

Water and Electrolytes

Water is the primary component of all body fluids. It is the most abundant substance within the human body and has an essential role in most physiological pathways including digestion, absorption and use of nutrients, distribution, waste excretion, and perfusion and maintenance of hemodynamics.

Total body water in an adult of 70 kg varies from 60 to 70% (36-49 litres) of total body weight when expressed as a percentage of lean body mass, i.e. the sum of the fat-free tissue (total body weight – body fat weight). The body water is known to be distributed mainly in two compartments:

1- Intracellular fluid (ICF)

The fluid present within the cells which is approximately 2/3 of total body water (28 L in 70 kg subject).

Total body water = 0.6 x wt. (kg), so a subject with 70 kg weight has around 42 L of water in his body.

2- Extracellular fluid (ECF)

The fluid present outside the cells which constitutes approximately 1/3 of total body water (14 L in a 70 kg subject).

The extracellular fluid (ECF) is considered to be present in the two compartments as follows:

- Plasma (intravascular):

The fluid that contains blood cells within the vascular system, represents approximately 1/4 of the ECF (3L in 70 kg subject).

- Interstitial tissue fluid:

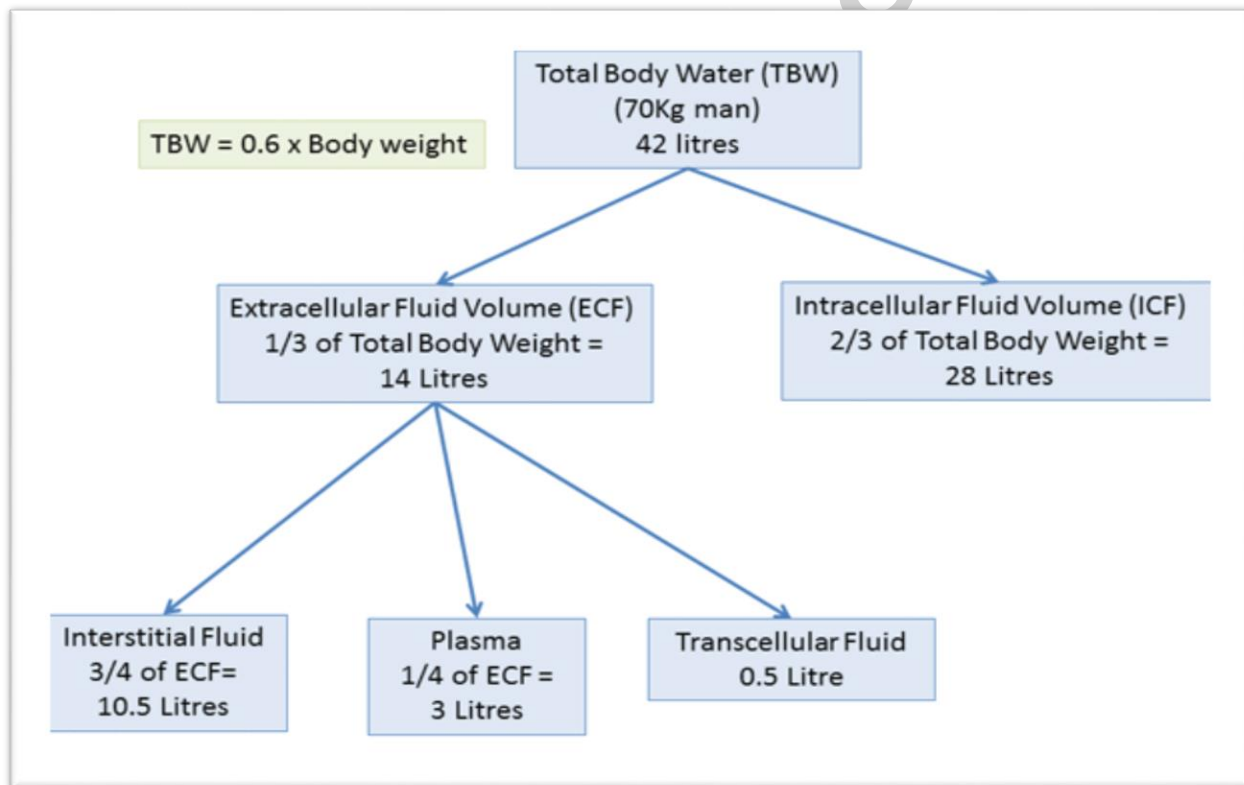
It is the fluid found in the spaces between the blood vessels and surrounding cells, represents approximately 3/4 of the ECF (11L in 70 kg subject).

- Transcellular fluid:

A variety of extracellular fluid collections formed by the transport or secretory activity of cells. These fluids are present within epithelial lined spaces.

Examples of transcellular fluids are:

- 1- Fluids found in salivary glands, pancreas, liver and biliary tract, skin, the mucous membrane of respiratory and GI tracts.
- 2- The fluids present in spaces within the eyes (aqueous humour), cerebrospinal fluid (CSF) in spinal canal and ventricles of the brain, and that within the lumen of GI tract (mostly reabsorbed and not lost).



Distribution of electrolytes in the body

Non-electrolytes particles such as glucose, urea, etc do not dissociate in solution, while substances like NaCl, KCl in solution dissociate into sodium (Na^+), potassium (K^+) and chloride (Cl^-) ions, they are called as electrolytes. Generally speaking, electrolytes are minerals with an electrical charge, dissolved in various body fluid and serving vital functions including:

- Transmission of the nerve impulse (sodium)
- Muscle contraction (calcium)
- Proper hydration (sodium)
- Acid-base balance (HCO_3^-)

Electrolytes include:

Sodium
Potassium
Chloride
Calcium
Magnesium
Phosphate
Bicarbonate

Water molecules completely surround these dissociated ions and prevent the union of positively charged particles with negatively charged ones.

The positive ions are called cations and the negatively charged ions are called anions. Fluid in any body compartments will contain an equal number of cations and anion.

Electrolytes Composition of ECF

Both plasma (IVF) and tissue fluid (ISF) may be considered as one single compartment for all practical purposes as both resemble each other and both differ grossly from ICF. Electrolytes composition of ISF is similar to plasma except that Cl^- largely replaces proteins as the anion. The predominant cation is Na^+ , and the predominant anion is Cl^- .

Electrolytes Composition of ICF

ICF contains 195 mEq of cations and anions. Values of various electrolytes in ICF differs in different tissues, but chief cations are K^+ and then Mg^+ . These are balanced by the chief anions PO_4^{-2} and next by proteins.

So, total electrolytes concentration is higher in ICF than ECF (195 vs 155 mEq/litre).

Solutes	Plasma mEq / L	Interstitial fluid (mEq/L)	Intracellular fluid (mEq/L)
Cations:			
Sodium	140	146	12
Potassium	4	5	160
Calcium	5	3	–
Magnesium	1.5	1	34
Anions:			
Chloride	105	117	2
Bicarbonate	24	27	10
Sulfate	1	1	–
Phosphate	2	2	140
Protein	15	7	54
Other anions	13	1	–
Note - mEq/L = mmol/L × valency			

Distribution of electrolytes in various compartment

Electrolytes movements in and out of cells

A much higher concentration of Na^+ and Cl^- in interstitial fluid and K^+ in the intracellular fluid are accompanied by differences in electrical potential. The resting skeletal muscle cells being about 90 *mv* -ve to the interstitial fluid.

It is believed that the lipid-protein membrane plays an important role in determining and maintaining these differences in concentration and potential.

K^+ ions tend to diffuse out of and the Cl^- ions into the cells because of their concentration gradients, but this is almost completely counterbalanced by a tendency to diffuse in the

opposite direction due to the difference in electrical potential, ie. the relative negativity on the inside of the cells tend to keep Cl out and K in.

In the case of Na, however, diffusion into the cells is favoured by both the concentration gradient and electrical potential. Cells do not allow accumulation of Na, hence under normal healthy conditions, there must be some mechanism for removing Na⁺ from the cell, virtually as rapidly as it enters.

Since this has to be accomplished in opposition to forces of concentration and electrical potential, it involves the expenditure of energy, derived from cellular metabolism.

This process of active transport of Na out of cells (pumping out) is done by the sodium pump, which effectively extrudes Na from the intracellular fluid.

This extrusion of Na from the cell is associated with splitting of ATP by "Na-K" ATP-ase" located at the inner surface of the cell membrane.

The energy of hydrolysis of ATP is used by the transport mechanism for the coupled exchange of Na⁺ for K⁺ ions between the intracellular and tissue fluids.

Normal water balance

Body water is constantly exchanged with the external environment.

The input of Water:

Sources of water include:

-Water intake which is normally absorbed into the body from the bowel.

-Metabolic water: Formed from the oxidation of foodstuffs; each gram of carbohydrates, fats and proteins yield 0.55 gm, 1.06 gm and 0.45 gm of water respectively on complete oxidation.

In ml, on oxidation of 1 gm of carbohydrates, fats and proteins produce 0.56 ml, 1.07 ml, and 0.34 ml water respectively. In general, 10 to 15 ml of water is produced per 100 calories of energy.

The output of Water:

Water is lost from the body constantly from various routes, they are as follows:

1- Via kidney as urine: 1000 to 1500 ml in 24 hours. Scientifically speaking, the normal urine output of an adult is 1ml/kg/h.

2- Via skin as insensible perspiration: 600 to 800 ml of water in 24 hrs.

Frank sweating is abnormal. Sweat is a "hypotonic" solution, 30 to 90 mEq/litre of NaCl are lost in sweating. In insensible perspiration there is no loss of salts, it is equivalent to distilled water.

3- Via lungs in the expired air: approximately 400 to 600 ml of water is lost in 24 hours.

4- Via feces: To a minor degree approximately 100 to 150 ml of water is lost in 24 hours from large intestine in feces.

Average water intake and output in an adult			
Intake		Output	
Drinking	1000-1500 ml	Urine	1000-1500 ml
Water in food	700 ml	Lung	400 ml
Metabolic water	400 ml	Skin	600 ml
		Feces	100 ml
Total	2100 – 2600 ml	Total	2100 – 2600 ml

Normally in a healthy subject, the intake of water is more than the loss via skin, lungs and feces and the excess water is excreted by the kidneys.

Thus, the urinary volume largely depends on the intake of water.

If the intake of water is low or excessive amounts are lost via extrarenal channels, the excretion of urine is diminished. Urinary volume may be reduced to 500-600 ml in 24 hours and this is called as the minimum excretory volume.

The loss through expired air (minimum 400 ml), by insensible perspiration through the skin (minimum 600 ml), loss through feces (minimum 100 ml) and the minimum excretory volume of the kidney to eliminate waste products, 500 ml, is called as obligatory losses (approximately 1600 ml). This loss will continue as long as the individual is surviving.

Normal electrolyte balance

Though human systems consume fluids and food which vary markedly both in quality and quantity, electrolyte levels in subjects from any two widely located regions of the world are within narrow normal ranges.

The organs which are constantly regulating the electrolyte levels are:

- 1- The Intestine
- 2- The kidneys

1- GI Tract

About 8 litres of fluid of different electrolytes enter GI tract every day and are reabsorbed almost completely with fluid loss approximately 100 to 150 ml, and electrolyte loss of Na around 10-30 mEq and of K⁺ around 10 mEq.

2- Kidneys

Internal circulation of salts constantly occurring in kidneys is at a much faster rate than that observed in the GI tract. In the kidneys, a volume of plasma equal to (12-15 L) is filtered and reabsorbed every 2 hours and about 25,000 mEq of Na⁺ is filtered and reabsorbed every day. Na is reabsorbed from the renal tubules in exchange with H⁺ and NH₄⁺ in proximal and distal tubules respectively.

Regulatory mechanisms

The volume and composition of various body fluid compartments are maintained within physiological limits even in the face of wide variations in intake of water and solutes.

The osmolarity of ICF is determined mainly by its K concentration, while that of ECF by Na concentration. If the volumes of these compartments are to be maintained at constant levels, a mechanism must be provided for adjustments in excretions of not only of water but also of Na and K in response to variations in amounts of each supplied to the organism. These adjustments are accomplished mainly by the kidneys. The kidneys respond promptly to deviations in osmolarity or individual ions concentration in ECF.

Homeostasis of body fluids, therefore, involves mechanisms that respond to fluctuations in volume, as well as to changes in concentration of total solutes or of individual ions.

Current concepts of the nature of the regulatory mechanisms include the existence of receptors sensitive to variations in:

- 1- Osmolar concentration (osmoreceptors)
- 2- Individual ions (chemoreceptors) concentration in ECF.
- 3- To local or general variation in intravascular pressures (baroreceptors)
- 4- Plasma / or ECF volume (volume receptors or stretch receptors)

The intrarenal mechanisms concerned with excretion of water and solutes may be influenced by stimuli initiated in the receptors mentioned above either:

- By direct neural connections
- Through the medium of humoral factors, i.e. alterations in production and release of certain hormones, these are mainly two:

- 1- Antidiuretic hormone (ADH) or vasopressin.
- 2- Aldosterone

ADH and vasopressin are concerned with the regulation of excretion of water, while aldosterone is concerned with the regulation of excretion Na and K.

Thirst mechanism (a neural mechanism)

The intake of fluid is regulated by the mechanism of "thirst".

A thirst centre is located in the hypothalamus, which regulates the amount of water, consumed as water or beverages. Deficient intake of water with continuing obligatory losses leads to concentration of body fluids with respect to solutes and a rise in osmotic pressure. This tends to draw water from ICF to ECF, causing dehydration of the cells which seems to be the main stimulus of thirst mechanism through osmoreceptors as well as sensory nerves of mouth and pharynx (IX, X) which respond to dryness of mouth and pharynx.

Hormonal mechanism

1- ADH :

This hormone is responsible for reabsorption of water from the collecting ducts, distal tubules, and parts of the loop of Henle. So, in case of increased osmolarity of any cause, ADH secretion is increased in order to reabsorb more and more water.

2- Aldosterone :

This hormone is synthesized by zona glomerulosa of the adrenal cortex, it is responsible for the regulation of Na reabsorption by renal tubules. Its potent action is on the distal tubules, collecting ducts, and loop of Henle. Aldosterone also increases the loss of K by kidneys.

Some definitions:

Hyperkalemia: potassium blood concentration higher than the reference range.

Hypokalemia: potassium blood concentration lower than the reference range.

Hypernatremia: sodium blood concentration higher than the reference range.

Hyponatremia: sodium blood concentration lower than the reference range.

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