Introduction

• The heart keeps the blood in motion
  • If blood stops moving, nutrient and oxygen supplies are exhausted

• The heart beats about 100,000 times per day
  • This is about 70 beats per minute

• The heart pumps about 1.5 million gallons of blood per year
  • This is about 2.9 gallons per minute
    • The heart pumps between 5 and 30 liters of blood per minute—it can vary widely
An Overview of the Cardiovascular System

• The heart is about the size of a clenched fist
• The heart consists of four chambers
  • Two atria
  • Two ventricles
• The heart pumps blood into two circuits
  • Pulmonary circuit
  • Systemic circuit
Figure 21.1 A Generalized View of the Pulmonary and Systemic Circuits

**Pulmonary Circuit**
- Pulmonary arteries
- Pulmonary veins

**Systemic Circuit**
- Systemic arteries
- Systemic veins

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

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An Overview of the Cardiovascular System

• Each circuit involves arteries, veins, and capillaries
  • **Arteries**
    • Transport blood away from the heart
  • **Veins**
    • Transport blood toward the heart
  • **Capillaries**
    • Vessels that interconnect arteries and veins
The Pericardium

- Pericardium is the serous membrane lining the pericardial cavity
- The pericardial membrane forms two layers
  - **Visceral pericardium**
    - Also called the epicardium
  - **Parietal pericardium**
    - The parietal pericardium is reinforced by a layer called the **fibrous pericardium**
    - The parietal pericardium and fibrous pericardium constitute the **pericardial sac**
b Relationships between the heart and the pericardial cavity. The pericardial cavity surrounds the heart like the balloon surrounds the fist (right).
Structure of the Heart Wall

• The walls of the heart consist of three layers:
  • **Epicardium**
    • External surface
  • **Myocardium**
    • Consists of cardiac muscle cells
  • **Endocardium**
    • Internal surface
Structure of the Heart Wall

• Cardiac Muscle Cells
  • Mostly dependent on aerobic respiration
  • The circulatory supply of cardiac muscle tissue is very extensive
  • Cardiac muscle cells contract without information coming from the CNS
  • Cardiac muscle cells are interconnected by intercalated discs
Histological view of cardiac muscle tissue. Distinguishing characteristics of cardiac muscle cells include (1) small size; (2) a single, centrally placed nucleus; (3) branching interconnections between cells; and (4) the presence of intercalated discs.
Structure of the Heart Wall

- The Intercalated Discs
  - Cardiac cells have specialized cell-to-cell junctions
    - The sarcolemmæae of two cardiac cells are bound together by desmosomes
    - The intercalated discs bind the myofibrils of adjacent cells together
    - Cardiac muscle cells are bound together by gap junctions
      - Ions move directly from one cell to another allowing all the muscle cells to contract as one unit

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Figure 21.3de Histological Organization of Muscle Tissue in the Heart Wall

- Gap junction
- Z lines bound to opposing cell membranes
- Desmosomes

**Intercalated disc**

- Cardiac muscle cell
- Mitochondria
- Intercalated disc (sectioned)
- Nucleus
- Cardiac muscle cell (sectioned)
- Bundles of myofibrils
- Intercalated disc

Diagrammatic three-dimensional view of cardiac muscle cells.

The structure of an intercalated disc.
Structure of the Heart Wall

- The Fibrous Skeleton
  - Each cardiac cell is wrapped in an elastic sheath
  - Each muscle layer is wrapped in a fibrous sheet
  - The fibrous sheets separate the superficial layer from the deep layer muscles
  - These fibrous sheets also encircle the base of the pulmonary trunk and ascending aorta
Structure of the Heart Wall

• Functions of the Fibrous Skeleton
  • Stabilizes the position of cardiac cells
  • Stabilizes the position of the heart valves
  • Provides support for the blood vessels and nerves in the myocardium
  • Helps to distribute the forces of contraction
  • Helps to prevent overexpansion of the heart
  • Provides elasticity so the heart recoils after contraction
  • Isolates atrial cells from ventricular cells
Orientation and Superficial Anatomy of Heart

- The heart lies slightly to the left of midline
  - Located in the mediastinum
  - The base is the superior portion of the heart
  - The apex is the inferior portion of the heart
  - The heart sits at an oblique angle
  - The right border is formed by only the right atrium
  - The inferior border is formed by the right ventricle
Orientation and Superficial Anatomy of Heart

• The heart is rotated slightly toward the left
  • Basically, the heart appears to be twisted just a bit
  • The sternocostal surface is formed by the right atrium and right ventricle
  • The posterior surface is formed by the left atrium
Figure 21.4 Position and Orientation of the Heart

- Base of heart
- Apex of heart
- Ribs
- Superior border
- Right border
- Left border
- Inferior border
Orientation and Superficial Anatomy of Heart

- The four chambers of the heart can be identified by sulci on the external surface
  - **Interatrial groove** separates the left and right atria
  - **Coronary sulcus** separates the atria and the ventricles
  - **Anterior interventricular sulcus** separates the left and right ventricles
  - **Posterior interventricular sulcus** also separates the left and right ventricles
Figure 21.5a Superficial Anatomy of the Heart, Part I

Left common carotid artery
Brachiocephalic trunk
Ascending aorta
Superior vena cava
Auricle of right atrium
Fat in coronary sulcus

Left subclavian artery
Arch of aorta
Ligamentum arteriosum
Descending aorta
Left pulmonary artery
Pulmonary trunk
Auricle of left atrium

Fat in anterior interventricular sulcus

RIGHT ATRIUM
RIGHT VENTRICLE
LEFT VENTRICLE

Anterior view of the heart and great vessels
Orientation and Superficial Anatomy of Heart

• The Left and Right Atria
  • Positioned superior to the coronary sulcus
  • Both have thin walls
  • Both consist of expandable extensions called auricles

• The Left and Right Ventricles
  • Positioned inferior to the coronary sulcus
  • Much of the left ventricle forms the diaphragmatic surface
Figure 21.5a Superficial Anatomy of the Heart, Part I

- Left common carotid artery
- Anterior view of the heart and great vessels
- Brachiocephalic trunk
- Ascending aorta
- Superior vena cava
- Auricle of right atrium
- Auricle of left atrium
- Fat in coronary sulcus
- Fat in anterior interventricular sulcus
- Right atrium
- Right ventricle
- Left atrium
- Left ventricle
- Left subclavian artery
- Arch of aorta
- Ligamentum arteriosum
- Descending aorta
- Left pulmonary artery
- Pulmonary trunk
- Right atrium
- Right ventricle
- Anterior view of the heart and great vessels

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Internal Anatomy and Organization of the Heart

- A frontal section of the heart reveals:
  - Left and right atria separated by the interatrial septum
  - Left and right ventricles separated by the interventricular septum
  - The atrioventricular valves are formed from folds of endocardium
    - The atrioventricular valves are situated between the atria and the ventricles
Diagrammatic frontal section through the relaxed heart shows the major landmarks and the path of blood flow through the atria and ventricles (arrows).
Internal Anatomy and Organization of the Heart

- The Right Atrium
  - Receives deoxygenated blood via the superior vena cava, inferior vena cava, and coronary sinus
    - Coronary sinus enters the posterior side of the right atrium
  - Contains pectinate muscles
  - Contains the fossa ovalis (fetal remnant of the foramen ovale)
Diagrammatic frontal section through the relaxed heart shows the major landmarks and the path of blood flow through the atria and ventricles (arrows).
Internal Anatomy and Organization of the Heart

• The Right Ventricle
  • Receives deoxygenated blood from the right atrium
  • Blood enters the ventricle by passing through the tricuspid valve
    • Right atrioventricular valve—right AV valve
  • Blood leaves the ventricle by passing through the pulmonary valve
    • Leads to the pulmonary trunk, then to the right and left pulmonary arteries
Internal Anatomy and Organization of the Heart

• The Right Ventricle
  • The right AV valve is connected to **papillary muscles via chordae tendineae**
    • Since there are three cusps to the valve, the chordae tendineae are connected to three papillary muscles
    • Papillary muscles and chordae tendineae prevent valve inversion when the ventricles contract
Internal Anatomy and Organization of the Heart

• The Right Ventricle
  • The internal surface of the right ventricle consists of:
    • Trabeculae carneae
    • Moderator band
      • Found only in the right ventricle
      • Muscular band that extends from the interventricular septum to the ventricular wall
      • Prevents overexpansion of the thin-walled right ventricle
Diagrammatic frontal section through the relaxed heart shows the major landmarks and the path of blood flow through the atria and ventricles (arrows).
Internal Anatomy and Organization of the Heart

• The Left Atrium
  • Receives oxygenated blood from the lungs via the right and left pulmonary veins
  • Does not have pectinate muscles
  • Blood passes through the **bicuspid valve**
    • Left atrioventricular valve
    • Also called the mitral valve
Diagrammatic frontal section through the relaxed heart shows the major landmarks and the path of blood flow through the atria and ventricles (arrows).
Internal Anatomy and Organization of the Heart

• The Left Ventricle
  • Has the thickest wall
    • Needed for strong contractions to pump blood throughout the entire systemic circuit
    • Compare to the right ventricle, which has a thin wall since it only pumps blood through the pulmonary circuit
  • Does not have a moderator band
  • The AV valve has chordae tendineae connecting to the two cusps and to two papillary muscles
Internal Anatomy and Organization of the Heart

• The Left Ventricle (continued)
  • Blood leaves the left ventricle by passing through the **aortic valve**
    • Blood enters the ascending aorta
    • Blood then travels to the aortic arch and then to all body parts (systemic)
Diagrammatic frontal section through the relaxed heart shows the major landmarks and the path of blood flow through the atria and ventricles (arrows).
Internal Anatomy and Organization of the Heart

• Structural Differences between the Left and Right Ventricles
  • Right ventricle
    • Thinner wall
    • Weaker contraction
    • Has a moderator band
  • Left ventricle
    • Thicker wall
    • Powerful contraction
      • Six to seven times more powerful than the right ventricle
Anterior view of a frontally sectioned heart showing internal features and valves.
Internal Anatomy and Organization of the Heart

• Structure and Function of the Heart Valves
  • There are four valves in the heart
    • Two AV valves
      • Tricuspid and bicuspid valves
    • Two semilunar valves
      • Aortic and pulmonary (pulmonic) valves
Internal Anatomy and Organization of the Heart

• Structure and Function of the Heart Valves
  • Each AV valve consists of four parts
    • **Ring of connective tissue**
      • Connects to the heart tissue
    • **Cusps**
    • **Chordae tendineae**
      • Connect to the cusps and papillary muscles
    • **Papillary muscles**
      • Contract in such a manner to prevent AV inversion
When the ventricles are relaxed, the AV valves are open and the semilunar valves are closed. The chordae tendineae are loose, and the papillary muscles are relaxed.
Internal Anatomy and Organization of the Heart

- Valve Function during the Cardiac Cycle
  - Papillary muscles relax
  - Due to the pressure in the atria, the AV valves open
  - When the ventricles contract, pressure causes the semilunar valves to open
  - Also upon contraction, the blood forces the AV valves closed, thus resulting in blood going through the semilunar valves
When the ventricles are relaxed, the AV valves are open and the 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 semilunar valves are open. In the frontal section notice the attachment of the left AV valve to the chordae tendineae and papillary muscles.
Coronary Blood Vessels

• Originate at the base of the ascending aorta
  • Supply the cardiac muscle tissue
• Select coronary vessels:
  • Right coronary artery (RCA)
    • Right marginal branch
    • Posterior interventricular branch
  • Left coronary artery (LCA)
    • Circumflex branch
    • Left marginal branch
    • Anterior interventricular branch
Internal Anatomy and Organization of the Heart

• The Right Coronary Artery
  • Passes between the right auricle and pulmonary trunk
  • Major branches off the right coronary artery:
    • Atrial branches
    • Right marginal branch
    • Posterior interventricular branch
    • Conducting system branches
Coronary vessels supplying the anterior surface of the heart.
Internal Anatomy and Organization of the Heart

- Left Coronary Artery
  - Major branches off the left coronary artery
    - Circumflex branch
      - Branches to form the left marginal branch
      - Branches to form the posterior left ventricular branch
    - Anterior interventricular branch
      - Branches that lead to the posterior interventricular branch called **anastomoses**
Coronary vessels supplying the anterior surface of the heart.
Coronary vessels supplying the posterior surface of the heart.
Internal Anatomy and Organization of the Heart

• The Coronary Veins
  • Drain cardiac venous blood ultimately into the right atrium
  • Select coronary veins:
    • Great cardiac vein
      • Delivers blood to the coronary sinus
    • Middle cardiac vein
      • Delivers blood to the coronary sinus
    • Coronary sinus
      • Drains directly into the posterior aspect of the right atrium
Internal Anatomy and Organization of the Heart

• The Coronary Veins
  • Select coronary veins (continued)
    • Posterior vein of the left ventricle
      • Parallels the posterior left ventricular branch
    • Small cardiac vein
      • Parallels the right coronary artery
    • Anterior cardiac veins
      • Branches from the right ventricle cardiac cells
Coronary vessels supplying the anterior surface of the heart.
Coronary vessels supplying the posterior surface of the heart.
The Coordination of Cardiac Contractions

• The cardiac cycle consists of alternate periods of contraction and relaxation
  • Contraction is **systole**
    • Blood is ejected into the ventricles
    • Blood is ejected into the pulmonary trunk and the ascending aorta
  • Relaxation is **diastole**
    • Chambers are filling with blood
The Coordination of Cardiac Contractions

- Cardiac contractions are coordinated by conducting cells
- There are two kinds of conducting cells
  - **Nodal cells**
    - Sinoatrial nodes and atrioventricular nodes
    - Establish the rate of contractions
    - Cell membranes automatically depolarize
  - **Conducting fibers**
    - Distribute the contractile stimulus to the myocardium
The Sinoatrial and Atrioventricular Nodes

• **Sinoatrial node (SA node)**
  - Sits within the floor of the right atrium
  - Located in the posterior wall of the right atrium
  - Also called the cardiac pacemaker
  - Generates 80–100 action potentials per minute

• **Atrioventricular node (AV node)**
  - Sits within the floor of the right atrium
The Sinoatrial and Atrioventricular Nodes

• Generates 80–100 action potentials per minute
  • Upon exposure to acetylcholine (parasympathetic response)
    • Action potential slows down (bradycardia)
  • Upon exposure to norepinephrine (sympathetic response)
    • Action potential speeds up (tachycardia)
The Cardiac Cycle

• Summary of Cardiac Events
  • Impulse travels from the SA node to the AV node
    • Atrial contraction occurs
  • Impulse travels from the AV node to the AV bundle
    • The AV bundle travels along the interventricular septum and then divides to form the right and left bundle branches
  • The bundle branches send impulses to the Purkinje fibers
    • Ventricle contraction occurs
Components of the Conducting System

- **Sinoatrial (SA) node**: contains pacemaker cells that initiate the electrical impulse that results in a heartbeat.
- **Internodal pathways**: are conducting fibers in the atrial wall that conduct the impulse to the AV node while simultaneously stimulating cardiac muscle cells of both atria.
- **Atrioventricular (AV) node**: slows the electrical impulse when it arrives from the internodal pathways.
- **AV bundle**: conducts the impulse from the AV node to the bundle branches.
- **Left bundle branch**: extends toward the apex of the heart and then radiates across the inner surface of the left ventricle.
- **Right bundle branch**: extends toward the apex of the heart and then radiates across the inner surface of the right ventricle.
- **Moderator band**: relays the stimulus through the ventricle to the papillary muscles, which tense the chordae tendineae before the ventricles contract.
- **Purkinje fibers**: convey the impulses very rapidly to the contractile cells of the ventricular myocardium.
Movement of Electrical Impulses through the Conducting System

1. Time = 0
   The SA node depolarizes and atrial activation begins.

2. Elapsed time = 50 msec
   Depolarization spreads across the atrial surfaces and reaches the AV node.

3. Elapsed time = 150 msec
   Atrial contraction begins. The AV node delays the spread of electrical activity to the AV bundle by 100 msecs.

4. Elapsed time = 175 msec
   Impulses travel along the AV bundle within the interventricular septum to the apex of the heart. Impulses also spread to the papillary muscles of the right ventricle by the moderator band.

5. Elapsed time = 225 msec
   The impulse is distributed by Purkinje fibers and relayed throughout the ventricular myocardium. Atrial contraction is completed and ventricular contraction begins.
Atrial systole begins: Atrial contraction forces a small amount of blood into the relaxed ventricles.

Atrial systole ends; atrial diastole begins: Atrial diastole continues until the start of the next cardiac cycle.

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

Ventricular diastole—early: As the ventricles relax, the ventricular blood pressure drops until reverse blood flow pushes the cusps of the semilunar valves together. Blood now flows into the relaxed atria.

Ventricular diastole—late: All chambers are relaxed. The AV valves open and the ventricles fill passively.

Ventricular systole—second phase: As ventricular pressure rises and exceeds the pressure in the arteries, the semilunar valves open and blood is ejected.
The pacemaker sets the heart rate but can be altered
  - Impulses from the autonomic nervous system modify the pacemaker activity

Nerves associated with the ANS innervate the:
  - SA node
  - AV node
  - Cardiac cells
  - Smooth muscles in the cardiac blood vessels
Autonomic Control of Heart Rate

• The effects of NE and ACh on nodal tissue
  • **Norepinephrine** from the ANS causes:
    • An increase in the heart rate
    • An increase in the force of contractions
  • **Acetylcholine** from the ANS causes:
    • A decrease in the heart rate
    • A decrease in the force of contractions
Autonomic Control of Heart Rate

- Cardiac centers in the medulla oblongata modify heart rate
  - Stimulation activates sympathetic neurons
    • Cardioacceleratory center is activated
    • Heart rate increases
  - Stimulation activates parasympathetic neurons
    • CN X is involved
    • Cardioinhibitory center is activated
    • Heart rate decreases
Figure 21.12 The Autonomic Innervation of the Heart

- Cardioinhibitory center
- Cardioacceleratory center
- Vagal nucleus
- Medulla oblongata
- Vagus nerve (N X)
- Spinal cord
- Sympathetic preganglionic fiber
- Sympathetic ganglia (cervical ganglia and superior thoracic ganglia [T₁–T₄])
- Sympathetic postganglionic fiber
- Cardiac nerve
- Parasympathetic preganglionic fiber
- Synapses in cardiac plexus
- Parasympathetic postganglionic fibers