Chapter 13 The Cardiovascular System: Cardiac Function

Overview of the Cardiovascular System
- The Path of Blood Flow through the Heart and Vasculature
- Anatomy of the Heart
- Electrical Activity of the Heart
- The Cardiac Cycle
- Cardiac Output and Its Control

13.1 Cardiovascular System Components and Functions
- **Components of Circulatory System:**
  - The heart pumps that drives the blood flow
  - Blood vessels carry the blood flow from high pressure region to low pressure region
  - Blood is the fluid that transport materials and it plays a role in immune

- **Functions of Circulatory System**
  - Transportation: Respiratory gases, nutrients & hormones, & waste removal
  - Regulation: Hormone and temperature
  - Protection: Clotting, and immune function

13.2 The Path of Blood Flow through the Heart and Musculature
- Series flow: blood travels through systemic and pulmonary circuits in series
- **Parallel Blood Flow within the Systemic or Pulmonary Circuit (Figure 13.3)**
  - Parallel flow allows independent regulation of blood flow to organs and ensures each organ receive oxygenated blood
  - **Coronary circulation (Figure 13.4)** containing coronary arteries (left and right) provide nourishment to cardiac muscle
- **Heart attack** or **myocardial infarction** is caused by the blockage of coronary artery

13.3 Anatomy of the Heart (Figure 13.1)
- **Myocardium and the Heart Wall (Figure 13.6)**
  - Three layers of the heart wall
    - Endocardium (inner): Layer of endothelial cells
    - Myocardium (middle): Cardiac muscle
    - Epicardium (outer): External membrane
  - Which ventricle wall is thicker? Why? ________________________________

- **Properties of Cardiac Muscle**
  - Similar to skeletal muscle: sarcomere structure; contractions regulated by troponin-tropomysin
  - Similar to smooth muscle: cells are connected by gap junctions
  - Within intercalated discs there are two kinds of membrane junctions
    - Desmosomes hold muscle fibers together
    - _______ junctions transmit AP from one cardiac muscle fiber to the adjacent muscle fiber
• **Function of Cardiac Muscle**
  - Rhythmic contraction and relaxation generates heart pumping action
  - Contraction pushes blood out of heart into vasculature
  - Relaxation allows heart to fill with blood

• **Heart Valves:** The heart has four valves to ensure unidirectional blood flow.

### 13.4 Electrical Activity of the Heart

- Two specialized types of cardiac muscle cells
  - ___________ cells generate own rhythm and transmit action potentials. They provide little or no contractile force. Conduction system = ___________ cells + _________ fibers
  - Contractile cells provide contraction: 99% of cardiac muscle cells

- **The Conduction System**
  - Pacemaker cells initiate action potentials: Spontaneously depolarizing membrane potentials to generate action potentials; and coordinate and provide rhythm to heartbeat
  - Conduction fibers (bundles and pathways)
    - Rapidly transmit and conduct action potentials initiated by pacemaker cells to myocardium
    - Conduction velocity = 4 meters/second
    - Ordinary muscle fibers, conduction velocity = 0.4 meter/second

- **Pacemaker Cells of the Myocardium**
  - Sinoatrial node (SA node): The main ______________
    - It initiates action potentials and generates a higher beat frequency than AV node
    - It makes cells in AV node go to refractory period
  - Backup system: Atrioventricular node (AV node); Bundle of His and Purkinje fibers

- **Control of the Heartbeat by Pacemakers**

<table>
<thead>
<tr>
<th>Location</th>
<th>Firing Rate at Rest</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA Node</td>
<td>70-80 APs/min*</td>
</tr>
<tr>
<td>AV Node</td>
<td>40-60 APs/min</td>
</tr>
<tr>
<td>Bundle of His</td>
<td>20-40 APs/min</td>
</tr>
<tr>
<td>Purkinje Fibers</td>
<td>20-40 APs/min</td>
</tr>
</tbody>
</table>

- Fastest depolarizing cells control other cells
- SA node = pacemaker = set rate for rest of heart (action potentials per minute)

- **Target Heart Rate for Exercise**
  - Your maximum heart rate is about 220 minus your age
  - Target heart rate = 50%-85% max. heart rate

- **Heartbeat**
  - Heart beat is the wave of contraction through cardiac muscle
  - Atria contract as a unit
  - Ventricles contract as a unit
  - Atrial contraction precedes ventricle contraction

- **Spread of Excitation between Cells (Figure 13.9):** APs generated from SA node travel to adjacent cells via gap junction.

- **Initiation and Conduction of an Impulse during a Heartbeat (Figure 13.10)**
  - SA node initiates pacemaker potential
  - Atrial excitation
    - Interatrial pathway: Rapid conducts APs. Atria contract simultaneously.
Spread of Excitation through Heart Muscle (Figure 13.11)

Electrical Activity in Pacemaker Cells (Figure 13.12)
- A pacemaker cell
  - Can fire an action potential without external stimulation.
  - Does not maintain a resting membrane potential.
  - Has a slow depolarization called a pacemaker potential.
  - Fires an action potential when the pacemaker potential depolarizes to threshold.

<table>
<thead>
<tr>
<th>Table 13.1 Ionic Bases of the Autorhythmic Cell Action Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autorhythmic Cell Potential</td>
</tr>
<tr>
<td>Pacemaker (initial period)</td>
</tr>
<tr>
<td>Pacemaker (latter period)</td>
</tr>
<tr>
<td>Rapid depolarization phase of AP</td>
</tr>
<tr>
<td>Repolarization phase of AP</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 13.2 Ionic Bases of the Contractile Cell Action Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phases</td>
</tr>
<tr>
<td>0: Rapid depolarization</td>
</tr>
<tr>
<td>1: Small repolarization</td>
</tr>
<tr>
<td>2:</td>
</tr>
<tr>
<td>3: Repolarization</td>
</tr>
<tr>
<td>4: Resting Potential</td>
</tr>
</tbody>
</table>

- AV node transmission
  - Slow conduction - AV nodal delay = 0.1 sec
  - What is the purpose of AV delay? It allows ________ contract before ventricles
- Ventricular excitation
  - Down bundle of His
  - Up Purkinje fibers: Purkinje fibers triggers ventricle contractions from apex up

What is the significance of the plateau phase?
• **Excitation-Contraction Coupling in Cardiac Contractile Cells (Figure 13.14)**
  o Properties similar to skeletal muscle: T tubules; calcium ions are released from Sarcoplasmic reticulum calcium; Troponin-tropomyosin regulation
  o Properties similar to smooth muscle: Gap junctions; need extracellular calcium
• **Relaxation of Cardiac Muscle**
  o Remove calcium from cytosol
    ▪ To lumen of SR: Ca\(^{2+}\) ATPase in sarcoplasmic reticulum
    ▪ To interstitial fluid:
      ➢ Ca\(^{2+}\) ATPase in plasma membrane
      ➢ Na\(^+\)-Ca\(^{2+}\) exchanger in plasma membrane
  o Troponin and tropomyosin return to position covering myosin binding sites on actin
• **Electrocardiogram is the external measure of electrical activity of the heart**
  o Body conducts currents in body to its surface (ECG, EKG, EMG, EEG)
• **Einthoven's Triangle (Figure 13.15)**
  o Lead I: LA (+) and RA (-)
  o Lead II: LL (+) and RA (-)
  o Lead III: LL (+) and LA (-)
• **ECG (Figure 13.16)**
  o P wave: atrial depolarization
  o QRS complex: ventricular depolarization and atrial repolarization
  o T wave: ventricular repolarization
  o PQ segment: AV nodal delay
  o QT interval: ventricular diastole
  o QT segment: ventricular systole
  o R-R: one heart beat
  o How many heart beats shown in Figure 13.16b?____

13.5 The Cardiac Cycle
• The cardiac cycle involves all events associated with the flow of blood through the heart during a single complete heartbeat
• Two main stages of cardiac cycle
  o ____________: Ventricle contraction
  o ____________: Ventricle relaxation
• **Opening of Valves during the Cardiac Cycle**
  o Valves open passively due to pressure gradients
  o AV valves open when pressure in atria > pressure in ventricles
  o Semilunar valves open when pressure in ventricles > pressure in arteries
• **Four Phases of Cardiac Cycle (Figure 13.18)**
  o ______ filling: Pressure atria > pressure ventricles: valves open; Passive phase—no atria or ventricular contraction; active phase—atria contract, blood enters ventricles
  o ____________,ventricular contraction: Ventricle contracts—increases pressure; AV and semilunar valves closed; no blood entering or exiting ventricle
  o ____________ejection: Pressure ventricles > pressure arteries; semilunar valves open, blood ejects from the ventricles
o Isovolumetric ventricular ____________: Ventricle relaxes—decreases pressure; AV and semilunar valves closed, no blood entering or exiting ventricle

- **Aortic Pressure (Figure 13.20)**
  o The minimum aortic pressure is called __________ pressure (DP)
  o The maximum aortic pressure is called __________ pressure (SP)
  o The average aortic pressure occurring during the cardiac cycle is called the mean arterial pressure (______)

- **Heart Sounds**
  o Due to turbulent flow when valves close
  o First heart sound: Soft lubb and AV valves close simultaneously
  o Second heart sound: Louder dubb, and semilunar valves close simultaneously

- **Continuous Blood Flow during Cardiac Cycle**
  o Aorta and large arteries are elastic. They store energy during systole as walls expand. They release energy during diastole as walls recoil inward therefore they maintain blood flow through entire cardiac cycle

- **Ventricular Volume (Figure 13.21)**
  o End-diastolic volume (EDV) = volume of blood in ventricle at the end of diastole
  o End systolic volume (ESV) = volume of blood in ventricle at the end of systole
  o Stroke volume (SV) = volume of blood ejected from ventricle each cycle (130-60 = 70ml).

- **Ejection Fraction**
  o Is the fraction of end-diastolic volume ejected during a heartbeat
  o Measures heart function
  o Ejection fraction = stroke volume / end diastolic volume= 70 mL / 130 mL = 0.54

- **Pressure-Volume Curve (Figure 13.22)**
  o Measures heart function
  o Phase 1: Ventricular volume increases from 60 mL to 130 mL; small pressure increment with filling
  o Phase 2: Volume remains constant; pressure increases dramatically
  o Phase 3: Volume decreases to 60 mL; pressure rises, then falls precipitously
  o Phase 4: Pressure continues to fall

**13.6 Cardiac Output and Its Control**

- Cardiac output = Volume of blood pumped by each ventricle per minute
- Cardiac output (CO) = SV x HR
- Average CO = 5 liters/min at rest
- Average blood volume = 5.5 liters
- **Regulation of Cardiac Output**: Regulate heart rate and stroke volume
  - Extrinsic regulation —neural and hormonal
  - Intrinsic regulation —autoregulation

- **Autonomic Inputs to Heart (Figure 13.24)**

<table>
<thead>
<tr>
<th>Autonomic Input</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sympathetic (cardiac) nerve</td>
<td>1.____ Node</td>
</tr>
<tr>
<td>Parasympathetic (vagus nerve)</td>
<td>2 ___ Node</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>NA</td>
</tr>
</tbody>
</table>

- **Factors Affecting Cardiac Output: Neural Control of Heart Rate (Figure 13.25-13.26)**
  o SA node intrinsic firing rate = 100 beats /min
SA node under control of ANS and hormones

- Rest: parasympathetic dominates, HR = 75
- Excitement: sympathetic takes over, HR increases

Sympathetic neurons increase heart rate by increasing

- Spontaneous depolarization and decreasing repolarization at SA node
- The speed of action potential conduction in AV node and conduction system

AV Nodal Innervation

- Sympathetic nerve activity increases conduction velocity through node
- Parasympathetic nerve activity decreases conduction velocity through node

Factors affecting Cardiac Output: Hormonal Control of Heart Rate

- Epinephrine: Same effect as sympathetic nervous system, increase HR
- Glucagon: Increases heart rate.

Factors Affecting Cardiac Output: Stroke Volume

- Ventricular contractility
- End-diastolic volume
- Afterload
- Ventricular Contractility
  - Ventricles never completely empty of blood, more forceful contraction will expel more blood
  - Extrinsic Control of ventricular contractility
    - Sympathetic innervation of contractile cells increases the strength and the rate of cardiac contractility by increase of epinephrine release, increase of strength of contraction, and increase of the rate of contraction and the rate of relaxation
    - Parasympathetic innervation of contractile cells is not significant
    - Thyroid hormones, insulin and glucagon increase force of contraction
  - Intrinsic controls of SV: Changes in EDV
    - Principle of Frank-Starling’s Law: When the venous return changes, the heart automatically adjusts its output to match the inflow.
    - The Starling Curves (Figure 13.29): Increased EDV stretches muscle fibers to their optimum length therefore increase SV
    - Factors Affecting End-Diastolic Volume: End-diastolic pressure = preload is affected by filling time, atrial pressure and central venous pressure

  - Afterload Influence on SV
    - Afterload= pressure in aorta during ejection
    - Increased afterload decreases SV

Summary of Factors Influencing Stroke Volume (Figure 13.31)

Autonomic Regulation of Cardiac Output (Figure 13.32)