CHAPTER 12

The Cardiovascular System: The Heart
Chapter 12 Learning Outcomes

• 12-1
  • Describe the anatomy of the heart, including blood supply and pericardium structure, and trace the flow of blood through the heart, identifying the major blood vessels, chambers, and heart valves.

• 12-2
  • Explain the events of an action potential in cardiac muscle, describe the conducting system of the heart, and identify the electrical events recorded in a normal electrocardiogram.

• 12-3
  • Explain the events of the cardiac cycle, and relate the heart sounds to specific events in this cycle.

• 12-4
  • Define cardiac output, describe the factors that influence heart rate and stroke volume, and explain how adjustments in stroke volume and cardiac output are coordinated at different levels of physical activity.
The Heart's Role in the Cardiovascular System
(Introduction)

- Heart beats about 100,000 times/day
- Pumps about 8000 L of blood/day
- Pumps blood through **pulmonary circuit** vessels to and from the lungs
- Pumps blood through **systemic circuit** to and from the rest of the body tissues
The Heart's Role in the Cardiovascular System
(Introduction)

- **Arteries** carry blood away from heart chambers
- **Veins** return blood to heart
- Heart has four muscular chambers
  1. **Right atrium** receives blood from systemic circuit
  2. **Right ventricle** pumps blood into the pulmonary circuit
  3. **Left atrium** receives blood from pulmonary circuit
  4. **Left ventricle** pumps blood into systemic circuit
Figure 12-1  An Overview of the Cardiovascular System.

**PULMONARY CIRCUIT**
- Pulmonary arteries
- Pulmonary veins

**SYSTEMIC CIRCUIT**
- Systemic arteries
- Systemic veins

- Capillaries in lungs
- Right atrium
- Right ventricle
- Capillaries in trunk and lower limbs
- Capillaries in head, neck, upper limbs
- Left atrium
- Left ventricle

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The Location of the Heart (12-1)

- Lies in the *mediastinum* behind the sternum
- Surrounded by *pericardial cavity*, lined by serous membrane, the *pericardium*
  - **Visceral pericardium** or **epicardium** covers heart
  - **Parietal pericardium** lines inner surface of pericardial sac
  - *Pericardial fluid* found between layers, reduces friction
An anterior view of the chest, showing the position of the heart and major blood vessels relative to the ribs, lungs, and diaphragm.
The pericardial cavity surrounding the heart is formed by the visceral pericardium and the parietal pericardium. The relationship between the heart and the pericardial cavity can be likened to a fist pushed into a balloon.
The Surface Anatomy of the Heart (12-1)

- Atria have thin walls that collapse when empty into a flap, the **auricle**
- **Coronary sulcus**
  - Marks border between atria and ventricles
  - Deep groove filled with fat
- **Anterior and posterior interventricular sulci**
  - Mark boundaries between left and right ventricles
The Surface Anatomy of the Heart (12-1)

- Superior end of heart
  - Called the base
  - Has the great vessels: aorta, venae cavae, pulmonary arteries, and pulmonary veins

- Inferior end of the heart
  - Called the apex
  - Pointed tip
Figure 12-3a The Surface Anatomy of the Heart.

- Left common carotid artery
- Brachiocephalic trunk
- Ascending aorta
- Superior vena cava
- Auricle of right atrium
- Fat and vessels in coronary sulcus
- Right atrium
- Right ventricle
- Fat and vessels in anterior interventricular sulcus
- Anterior interventricular sulcus
- Parietal pericardium fused to diaphragm
- Parietal pericardium
- Superior vena cava
- Auricle of right atrium
- Right atrium
- Right ventricle
- Ascending aorta
- Ligamentum arteriosum
- Descending aorta
- Left pulmonary artery
- Pulmonary trunk
- Left subclavian artery
- Arch of aorta
- Coronary sulcus
- Parietal pericardium
- Fibrous pericardium
- Auricle of left atrium
- Parietal pericardium
- Auricle of left atrium
- Parietal pericardium
- Pulmonary trunk
- Auricle of left atrium
- Right atrium
- Right ventricle
- Fat and vessels in anterior interventricular sulcus
- Anterior interventricular sulcus
- Parietal pericardium

Major anatomical features on the anterior surface.
Major landmarks on the posterior surface. Coronary arteries (which supply the heart itself) are shown in red; coronary veins are shown in blue.
Figure 12-3c The Surface Anatomy of the Heart.

Heart position relative to the rib cage.

Base of heart

Ribs

Apex of heart
The Three Layers of the Heart Wall (12-1)

1. **Epicardium**
   - Covers the outer surface of heart

2. **Myocardium**
   - Contains cardiac muscle cells
   - Forms bands that wrap and spiral that produces twisting and squeezing during contraction

3. **Endocardium**
   - Covers inside of chambers and heart valves
Cardiac Muscle Cells (12-1)

- Smaller than typical skeletal muscle cell
- Contain single nucleus
- Myofibrils are organized into sarcomeres
- Large amount of mitochondria
- Cells are joined at **intercalated discs**
  - Cells are linked by desmosomes and gap junctions
  - Increases efficiency during contraction
Connective Tissue in the Heart (12-1)

- A lot of collagen and elastic fibers wrap around muscle cells
  - Provides support for muscles, vessels, nerves
  - Adds strength, prevents overexpansion of heart
  - Helps heart return to normal, at-rest shape after contraction
- Also forms *cardiac skeleton* of heart
Figure 12-4a The Heart Wall and Cardiac Muscle Tissue.

A diagrammatic section through the heart wall, showing the relative positions of the epicardium, myocardium, and endocardium. The proportions are not to scale; the relative thickness of the myocardial wall has been greatly reduced.
Figure 12-4b-d  The Heart Wall and Cardiac Muscle Tissue.

Cardiac muscle tissue forms concentric layers that wrap around the atria or spiral within the walls of the ventricles.

Cardiac muscle tissue

LM x 575

Cardiac muscle cells.

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Internal Anatomy of the Heart (12-1)

- Interatrial septum separates two atria
- Interventricular septum separates two ventricles
- Atrioventricular (AV) valves allow blood to flow one way from atrium to ventricle on same side
- Superior vena cava, inferior vena cava, and coronary sinus all return blood to right atrium
Fossa Ovalis (12-1)

- A small depression in the interatrial septum
- Open during fetal development
  - Called the *foramen ovale*
  - Allows blood to circulate from right atrium to left atrium
  - At birth foramen ovale closes
Right Atrioventricular Valve Structure (12-1)

- Also called the **tricuspid valve**, has three flaps or cusps
  - Opening between right atrium and ventricle
  - Cusps are braced by fibers called **chordae tendineae**
    - Connect to **papillary muscles** on inner ventricle
- Combination of papillary muscles and chordae
  - Limits cusp movement
  - Prevents backflow into the atrium
The Pulmonary Circuit (12-1)

- Blood leaves right ventricle, flows through:
  - Pulmonary semilunar valve
  - Pulmonary trunk
  - Right and left pulmonary arteries
  - Pulmonary capillaries
  - Right and left pulmonary veins
- Flows into left atrium
Left Atrioventricular Valve Structure (12-1)

- Also called the **bicuspid valve**, has two flaps or cusps
  - Also has chordae tendineae and papillary muscles
- Trabeculae carneae are muscular ridges on inner surface of both ventricles
The Systemic Circuit (12-1)

• Blood leaves left ventricle, flows through:
  • Aortic semilunar valve
  • Ascending aorta and aortic arch
  • Descending aorta
  • Numerous branches to capillary beds in the tissues
  • Inferior and superior venae cavae, coronary sinus

• Flows into right atrium

PLAY ANIMATION The Heart: Blood Flow
Differences between the Ventricles (12-1)

- **Right ventricle**
  - Thinner myocardium and wall
  - Lower pressure system

- **Left ventricle**
  - Very thick myocardium and wall
  - Produces 4–6 times as much pressure than right
  - Contracts in twist/squeeze motion
Figure 12-5  Sectional Anatomy of the Heart.

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The Function of Heart Valves (12-1)

- **AV valves**
  - When ventricles contract, cusps are pushed closed
  - Chordae and tension in papillary muscles prevent backflow or _regurgitation_ into atria
  - Heart _murmurs_ are small amounts of regurgitation

- **Semilunar valves**
  - Prevent backflow into ventricles
  - _Aortic sinuses_, sacs at each cusp, prevent sticking

[ANIMATION The Heart: Valves]
When the ventricles are relaxed, the AV valves are open and the aortic and pulmonary semilunar valves are closed. The chordae tendineae are loose, and the papillary muscles are relaxed.
When the ventricles are contracting, the AV valves are closed and the aortic and pulmonary semilunar valves are open. In the frontal section notice the attachment of the left AV valve to the chordae tendineae and papillary muscles.
The Cardiac Skeleton (12-1)

- *Fibrous skeleton* of dense, elastic tissue
  - Encircles bases of large vessels leaving heart
  - Encircles each heart valve
  - Stabilizes position of valves
  - Physically isolates atrial muscle from ventricular muscle
    - Important for normal timing of cardiac contraction
Coronary Circulation (12-1)

• Supplies blood to cardiac muscle tissue

• Left and right **coronary arteries**
  • Originate at base of aorta at aortic sinuses

• Right branches
  • Into marginal and *posterior interventricular arteries*

• Left branches
  • Circumflex and *anterior interventricular arteries*
Coronary Circulation (12-1)

- Small branches from all four major coronary arteries interconnect, forming anastomoses.
- **Great** and **middle cardiac veins**
  - Drain blood from coronary capillaries
  - Into **coronary sinus**
- **Myocardial infarction** (MI), or heart attack
  - Coronary vessels become blocked and cardiac tissue dies.
Coronary vessels supplying and draining the anterior surface of the heart

- Aortic arch
- Ascending aorta
- Right coronary artery
- Anterior cardiac veins
- Small cardiac vein
- Marginal artery
- Left coronary artery
- Pulmonary trunk
- Circumflex artery
- Anterior interventricular artery
- Great cardiac vein
- Anastomoses
Figure 12-7b The Coronary Circulation.

- Circumflex artery
- Great cardiac vein
- Marginal artery
- Posterior interventricular artery
- Posterior cardiac vein
- Left ventricle
- Coronary sinus
- Middle cardiac vein
- Marginal artery
- Small cardiac vein
- Right coronary artery

Coronary vessels supplying and draining the posterior surface of the heart.
1. Damage to the semilunar valve of the right ventricle would affect blood flow into which vessel?

2. What prevents the AV valves from swinging into the atria?

3. Why is the left ventricle more muscular than the right ventricle?
Contractile Cells (12-2)

- 99 percent of all cardiac muscle cells
- Action potential of contractile cells similar to skeletal muscle, but has longer duration
  - Rapid depolarization due to sodium ion influx
  - The plateau mostly due to sodium pumping out and calcium influx
  - Repolarization due to potassium efflux
Contractile Cells (12-2)

- Skeletal muscle action potential lasts 10 msec
- Cardiac contractile cell AP lasts 250–300 msec
- Until membrane repolarizes it cannot respond to another stimulus
  - This extends the refractory period
  - Limits the number of contractions per minute
  - Makes *tetanus* impossible
Figure 12-8a  Action Potentials and Muscle Cell Contraction 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

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**Stimulus**

**Time (msec)**

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**Refractory period**
Figure 12-8b  Action Potentials and Muscle Cell Contraction in Skeletal and Cardiac Muscle.

b  Action potentials and twitch contractions in a skeletal muscle (above) and cardiac muscle (below). The shaded areas indicate the duration of the refractory periods.
The Conducting System (12-2)

- Allows for automaticity or autorhythmicity
  - Cardiac muscles contract without neural input
- **Nodal cells** initiate rate of contraction
  - Sinoatrial (SA) and atrioventricular (AV) nodes
- **Conducting cells** distribute stimuli to myocardium
  - AV bundle (bundle of His), right and left bundle branches, and Purkinje fibers
The Conducting System (12-2)

• **Pacemaker cells**
  • Are nodal cells that reach threshold and fire first

• **SA node**
  • In posterior right atrium is cardiac pacemaker
  • Signal distributed so both atria contract together first then both ventricles contract together at 70–80 bpm
  • Atria contract from top down
  • Ventrices contract from bottom up
  • If SA node fails, AV node takes over at 40–60 bpm
The Conducting System (12-2)

• Signal from SA node is delayed at AV node
  • Ensures atria contract before ventricles

• Clinical problems with pacemaker activity
  • **Bradycardia** is rate slower than 60 bpm
  • **Tachycardia** is rate faster than 100 bpm
  • **Ectopic pacemaker** when abnormal cells generate abnormal signals

**ANIMATION** The Heart: Conduction System
Components of the conducting system:

- Sinoatrial (SA) node
- Atrioventricular (AV) node
- AV bundle
- Internodal pathways
- Bundle branches
- Purkinje fibers
Figure 12-9b The Conducting System of the Heart.

1. SA node activity and atrial activation begin.

   SA node

   Time = 0

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

   AV node

   Elapsed time = 50 msec

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

   AV bundle
   Bundle branches

   Elapsed time = 150 msec

4. The impulse travels along the interventricular septum within the AV bundle and the bundle branches to the Purkinje fibers.

   Elapsed time = 175 msec

5. 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
The Electrocardiogram (12-2)

- **ECG or EKG**
  - Electrical events of the heart travel through body
  - Can be monitored with electrodes for diagnosis of cardiac arrhythmias, abnormal cardiac activity
  - **P wave** indicates atrial depolarization
  - **QRS complex** indicates ventricular depolarization and "hidden" atrial repolarization
  - **T wave** indicates ventricular repolarization
The Electrocardiogram (12-2)

- Times between waves are segments, intervals include a segment and at least one wave
- **P–R interval** occurs while impulse is traveling from SA node to AV node
- **Q–T interval** indicates time required for ventricular depolarization and repolarization
The small \textbf{P wave} accompanies the depolarization of the atria. The impulse spreads across atria, triggering atrial contractions.

The \textbf{QRS complex} appears as the ventricles depolarize. The ventricles begin contracting shortly after the peak of the \textbf{R wave}.

The smaller \textbf{T wave} coincides with ventricular repolarization.

An ECG printout is a strip of graph paper containing a record of the electrical events monitored by the electrodes. The placement of electrodes on the body surface affects the size and shape of the waves recorded. The example is a normal ECG; this enlarged section at right indicates the major components of the ECG and the measurements most often taken during clinical analysis.
4. How does the fact that cardiac muscle does not undergo tetanus (as skeletal muscle does) affect the functioning of the heart?

5. If the cells of the SA node were not functioning, how would the heart rate be affected?

6. Why is it important for the impulses from the atria to be delayed at the AV node before passing into the ventricles?

7. What might cause an increase in the size of the QRS complex in an electrocardiogram?
The Cardiac Cycle (12-3)

- Period between start of one heartbeat and start of the next
  - Includes alternating **systole** (contraction of a chamber) and **diastole** (relaxation)
  - During diastole the chambers are filling with blood
  - During systole the chambers are ejecting blood
  - Blood flows due to increases in pressures in one chamber above the pressure in the next chamber
Phases of the Cardiac Cycle (12-3)

1. Atrial systole
   - AV valves are open
   - Active ventricular filling

2. Atrial diastole and early ventricular systole
   - AV valves shut
   - Semilunar valves still closed due to lower artery pressure
   - Volume in ventricles does not change
Phases of the Cardiac Cycle (12-3)

3. **Ejection phase of ventricular systole**
   - Pressure in ventricles rises higher than arteries
   - Blood is ejected from ventricles

4. **Ventricular diastole**
   - Early diastole, semilunar valves close, AV valve still closed
   - Once ventricular pressure drops below atrial pressure, AV valves open, passive ventricular filling
Figure 12-11 The Cardiac Cycle.

Atrial systole begins: Atrial contraction forces a small amount of additional blood into relaxed ventricles.

Atrial systole ends, atrial diastole begins

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

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

Ventricular diastole—late: All chambers are relaxed. Ventricle fills passively.

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.
Heart Sounds (12-3)

• **Stethoscopes** are used to listen for four heart sounds
  • First heart sound ("lubb") due to AV valves closing
  • Second heart sound ("dupp") due to semilunar valves closing
  • Third and fourth heart sounds
    • Are faint
    • Due to atrial contraction and blood flow into ventricles
8. Provide the alternate terms for the contraction and relaxation of heart chambers.

9. Is the heart always pumping blood when pressure in the left ventricle is rising? Explain.

10. What events cause the "lubb-dupp" heart sounds as heard with a stethoscope?
Heart Dynamics (12-4)

- Refers to movements and forces generated in cardiac contractions
  - **Stroke volume (SV)** is volume of blood ejected by a ventricle in one beat
  - **Cardiac output (CO)** is volume of blood ejected from a ventricle in one minute
  - Cardiac output is an indicator of blood flow to the tissues, or **perfusion**
Calculating Cardiac Output (12-4)

- \( CO = SV \times HR \) (heart rate, beats per minute)
- If HR is 65 bpm and SV is 75 mL/beat
- \( CO = 75 \text{ bpm} \times 80 \text{ mL/beat} = 6000 \text{ mL/min} \)
- Increases in HR and/or SV will increase CO up to as much as 30 L/min
- CO is highly regulated to ensure adequate perfusion of peripheral tissues
Blood Volume Reflexes (12-4)

• Direct relationship between:
  • Volume returning to heart (venous return) and
  • The volume ejected during next contraction
    • In other words, "more in = more out"

• Atrial reflex
  • Adjusts HR in response to increase in venous return
    • An ANS sympathetic response to wall stretch
Blood Volume Reflexes (12-4)

- **Frank–Starling principle**

- Major effect is CO-right is balanced with CO-left
  - Increase in venous return leads to:
    - Increased stretch on myocardial cells
    - Cells respond by contracting harder, increasing CO
Autonomic Innervation of the Heart (12-4)

- Pacemaker cells are autonomous, but can be modified by ANS
- Heart has dual innervation
  - Parasympathetic innervation by vagus nerves
  - Sympathetic fibers extend from cervical and upper thoracic ganglia
Autonomic Effects on the Heart Rate (12-4)

- Primarily affect SA node
  - Parasympathetic pathway releases ACh
    - Slows rate
  - Sympathetic pathway releases NE
    - Increases rate
Autonomic Effects on Stroke Volume (12-4)

- **ANS** alters force of myocardial contraction
  - Sympathetic neurotransmitters from neural synapses in heart (NE) and release of NE and E by adrenal glands
    - Increase force of contraction, increasing SV
  - Parasympathetic release of ACh
    - Ventricular myocardium has very limited cholinergic receptors
    - Only a slight decrease in force of contraction in atria
Figure 12-12  Autonomic Innervation of the Heart.

- Vagal nucleus
- Medulla oblongata
- Vagus (N X)
- Spinal cord

**Sympathetic**
- Sympathetic ganglia (cervical ganglia and superior thoracic ganglia)
- Sympathetic preganglionic fiber
- Sympathetic postganglionic fiber
- Cardiac nerve

**Parasympathetic**
- Parasympathetic preganglionic fiber
- Synapses in cardiac plexus
- Parasympathetic postganglionic fibers

Cardioinhibitory center
Cardioacceleratory center
Medulla oblongata has integration centers for cardiac reflexes

- **Cardioacceleratory center** is sympathetic
- **Cardioinhibitory center** is parasympathetic

  - Respond to changes in:
    - BP, arterial concentrations of O$_2$ and CO$_2$
    - Monitored by baro- and chemoreceptors
Hormonal Effects on the Heart (12-4)

• E and NE from adrenal medulla increase HR and SV

• Thyroid hormones and glucagon increase SV
11. Define cardiac output.
12. If the cardioinhibitory center of the medulla oblongata were damaged, which part of the autonomic nervous system would be affected, and how would the heart be influenced?
13. What effect does stimulation of the acetylcholine receptors of the heart have on cardiac output?
14. What effect does increased venous return have on stroke volume?
15. Why is it a potential problem if the heart beats too rapidly?