Fluids and Electrolytes, Acids and Bases

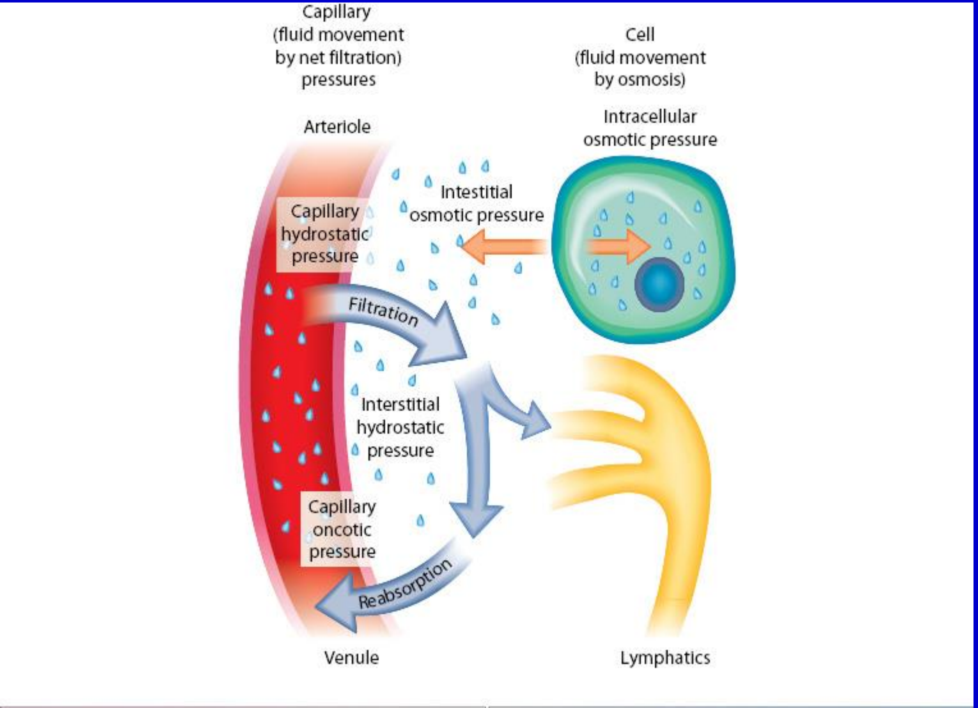
Distribution of Body Fluids

- Total body water (TBW)
  - Intracellular fluid
  - Extracellular fluid
    - Interstitial fluid
    - Intravascular fluid
    - Lymph, synovial, intestinal, biliary, hepatic, pancreatic, CSF, sweat, urine, pleural, peritoneal, pericardial, and intraocular fluids

Water Movement Between the ICF and ECF

- Osmolality
- Osmotic forces
- Aquaporins
- Starling hypothesis
  - Net filtration = forces favoring filtration – forces opposing filtration
  - Hydrostatic pressure in the capillary
  - Hydrostatic pressure in the insterstitium
  - Oncotic pressure in the capillary
  - Oncotic pressure in the interstitium

Water Movement Between the ICF and ECF

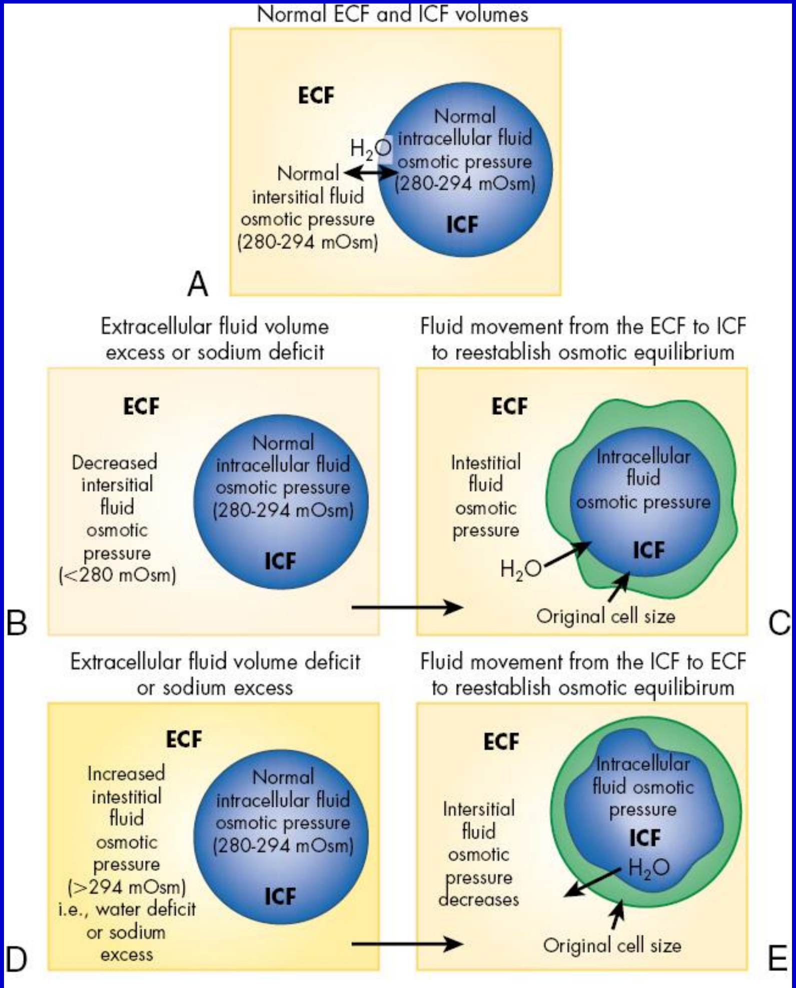


Arterial Capillary Pressures		Venous Capillary Pressures	
Capillary hydrostatic pressure	35 mmHg	Capillary hydrostatic pressure	18 mmHg
Interstitial fluid hydrostatic pressure	2 mmHg	Interstitial fluid hydrostatic pressure	1 mmHg
Net hydrostatic pressure	**33 mmHg**	**Net hydrostatic pressure**	**17 mmHg**
Capillary oncotic pressure	24 mmHg	Capillary oncotic pressure	25 mmHg
Interstitial fluid oncotic pressure	0 mmHg	Interstitial fluid oncotic pressure	0 mmHg
Net oncotic pressure	**24 mmHg**	**Net oncotic pressure**	**25 mmHg**
Net filtration pressure	**+9 mmHg**	Net filtration pressure	**−8 mmHg**

Net Filtration

- Forces favoring filtration
  - Capillary hydrostatic pressure (blood pressure)
  - Interstitial oncotic pressure (water-pulling)
- Forces favoring reabsorption
  - Plasma oncotic pressure (water-pulling)
  - Interstitial hydrostatic pressure

Osmotic Equilibrium



Water Balance

- Thirst perception
  - Osmolality receptors
    - Hyperosmolality
  - Baroreceptors stimulated
    - Plasma volume depletion
- ADH secretion

Na^+ and Cl^- Balance

- Sodium
  - Primary ECF cation
  - Regulates osmotic forces
  - Roles
    - Neuromuscular irritability, acid-base balance, and cellular reactions
- Chloride
  - Primary ECF anion
  - Provides electroneutrality

Na^+ and Cl^- Balance

- Renin-angiotensin-aldosterone system
  - Aldosterone
- Natriuretic peptides
  - Atrial natriuretic peptide

Potassium

- Major intracellular cation
- Concentration maintained by the Na^+,K^+ pump
- Regulates intracellular electrical neutrality in relation to Na^+ and H^+
- Essential for transmission and conduction of nerve impulses, normal cardiac rhythms, and skeletal and smooth muscle contraction

Potassium Levels

- Changes in pH affect K^+ balance
  - Hydrogen ions accumulate in the ICF during states of acidosis. K^+ shifts out to maintain a balance of cations across the membrane.
- Aldosterone, insulin, and catecholamines influence serum potassium levels

Calcium

- Most calcium is located in the bone as hydroxyapatite
- Necessary for structure of bones and teeth, blood clotting, hormone secretion, and cell receptor function

Phosphate

- Like calcium, most phosphate (85%) is also located in the bone
- Necessary for high-energy bonds located in creatine phosphate and ATP and acts as an anion buffer
- Calcium and phosphate concentrations are rigidly controlled
  - $Ca^{++} \times HPO_4^{--} = K^{+}$ (constant)
  - If concentration of one increases, that of the other decreases

Calcium and Phosphate

- Regulated by three hormones
  - Parathyroid hormone (PTH)
    - Increases plasma calcium levels via bone reabsorption
  - Vitamin D
    - Fat-soluble steroid; increases calcium absorption from the GI tract
  - Calcitonin
    - Decreases plasma calcium levels

Magnesium

- Intracellular cation
- Plasma concentration is 1.8 to 2.4 mEq/L
- Acts as a co-factor in protein and nucleic acid synthesis reactions
- Required for ATPase activity
- Decreases acetylcholine release at the neuromuscular junction

pH: What Is It?

- Negative logarithm of the H^+ concentration

0 7 14

Increasing H+ — pH scale — Decreasing H+

Very acidic — Neutral — Very alkaline

- Each number represents a factor of 10. If a solution moves from a pH of 7 to a pH of 6, the H^+ ions have increased 10-fold.

pH

- Inverse logarithm of the H^+ concentration
- H^+ high in number, pH is low (acidic)
- H^+ low in number, pH is high (alkaline)
- Ranges from 0 to 14
- Each number represents a factor of 10.
  - If a solution moves from a pH of 6 to a pH of 5, the H^+ has increased 10 times

pH

- Acids are formed as end products of protein, carbohydrate, and fat metabolism
- To maintain the body's normal pH (7.35-7.45) the H^+ must be neutralized or excreted
- Bones, lungs, and kidneys are major organs involved in regulation of acid-base balance

pH

- Body acids exist in two forms
  - Volatile
    - H_2CO_3 (can be eliminated as CO_2 gas)
  - Nonvolatile
    - Sulfuric, phosphoric, and other organic acids
    - Eliminated by the renal tubules with the regulation of HCO_3^-

Buffering Systems

- Buffer systems exist as buffer pairs
  - Associate and dissociate very quickly (instantaneous)
  - Buffer changes occur in response to changes in acid-base status

Buffering Systems

- A buffer is a chemical that can bind excessive H^+ or OH^- without a significant change in pH
- A buffering pair consists of a weak acid and its conjugate base
- The most important plasma buffering systems are the carbonic acid–bicarbonate system and hemoglobin

Carbonic Acid–Bicarbonate Pair

- Operates in the lung and the kidney
- HCO3- is synthesized and reabsorb by kidneys
- If there is excess H+, HCO3- can function as weak base; if there is shortage of H+, H2CO3 can act as weak acid
- H2CO3 can dissociate into H2O and CO2 and CO2 exhaled in lungs

Carbonic Acid–Bicarbonate Pair

- If amount of bicarbonate decreases, the pH decreases, causing a state of acidosis
- The pH can be returned to normal if the amount of carbonic acid also decreases
  - This type of pH adjustment is called compensation
- The respiratory system compensates by increasing or decreasing ventilation
- The renal system compensates by producing acidic or alkaline urine

Other Buffering Systems

- Protein buffering
  - Proteins have negative charges, so they can serve as buffers for H^+
  - Albumin is a good buffer
    - Free carboxyl (-COOH) can act as acid if H+ decreases
    - Free amino group (-NH2) can act as base when H+ increases
  - Hgb is also a buffer
    - CO2 combines with H2O → H2CO3 → H+ + HCO3-

Exhalation of CO_2

- Increase in CO_2 → dec pH
- Decrease in CO_2 → Inc pH
- Changes in rate and depth of breathing can alter the pH of body fluids within a couple of minutes
- pH of body fluids and rate and depth of breathing interact thru negative feedback
- Dec blood pH → detected by chemoreceptors in medulla oblongata, aorta and carotid arteries → stimulate inspiratory area in the medulla oblongata → diaphragm and respiratory muscles contract more forcefully and frequently to inc exhalation of CO_2

Kidney excretion of H+

- Kidneys can excrete excess H+ in response to increase metabolic reactions resulting to inc production of nonvolatile acids
- Intercalated cells in the collecting duct has proton pumps that secrete H+ into the tubular fluid
- HCO3- is also reabsorbed in the peritubular capillaries