Chapter 12

The Cardiovascular System: The Heart

PowerPoint® Lecture Slides
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Introduction to Cardiovascular System

• The Pulmonary Circuit
  – Carries blood to and from gas exchange surfaces of lungs

• The Systemic Circuit
  – Carries blood to and from the body

• Blood alternates between pulmonary circuit and systemic circuit
Introduction to Cardiovascular System

• Three Types of Blood Vessels

  – Arteries:
    • Carry blood *away from* the heart

  – Veins:
    • Carry blood *to* the heart

  – Capillaries:
    • Networks *between* arteries and veins
• Capillaries
  – Also called exchange vessels
  – Exchange materials between blood and tissues
  – Materials include dissolved gases, nutrients, wastes
Overview of the Cardiovascular System

Figure 12-1
12-1 The heart is a four-chambered organ, supplied by coronary circulation, that pumps oxygen-poor blood to the lungs and oxygen-rich blood to the rest of the body.
Four Chambers of the Heart

• Right Atrium
  – Collects blood from systemic circuit

• Right Ventricle
  – Pumps blood to pulmonary circuit

• Left Atrium
  – Collects blood from pulmonary circuit

• Left Ventricle
  – Pumps blood to systemic circuit
Anatomy of the Heart

• Great veins and arteries at the base
• Pointed tip is **apex**
• Surrounded by pericardial sac
• Sits between two pleural cavities in the **mediastinum**
The Location of the Heart in the Thoracic Cavity

Figure 12-2a
Anatomy of the Heart

• The Pericardium
  – Double lining of the pericardial cavity
  – Parietal pericardium:
    • Outer layer
    • Forms inner layer of pericardial sac
  – Visceral pericardium:
    • Inner layer of pericardium
Anatomy of the Heart

• The Pericardium
  – Pericardial cavity:
    • Is between parietal and visceral layers
    • Contains pericardial fluid
  – Pericardial sac:
    • Fibrous tissue
    • Surrounds and stabilizes the heart
The Location of the Heart in the Thoracic Cavity

Figure 12-2b
The Surface Anatomy of the Heart

• Atria
  – Thin walled
  – Expandable outer auricle (atrial appendage)

• Sulci
  – Coronary sulcus: divides atria and ventricles
  – Anterior interventricular sulcus and posterior interventricular sulcus:
    • separate left and right ventricles
    • contain blood vessels of cardiac muscle
The Surface Anatomy of the Heart

Figure 12-3a

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The Heart Wall

• **Epicardium** (Outer Layer)
  – Visceral pericardium
  – Covers the heart

• **Myocardium** (Middle Layer)
  – Muscular wall of the heart
  – Concentric layers of cardiac muscle tissue
  – Atrial myocardium wraps around great vessels
  – Two divisions of ventricular myocardium

• **Endocardium** (Inner Layer)
  – Simple squamous epithelium
The Heart Wall and Cardiac Muscle

Figure 12-4 a,b
The Heart Wall

- Cardiac Muscle Tissue
  - Intercalated discs:
    - Interconnect **cardiac muscle cells**
    - Secured by desmosomes
    - Linked by gap junctions
    - Convey force of contraction
    - Propagate action potentials
Cardiac Muscle Cells

(c) Cardiac muscle tissue

(d) Cardiac muscle cells

Figure 12-4 c,d
Internal Anatomy and Organization

- **Interatrial septum**: separates atria
- **Interventricular septum**: separates ventricles
- **Atrioventricular (AV) valves**
  - Connect right atrium to right ventricle and left atrium to left ventricle
  - The fibrous flaps that form bicuspid (2) and tricuspid (3) valves
  - Permit blood flow in one direction: atria to ventricles

The Heart: Valves
Internal Anatomy and Organization

• The Right Atrium
  – Superior vena cava:
    • Receives blood from head, neck, upper limbs, and chest
  – Inferior vena cava:
    • Receives blood from trunk, viscera, and lower limbs
  – Coronary sinus:
    • Cardiac veins return blood to coronary sinus
    • Coronary sinus opens into right atrium
Sectional Anatomy of the Heart

Figure 12-5
• The Right Ventricle
  – Free edges attach to chordae tendineae from papillary muscles of ventricle
  – Prevent valve from opening backward
  – Right atrioventricular (AV) valve:
    • Also called tricuspid valve
    • Opening from right atrium to right ventricle
    • Has three cusps
    • Prevents backflow
Internal Anatomy and Organization

• The Left Atrium
  – Blood gathers into *left* and *right* pulmonary veins
  – Pulmonary veins deliver to left atrium
  – Blood from left atrium passes to left ventricle through *left atrioventricular* (AV) valve
  – A two-cusped *bicuspid valve* or *mitral valve*
The Left Ventricle

- Holds same volume as right ventricle
- Is larger; muscle is thicker and more powerful
- Similar internally to right ventricle but does not have moderator band
- Systemic circulation:
  - Blood leaves left ventricle through aortic valve into ascending aorta
  - Ascending aorta turns (aortic arch) and becomes descending aorta
Internal Anatomy and Organization

• Structural Differences between the Left and Right Ventricles
  – Right ventricle wall is thinner, develops less pressure than left ventricle
  – Right ventricle is pouch-shaped; left ventricle is round
• The Heart Valves
  – Two pairs of one-way valves prevent backflow during contraction
  – Atrioventricular (AV) valves:
    • Between atria and ventricles
    • Blood pressure closes valve cusps during ventricular contraction
    • Papillary muscles tense chordae tendineae: prevent valves from swinging into atria
• The Heart Valves

  – **Semilunar valves:**

    • Pulmonary and aortic tricuspid valves
    • Prevent backflow from pulmonary trunk and aorta into ventricles
    • Have no muscular support
    • Three cusps support like tripod
Aortic Sinuses

- At base of ascending aorta
- Sacs that prevent valve cusps from sticking to aorta
- Origin of right and left coronary arteries
Figure 12-6a

The Valves of the Heart
Figure 12-6b
• The Cardiac Skeleton of the Heart
  – Physically support cardiac muscle fibers
  – Distribute forces of contraction
  – Add strength and prevent overexpansion of heart
  – Elastic fibers return heart to original shape after contraction
Internal Anatomy and Organization

• The Cardiac (Fibrous) Skeleton
  – Four bands around heart valves and bases of pulmonary trunk and aorta
  – Stabilize valves
  – Electrically insulate ventricular cells from atrial cells
The Blood Supply to the Heart = Coronary Circulation

- **Coronary arteries** and **cardiac veins**
- Supplies blood to muscle tissue of heart
• The Coronary Arteries
  – Left and right
  – Originate at aortic sinuses
  – High blood pressure, elastic rebound forces blood through coronary arteries between contractions
Internal Anatomy and Organization

• Right Coronary Artery
  – Supplies blood to:
    • Right atrium
    • Portions of both ventricles
    • Cells of sinoatrial (SA) and atroventricular nodes
    • **Marginal arteries** (surface of right ventricle)
    • **Posterior interventricular artery**
• Left Coronary Artery
  – Supplies blood to:
    • Left ventricle
    • Left atrium
    • Interventricular septum
Two main branches of left coronary artery
  - Circumflex artery
  - Anterior interventricular artery

Arterial Anastomoses
  - Interconnect anterior and posterior interventricular arteries
  - Stabilize blood supply to cardiac muscle
• The Cardiac Veins

  – **Great cardiac vein:**
    • Drains blood from area of anterior interventricular artery into coronary sinus

  – **Anterior cardiac veins:**
    • Empties into right atrium

  – **Posterior cardiac vein, middle cardiac vein, and small cardiac vein:**
    • Empty into great cardiac vein or coronary sinus
Coronary Circulation

Figure 12-7a
12-2 Contractile cells and the conducting system produce each heartbeat, and an electrocardiogram records the associated electrical events
The Conducting System

• Heartbeat
  – A single contraction of the heart
  – The entire heart contracts in series:
    • First the atria
    • Then the ventricles
The Conducting System

- Two Types of Cardiac Muscle Cells
  - Contractile cells:
    - Produce contractions that propel blood
  - Conducting system:
    - Controls and coordinates heartbeat
The Action Potential in Skeletal and Cardiac Muscle

1. **Rapid Depolarization**
   - Cause: Na\(^+\) entry
   - Duration: 3–5 msec
   - Ends with: Closure of voltage-gated sodium channels

2. **The Plateau**
   - Cause: Ca\(^{2+}\) entry
   - Duration: ~175 msec
   - Ends with: Closure of calcium channels

3. **Repolarization**
   - Cause: K\(^+\) loss
   - Duration: 75 msec
   - Ends with: Closure of potassium channels

Figure 12-8a
The Action Potential in Skeletal and Cardiac Muscle

Figure 12-8b
• The Role of Calcium Ions in Cardiac Contractions
  – Contraction of a cardiac muscle cell is produced by an increase in calcium ion concentration around myofibrils
Contractile Cells

• The Role of Calcium Ions in Cardiac Contractions

  – 20% of calcium ions required for a contraction:
    • Calcium ions enter plasma membrane during plateau phase
  
  – Arrival of extracellular Ca^{2+}:
    • Triggers release of calcium ion reserves from sarcoplasmic reticulum
The Conducting System

- A system of specialized cardiac muscle cells
  - Initiates and distributes electrical impulses that stimulate contraction

- **Automaticity**
  - Cardiac muscle tissue contracts automatically
The Conducting System

• Structures of the Conducting System
  – Sinoatrial (SA) node — wall of right atrium
  – Atrioventricular (AV) node — junction between atria and ventricles
  – Conducting cells — throughout myocardium
The Conducting System

• Conducting Cells
  – Interconnect SA and AV nodes
  – Distribute stimulus through myocardium
  – In the atrium:
    • Internodal pathways
  – In the ventricles:
    • AV bundle and the bundle branches
The Conducting System

• Heart Rate
  – SA node generates 70 to 80 action potentials per minute
  – AV node generates 40 to 60 action potentials per minute
The Conducting System

Figure 12-9a

- Sinoatrial (SA) node
- Atrioventricular (AV) node
- AV bundle
- Bundle branches
- Purkinje fibers
STEP 1

SA node activity and atrial activation begin.

Time = 0

Figure 12-9
The Conducting System

**STEP 2**

Stimulus spreads across the atrial surfaces and reaches the AV node.

Elapsed time = 50 msec

Figure 12-9

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STEP 3

There is a 100-msec delay at the AV node. Atrial contraction begins.

AV bundle

Bundle branches

Elapsed time = 150 msec

Figure 12-9
The impulse travels along the interventricular septum within the AV bundle and the bundle branches to the Purkinje fibers.

Elapsed time = 175 msec

Figure 12-9
The impulse is distributed by Purkinje fibers and relayed throughout the ventricular myocardium. Atrial contraction is completed, and ventricular contraction begins.

Elapsed time = 225 msec

Figure 12-9
The Conducting System

• Abnormal Pacemaker Function
  – **Bradycardia**: abnormally slow heart rate
  – **Tachycardia**: abnormally fast heart rate
  – **Ectopic pacemaker**:
    • Abnormal cells
    • Generate high rate of action potentials
    • Bypass conducting system
    • Disrupt ventricular contractions
The Electrocardiogram

• A recording of electrical events in the heart
• Obtained by electrodes at specific body locations
• Abnormal patterns diagnose damage
The Electrocardiogram

• Features of an ECG
  – P wave:
    • Atria depolarize
  – QRS complex:
    • Ventrices depolarize
  – T wave:
    • Ventricles repolarize
Figure 12-10a
Figure 12-10b

ECG rhythm strip

- **P wave**: Impulse spreads across atria, triggering atrial contractions
- **QRS complex**: Impulse spreads to ventricles, triggering ventricular contractions
- **T wave**: Ventricles return to resting state

Time: 800 msec

Millivolts: +1 (positive), 0 (neutral), -1 (negative)
12-3 Events during a complete heartbeat make up a cardiac cycle
The Cardiac Cycle

• Cardiac cycle = the period between the start of one heartbeat and the beginning of the next

• Includes both contraction and relaxation
The Cardiac Cycle

• Phases of the Cardiac Cycle
  – Within any one chamber:
    • **Systole** (contraction)
    • **Diastole** (relaxation)
(a) Atrial systole begins: Atrial contraction forces a small amount of additional blood into relaxed ventricles.

(b) Atrial systole ends, atrial diastole begins

(c) Ventricular systole—first phase: Ventricular contraction pushes AV valves closed but does not create enough pressure to open semilunar valves.

(d) Ventricular systole—second phase: As ventricular pressure rises and exceeds pressure in the arteries, the semilunar valves open and blood is ejected.

(e) Ventricular diastole—early: As ventricles relax, pressure in ventricles drops; blood flows back against cusps of semilunar valves and forces them closed. Blood flows into the relaxed atria.

(f) Ventricular diastole—late: All chambers are relaxed. Ventricles fill passively.

Cardiac cycle
The Cardiac Cycle

• Blood Pressure

  – In any chamber:
    • Rises during systole
    • Falls during diastole

  – Blood flows from high to low pressure:
    • Controlled by timing of contractions
    • Directed by one-way valves
• Cardiac Cycle and Heart Rate
  – At 75 beats per minute:
    • Cardiac cycle lasts about 800 msecs
  – When heart rate increases:
    • All phases of cardiac cycle shorten, particularly diastole
Heart Sounds

- **S₁**
  - Loud sounds
  - Produced by AV valves

- **S₂**
  - Loud sounds
  - Produced by semilunar valves

- **S₃, S₄**
  - Soft sounds
  - Blood flow into ventricles and atrial contraction
12-4 Heart dynamics examines the factors that affect cardiac output
Cardiodynamics

- Cardiac Output
- \( CO = HR \times SV \)
- \( CO \) = cardiac output (mL/min)
- \( HR \) = heart rate (beats/min)
- \( SV \) = stroke volume (mL/beat)
Cardiodynamics

• Factors Affecting Cardiac Output

  – Cardiac output:
    • Adjusted by changes in heart rate or stroke volume

  – Heart rate:
    • Adjusted by autonomic nervous system or hormones

  – Stroke volume:
    • Adjusted by changing EDV or ESV
Blood Volume Reflexes

• Atrial Reflex
  – Also called Bainbridge reflex
  – Adjusts heart rate in response to venous return
  – Stretch receptors in right atrium:
    • Trigger increase in heart rate
    • Through increased sympathetic activity
Autonomic Innervation

• Factors Affecting the Heart Rate
  – Cardiac plexuses: innervate heart
  – Vagus nerves (X): carry parasympathetic preganglionic fibers to small ganglia in cardiac plexus
  – Cardiac centers of medulla oblongata:
    • **Cardioacceleratory center** controls sympathetic neurons (increases heart rate)
    • **Cardioinhibitory center** controls parasympathetic neurons (slows heart rate)
Figure 12-12

- Cardioinhibitory center
- Cardioacceleratory center
- Medulla oblongata
- Vagus nerve (N X)
- Spinal cord
- Sympathetic preganglionic fiber
- Sympathetic ganglia
- Sympathetic postganglionic fiber
- Cardiac nerve
- Parasympathetic preganglionic fiber
- Synapses in cardiac plexus
- Parasympathetic postganglionic fibers
Autonomic Innervation

- Autonomic Affects on Stroke Volume
  - Sympathetic stimulation:
    - NE released by postganglionic fibers of cardiac nerves
    - Epinephrine and NE released by suprarenal (adrenal) medullae
    - Causes ventricles to contract with more force
    - Increases ejection fraction and decreases ESV
Autonomic Innervation

• Autonomic Affects on Stroke Volume
  – Parasympathetic activity:
    • Acetylcholine released by vagus nerves
    • Reduces force of cardiac contractions
Hormones

• Many hormones affect heart contraction

• Pharmaceutical drugs mimic hormone actions
  – Stimulate or block beta receptors
  – Affect calcium ions (e.g., calcium channel blockers)