12

The Cardiovascular System: The Heart

PowerPoint® Lecture Outlines
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Slides 1 to 65
Heart’s Place in the Circulation

Heart Pumps Blood into Two Circuits in Sequence

• *Pulmonary* circuit
  • To and from the lungs

• *Systemic* circuit
  • To and from the rest of the body
Heart’s Place in the Circulation

Three Kinds of Blood Vessels

- **Arteries**
  - Carry blood *away* from heart and carry it to the capillaries

- **Capillaries**
  - Microscopic vessels where exchange between cells and blood takes place

- **Veins**
  - Receive blood from capillaries and carry it *back* to the heart
Heart’s Place in the Circulation

Two Sets of Pumping Chambers in Heart

• Right atrium
  • Receives systemic blood
• Right ventricle
  • Pumps blood to lungs (pulmonary)
• Left atrium
  • Receives blood from lungs
• Left ventricle
  • Pumps blood to organ systems (systemic)
Overview of the Cardiovascular System

Figure 12-1

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SYSTEMIC CIRCUIT

- Capillaries in head, neck, and upper limbs
- Systemic vein
- Systemic artery
- Systemic vein
- Capillaries in trunk and lower limbs

PULMONARY CIRCUIT

- Pulmonary arteries
- Capillaries in lungs
- Pulmonary veins

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Pericardial Cavity

- Surrounds the heart
- Lined by pericardium
  - Two layers
  - Visceral pericardium (epicardium)
    - Covers heart surface
  - Parietal pericardium
    - Lines pericardial sac that surrounds heart
The Anatomy of the Heart

The Location of the Heart in the Thoracic Cavity

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The Anatomy of the Heart

Surface Features of the Heart

- *Auricle*—Outer portion of atrium
- *Coronary sulcus*—Deep groove that marks boundary of atria and ventricles
- *Anterior interventricular sulcus*
- *Posterior interventricular sulcus*
  - Mark boundary between left and right ventricles
  - *Sulci* contain major cardiac blood vessels
  - Filled with protective fat
The Surface Anatomy of the Heart

Figure 12-3(a)
1 of 2

(a) Anterior surface (1 of 2)
The Anatomy of the Heart

The Surface Anatomy of the Heart

Figure 12-3(a)
2 of 2

(a) Anterior surface (2 of 2)
The Surface Anatomy of the Heart

(b) Posterior surface
The Anatomy of the Heart

The Heart Wall

- **Epicardium (visceral pericardium)**
  - Outermost layer
  - *Serous membrane*
- **Myocardium**
  - Middle layer
  - Thick muscle layer
- **Endocardium**
  - Inner lining of pumping chambers
  - Continuous with *endothelium*
The Anatomy of the Heart

The Heart Wall and Cardiac Muscle Tissue

Figure 12-4
The Anatomy of the Heart

The Heart Wall and Cardiac Muscle Tissue

Figure 12-4(a)
The Anatomy of the Heart

The Heart Wall and Cardiac Muscle Tissue

Figure 12-4(b)
The Anatomy of the Heart

The Heart Wall and Cardiac Muscle Tissue

(c) Intercalated disc

Figure 12-4(c)
The Anatomy of the Heart

The Heart Wall and Cardiac Muscle Tissue

Cardiac muscle cell (intact)
Intercalated disc (sectioned)
Mitochondrion
Nucleus
Cardiac muscle cell (sectioned)
Myofibrils
Intercalated disc

Figure 12-4(d)
Cardiac Muscle Cells

- Shorter than skeletal muscle fibers
- Have single nucleus
- Have striations (sarcomere organization)
- Depend on aerobic metabolism
- Connected by intercalated discs
  - Desmosomes transmit tension
  - Gap junctions transmit action potential
The Anatomy of the Heart

Internal Anatomy and Organization

- *Interatrial septum*
  - Separates atria

- *Interventricular septum*
  - Separates ventricles

- *Atrioventricular valves*
  - Located between atrium and ventricle
  - Ensure one-way flow from atrium to ventricle
Blood Flow in the Heart

- **Superior and inferior venae cavae**
  - Large veins carry systemic blood to right atrium
- Right atrium sends blood to right ventricle
  - Flows through right AV valve
    - Bounded by three cusps (tricuspid valve)
    - Cusps anchored by chordae tendinae
    - Chordae attached to papillary muscles
Blood Flow in the Heart (cont’d)

- Right ventricle pumps blood through *pulmonary semilunar valve*
  - Enters *pulmonary trunk*
  - Flows to lungs through right, left pulmonary arteries where it picks up oxygen
- Pulmonary veins carry blood to left atrium
- Left atrium sends blood to left ventricle
  - Enters through left AV valve (*bicuspid* or *mitral*)
- Left ventricle pumps blood to aorta
  - Through aortic semilunar valve to systems
The Anatomy of the Heart

The Sectional Anatomy of the Heart

Figure 12-5
The Anatomy of the Heart

Functional Anatomy of the Heart

• Left ventricular myocardium much thicker than right
  • Reflects functional difference in load
• Valves ensure one-way flow of blood
  • Prevent backward flow (*regurgitation*)
• Fibrous skeleton supports valves and muscle cells
The Anatomy of the Heart

The Valves of the Heart

(a) Relaxed ventricles
The Anatomy of the Heart

The Valves of the Heart

Fibrous skeleton (network of connective tissue)

Right AV (tricuspid) valve (closed)

Left AV (bicuspid) valve (closed)

Aorta

Aortic sinus

Aortic semilunar valve (open)

Pulmonary semilunar valve (open)

Transverse section

(b) Contracting ventricles

Frontal section

Left AV (bicuspid) valve (closed)

Chordae tendineae (tense)

Papillary muscles (contracted)

Left ventricle (contracted)

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Figure 12-6(b)
The Anatomy of the Heart

Key Note

The heart has four chambers, the right atrium and ventricle with the pulmonary circuit and left atrium and ventricle with the systemic circuit. The left ventricle’s greater workload makes it more massive than the right, but the two pump equal amounts of blood. AV valves prevent backflow from the ventricles into the atria, and semilunar valves prevent backflow from the outflow vessels into the ventricles.
The Anatomy of the Heart

The Blood Supply to the Heart

- *Coronary circulation* meets heavy demands of myocardium for oxygen, nutrients
- *Coronary arteries* (right, left) branch from *aorta* base
- *Anastomoses* (arterial interconnections) ensure constant blood supply
- Drainage is to right atrium
  - Great, middle cardiac veins drain capillaries
  - Empty into *coronary sinus*
The Anatomy of the Heart

The Coronary Circulation

(a) Anterior view

- Aorta
- Pulmonary trunk
- Right coronary artery (RCA)
- Anterior cardiac veins
- Small cardiac vein
- Marginal branch of RCA
- Left atrium
- Left coronary artery (LCA)
- Circumflex branch of LCA
- Anterior interventricular branch of LCA
- Great cardiac vein

Figure 12-7(a)
The Anatomy of the Heart

The Coronary Circulation

- Circumflex branch of LCA
- Great cardiac vein
- Posterior cardiac vein
- Posterior left ventricular branch of LCA
- Coronary sinus
- Small cardiac vein
- Right coronary artery (RCA)
- Marginal branch of RCA
- LEFT ATRIUM
- LEFT VENTRICLE
- RIGHT VENTRICLE
- (b) Posterior view

Figure 12-7(b)
Heartbeat Needs two Types of Cardiac Cells

• Contractile cells
  • Provide the pumping action

• Cells of the conducting system
  • Generate and spread the action potential
The Heartbeat

Differences between Cardiac and Skeletal Muscle Cells

- Cardiac action potential has long plateau phase
- Cardiac muscle has long, slow twitch
- Cardiac muscle has long refractory period
  - Can’t be tetanized
**1. Rapid Depolarization**

Cause: Na\(^+\) entry  
Duration: 3-5 msec  
Ends with: Closure of voltage-regulated 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**

-90 mV  
+30 mV

**Time (msec)**

0 100 200 300

**Figure 12-8(a)**

1 of 5
Rapid Depolarization

Cause: Na$^+$ entry
Duration: 3-5 msec
Ends with: Closure of voltage-regulated sodium channels

![Graph showing time (msec) on the x-axis and mV on the y-axis, with a stimulus at -90 mV and a peak at +30 mV.](Figure 12-8(a))

2 of 5
Rapid Depolarization
- Cause: $\text{Na}^+$ entry
- Duration: 3-5 msec
- Ends with: Closure of voltage-regulated sodium channels

The Plateau
- Cause: $\text{Ca}^{2+}$ entry
- Duration: $\sim$175 msec
- Ends with: Closure of calcium channels
Rapid Depolarization
Cause: Na\(^+\) entry
Duration: 3-5 msec
Ends with: Closure of voltage-regulated sodium channels

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

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

Figure 12-8(a)
1. **Rapid Depolarization**
   - Cause: Na\(^+\) entry
   - Duration: 3-5 msec
   - Ends with: Closure of voltage-regulated 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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**Figure 12-8(a)**

- **Stimulus**
- **Refractory period**
- **Time (msec)**

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The Heartbeat

Action Potentials and Muscle Cell
Contraction in Skeletal and Cardiac Muscle

Figure 12-8(b)
The Conducting System

- Initiates and spreads electrical impulses in heart
- Two types of cells
  - Nodal cells
    - Pacemaker cells
      Reach threshold first
      Set heart rate
  - Conducting cells
    - Distributes stimuli to myocardium
The Heartbeat

The Conducting System (cont’d)

- Heart is self-exciting
  - Pacemaker cells establish heart rate
    - Normal pacemaker is sinoatrial (SA) node
  - Impulse spreads from SA node:
    - Across atria
    - To atrioventricular (AV) node
    - To AV bundle and bundle branches
    - Via Purkinje fibers to ventricles
The Heartbeat

The Conducting System of the Heart

The Heart: Conduction System

- Sinoatrial (SA) node
- Atrioventricular (AV) node
- AV bundle
- Bundle branches
- Purkinje fibers
SA node activity and atrial activation begin.

Time = 0

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

Elapsed time = 50 msec

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

Elapsed time = 150 msec

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

Elapsed time = 175 msec

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(b)

**STEP 1**

SA node activity and atrial activation begin.

Time = 0
**STEP 1**

SA node activity and atrial activation begin.

Time = 0

**STEP 2**

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

Elapsed time = 50 msec
Figure 12-9(b)

**STEP 1**
SA node activity and atrial activation begin.

Time = 0

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

Elapsed time = 50 msec

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

Elapsed time = 150 msec
**STEP 1**

SA node activity and atrial activation begin.

Time = 0

**STEP 2**

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

Elapsed time = 50 msec

**STEP 3**

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

Elapsed time = 150 msec

**STEP 4**

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

Elapsed time = 175 msec
SA node activity and atrial activation begin.

Time = 0

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

Elapsed time = 50 msec

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

Elapsed time = 150 msec

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

Elapsed time = 175 msec

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 Heartbeat

The Electrocardiogram (ECG or EKG)

• A recording of the electrical activity of the heart

• Three main components
  • $P$ wave
    • Atrial depolarization
  • $QRS$ complex
    • Ventricular depolarization
  • $T$ wave
    • Ventricular repolarization
The Heartbeat

An Electrocardiogram

ECG rhythm strip

800 msec

Millivolts

0 1

P wave

Impulse spreads across atria, triggers atrial contractions

QRS complex

Impulse spreads to ventricles, triggering ventricular contraction

Ventricles return to resting state

Figure 12-10
The Heartbeat

Key Note

The heart rate is established by the SA node, as modified by autonomic activity, hormones, ions, etc. From there, the stimulus is conducted through the atrium to the AV node, the AV bundle, the bundle branches, and Purkinje fibers to the ventricular myocardium. The ECG shows the electrical events associated with the heartbeat.
The Cardiac Cycle

- Two phases in cardiac cycle
  - **Systole**
    - Contraction phase
    - Both ventricles simultaneously
  - **Diastole**
    - Relaxation phase
(f) Ventricular diastole—late: All chambers are relaxed. Ventricles fill passively.

(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.

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

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

0 msec

100 msec

Cardiac cycle
(a) Atriole systole begins: Atrial contraction forces a small amount of additional blood into relaxed ventricles.

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

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Cardiac cycle

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(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.

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

- Generated by *closing* of valves
- Two main heart sounds
  - First sound (*lubb*)
    - Closing of AV valve
  - Second sound (*dupp*)
    - Closing of aortic valve
- Indicate start/stop of systole
- Heard with *stethoscope*
Heart Dynamics

Some Essential Definitions

• *Heart dynamics*—Movements and forces generated during cardiac contraction

• *Stroke volume*—Amount of blood pumped in a single beat

• *Cardiac output*—Amount of blood pumped each minute
Factors Controlling Cardiac Output

- Blood volume reflexes
- Autonomic innervation
  - Heart rate effects
  - Stroke volume effects
- Hormones
Heart Dynamics

Blood Volume Reflexes

• Stimulated by changes in *venous return*
  • VR is amount of blood *entering* heart

• **Atrial reflex**
  • Speeds up heart rate
  • Triggered by stretching wall of right atrium

• **Frank-Starling principle**
  • Increases ventricular output
  • Triggered by stretching wall of ventricles
Autonomic Control of the Heart

- Parasympathetic innervation
  - Releases acetylcholine (ACh)
  - Lowers heart rate and stroke volume
- Sympathetic innervation
  - Releases norepinephrine (NE)
  - Raises heart rate and stroke volume
Heart Dynamics

Autonomic Innervation of the Heart

Figure 12-12

Cardioinhibitory center
Cardioacceleratory center

Medulla oblongata
Vagus nerve (N X)

SYMPATHETIC
Spinal cord
Sympathetic preganglionic fiber
Sympathetic ganglia
Sympathetic postganglionic fiber
Cardiac nerve

PARASYMPATHETIC
Parasympathetic preganglionic fiber
Synapses in cardiac plexus
Parasympathetic postganglionic fibers
Hormone Effects on Cardiac Output

- Adrenal medulla hormones
  - Epinephrine, norepinephrine released
  - Heart rate and stroke volume increased
- Other hormones that increase output
  - Thyroid hormones
  - Glucagon
CNS Control of the Heart

• Basic control in *medulla oblongata*
  • *Cardioacceleratory center*
    • Activation of sympathetic neurons
  • *Cardioinhibitory center*
    • Governing of parasympathetic neurons
• Other inputs
  • Higher centers
  • Blood pressure sensors
  • Oxygen, carbon dioxide sensors
Key Note

Cardiac output is the amount of blood pumped by the left ventricle each minute. It is adjusted moment-to-moment by the ANS, and by circulating hormones, changes in blood volume and in venous return. A healthy person can increase cardiac output by three-fold to five-fold.