Chapter 25:
Fluid, Electrolyte, and Acid / Base Balance

Body Fluids:

1) Water: (universal solvent)

Body water varies based on of age, sex, mass, and body composition

H_2O ~ 73% body weight

Low body fat
Low bone mass

H_2O (♂) ~ 60% body weight
H_2O (♀) ~ 50% body weight
♀ = ↑ body fat / ↓ muscle mass

H_2O ~ 45% body weight

Body Fluids:

1) Water: (universal solvent)

Total Body Water

Volume = 40 L
(60% body weight)

Intracellular Fluid (ICF)
Volume = 25 L
(40% body weight)

Interstitial Fluid
Volume = 12 L

Plasma Volume = 3 L

Extracellular Fluid (ECF)
Volume = 15 L
(20% body weight)

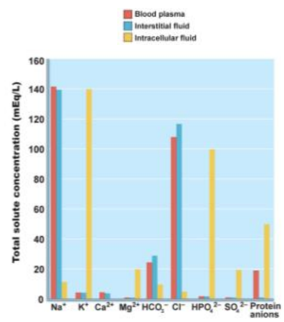
Body Fluids:

2) Solutes:

A) Non-electrolytes
(do not dissociate in solution – neutral)
- Mostly organic molecules
(e.g., glucose, lipids, urea)

B) Electrolytes
(dissociate into ions in solution – charged)
- Inorganic salts
- Inorganic / organic acids
- Proteins

Although individual [solute] are different between compartments, the osmotic concentrations of the ICF and ECF are usually identical…



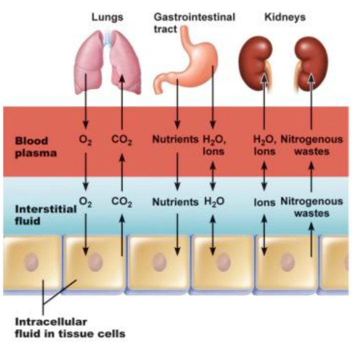
Marieb & Hoehn – Figure 25.2

Body Fluids:

2) Solutes:

What happens to ICF volume if we increase osmolarity of ECF?

IV bags of varying osmolarities allow for manipulation of ECF / ICF levels…



Marieb & Hoehn – Figure 25.2

Water Balance:

For proper hydration: $Water_{intake}$ = $Water_{output}$

ICF functions as a reservoir

Water Intake	Water Output
Metabolism (10%)	Feces (2%)
Solid foods (30%)	Sweat (8%)
Ingested liquids (60%)	Skin / lungs (30%)
	Urine (60%)
2500 ml/day	2500 ml/day

< 0

Osmolarity rises:
- Thirst
- ADH release

> 0

Osmolarity lowers:
- Thirst
- ADH release

= 0

Water Balance:

Thirst Mechanism:

(-)

↓ osmolarity / ↑ volume of extra. fluid

Osmoreceptors stimulated (Hypothalamus)

↓ volume / ↑ osmolarity of extracellular fluid

Sensation of thirst → Drink

↓ saliva secretion → Dry mouth

Water Balance:

Water Balance Disorders:

1) Dehydration (long-term water deficiency)

a) Injury (e.g., burn, hemorrhage)

b) Exercise (profuse sweating)

c) Drugs (e.g., diuretic abuse)

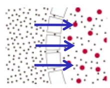
2) Hypotonic hydration (water intoxication)

Leads to dilution of electrolytes

- ↑ capillary hydrostatic pressure
- ↑ capillary permeability

3) Edema (↑ fluid in interstitial space)

Electrolyte Balance:



Importance:

1) Total [electrolyte] directly affects water balance
2) Individual [electrolyte]s affect cell functions

Uptake into System:

- Across digestive epithelium
- Through metabolic activity

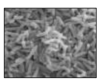
Obtaining electrolytes not a problem…

Pica: Appetite for abnormal substances

Release from System:

- Through digestive tract / kidney
- Through perspiration
- Gastrointestinal disorders

Replenish both fluids and electrolytes…



Cholera: Electrolyte / fluid loss due to bacterial toxin

Electrolyte Balance:

A) Sodium Balance:

Most abundant cation in ECF (~ 280 mosm)

Importance:

1) Contributes to osmotic pressure
2) Maintains neuron / muscle function

Osmoreceptors stimulated → ↑ ADH release; ↑ thirst → Additional water dilutes ECF

↑ $[Na^+]$ in ECF

Eat salty potato chips

Normal $[Na^+]$ in ECF (homeostasis)

Drink pure water

↓ $[Na^+]$ in ECF

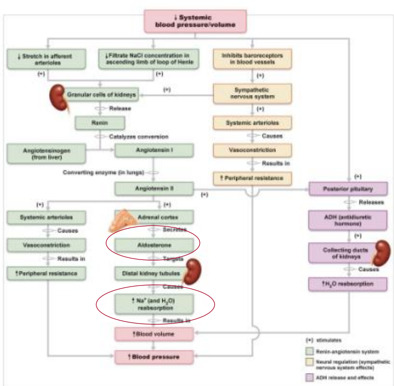
Osmoreceptors inhibited → ↓ ADH release; ↓ thirst → Decreased water concentrates ECF

- Most common ion associated with electrolyte balance problems
  - Hyponatremia = ↓ $[Na^+]$
  - Hypernatremia = ↑ $[Na^+]$

Estrogens enhance Na^+ reabsorption; thus, edema during menstrual cycle / pregnancy

Electrolyte Balance:

Baroreceptor-initiated reflexes also affect $[Na^+]$ in body



Marieb & Hoehn – Figure 25.10

Hypokalemia = ↓ $[K^+]$

Hyperkalemia = ↑ $[K^+]$

Electrolyte Balance:

B) Potassium Balance:

Importance:

1) Maintains neuron / muscle function
2) Assists in maintenance of pH

- As a rule, K^+ levels in ECF sufficiently high that K^+ needs to be secreted
  - Rate lost at kidney depends on:
    1) Changes in $[K^+]$ of ECF (↑ $[K^+]$ = ↑ rate of secretion)
    2) Changes in pH (↓ pH = ↓ rate of secretion)
    3) Aldosterone levels (↑ aldosterone = ↑ rate of secretion)

C) Calcium Balance:

Importance:

1) Maintains neuron / muscle function
2) Allows for normal blood clotting

- Levels in ECF regulated primarily by parathyroid hormone:
  1) ↑ PTH = ↑ bone desorption
  2) ↑ PTH = ↑ intestinal Ca^{++} absorption
  3) ↑ PTH = ↑ renal Ca^{++} reabsorption

Chvostek's sign

Hypocalcemia = ↓ $[Ca^{++}]$

Hypercalcemia = ↑ $[Ca^{++}]$

Acid-Base Balance:

Acidosis = pH < 7.35
Alkalosis = pH > 7.45

Critical for body to maintain pH between 7.35 – 7.45

Problems Encountered:

1) Disruption of cell membrane stability
2) Alteration of protein structure
3) Enzymatic activity change

Acid Types:

1) Volatile Acids: Acids that can leave solution and enter the atmosphere

$$CO_2 + H_2O \rightleftharpoons \underbrace{H_2CO_3}_{\text{carbonic acid}} \rightleftharpoons HCO_3^- + H^+$$

2) Fixed Acids: Acids that do not leave solution

- Result from metabolism (e.g., phosphoric acid / lactic acid / ketone bodies)
- Can only be eliminated via kidneys

Acid-Base Balance:

H^+ Gain:
- Across digestive epithelium
- Cell metabolic activities

Distant from one another →

H^+ Loss:
- Release at lungs
- Secretion into urine

Chemical Buffering Systems:

Dissolved compounds that neutralize H^+ during transport by binding H^+ when pH drops and releasing H^+ when pH rises

1) Bicarbonate Buffer System: (primary ECF buffer)

$$H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

- Limitation: Can't protect system from pH changes resulting from elevated / depressed CO_2 levels

Respiratory system must be working normally

Acid-Base Balance:

2) Phosphate Buffer System: (primary ICF buffer)

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

- Also an important buffer in urine

3) Protein Buffer System: (both ECF and ICF buffer)

If pH rises $\quad R-COOH \longrightarrow R-COO^- + H^+$

$R-NH_2 + H^+ \longrightarrow R-NH_3^+\quad$ If pH falls

- Proteins are most plentiful and powerful source of buffers in body

Buffers are a short-term fix to the problem;
In the long term, H^+ must be removed from the system…

Maintenance of Acid-Base Balance:

Doubling / halving of areolar ventilation can raise / lower blood pH by 0.2 pH units

1) Respiratory Regulation:

Bicarbonate buffer system

$$CO_2 + H_2O \rightleftharpoons \underbrace{H_2CO_3}_{\text{carbonic acid}} \rightleftharpoons HCO_3^- + H^+$$

If H^+ begins to rise in system, respiratory centers excited

↑ CO_2 leaves system

$$CO_2 + H_2O \leftarrow \underbrace{H_2CO_3}_{\text{carbonic acid}} \leftarrow HCO_3^- + H^+$$

(↓ H; homeostasis restored)

If H^+ begins to fall in system, respiratory centers depressed

↓ CO_2 leaves system

$$CO_2 + H_2O \rightarrow \underbrace{H_2CO_3}_{\text{carbonic acid}} \rightarrow HCO_3^- + H^+$$

(↑ H; homeostasis restored)

Maintenance of Acid-Base Balance:

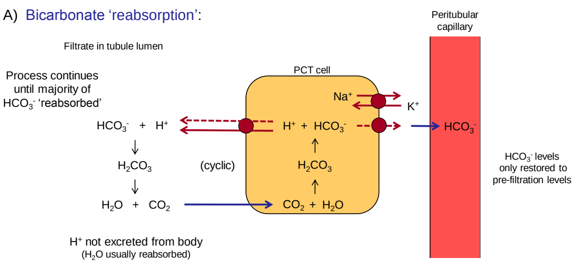
Kidneys are ultimate acid-base regulatory organs

- Remove both volatile / metabolic acids

2) Renal Regulation:

Kidneys focus on maintaining adequate HCO_3^- levels in body

A) Bicarbonate 'reabsorption':



Maintenance of Acid-Base Balance:

2) Renal Regulation:

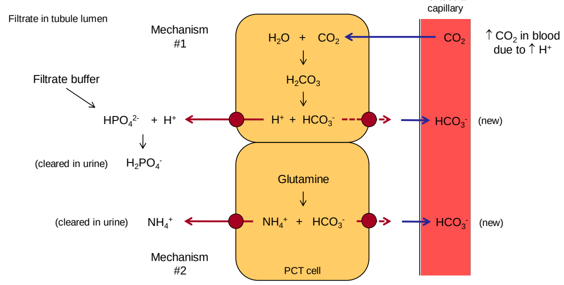
B) Bicarbonate generation:

C) Bicarbonate secretion:

If high pH (low [H^+]) exists in blood

HCO_3^- can be secreted by PCT cells

If low pH (high [H^+]) exists in blood



Disturbances of Acid-Base Balance:

In the short term, respiratory / urinary system will compensate for disorders…

1) Respiratory Acid / Base Disorders:

Cause:
Hypoventilation
(e.g., emphysema)

(Most common acid / base disorder)

A) Respiratory Acidosis:
↑ CO_2 retained in body

Cause:
Hyperventilation
(e.g., stress)

(Rarely persists long enough to cause clinical emergency)

B) Respiratory Alkalosis:
↓ CO_2 retained in body

2) Metabolic Acid / Base Disorders:

Causes:
Starvation
(↑ ketone bodies)
↑ Alcohol consumption
(↑ acetic acid)
Excessive HCO_3^- loss
(e.g., chronic diarrhea)

A) Metabolic Acidosis:
↑ fixed acids generated in body

Causes:
Repeated vomiting
(alkaline tide 'amped')
Antacid overdose

(Rare in body)

A) Metabolic alkalosis:
↑ HCO_3^- generated in body