Fluid, Electrolyte and Acid Base Balance

Integrating Respiratory, Urinary and Digestive Physiology

Lecture Outline

- Body Fluid, Fluid Compartments
- Body Water
  - Regulation of Gain
  - Regulation of Loss
- The Electrolytes
- Movement of body fluids
  - between plasma and interstitial fluid
  - between interstitial and intracellular
- Acid Base Balance
  - Buffer systems
  - Exhalation of Carbon Dioxide
  - Kidney Excretion
- Acid Base Imbalances
  - Acidosis vs Alkalosis

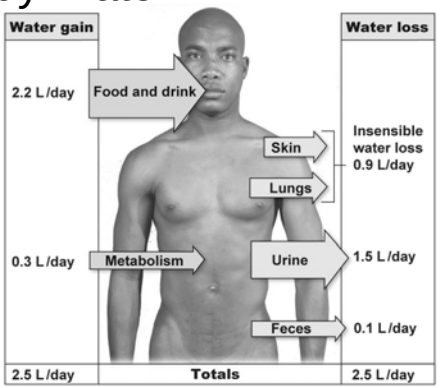
Body Fluid, Fluid Compartments & Fluid Balance

- What is body fluid?
  - Water and solutes located in fluid compartments
  - 45-75% of body weight is due to fluid (water)
    - Variations due to differences between individuals and adipose levels
- ECF vs. ICF Fluid Compartments
  - 2/3 of fluid in the body is in the ICF compartment
  - 1/3 of the fluid in the body is in the ECF
    - made up of:

plasma
CSF
GI fluids
interstitial fluid
pleural fluid
pericardial fluid
lymph
ocular fluid
peritoneal fluid
synovial fluid
glomerular filtrate
auditory fluid

Gain (inputs) vs. Loss (outputs) of Body Water

- Net Balance
  - Gain = Loss
- Balance between ECF and ICF
  - Movement of water depends on makeup of individual compartments



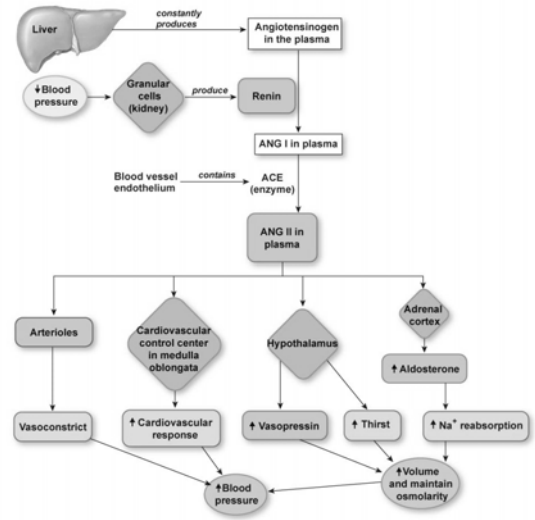
Intake 2.2 L/day	+	Metabolic production 0.3 L/day	–	Output 2.5 L/day	= 0

Regulation of Gain & Loss

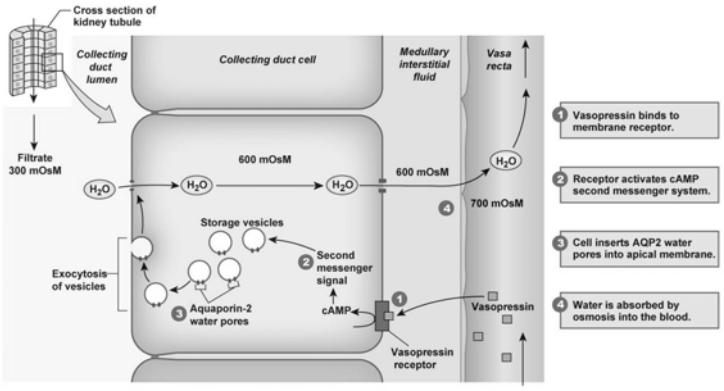
- Gain & Loss controlled by?
  - Water intake & water reabsorption!
  - Loss of fluid possibly manifests as
    - Drop in MAP!
  - Too much fluid possibly manifests as
    - Elevation in MAP!

Regulation of Gain & Loss

- Drop in blood pressure initiates…

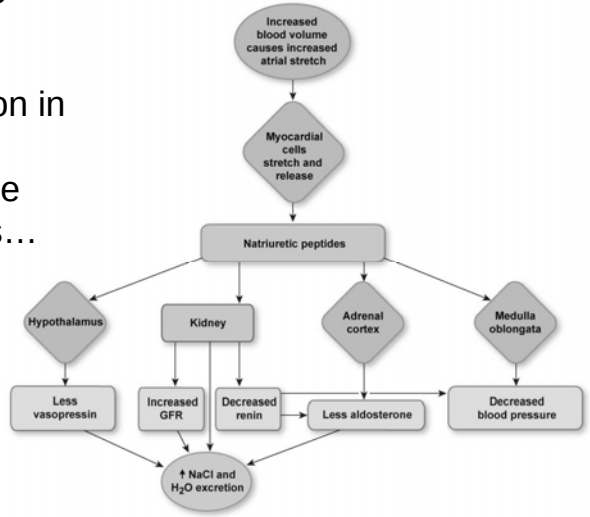


Affect of Vasopressin



Regulation of Gain & Loss

- Elevation in blood pressure initiates…



Electrolyte Function

- Job of the urinary system to regulate the volume and composition of the ECF
  - And therefore the ICF as well!
- What do the electrolyte portion of the composition of body fluids do?
  1. Controls osmolarity (and therefore movement of fluid between the compartments)
  2. help to maintain the acid - base balance
  3. carry electrical current within the body

Electrolyte Function

- What are the main electrolytes?
  1. Na^+ – most abundant ECF ions (cation)
     a. impulse transmission
     b. muscle contraction
     c. water balance
     d. controlled by aldosterone in kidney
  2. Chloride ions – major extracellular anions
     a. regulate osmotic pressure
     b. involved in pH as they will form HCl
     c. controlled by aldosterone (why? -- follows Na^+)
  3. Potassium ions – most abundant cations in ICF
     a. maintaining fluid volume
     b. impulse conduction
     c. muscle contractions
     d. regulating pH
     e. controlled by aldosterone

Electrolyte Function

4. Bicarbonate ions ($HC0_3^-$)
   a. second most abundant anion in ECF
   b. THE MOST IMPORTANT BUFFER IN PLASMA!
5. Calcium – an extracellular cation
   a. very important mineral as it is a structural one (bones & teeth)
   b. plays a role in hemostasis
   c. neurotransmitter release
   d. contraction of muscle
   e. controlled by PTH and CT – calcitonin
6. Phosphate ions – ICF anions ($H_2PO_4^-$, HPO_4^{2-}, PO_4^{3-})
   a. structural components of teeth and bone
   b. needed for nucleic acid synthesis, ATP synthesis
   c. also used in buffering reactions in the cell
   d. controlled by PTH and CT
7. Magnesium (Mg^{2+}) – ICF cations mostly
   a. acting as cofactors (aiding in enzyme reactions)

Intercompartmental Fluid Movement

A. between plasma and interstitial fluid
   - at arterial end
     - filtration occurs in a capillary moving fluid into the interstitial space
   - at venous end
     - reabsorption moves fluid back into the capillary
   - 3 L/day is not reabsorbed and is returned via the lymphatic system
B. between interstitial and intracellular fluids
   - movement here depends on the concentrations of Na^+ and K^+
     - which is controlled by the kidney in response to aldosterone, ADH (vasopressin) and ANP
C. if there is an imbalance in osmolarity?
   - hypovolemic shock (not enough blood volume)
   - water intoxication

Osmolarity vs. Volume

Volume	Osmolarity: Decrease	Osmolarity: No change	Osmolarity: Increase
Increase	Drinking large amount of water	Ingestion of isotonic saline	Ingestion of hypertonic saline
No change	Replacement of sweat loss with plain water	Normal volume and osmolarity	Eating salt without drinking water
Decrease	Incomplete compensation for dehydration	Hemorrhage	Dehydration (e.g., sweat loss or diarrhea)

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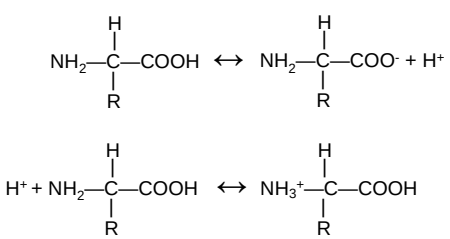
Acid Base Balance

- Normal range of pH
  - 7.38 – 7.42
- Controlled by systems which maintain H^+ levels:
  - Buffering Systems, Ventilation Rates, & Renal Function

Buffering System

1. PROTEINS



Hemoglobin when reduced can also pick up H^+ in RBC's and is used in conjunction with the bicarbonate buffering system

Acid Base Balance

Buffering System 2. Bicarbonate buffering system

$$H_2O + CO_2 \leftrightarrow H_2CO_3 \leftrightarrow HCO_3^- + H^+$$

Buffering System 3. Phosphate buffering system

$$OH^- + H_2PO_4^- \leftrightarrow H_2O + HPO_4^{2-}$$

$$H^+ + HPO_4^{2-} \leftrightarrow H_2PO_4^-$$

Any molecule capable of picking up H ion can act as a buffer: such as ammonia (NH3)

Acid Base Balance

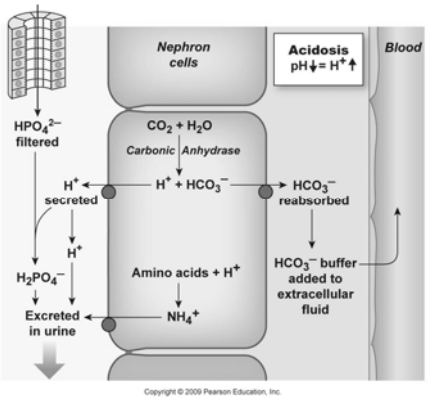
- Ventilation Rates & Effect on pH Balance
  - It's all about CO_2 and the bicarbonate buffering system
    - Increased ventilation rate causes
      - Removal of CO_2 and H_2O
      - Drives this reaction to…?

$$H_2O + CO_2 \leftrightarrow H_2CO_3 \leftrightarrow HCO_3^- + H^+$$

      - hyperventilation drives the reaction to the left causing removal of H^+, pH goes up
      - Hypoventilation drives the reaction to the right, causing additional H^+, pH goes down

Acid Base Balance

- Renal Function
  - Through the aspects of tubular secretion and reabsorption
    - Bicarbonate (HCO_3^-) is produced and reabsorbed, acting as a buffer, stabilizing pH
    - H^+ is capable of being secreted and excreted, reducing its concentration and causing pH to go up.



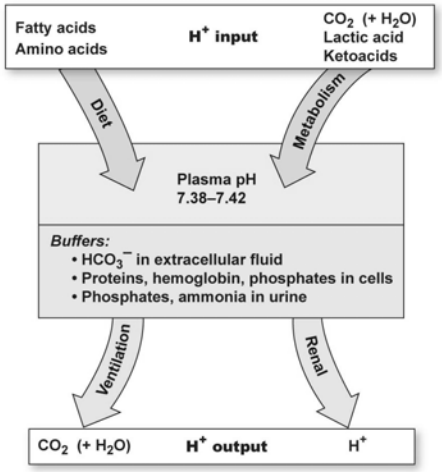
Acid Base Imbalances

- What happens when there is an abundance (or lack) of H^+?
  - Acidosis = too much H^+ causing pH to drop
  - Alkalosis = too little H^+ causing pH to rise

  - The urinary and respiratory systems work together to control and maintain pH within homeostatic parameters
    - Urinary system works slower
    - Respiratory system works almost immediately
    - The systems will compensate for each other if needed

Acid Base Imbalance

- Overview of H^+ inputs and outputs as well as controlling mechanisms



Acid Base Imbalance

Acidosis – occurs when the blood pH is below 7.38

Causes may be respiratory or metabolic (kidney):

1. **respiratory acidosis**

   elevation of P_{CO_2} levels in arterial blood causes the pH to drop due to decreased movement of CO_2 from lungs to the air

   – why?
   - emphysema, pulmonary edema, medullary injury, airway obstruction, disorders of the muscle

   – effects?
   - Kidneys increase secretion of H+ ions and absorption of HCO_3- ions (metabolic compensation)

   – treatments?
   - increase exhalation of CO_2, IV of HCO_3- artificial respiration, suction, and ventilation therapy

Acid Base Imbalance

2. Metabolic Acidosis

blood concentration of HCO_3- drops (↓22mEq/L)

•because it is a buffer, the blood will loose its ability to pick up H^+ and will become more acidic (lower pH)

– **Causes?**

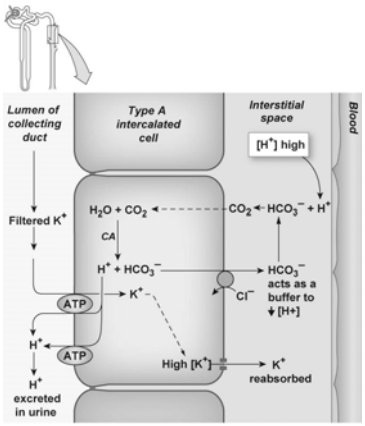
1. Loss of HCO_3- (diarrhea or renal failure)
2. accumulation of acid (ex. ketosis)
3. kidney's failure to excrete H+ from metabolism of dietary protein

– **Effects?**

causes hyperventilation (respiratory compensation)

– **Treatments?**

IV solutions of sodium bicarbonate ($NaHCO_3$), and fixing the problem



Acid Base Imbalance

Alkalosis – occurs when the blood pH is above 7.42

Causes may be respiratory or metabolic (kidney):

1. **respiratory alkalosis**

   decreased P_{CO_2} levels in arterial blood causes the pH to rise due to increased movement of CO_2 from lungs to the air

   – why?
   - Hyperventilation due to
     – voluntary behavior
     – oxygen deficiency at high altitudes
     – pulmonary dysfunction, stroke, anxiety

   – effects?
   - Kidneys stop excreting H^+, and reabsorbing bicarbonate creates a metabolic compensation

   – treatments?
   - Rebreathe CO_2, treat underlying behavior, reduce altitude

Acid Base Imbalance

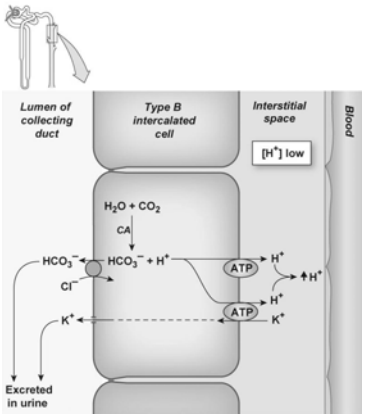
1. **Metabolic alkalosis**

   blood HCO_3- concentration increases (↑*26 mEq/L*)

   – Cause?
   - can be due to loss of acid not related to respirations
     – ex. vomiting – most common, diuretics, endocrine problems
   - Overconsumption of antacids
   - severe dehydration

   – effects?
   - causes hypoventilation (quick temp. fix)

   – treatments?
   - fluid electrolyte therapy for electrolyte fixing (gatorade)
   - remedying the cause of distress



Acid Base Imbalances

- How can you tell which is the cause of altered pH?
  1. Determine if pH is high (acidosis) or low (alkalosis)
  2. Determine if the PCO_2 is high or low, or if the HCO_3- is high or low
     - This will be the primary cause
  3. If a change in P_{CO_2}, the cause is respiratory, and if the change is in the HCO_3-, then the cause is metabolic
  4. If both are out of balance, then compensation is occurring.

Ex. conditions:

pH = 7.48 alkalosis

HCO_3- = 30 mEq/L **High** *Agrees! Can be the primary cause!*

P_{CO_2} = 45 mm Hg High *Disagrees with the observed pH, can't be the primary cause of condition!*

Metabolic alkalosis with respiratory compensation.

TABLE 20-2 **Plasma P_{CO_2}, Ions, and pH in Acid-Base Disturbances**

DISTURBANCE	P_{CO_2}	H^+	PH	HCO_3^-
Acidosis				
Respiratory	↑	↑	↓	↑
Metabolic	Normal* or ↓	↑	↓	↓
Alkalosis				
Respiratory	↓	↓	↑	↓
Metabolic	Normal* or ↑	↓	↑	↑

* These values are different from what you would expect from the law of mass action because almost instantaneous respiratory compensation keeps P_{CO_2} from changing significantly.

So….

- Why do we care about ion balance?
- Why do we care about pH?