Circulation

Chapters 13 and 14

Circulatory System

- Transportation
  - nutrients, metabolic wastes (excretion), water, ions and respiratory gases (O₂, CO₂).
- Regulatory
  - hormonal — transportation of hormones from endocrine glands to target tissues
  - temperature — blood shunting to conserve or dissipate heat through the skin
- Protection
  - blood clotting — protects against blood loss
  - immunity — leukocytes protect against disease

Subdivisions

- Cardiovascular system
  - heart and blood vessels
  - transport blood
- Lymphatic system
  - lymph vessels and lymphoid tissues (spleen, thymus, tonsils and lymph nodes)
  - transport lymph

Cardiovascular System

- Blood
  - transport medium (cells suspended in fluid)
- Heart
  - pump: forces blood through BV’s
- Blood vessels
  - tubing that carries blood (60,000 miles)

Blood

- Transport medium for gases, nutrients, wastes etc.
- Volume
  - Women = 5 liters
  - Men = 5.5 liters
- Blood is composed of:
  - Plasma (55% of blood volume)
    - fluid portion
  - Formed Elements (45%)
    - cells and cell fragments

Plasma

- Water (90%)
  - dissolves materials (gases, nutrients, etc.)
  - acts as fluid medium for transport of blood cells and plasma proteins
- Proteins (7-9%)
  - Maintain osmotic pressure of blood (albumins)
  - Lipid transport (globulins)
  - Immunity (antibodies, complement proteins)
  - Clotting factors
  - Various enzymes

Fig 13-1
Formed Elements

<table>
<thead>
<tr>
<th>Elements</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erythrocytes</td>
<td>thin, disc-like cells, 25-30 trillion RBCs circulating at a given time</td>
</tr>
<tr>
<td>Leukocytes</td>
<td>White Blood Cells</td>
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<tr>
<td>Thrombocytes</td>
<td>Platelets</td>
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Erythrocytes

- thin, disc-like cells
- 25-30 trillion RBCs circulating at a given time
- Lack nuclei and mitochondria
  - anaerobic respiration only
- transport respiratory gases (mainly O₂)

Leukocytes

- Immunity
  - ability to resist or destroy harmful foreign invaders or abnormal cells
- Functions
  - destroy pathogens
    - bacteria, viruses, protozoans and worms
  - destroy cancer cells
  - remove dead or injured cells
  - wound healing

Leukocyte Types

- Granulocytes
  - cytoplasmic granules
  - eosinophils
    - enhance allergic conditions
    - chemically attack parasites (worms)
  - basophils / mast cells
  - promote inflammation response
  - neutrophils
    - phagocytes (devour pathogens and dead cells)

- Agranulocytes
  - no cytoplasmic granules
  - monocytes
    - circulating phagocytes
    - differentiate into macrophages in tissues
  - lymphocytes
    - found mainly in lymphatic system
    - specific immune responses
    - B Lymphocytes - produce antibodies
    - T Lymphocytes - destroy virally infected or cancerous cells
Platelets (Thrombocytes)

- Cell fragments from megakaryocytes in myeloid tissue
- Contain actin and myosin (contraction)
- Formation of a blood clot to stop bleeding

Blood Clot Formation

- Platelets touch underlying collagen in connective tissue
- Secrete chemical messengers and “glue”
  - Messengers induce vasoconstriction
    - Decrease blood flow to damaged vessel
  - Formation of platelet plug
    - Platelets stick to collagen and to each other

Blood Clot Formation

- Enzymatic cascade of clotting factors occurs
  - Prothrombin (inactive enzyme) → thrombin (activated enzyme)
  - Catalyzes fibrinogen (soluble) → fibrin (insoluble)
- Forms protein meshwork over the platelet clot
- Platelets contract to seal the breach

The Heart

- Hollow, muscular organ
- Located in center of thoracic cavity
- Pumps constantly
  - Variable rate

Blood Circuits

- Pulmonary circuit
  - From heart (right) → lungs → heart (left)
  - Gas exchange with atmosphere
    • Release CO₂, pick up O₂
- Systemic circuit
  - From heart (left) → tissues → heart (right)
  - Gas exchange with tissues
    • Release O₂, pick up CO₂

Heart Anatomy: Chambers

- Four chambers
  - Atria (auricles)
    • Receive blood from veins
  - Ventricles
    • Pump blood into arteries
Cardiac Muscle

- found in myocardium
- striated (sarcomeres)
- single nucleus in cells
- fibers linked by intercalated disks
  - electrical synapses
  - allow linked fibers to contract as a unit
- Atrial and ventricular fibers not linked by intercalated disks
  - allows atria and ventricles to contract separately

Heart Anatomy: Interventricular Septum

- Interventricular septum
  - divides heart into two halves
- Right side pumps deoxygenated blood
- Left side pumps oxygenated blood

Heart Anatomy - Valves

- Atroventricular valves
  - Right (tricuspid)
  - Left (bicuspid)
- Allow blood to flow from atrium to ventricle only
- Chordae tendinae attached to papillary muscles
  - prevent valves from evertting during ventricular contraction

Heart Anatomy - Valves

- Semilunar valves
  - Pulmonary (Right)
  - Aortic (Left)
- at openings of the arteries leaving the ventricles
- prevent backflow of blood during ventricular relaxation

Blood Flow Through the Heart

- Deoxygenated blood enters right side through vena cavae
- right atrium
- right AV valve
- right ventricle
- pulmonary semilunar valve
- pulmonary artery
- lungs (pulmonary circuit)

Blood Flow Through the Heart

- Oxygenated blood enters left side through pulmonary veins
- left atrium
- left AV valve
- left ventricle
- aortic semilunar valve
- aorta
- tissues (systemic circuit)
Cardiac Cycle
- contraction (systole) + relaxation (diastole) of ventricles
- lasts 0.8 sec (based on 72 beats/min)

Cardiac Cycle - Blood Volumes
- End-diastolic volume
  - amt of blood in ventricles at end of diastole
- End-systolic volume
  - amt of blood in ventricles at end of systole
  - ~1/3 of end-diastolic vol.
- Stroke volume (SV)
  - Amt of blood ejected by ventricles
  - Equal to EDV – ESV

Cardiac Cycle - Heart Sounds
- “lub” = closing of the AV valves
- “dub” = closing of the semilunar valves

Cardiac Excitation
- Heart is generates its own APs
- Pacemaker cells
  - undergo spontaneous depolarizations during diastole
  - pacemaker potentials
    - (-60mV → -40mV)

Pacemaker Potentials
- Begins to depolarize due to hyperpolarization of membrane to near -60 mV
  - “Funny channels” – open in response to hyperpolarization
    - Allow Na⁺ and K⁺ to flow (depolarizer)
    - Triggers opening of “slow” Ca²⁺ channels (further depolarization)
- Reaches threshold for other v.g. Ca²⁺ channels (“fast channels”)
  - Ca²⁺ flows in
  - rapid depolarization and overshoot
- Repolarized by opening of v.g. K⁺ channels and outflow of K⁺

Pacemakers
- Sinoatrial (SA) Node
  - pacemaker of the heart
- Atrioventricular (AV) Node
  - Delays conduction to ventricles
- Bundle of His
  - conducts signal through interventricular septum
- Purkinje fibers
  - conduct signal up lateral walls of ventricle
Path of Cardiac Excitation

- SA node cells produce APs
- Atrial fibers activated
  - atrial contraction
- APs excite AV node
  - delay (complete atrial contract)
- APs of AV node travel down
  AV bundle to apex of heart
- signal conducted to Purkinje
  fibers throughout ventricles
- Myocardial fibers activated
  - ventricular contraction

Myocardial Action Potentials

- Prolonged action potential
  duration
  - influx of Na+ - depolarization
  - Plateau phase due to Ca2+
    influx and slow opening of
    K+ channels
  - Repolarization by delayed
    opening of v.g. K+ channels
- Prolonged refractory period
  ensures pumping action

Cardiac Output

- Amount of blood pumped by the heart in one
  minute
  - heart rate (beats/min) X stroke volume (ml)
- At rest, HR = 70 bpm, SV = 70-80 ml
  - Cardiac Output = 5.0 - 5.5 L/min
  - Heart pumps entire blood volume each min.
- During exercise can increase 4-5x to 25 liters/min.

Heart Rate Regulation

- Parasympathetic nervous
  system
  - Slows HR
- Sympathetic nervous system
  - Speeds up HR
- Hormones (Epinephrine)

Stroke Volume Regulation

- end-diastolic volume
  - ↑EDV, ↑SV
  - function of venous return
- total peripheral resistance
  - ↑Resistance, ↓SV
  - Function of blood vessel diameter

Stroke Volume Regulation

- contractility
  - function of sarcomere
    length in muscle fibers
  - sympathoadrenal
    stimulation (↑ Ca2+
    concentrations)
Blood Vessels
• Tubes that conduct blood
  – Arteries
  – Aterioles
  – Capillaries
  – Venules
  – Veins

Blood Pressure
• Pressure blood exerts on blood vessel walls
  – produced by heart contractions
  – main driving force for the flow of blood through the blood vessels
  – decreases as blood moves further from the heart

Arteries
• Large vessel receiving blood from the heart
• Functions
  – rapid transport of blood
    • large radius, high pressure
  – pressure reservoirs
    • walls expand upon systole
    • recoil during diastole maintains blood flow

Arterial Blood Pressure
• Systolic blood pressure
  – pressure of blood in arteries during ventricular systole
• Diastolic blood pressure
  – pressure of blood in arteries during ventricular diastole
• Indicates
  – blood flow to the body
  – work load of the heart

Arterial Blood Pressure Regulation
• Blood pressure monitored by baroreceptors in carotid sinuses and aorta
• Signals sent to medulla
  – cardiac + vasomotor centers
• response sent out via autonomic MNs
  – sympathetic - ↑ HR, vasoconstriction
  – parasympathetic - ↓ HR, vasodilation

Arterioles
• Major resistance vessels
  – ↓ fluctuations in blood pressure btw systole & diastole
• Control of perfusion
  – smooth muscle in vessel walls under autonomic control
    – vasoconstriction
      • ↓ diameter, ↓ blood flow
      – vasodilation
        • ↑ diameter, ↑ blood flow
Capillaries
- Single endothelial cell layer
- Connect arterioles to venules
- Exchange of materials between blood and interstitial fluid

Properties of Capillaries
- Short diffusion distance
  - thin capillary walls
  - narrow diameter
- High surface area
  - extensive branching (close to all cells)
- Slow blood flow
  - increases time for diffusion to occur

Ultrafiltration
- Blood passing through capillaries undergoes ultrafiltration
  - Blood pressure causes plasma fluid to be pushed out (proteins remain)
  - As fluid is pushed out, blood osmotic pressure increases
  - Fluid drawn back into the capillaries when osmotic pressure exceeds blood pressure
  - More fluid forced out than pulled in

Venules and Veins
- Return blood to the heart after exchanging materials in capillaries
- Hold most of the blood in the body
  - capacitance vessels
- Regulate rate of blood return to the heart

Venous Return
Venous return
- amt of blood veins deliver back to the heart
Factors influencing return
- pressure gradient
  - mean pressure is low
  - vein walls are highly elastic
- large radii of veins - little resistance
  - modified by vasoconstriction

Venous Return
- Venous Valves
  - prevent backflow of blood
- Skeletal Muscle Activity
  - contraction acts to “pump” veins
  - increases venous return with increased activity
Lymphatic System

- Blood passing through capillaries undergoes ultrafiltration
  - Net loss of fluid from the blood
  - Must be returned to the blood

Lymphatic System

- Network of vessels
  - picks up lost fluid (lymph) and returns it to circulation
- Pass through lymph nodes
  - Immune functions
- Vessels deposit lymph into subclavian veins