TOPIC 22: FLUID AND ION BALANCE

I. Input and Output of Fluids and Ions
   A. Balance concept (Fig 19.2)
      1. If the amount of fluids & ions are to remain stable in body, input must equal output.
      2. Not all input and output pathways are regulated
         a) most input pathways are poorly regulated
            (1) people will eat & drink what they want even if they don’t need it
            (2) H+ ions are uncontrollably produced internally
         b) some output poorly regulated
            (1) Salt, water and H+ are lost uncontrollably through vomiting and sweating
            c) Humans regulate water, salt and H+ balances primarily through kidney function
   B. Types of input and output (Fig 19.1 & 19.3)
      1. Input
         a) From Environment
            (1) ingestion, inhalation, absorption
         b) Metabolically produced
            (1) products (e.g., amino acids) and by-products (e.g., H+ and water) of metabolic processes
      2. Output
         a) Excretion to environment
            (1) through kidneys, digestive tract, lungs, body surface (e.g., urine, feces, sweat, water vapor in breath, sloughed off skin)
         b) Metabolically consumed

II. Fluid and Ion Distribution in Body (review from Topic 1)
   A. Fluid Compartments within Body (Fig 1.5)
      1. Intracellular Fluid (ICF)
         a) within cells
      2. Extracellular Fluid (ECF)
         a) outside cells
         b) further compartmentalized into
            (1) Plasma
            (2) Interstitial fluid
            (3) Boundry is capillary walls
      3. Boundry between ECF and ICF are cell membranes
   B. Ion Distribution among compartments
      1. Table 4.1
   C. Movement of water and ions within the ECF
      1. Water moves freely by osmosis between plasma and interstitial fluid
      2. Most solutes (EXCEPT plasma proteins) move freely by passive means between plasma and interstitial fluid
   D. Movement of water and ions between ECF and ICF
      1. Water moves freely between ECF and ICF
         a) This movement is determined by osmotic effects alone
      2. Ions do not move easily between ECF and ICF
         a) Solute movement restricted across cellular membranes
         b) Cellular proteins in the ICF usually can’t leave cells and generally are not found in the ECF.
c) Na\(^+\) and K\(^+\) and their associated anions are unequally distributed between ECF and ICF; this is maintained in large part by the Na\(^+\)-K\(^+\)-ATPase pump.

E. Regulation of fluid and ion distribution

1. The ECF is intermediate between the ICF and the external environment.
   a) All exchanges of water and solutes between the ICF and the external environment must go through the ECF.

2. **Plasma is the only fluid that has its volume and composition regulated.** However, if plasma volume or composition changes:
   a) the interstitial fluid also changes
   b) the ICF changes to the extent allowed by cell membrane permeability

3. Why you must regulate fluid and ion levels:
   a) **ECF volume** must be regulated to maintain **blood pressure**. **Maintenance of salt balance** is the primary way that ECF volume is regulated over the long term
   b) **ECF osmolarity** (mg solutes/ml fluid) must be regulated to prevent shrinking or swelling of cells because ECF osmolarity affects **ICF osmolarity**. **Maintenance of water balance** is the primary way this is accomplished.
   c) **ECF volume and ECF osmolarity are intimately related to each other!**

III. Regulation of ECF Volume: Controlling the Amount of Na\(^+\).

A. Purpose: Long term regulation of blood pressure by regulating plasma volume, which is accomplished by regulating the **total quantity of Na\(^+\).**

1. Baroreceptor reflex and fluid shifts between the plasma and interstitial fluid are important **short term** mechanisms of regulating blood pressure.

2. If plasma volume is too far from normal, short term mechanisms are ineffective, so amount of Na\(^+\) must be regulated

3. Increases in Na\(^+\) lead to increases in ECF volume (because of osmotic forces: if you hold on to Na\(^+\), you automatically hold onto water too) and hence increase blood pressure; decreases in Na\(^+\) lead to decreases in ECF volume and hence decreases in blood pressure.

B. Na\(^+\) Balance

1. Input: eating salt; not well controlled (most Americans eat way more salt than is needed)

2. Output: Loss of salt in sweat, feces, and urine; only excretion in urine is regulated.

C. Mechanisms regulating Na\(^+\) excretion in kidney

1. Control of filtration rate in kidney
   a) increasing filtration rate causes an increase in Na\(^+\) filtration and hence Na\(^+\) excretion; water is excreted along with the Na\(^+\), so ECF volume decreases
   b) decrease in filtration rate leads to decrease in Na\(^+\) filtration and excretion; Na\(^+\) and associated water conserved, which leads to an increase in ECF volume.

2. Control of Na\(^+\) reabsorbed in kidneys (Fig 18.3, 19.15, 19.16, 19.17, 19.18)
   a) In proximal tubule and loop of Henle, a constant percentage of filtered Na\(^+\) is reabsorbed, regardless of the absolute amount present.
   b) In the distal tubule, Na\(^+\) reabsorption is regulated.
   c) Primary positive regulation system is the renin-angiotensin-aldosterone system; you can upregulate or downregulate this system to alter Na\(^+\) and hence bp.
      (1) If Na\(^+\) levels fall (which causes a decline in ECF volume and blood pressure), the juxtaglomerular apparatus secretes the hormone renin into the blood.
      (2) Renin activates angiotensinogen by converting it to angiotensin I, which is then converted to
3) angiotensin II by angiotensin converting enzyme found mostly in lungs.
4) Angiotensin II then stimulates the adrenal cortex to secrete aldosterone, which increases Na\(^+\) reabsorption in the distal and collecting tubules by adding more Na\(^+\)-K\(^+\)-ATPase pumps to the basolateral membranes.
5) This promotes Na\(^+\) retention, and so increases ECF volume and arterial blood pressure
6) Angiotensin II also is vasoconstrictor, stimulates thirst, and stimulates vasopressin (which induces water retention by the kidneys) all of which also result in an increase in ECF volume and arterial blood pressure.

d) Primary negative system is the atrial natriuretic peptide (ANP) system
1) the heart produces ANP and stores it in the atria
2) when ECF volume increases too much, cardiac cells are stretched and ANP is released.
3) ANP inhibits Na\(^+\) retention in the distal parts of the nephron, inhibits renin and aldosterone secretion, and increases GFR by dilating the afferent arterioles in the nephrons.
4) These actions decrease Na\(^+\) retention, and hence lower ECF volume and arterial blood pressure

IV. Regulation of ECF Osmolarity: Controlling Water Balance

A. Purpose: Regulation of ICF Osmolarity
B. How ECF osmolarity (mg solutes/ml fluid) affects ICF osmolarity.
1. ECF hypertonicity (usually by dehydration) leads to ICF hypertonicity because water moves from ICF to ECF by osmosis. This causes cells to shrink which can lead to mental impairment and circulatory shock.
2. ECF hypotonicity (usually overhydration) leads to ICF hypotonicity because water moves by osmosis from ECF to ICF. This can lead to brain dysfunction and muscle weakness.
3. Isotonic fluid loss (usually by hemorrhage) occurs when water and solutes lost together. This does not impact ICF volumes, but does lead to a decline in ECF volume.

C. Mechanisms of water regulation
1. Hypothalamic osmoreceptors monitor ECF osmolarity and initiate responses.
2. High osmolarity = hypertonic (too little water) Fig 19.12
   a) Vasopressin released and thirst stimulated; the vasopressin causes the kidneys to reabsorb more water so less is lost in the urine, and being thirsty causes you to drink more water. Urine still produced, but it has a very high concentration of solutes (maximum of 1400 mosm/l).
3. Low osmolarity = hypotonic (too much water)
   a) Vasopressin release inhibited; thirst inhibited, and reabsorption of water in the kidneys slowed or discontinued. Urine produced has a low concentration of solutes (minimum of 100 mosm/l).