	100

14.4 OSMOLARITY AND OSMOLALITY

The number of molecules of a particular substance per unit volume of a particular body fluid is expressed in moles or osmoles.

A mole is the gram molecular weight of a substance i.e. the molecular weight of the substance in grams.

Osmolarity: The number of osmoles per litre of solution is called osmolarity.

Osmolality: The number of osmoles per kilogram of solvent is called osmolality

14.4.1 Body Fluid Osmolality

Normally, the osmolality of the ECF and ICF are at equilibrium in spite of difference in composition of electrolytes. The osmotic equilibrium between ECF and ICF is maintained by easy transfer of water between the compartments. Plasma osmolality can be easily measured which reflects the osmolality of ECF and ICF.

Normal Plasma osmolality ranges between 280 to 295 mosm/kg H_2O. Sodium and Chloride contributes to 90% of plasma osmolality and the rest is by glucose, urea, proteins and other ions. Chloride movement from one compartment to other always follows the movement of sodium. Therefore, it is mainly sodium that maintains the osmolality.

Hence Plasma osmolality is calculated as,

Plasma osmolality (mmol/kg) = 2 × Plasma Na^+ (mmol/L)

14.5 TONICITY OF FLUID

Isotonic fluid

Isotonic fluid is fluid having the same osmolality as that of plasma. Isotonic fluid do not change the volume of cells. Examples: 0.9% NaCl, 5% glucose, 10% mannitol, 20% urea.

Hypotonic fluid

Hypotonic fluid is fluid having osmolality less than that of plasma. The cells swell when placed in hypotonic solution.

Hypertonic fluid

Hypertonic fluid is fluid having osmolality more than that of plasma. The cells shink when placed in hypertonic solution.

14.6 DISORDERS OF FLUID VOLUME

Iso-osmotic dehydration

This occurs during loss of isotonic fluid from the body. Examples are diarrhea, vomiting, hemorrhage

Hypo-osmotic dehydration

This occurs during loss of salt in excess of water from the body. It's seen in Adrenocortical insufficiency.

Hyperosmotic dehydration

This occurs during loss of water in excess of solutes from the body. It's seen in Diabetes insipidus, excessive sweating.

Iso-osmotic volume expansion

This occurs during excessive infusion of isotonic fluid into the body.

Hypo-oosmotic volume expansion

This occurs during excessive water gain into the body. It's seen during ingestion of large volume of water.

Hyperosmotic volume expansion

This occurs during excessive infusion of hypertonic saline.

INTEXT QUESTIONS 14.1

1. Short notes

1. Classify the body fluid comparments
2. Write down the ionic composition of different fluid compartment in the body.
3. Define osmolality and give normal value of plasma osmolality. Give examples of isotonic, hypotonic and hypertonic fluid.

2. Fill in the blanks.

1. Plasma constitutes …………… percentage of ECF.
2. Major cation present in the ECF is…………………..
3. Major cation present in TCF is ………………
4. Plasma osmolality is determined by …………… ion.
5. 20% urea is an example of ………………… fluid.

3. State if the following statements are true or false.

1. 0.9% saline is hypotonic fluid.
2. Cells swell when placed in hypotonic solution.
3. Diarrhoea causes hypotonic dehydration.
4. K^+ ion is the major ion contributing to plasma osmolality.
5. 60% of body fluid is comprised by ECF.

14.7 BUFFER SYSTEM IN BLOOD, ROLE OF LUNGS AND KIDNEYS IN ACID-BASE BALANCE

Acid – Base homeostasis is essential to the body. Many enzymatic activities and metabolic processes need an optimal pH. Hence, any disturbance in the acid-base balance leads to derangement in the vital functions of the body.

14.7.1 Definitions

Acid: chemical substance that can donate H^+

Base: chemical substance that can accept H^+

Examples : Strong acids (e.g. HCl, H_2SO_4)

Strong bases (e.g. NaOH, KOH)

Weak acids (e.g. H_2CO_3, CH_3COOH)

Weak bases (e.g. NH_3)

pH: The pH of the solution is defined as the negative logarithm of the hydrogen ion concentration in the solution.

pK and K_a : The pK is defined as the negative logarithm of the ionization constant of an acid (K_a) in a solution. pK is the pH at which concentration of acid and its conjugate base are in equal proportion.

Buffer: An aqueous solution of weak acid & its conjugate base or a weak base & its conjugate acid, that resist changes in pH to addition or removal of small amounts of acids/ bases.

$$HB \leftrightarrow H^+ + B^-$$

The efficiency of a buffer is given by Henderson-Hasselbach equation:

$$pH = pKa + \log \frac{[Anion]}{[Acid]}$$

14.7.2 Concept of Acid–Base Balance

Normal pH of the body is maintained over a very narrow range of 7.35 to 7.45. Acids are continuously produced in the body. But there are mechanisms that buffer the acids.

Acidosis : decreased pH.

Alkalosis: increased pH.

Volatile acid: Carbonic acid (H_2CO_3) à dissociates into CO_2: excreted by lungs

Non-volatile/ fixed acids: H_2SO_4, H_3PO_4 & organic acids; excreted exclusively by kidneys

Acid load in the body :

- volatile acids
- non volatile acids ingested in diet
- non volatile acids produced from metabolism
- Bicarbonate excreted in feces also contributes to acid load

This acid load is excreted by both lungs and kidneys to maintain the homeostasis.

The reabsorption of the bicarbonate which is filtered by the kidneys also corresponds to the acid – base balance, apart from the excretion of the acid load.

14.7.3 Buffer Systems in the Body

There are four buffer systems in the body:

I. Bicarbonate-carbonic acid buffer system

II. Plasma protein buffer system

III. Phosphate buffer system

IV. Hemoglobin buffer system

Bicarbonate-carbonic acid buffer system

- Most important buffer system in plasma
- In lungs it is involved in removal of acid in the form of CO_2
- In kidneys it is involved in reabsorption of bicarbonates.

Plasma protein buffer system

- Accounts for 95 % of non bicarbonate buffer in plasma.
- Mainly is contributed by abumin.

Phosphate buffer system

- Is an important intracellular buffer
- Has organic and inorganic components
- Organic phosphate : ATP, AMP, ADP
- Inorganic phosphate : Disodium hydrogen phosphate, sodium dihydrogen phosphate

Hemoglobin buffer system

- Major buffer in RBCs, around 85%.
- The rest 15 % is by 2,3- Diphosphoglycerate.
- Histidine residue in Hb is responsible for buffering action.

14.7.4 Role of Lungs in Acid – Base Balance

The respiratory mechanism gets mainly operated by changing the rate and depth of respiration. The bicarbonate buffer system is the major regulator.

The carbonic acid in the body reacts with H^+ and produces CO_2.

$$HCO_3^- + H^+ \longrightarrow H_2O + CO_2$$

The level of CO_2 in the body in turn stimulates the chemoreceptors and increases ventilation. The increased ventilation causes removal of CO_2.

14.7.5 Role of Kidneys in Acid – Base Balance

Three major mechanisms operate in kidneys:

HCO_3^- reabsorption

Excretion of H^+ as titratable acid (with PO_4^{3-} buffer)

Excretion of H^+ as NH_4^+

14.7.5.1 HCO_3^- reabsorption

- Almost all the filtered of HCO_3^- reabsorbed (4320 mEq per day)
  - 80% in Proximal Convoluted Tubule
  - 10% in Thick Ascending Limb
  - 6% in Distal Convoluted Tubule
  - 4% in Collecting Duct
- Mechanisms: different in different sites

14.7.5.1.1 HCO_3^- reabsorption In PCT and TAL

1. H^+ secretion in the apical membrane using:
   (a) Na^+ - H^+ exchanger/ antiporter (NHE3):
   - predominant pathway
   - a form of secondary active transport

   (b) H^+-ATPase: a form of active transport
2. HCO_3^- exit at the basolateral membrane using:
   (a) Na^+-HCO_3^- cotransporter (NBC1)
   (b) Cl^--HCO_3^- antiporter

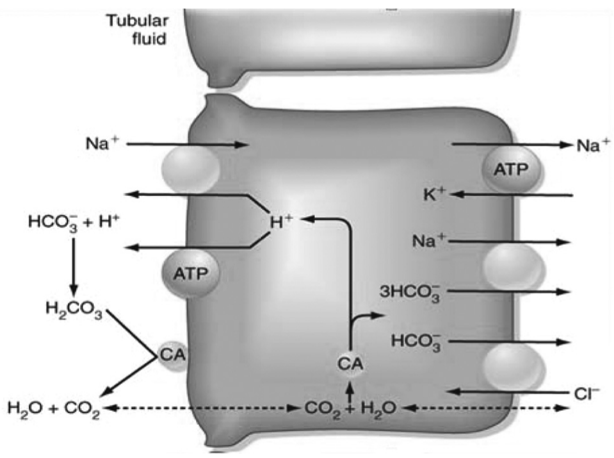

Fig. 14.2: Bicarconate reabsorption in PCT

14.7.5.1.2 HCO_3^- reabsorption In DCT and CD

1. H^+ secretion in the apical membrane:
   (a) H^+-ATPase: a form of active transport
   (b) H^+/K^+-ATPase: similar to that found in gastric parietal cell
2. HCO_3^- exit at the basolateral membrane:
   (a) by Cl^- - HCO_3^- antiporter (AE-1)

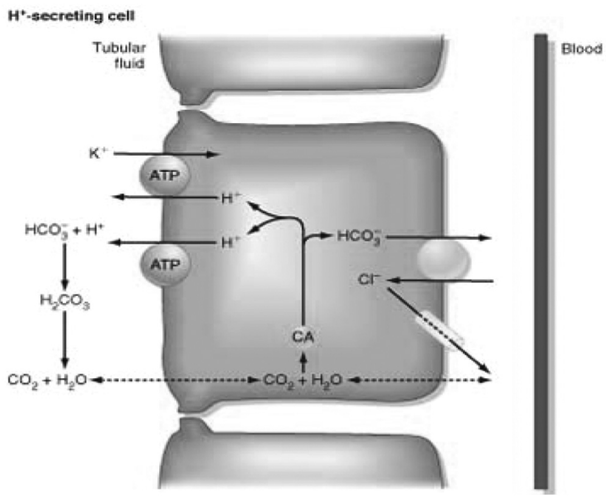

Fig. 14.3: Bicarconate reabsorption in DCT and CD

14.7.5.2 Role of phosphate buffer

H^+ excreted in urine binds with phosphate buffer (HPO_4^-)and gets excreted as $H_2PO_4^-$. There is formation of new bicarbonate.

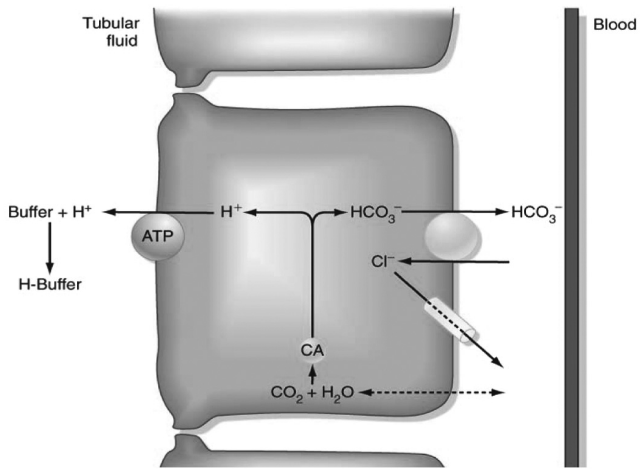

Fig. 14.4: Role of phosphate buffer

*There is no new bicarbonate formation in bicarbonate buffer system.

Notes

Titratable acid

- amount of base to be added to a sample of urine to bring its pH to that of plasma.
- reflects the amount of H^+ excreted by phosphate buffer.

14.7.5.3 Role of ammonium buffer

- NH_3 is synthesized in PCT by glutamine metabolism (Ammoniagenesis)
- This NH_3 gets excreted in collecting duct as NH_4^+ by combining with H^+ excreted in urine.
- There is also new bicarbonate formation during the process.

14.7.6 Acid-Base Disorders

14.7.6.1 Metabolic acidosis:

- Decreased pH
- Decreased ECF bicarbonate
- Increased metabolic acid production or reduced acid elimination
- Eg. diabetes mellitus

14.7.6.2 Metabolic alkalosis

- Increased pH
- Increased ECF bicarbonate
- Increased bicarbonate or increased acid elimination
- Eg. Excess vomiting

14.7.6.3 Respiratory acidosis

- Decreased pH
- Decreased CO_2 elimination
- Eg. Respiratory diseases

14.7.6.4 Respiratory alkalosis

- Increased pH
- Increased CO_2 elimination
- Eg. Hyperventilation

INTEXT QUESTIONS 14.2

1. Enumerate the role of kidneys in acid- base homeostasis.
2. Write briefly on the buffer systems of the body.
3. Give a brief description on various acid – base disorders.
4. Role of lungs in acid-base balance.
5. Fill in the blanks
    1. The important ECF buffer is ....
    2. Phosphate is an important .... buffer.
    3. New bicarbonate formation occurs in .... & .... buffer.
    4. Normal pH of the body is ....
    5. Titrable acid is contributed by .... buffer.

WHAT HAVE YOU LEARNT

- Water is solvent of life. It bathes our cells, dissolves and transposrts compounds in the blood, provides a medium for movement of molecules into and throughout cellular components, separates charged molecules, dissipates heat
- Total body weight is roughly 50 to 60% of body weight in adults and 75% of body weights in children
- Total body water is present as Extracellular and Intracellular fluids
- Extracellular fluids are plasma, Interstitial water and Transcellular water
- Osmolarity is the number of osmoles per litre of solution
- Osmolality is the number of osmoles per kilogram of solvent
- Normality, the osmolality of the ECF and ICF are at equilibrium in spite of difference in composition of electrolytes
- Based on the Osmolality fluids are classified as Isotonic, Hypotonic and Hypertonic
- Acid-Base homeostasis is essential to the body. Many enzymatic activities and metabolic processes need an optimal pH.

- pH of a solution is the negative logarithm of the hydrogen ion concentration in the solution
- pK is the negative logarithm of the ionization constant of an acid in a solution
- Buffer is an aqueous solution of weak acid and its conjugate base or a weak base and its conjugate acid, that resist changes in pH to addition or removal of small amounts of acids/bases
- Bicarbonate-carbonate acid buffer system, Plasma protein buffer system, Phosphte byffer system and Hemoglobin buffer system are the buffer sytems in the body

ANSWERS TO INTEXT QUESTIONS

14.1

2. 1. 25%
   2. Sodium (Na^+)
   3. Potassium (K^+)
   4. Sodium
   5. Isotonic Fluid
3. 1. False
   2. True
   3. False
   4. False
   5. True

14.2

5. 1. Bicarbonate carbonic acid buffer
   2. Intracellular
   3. Phosphate and Ammonium
   4. 7.35-7.45
   5. Phosphate