Overview of Blood

Blood is what type of tissue? Connective tissue.

Functions
- transports vital substances (O₂, waste)
- maintains stability of interstitial fluid
- distributes heat
- hemostasis
- prevents infection

Blood Cells (formed elements – 45%)
- form in red bone marrow
- red blood cells
- white blood cells
- platelets (cell fragments)

Plasma (liquid portion - matrix)
- contains dissolved substances
- mostly water and proteins

- amount of blood varies with
- body size
- changes in fluid concentration
- changes in electrolyte concentration
- amount of adipose tissue
- about 7-8% of body weight (kg)

- About 5.0 liters of blood in adult

Hemostasis
- cessation of bleeding

Blood Vessel Spasm
- triggered by pain receptors, platelet/endothelial cell release of various substances
- smooth muscle in vessel contracts (vascular spasm)

Platelet Plug Formation
- triggered by exposure of platelets to collagen
- platelets adhere to rough surface to form a plug
- thromboxane, serotonin, Ca²⁺

Blood Coagulation
- triggered by cellular damage and blood contact with foreign surfaces
- blood clot forms

1. Vascular phase
2. Platelet phase
3. Coagulation phase (clotting cascade here)
## Summary of Factors Affecting Cardiac Output

<table>
<thead>
<tr>
<th>Factor</th>
<th>Effect on HR and/or SV</th>
<th>Effect on Cardiac Output</th>
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</thead>
<tbody>
<tr>
<td>Parasympathetic activity (vagus nerves)</td>
<td>↓ HR</td>
<td>↓</td>
</tr>
<tr>
<td>K+ (hyperkalemia)</td>
<td>↓ HR and SV (weak, irreg. beats)</td>
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<td>Ca2+ (hypocalcemia)</td>
<td>↓ SV (flaccidity)</td>
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<td>Decreased temperature</td>
<td>↓ HR</td>
<td>↓</td>
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<td>Sympathetic activity</td>
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<tr>
<td>Epinephrine</td>
<td>↑ HR and SV</td>
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<td>T3, T4 (hyperthyroidism)</td>
<td>↑ SV (spastic contraction)</td>
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<td>↑ HR</td>
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<td>Increased venous return</td>
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Figure from: Martini, Anatomy & Physiology, Prentice Hall, 2004
Pacemaker and Cardiac Conduction System

Specialized myocardial cells.

Instead of contracting, they initiate and distribute impulses throughout the heart.

Pacemaker firing rates:
- SA Node - 80-100 bpm
- AV Node - 40-60 bpm
- Purkinje - 30-40 bpm

Factors Affecting Blood Pressure (MAP)

MAP = \text{Mean Arterial Pressure} = \text{Average effective pressure driving blood flow through the systemic organs}

MAP is dependent upon \text{CO} and \text{TPR}, i.e., \text{MAP} = \text{CO} \times \text{TPR}

\text{TPR} = \text{Total Peripheral Resistance} \quad \text{depends upon} \quad \text{blood vessel radius, vessel length, blood viscosity, turbulence}

Figure adapted from: Aaronson & Ward, The Cardiovascular System at a Glance, Blackwell Publishing, 2007

Regulation of Cardiac Output

\text{MAP} = \frac{\text{CARDIAC OUTPUT}}{\text{TPR}}

\text{TPR} = \frac{1}{\text{radius}^4} \quad \text{Vessel length} \quad \text{Viscosity} \quad \text{Turbulence}
Exchange in the Capillaries

- Major mechanism involved in exchange of solutes is diffusion
- Substances move in and out along the length of the capillaries according to their respective concentration gradients
- Fluid movement in systemic capillaries is determined by two major factors:
  1. Hydrostatic pressure; varies along portions of capillary
  2. Osmotic pressure; remains about the same along the length of the capillary

Excess tissue fluid is drained via lymphatics

Veins That Drain the Abdominal Viscera

Practical Classification of Immunity

- Natural
  - Passive (maternal Ig)
  - Active (live pathogens)
- Artificial
  - Passive (Ig or antitoxin)
  - Active (vaccination)

Know this
Major Lymphatic Organs

- filter potentially harmful particles from lymph
- immune surveillance by macrophages and lymphocytes
- large in children, small in an adult - decreases in size after puberty
- site of T lymphocyte 'education'
- upper left abdominal quadrant
- filters blood
- destroys worn out RBCs

Two major types of lymphatic tissues: 1) diffuse 2) nodular

Movements/Innervation of the Alimentary Canal

- mixing movements (segmentation)
- peristalsis - The wavelike muscular contractions of the alimentary canal or other tubular structures by which contents are forced onward toward the opening

- submucosal plexus – controls secretions/blood flow
- myenteric plexus – controls gastrointestinal motility/sphincters

- parasympathetic division of ANS – increases activities of digestive system and relaxes sphincters
- sympathetic division of ANS – generally inhibits digestive actions and contracts sphincters

Lining and Gastric Glands of Stomach

- Secrete mucous; important for protection of stomach wall
- Secrete 1) HCl – converts pepsinogen into pepsin
  2) Intrinsic factor – bind vitamin B₁₂
- Secrete pepsinogen; after being converted to pepsin by HCl, this digests proteins
- Secrete gastrin; the ‘Go’ hormone of stomach motility and secretion
Bile (Chole-)

Yellowish-green liquid continually secreted by hepatocytes

Secretin causes the bile ducts (and pancreatic ducts) to secrete bile rich in $\text{HCO}_3^-$ (bicarbonate ion)

$\text{HCO}_3^-$ helps to neutralize acid in small intestine

Bile salts (bile acids)
- derived from cholesterol
- emulsification of fats (increases surface area for digestive enzymes)
- absorption of fatty acids, cholesterol, and fat-soluble vitamins

Overview of Gastric Control/Secretion

Key
- Simulation
- Inhibition

Endocrine Factor
- Gastrin
- Somatostatin

Exocrine Factor
- $\text{H}^+ + \text{Cl}^-$
- $\text{HCO}_3^-$ (alkaline tide)

Liver

Hepatic lobules are the functional units of the liver

Liver’s role in digestion is production of bile

Know pathway of bile and blood flow
Absorption of Fats in the Small Intestine

• Fatty acids and glycerol
• Several steps
• Absorbed into lymph into blood

Chylomicrons contain TG, cholesterol, and phospholipids

Metabolism

• Glycolysis – metabolism of glucose to pyruvate (Fed)
• Gluconeogenesis – metabolism of pyruvate to glucose (CHO from non-CHO source) – (Fed)
• Glycogen synthesis – metabolism of glucose to glycogen (Fed)
• Glycogenolysis – metabolism of glycogen to glucose (Fasted)
• Lipolysis – breakdown of triglyceride into glycerol and fatty acids (Fasted)
• Lipogenesis – creation of new triglyceride (fat) – (Fed)

Regulation of Pancreas/Intestinal Digestion

Key

Stimulation

Acidic Chyme Enters Duodenum

Cholecystokinin (CCK)

Trypsinogen

Gallbladder

Contraction

Relaxation of hepatopancreatic sphincter

Bile

Triglycerides

Cholesterol

Fat Soluble Vitamins

Fatty acids, monoglycerides

Di- and tripeptides

Amino acids

Lacteals

Mono-, di-, trisaccharides

Subclavian vein

Portal Vein

Bile and Pancreatic ducts

Trypsin

Trypsinogen

Trypsinogen

Trypsin

Chymotrypsinogen

Chymotrypsin

Pancreatic amylase

Gastrin

Cholecystokinin

Acidic Chyme Enters Duodenum

Bile and Pancreatic ducts

Blood

Acidic Chyme

Bicarbonate (HCO₃⁻, PO₄³⁻)

↑ pH to ≈ 8 (req. for enzyme action)

Conversion to chylomicrons

Monosaccharides

Nucleotides

Proteins

Bi- and tripeptides

Amino acids
Pancreatic Proteolytic Enzymes

- Pancreas
  - Trypsinogen
  - Proelastase
  - Procarboxypeptidase
  - Enteropeptidase (Enterokinase)
    - Brush border of small intestine
  - Enteropeptidase
  - Chymotrypsinogen
  - Prochymotrypsin
  - Chymotrypsin
  - Carboxypeptidase
  - Elastase

Proteins
- Dipeptides, tripeptides, amino acids

Purpose of proteolytic enzymes is continued breakdown of proteins that began in the stomach

The Fat-soluble Vitamins

- Absorbed with fats in digestive tract
- Function/Other sources
  - Vitamin A: structural component of retinal
  - Vitamin D
    - Increases absorption of calcium and phosphorus from intestine
    - Skin and UV light
  - Vitamin E
    - Stabilizes internal cellular membranes
    - Antioxidant
  - Vitamin K
    - Clotting ('K'lotting)
    - Bacteria in intestine and green, leafy vegetables

Water-soluble Vitamins

- Rapidly exchanged between fluid compartments of digestive tract and circulating blood
- Excesses excreted in urine
- Vitamins B12 and C are stored in larger quantities than other water-soluble vitamins
  - B vitamins [know these functions]
    - As a group, are coenzymes used to harvest energy
    - Vitamin B12 is important in hematopoiesis and maintenance of myelin sheath and epithelial cells
  - Vitamin C (ascorbic acid) [know these functions]
    - Collagen production
    - Antioxidant / immune system booster
    - Increase absorption of iron
### Minerals and Their Functions

#### Calcium (Ca)
- **Major Sources**: Milk, dairy, leafy greens
- **Conditions**: Stunted growth
- **Function(s)**: Bones & Teeth structure, nerve impulse conduction, muscle contraction

#### Phosphorus (P)
- **Major Sources**: Meats, cheese, milk
- **Conditions**: Stunted growth
- **Function(s)**: Bones & Teeth structure, ATP, nucleic acid & proteins

#### Potassium (K)
- **Major Sources**: Avocados, bananas, potatoes
- **Conditions**: Muscular & cardiac problems
- **Function(s)**: Intracellular fluid maintenance, RMP

#### Sodium (Na)
- **Major Sources**: Table salt, cured ham
- **Conditions**: Hypertension, edema
- **Function(s)**: Extracellular fluid, maintenance of RMP, electrolyte, water, & pH balance

#### Chlorine (Cl)
- **Major Sources**: Table salt, cured ham
- **Conditions**: Vomiting, muscle cramps
- **Function(s)**: Extracellular fluid, maintenance of RMP, electrolyte, water, & pH balance

#### Magnesium (Mg)
- **Major Sources**: Milk, dairy, legumes
- **Conditions**: Diarrhea, neuromuscular problems
- **Function(s)**: Bones, ATP/ADP conversion

#### Iron (Fe)
- **Major Sources**: Liver + liver damage
- **Conditions**: Anemia

#### Iodine (I)
- **Major Sources**: Iodized salt
- **Conditions**: Thyroid hormone imbalance, goiter
- **Function(s)**: Essential in the synthesis of thyroid hormones

#### Zinc (Zn)
- **Major Sources**: Meats, cereals
- **Conditions**: Slurred speech, decreased immunity
- **Function(s)**: Liver, kidneys, brain, wound healing; part of several enzymes

### Oxygen Transport

- Oxygen travels in the blood bound to Hb
- Four O₂ molecules can be bound to 1 Hb
- O₂ bound to Hb - oxyhemoglobin
- Uptake and release of O₂ is dependent upon PₐO₂ in alveoli and tissues
- Several factors can increase the release of O₂ from Hb
  - Increased PₐCO₂
  - Increased [H⁺] (decreased pH)
  - Increased temperature of blood
CO₂ Transport

• Carbon dioxide can travel in several ways
  – Dissolved in plasma (7%)  
  – As carbaminohemoglobin (15-25%)  
  – As HCO₃⁻ ion (70%)
    • Recall: H₂O + CO₂ ↔ H₂CO₃ ↔ H⁺ + HCO₃⁻
    • Carbonic anhydrase in RBCs accelerates interconversion between CO₂ and HCO₃⁻
    • H⁺ combines with or dissociates from Hb
    • HCO₃⁻ diffuses into plasma or into RBCs
    • Cl⁻ diffuses into RBC (chloride shift) as HCO₃⁻ exits

• Diffusion of CO₂ is related to PₐCO₂ in alveoli and tissues

Control of Respiration

• Control of respiration is accomplished by:
  1) Local regulation
  2) Nervous system regulation

• Local regulation
  – ↓ alveolar ventilation (O₂), ↓ Blood flow to alveoli
  – ↑ alveolar ventilation (O₂), ↑ Blood flow to alveoli
  – ↑ alveolar CO₂, bronchodilation
  – ↓ alveolar CO₂, bronchoconstriction

Nervous System Control

• Normal rhythmic breathing -> DRG in medulla
• Forced breathing -> VRG in medulla

• Changes in breathing
  – CO₂ is most powerful respiratory stimulant
  – Recall: H₂O + CO₂ ↔ H₂CO₃ ↔ H⁺ + HCO₃⁻
  – Peripheral chemoreceptors (aortic/carotid bodies)
    • ↑ PₐCO₂, ↓ pH, ↓ PₐO₂ stimulate breathing
  – Central chemoreceptors (medulla)
    • ↑ PₐCO₂, ↓ pH stimulate breathing
Inspiration/Expiration

- Normal inspiration
  - An active process
  - Phrenic nerve -> diaphragm contraction
  - External (inspiratory) intercostal muscles
  - Role of the lung pleura

- Normal expiration
  - A PASSIVE process
  - Due to elasticity of lung/abdominal organs and alveolar surface tension
  - Diaphragmatic relaxation

- Forced inspiration
  - Active process
  - Sternocleidomastoid, Pectoralis minor

- Forced expiration
  - Active process
  - Internal intercostals, abdominal muscles

Bronchial Tree

- Bronchi
  - Primary; w/ blood vessels
  - Secondary (lobar); two on left, three on right
  - Tertiary (segmental); supplies a bronchopulmonary segment; 10 on right, 8 on left

- Bronchioles
  - Intralobular; supply lobules, the basic unit of lung
  - Terminal; 50-80 per lobule
  - Respiratory; a few air sacs budding from these

Bronchioles are to the respiratory system what arterioles are to the circulatory system

Figure from: Martini, "Anatomy & Physiology", Prentice Hall, 2001
Pituitary Gland Control

- Hypothalamic releasing hormones stimulate cells of the anterior pituitary to release their hormones.
- Nerve impulses from hypothalamus stimulate nerve endings in the posterior pituitary gland to release its hormones.

Hormones of the Anterior Pituitary (Get GAP)

Hormones from Hypothalamus

- TSH (Thyroid-stimulating hormone)
- ACTH (Adrenocorticotropic hormone)
- GH (Growth hormone)
- LH (Luteinizing hormone)
- FSH (Follicle-stimulating hormone)
- GnRH (Gonadotropin-releasing hormone)
- TRH (Thyrotropin-releasing hormone)

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Tropic hormones control the activity of other endocrine glands.

All anterior pituitary hormones use second messengers.

Hormone Summary Table I

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<th>Target Tissue</th>
<th>Action on Target Tissue</th>
<th>Control of Release</th>
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<td>production of cortisol</td>
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<td>secretion of steroids</td>
<td>CRH (Corticotropin-releasing hormone)</td>
</tr>
<tr>
<td>PROLACTIN (PRL)</td>
<td>mammary glands</td>
<td>secretion of milk</td>
<td>PRLH (Prolactin-releasing hormone)</td>
</tr>
<tr>
<td>GROWTH HORMONE (GH)</td>
<td>bone, muscle, fat</td>
<td>growth of tissues</td>
<td>GHRH (Growth hormone-releasing hormone)</td>
</tr>
<tr>
<td>THYROID STIMULATING HORMONE (TSH)</td>
<td>thyroid</td>
<td>secretion of hormones</td>
<td>TRH (Thyrotropin-releasing hormone)</td>
</tr>
<tr>
<td>FOLLICLE STIMULATING HORMONE (FSH)</td>
<td>ovary</td>
<td>gonadal development, follicular development</td>
<td>GnRH (Gonadotropin-releasing hormone)</td>
</tr>
<tr>
<td>LUTEINIZING HORMONE (LH)</td>
<td>ovary, testes</td>
<td>ovulation, follicle maturation</td>
<td>GnRH (Gonadotropin-releasing hormone)</td>
</tr>
<tr>
<td>ADRENOCORTICOTROPIC HORMONE (ACTH)</td>
<td>adrenal gland</td>
<td>secretion of steroids</td>
<td>CRH (Corticotropin-releasing hormone)</td>
</tr>
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<td>PROLACTIN (PRL)</td>
<td>mammary glands</td>
<td>secretion of milk</td>
<td>PRLH (Prolactin-releasing hormone)</td>
</tr>
</tbody>
</table>
## Hormone Summary Table II

<table>
<thead>
<tr>
<th>Hormone</th>
<th>Origin</th>
<th>Destination</th>
<th>Action on Target Tissue</th>
<th>Control of Release</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aldosterone</td>
<td>Adrenal Cortex</td>
<td>Kidneys; sweat glands; salivary glands; pancreas</td>
<td>Reabsorption of water and Na (increases blood pressure) and excretion of K (mineralocorticoid)</td>
<td>Angiotensin II ↓ plasma [Na+] ↑ plasma [K+]</td>
</tr>
<tr>
<td>Cortisol</td>
<td>Adrenal Cortex</td>
<td>all cells</td>
<td>Diabetogenic; anti-inflammatory (glucocorticoid)</td>
<td>ACTH</td>
</tr>
<tr>
<td>Estrogen</td>
<td>Ovaries</td>
<td>secondary sex organs</td>
<td>Development of sex organs at puberty and maintenance throughout life</td>
<td>LH</td>
</tr>
<tr>
<td>Testosterone</td>
<td>Testes</td>
<td>secondary sex organs</td>
<td>Development of sex organs and maintenance throughout life</td>
<td>LH</td>
</tr>
<tr>
<td>Insulin</td>
<td>β-cells of Pancreatic Islets</td>
<td>all cells, liver and skeletal muscle</td>
<td>Pushes glucose into cells from blood, glycogen formation (decreases blood glucose)</td>
<td>Glucose ↑</td>
</tr>
<tr>
<td>Glucagon</td>
<td>α-cells of Pancreatic Islets</td>
<td>liver and skeletal muscle</td>
<td>Breakdown of glycogen (increase in blood glucose)</td>
<td>Glucose ↓</td>
</tr>
<tr>
<td>Adrenaline</td>
<td>Adrenal Medulla</td>
<td>cardiac muscle, arteriole and bronchiole smooth muscle, diaphragm, etc</td>
<td>Increases heart rate and blood pressure (fight or flight)</td>
<td>Sympathetic Nervous System</td>
</tr>
<tr>
<td>Nitric Oxide</td>
<td>Aorta and vena cava</td>
<td>arteries, veins, capillaries, veins</td>
<td>Increases blood flow and helps prevent blood clots</td>
<td>Nitric Oxide</td>
</tr>
<tr>
<td>TRH</td>
<td>Hypothalamus</td>
<td>Hypothalamus, median eminence, tuber cinereum</td>
<td>Increases release of anterior pituitary hormones and growth hormone release</td>
<td>Hypothalamus</td>
</tr>
<tr>
<td>Parathormone</td>
<td>Parathyroid</td>
<td>intestine, bone, kidney</td>
<td>Increases plasma [Ca2+] (increases intestinal absorption of Ca, decreases action of osteoclasts, increases excretion of Ca by kidney)</td>
<td>Parathyroid Hormone (PTH) ↓ plasma [Ca2+]</td>
</tr>
<tr>
<td>Calcitonin</td>
<td>Thyroid (C cells)</td>
<td>intestine, bone, kidney</td>
<td>Decreases plasma [Ca2+] (decreases intestinal absorption of Ca, increases action of osteoclasts, decreases excretion of Ca by kidney)</td>
<td>Parathyroid Hormone (PTH) ↑ plasma [Ca2+]</td>
</tr>
</tbody>
</table>

### Control of Hormone Secretion

1) Neural control
2) Humoral control
3) Hormonal control

### Summary of Factors Affecting GFR

<table>
<thead>
<tr>
<th>Factor</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vasoconstriction</td>
<td></td>
</tr>
<tr>
<td>Afferent arteriole</td>
<td>↓ GFR</td>
</tr>
<tr>
<td>Efferent arteriole</td>
<td>↓ GFR</td>
</tr>
<tr>
<td>Vasodilation</td>
<td></td>
</tr>
<tr>
<td>Afferent arteriole</td>
<td>↑ GFR</td>
</tr>
<tr>
<td>Efferent arteriole</td>
<td>↑ GFR</td>
</tr>
<tr>
<td>Increased capillary hydrostatic pressure</td>
<td>↓ GFR</td>
</tr>
<tr>
<td>Increased colloid osmotic pressure</td>
<td>↓ GFR</td>
</tr>
<tr>
<td>Increased capsular hydrostatic pressure</td>
<td>↓ GFR</td>
</tr>
</tbody>
</table>
**Glomerular Filtration Rate (GFR)**

NFP = HP - (HP + OP)

Net Filtration Pressure = force favoring filtration – forces opposing filtration

( Glomerular capillary hydrostatic pressure
+ Glomerular capillary osmotic pressure
)

Net filtration pressure is normally positive, i.e., favors the movement of fluid out of the glomerular capillaries

GFR = amount of filtrate produced each minute (~125 ml/min)

**Summary of Reabsorption and Secretion**

<table>
<thead>
<tr>
<th>Process</th>
<th>PCT</th>
<th>Descending</th>
<th>Ascending</th>
<th>DCT</th>
<th>Collecting duct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reabsorption</td>
<td>Glucose, amino acids, urea, uric acid, Na⁺, Cl⁻, HCO₃⁻</td>
<td>H₂O</td>
<td>Na⁺/Cl⁻, K⁺</td>
<td>Na⁺/Cl⁻, H₂O</td>
<td>H₂O, urea</td>
</tr>
<tr>
<td>Secretion</td>
<td>Creatinine, HC⁺, Some drugs</td>
<td>Urea</td>
<td>-</td>
<td>H⁺/K⁺, NH₄⁺</td>
<td>-</td>
</tr>
</tbody>
</table>

**Summary of Events in the Nephron**

1. Filtrate produced
2. Reabsorption of 65% of filtrate
3. Obligatory water reabsorption
4. Reabsorption of Na⁺ and Cl⁻ by active transport
5,6. Facultative reabsorption of water
7. Absorption of solutes and water by vasa recta
Urine Formation

Fluid from plasma passes into the glomerular capsule and becomes filtrate at an average rate of 125 ml/minute. This is known as the Glomerular Filtration Rate (GFR)

- Glomerular Filtration (GF) *Adds to volume of urine produced
  - substances move from blood to glomerular capsule

- Tubular Reabsorption (TR) *Subtracts from volume of urine produced
  - substances move from renal tubules into blood of peritubular capillaries
  - glucose, water, urea, proteins, creatine
  - amino, lactic, citric, and uric acids
  - phosphate, sulfate, calcium, potassium, and sodium ions

- Tubular Secretion (TS) *Adds to volume of urine produced
  - substances move from blood of peritubular capillaries into renal tubules
  - drugs and ions, urea, uric acid, H+

\[ \text{Urine formation} = GF + TS - TR \]

Renin-Angiotensin System

Renin is released by the juxtaglomerular apparatus due to:
1) Decline of BP
   \( \text{Renin} \propto \frac{1}{\text{Pressure}} \)
2) Juxtaglomerular stimulation by sympathetic NS
3) Decline in osmotic concentration of tubular fluid at macula densa
   \( \text{Renin} \propto \frac{1}{[\text{NaCl}]} \)

Stabilizes systemic blood pressure and extracellular fluid volume

Acid/Base Buffers

A buffer resists changes in pH

<table>
<thead>
<tr>
<th>Buffer</th>
<th>Type</th>
<th>Speed</th>
<th>Eliminate H+ from body?</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical</td>
<td>Physical (first line of defense)</td>
<td>Seconds</td>
<td>No</td>
<td>Bicarbonate, phosphate, proteins (ICF, plasma proteins, Hb)</td>
</tr>
<tr>
<td>Respiratory</td>
<td>Physiological</td>
<td>Minutes</td>
<td>Yes (indirectly as CO2)</td>
<td>( \text{H}_{2}O + \text{CO}_2 \rightarrow \text{H}^+ + \text{HCO}_3^- )</td>
</tr>
<tr>
<td>Renal</td>
<td>Physiological</td>
<td>Hours - Days</td>
<td>Yes</td>
<td>( \text{H}^+ ) excretion ( \text{HCO}_3^- ) excretion/retention*</td>
</tr>
</tbody>
</table>

*Normal plasma \([\text{HCO}_3^-] = 25 \text{ mEq/L}\)
Electrolyte Balance

Electrolyte balance is important because:

1. It regulates fluid (water) balance
2. Concentrations of individual electrolytes can affect cellular functions

<table>
<thead>
<tr>
<th>Electrolyte</th>
<th>Normal plasma concentration (mEq/L)</th>
<th>Major mechanism(s) regulating retention and loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl⁻</td>
<td>105</td>
<td>Follows Na⁺</td>
</tr>
<tr>
<td>K⁺</td>
<td>4.0</td>
<td>1. Renin at DCT (aldosterone sensitive)</td>
</tr>
<tr>
<td>Ca²⁺</td>
<td>5.0</td>
<td>1. Calcitonin (children mainly) 2. Parathyroid hormone 3. Vitamin D (dietary uptake from intestines)</td>
</tr>
</tbody>
</table>

Major Regulators of H₂O Intake and Output

- **Regulation of water intake**
  - Increase in osmotic pressure of ECF → osmoreceptors in hypothalamic thirst center → stimulates thirst and drinking

- **Regulation of water output**
  - Obligatory water losses (must happen)
    - Insensible water losses (lungs, skin)
    - Water loss in feces
    - Water loss in urine (min about 500 ml/day)
  - Increase in osmotic pressure of ECF → ADH is released
    - Concentrated urine is excreted
    - More water is retained
    - LARGE changes in blood vol/pressure → Renin and ADH release

Acidosis and Alkalosis

If the pH of arterial blood drops to 6.8 or rises to 8.0 for more than a few hours, survival is jeopardized

- Accumulation of acids
- Loss of bases
- Increased concentration of H⁺
- Decreased concentration of H⁺
- Alkalosis
- Acidosis

Classified according to:
1. Whether the cause is respiratory (CO₂), or metabolic (other acids, bases)
2. Whether the blood pH is acid or alkaline

Respiratory system compensates for metabolic acidosis/alkalosis. Renal system compensates for respiratory acidosis/alkalosis.
The Countercurrent Multiplier

Approximate normal osmolarity of body fluids

The mechanism shown is called the "countercurrent multiplier"

Countercurrent multiplier allows the kidneys to vary the concentration of urine

Vasa recta maintains the osmotic gradient of the renal medulla so the countercurrent multiplier can work

Reduced osmolarity of tubular fluid due to action of countercurrent multiplier

Plasma Concentrations of Common Electrolytes

<table>
<thead>
<tr>
<th>Electrolyte</th>
<th>Concentration Range (mEq/L)</th>
<th>Typical Value (mEq/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>136 - 142</td>
<td>140</td>
</tr>
<tr>
<td>K</td>
<td>3.8 - 5.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Ca²⁺</td>
<td>4.5 – 5.8</td>
<td>5.0</td>
</tr>
<tr>
<td>Cl⁻</td>
<td>96 - 106</td>
<td>105</td>
</tr>
<tr>
<td>HCO₃⁻</td>
<td>24 - 28</td>
<td>25</td>
</tr>
</tbody>
</table>

Body Fluid Ionic Composition

Remember:
- # mEq or # mOsm > # mmol
- mEq = mmol x # charges
- mOsm = mmol x # particles

ECF major ions:
- sodium, chloride, and bicarbonate

ICF major ions:
- potassium, magnesium, and phosphate (plus negatively charged proteins)

You should know these chemical symbols and charges of ions
Urine composition varies depending upon
- Diet
- Level of activity

Major constituents of urine
- H₂O (95%)
- Creatinine (remember, NONE of this is reabsorbed)
- Urea (most abundant solute), uric acid
- Trace amounts of amino acids
- Electrolytes
- Urochrome (yellow color), urobilin, trace of bilirubin

Normal urine output is 0.6-2.5 L/day (25-100 ml/hr)
Output below about 25 ml/hour = kidney failure (oliguria - anuria)