Chapter 9

The Cardiovascular System
Objectives

- Describe the anatomy of the heart and vascular systems.
- State the key characteristics of cardiac tissue.
- Calculate systemic vascular resistance given mean arterial pressure, central venous pressure, and cardiac output.
- Describe how local and central control mechanisms regulate the heart and vascular systems.
- Describe how the cardiovascular system coordinates its functions under normal and abnormal conditions.
Objectives (cont.)

- Calculate cardiac output given stroke volume and heart rate.
- Calculate ejection fraction given stroke volume and end-diastolic volume.
- Identify how the electrical and mechanical events of the heart relate to a normal cardiac cycle.
Functional Anatomy

- Heart is hollow, muscular, roughly fist-sized
- Lies just behind the sternum, two thirds lie to left
- Heart apex at fifth intercostal space
- Surface grooves (sulci) delineate chambers
Functional Anatomy (cont.)

- Heart enclosed by the pericardial sac
  - Outer layer is parietal.
  - Innermost layer is the visceral, which is also the outermost layer of the heart (epicardium).
The Heart

- The heart is composed of three layers.
  - Outer is epicardium.
  - Middle myocardium comprises the bulk of the heart and is composed of muscle tissue.
  - Innermost layer, the endocardium, forms a thin continuous tissue with blood vessels.

- Heart forms four muscular chambers.
  - Upper chambers, right and left atria
  - Lower chambers are right and left ventricles.
    - Responsible for forward movement of blood
Atrioventricular Valves

- AV valves lie between the atria and ventricles.
  - Tricuspid valve is at the right atrium exit.
  - Mitral valve at the left atrium exit.
  - Ventricular contraction forces closed valves, preventing backflow of blood into atria.
  - The lower ends of the valves anchor to ventricular papillary muscles by chordae tendineae.
    - Papillary contraction during systole pulls on chordae, preventing valve reversing into atria.
Semilunar Valves

- Consist of three half-moon–shaped cusps.
- Situated at ventricle exits to arterial trunks
  - Pulmonary valve lies between right ventricle and pulmonary artery.
  - Aortic valve lies between left ventricle and aorta.
- Systole: valves open, allowing ventricular ejection into arteries
  (pulmonary artery and aorta)
- Diastole: valves close preventing back flow of blood into ventricles.
Coronary Circulation

- Heart’s high metabolic demands require an extensive circulatory system.

- Right and left coronary arteries arise behind aortic valve cusps.
  - Cusps obstruct flow into system during systole.
  - Diastole is when blood flow occurs, so diastolic pressure is very important.
Left Coronary Artery (LCA)

- LCA branches into
  - Left anterior descending (LAD): courses between left and right ventricles
  - Circumflex: courses around left side of heart between left atrium and left ventricle

- LCA provides blood to left atrium, left ventricle, majority of interventricular septum, half of interatrial septum, and part of right atrium

- See Figure 9-4.
Right Coronary Artery (RCA)

- RCA proceeds around the right side of heart between the right atrium and right ventricle.
  - Many small branches as RCA moves around the right ventricle
  - RCA ends in its posterior descending (RPD) branch, which courses between right and left ventricles.
  - Provides blood flow to most of right ventricle and right atrium, including sinus node

- See Figure 9-4.
Coronary Veins

- Veins closely parallel coronary arteries.
  - Great cardiac vein follows LAD.
  - Small cardiac vein follows RCA.
  - Left posterior vein follows the circumflex.
  - Middle vein follows the RPD.
  - These come together to form the coronary sinus, which empties into the right atrium.
  - Thebesian veins drain into all heart chambers.
    - Those draining into the left atrium and left ventricle bypass the lungs, creating an anatomic shunt.
Properties of Heart Muscle

- Heart’s ability to pump depends on
  - Initiating and conducting electrical impulses
  - Synchronous myocardial contraction

- Above are made possible by key properties
  - Excitability: ability to respond to stimuli
  - Automaticity: initiation of spontaneous electrical impulse
  - Conductivity: spreads impulses quickly
  - Contractility: contraction in response to electrical impulse
    - Unique feature – cannot go into tetany
The Vascular System

- Systemic venous blood returns to the right atrium via
  - Superior vena cava (SVC), which drains upper extremities and head
  - Inferior vena cava (IVC), which drains lower body

- Blood flows through tricuspid valve into right ventricle.

- Pumped from right ventricle through pulmonary valve into pulmonary artery, which carries it to lungs (oxygenation).

- Pulmonary arterial blood returns via pulmonary veins to left atrium.
The Vascular System (cont.)

- From left atrium oxygenated blood flows through the mitral valve into left ventricle.
- Left ventricle pumps the blood out through aortic valve into systemic circulation.
- The blood passes through systemic capillary beds into the systemic veins and back to the SVC and IVC.
The Vascular System (cont.)
Systemic Vasculature

- Has three components
  - Arterial system (conductance vessels)
    - Large elastic low resistance arteries
    - Small muscular arterioles
      - Like faucets, control local blood flow
  - Capillary system (exchange vessels)
    - Transfer of nutrients and waste products
  - Venous system (capacitance vessels)
    - Reservoir for circulatory system
      - Generally hold three-fourths of body’s blood volume
Vascular Resistance

- The sum of all opposing forces to blood flow through the systemic circulation is systemic vascular resistance (SVR)

- SVR = Change (Δ) in pressure from beginning to end of system, divided by flow

\[ SVR = \frac{\text{MAP} - \text{RAP}}{\text{CO}} \]

Where:
- MAP = mean aortic pressure
- RAP = right atrial pressure or CVP
- CO = cardiac output
Pulmonary Vascular Resistance (PVR)

- PVR is sum of all opposing forces to blood flow through the pulmonary circulation
- PVR then calculated as is SVR (ΔP/flow)

\[ PVR = \frac{MPAP - LAP}{CO} \]

Where:
- MPAP = mean pulmonary artery pressure
- LAP = left atrial pressure or wedge pressure
- CO = cardiac output

- PVR is normally much lower than SVR as the pulmonary system is low pressure, low resistance
Determinants of Blood Pressure (BP)

- Normal CV function maintains blood flow throughout the body.

- Under changing conditions, need constant BP.

\[ \text{MAP} = \text{CO} \times \text{SVR} \]

And

\[ \text{MAP} = \frac{\text{Volume}}{\text{Capacity}} \]

- To maintain BP, capacity must vary inversely with CO or volume.
Control of Cardiovascular System

- The heart works as a demand pump.
  - CV system may alter capacity and, thus, how much blood it holds.
  - Decreased capacity results in greater venous return and, thus, greater CO.
  - Thus, the CV system tells the heart how much to pump.
  - This is accomplished by local and central control mechanisms.
Cardiac Output and its Regulation

- \( CO = \text{Heart rate (HR)} \times \text{stroke volume (SV)} \)
  - HR is primarily determined by CNS.
    - CO is directly related to HR.
      - HR > 160–180 is exception; too little time for filling results in decreased EDV, EF, SV, and thus CO
  - SV is determined by
    - Preload
    - Afterload
    - Contractility
Stroke Volume and Preload

- Preload essentially equals venous return.
  - Amount of volume and pressure at end diastole (EDV, EDP) stretches myocardium.
    - Greater the stretch, the stronger the contraction
      - Frank-Starling Law
  - Normal EDV is ~110–120 ml
  - Normal SV is ~70 ml
  - Ejection fraction (EF) = SV/EDV
    - Normal ~65%
Stroke Volume and Afterload

- Afterload is the resistance against which the ventricles pump, so more afterload makes it harder for the ventricles to eject the SV.
  - RV afterload is equal to PVR.
  - LV afterload is equal to SVR.
  - All else constant, an increase in vascular resistance would decrease SV.
    - Usually this does not occur as contractility increases to maintain SV and thus CO.
Stroke Volume and Contractility

- Contractility is the amount of force the myocardium produces at any EDV.
  - Increased contractility results in greater EF for any EDV.
    - Called positive inotropism.

- If both afterload and contractility increase together, SV is maintained.
Stroke Volume and Contractility (cont.)

![Diagram showing changes in cardiac output with preload, afterload, contractility, and heart rate changes.](Modified from Green J.F. Fundamental cardiovascular and pulmonary physiology, ed 2, Philadelphia, 1987, Lea & Febiger.)
Cardiovascular Control Mechanisms

- Integration of local and central mechanisms to ensure all tissues have enough blood flow
  - Normally, local control is primary determinant.
  - With large changes in demand, central control becomes primary.

- Central control in medulla has areas for
  - Vasoconstriction—increases adrenergic output
  - Vasodepressor—inhibits vasoconstrictor center
  - Cardioacceleratory—increases heart rate
  - Cardioinhibitory—increases vagal output to heart
Peripheral Receptors: Baroreceptors

- Baroreceptors respond to pressure changes:
  - First set: Arch of aorta and carotid sinus
    - Monitor arterial pressures generated by left ventricle.
  - Second set: Atrial walls, large thoracic and pulmonary veins—low-pressure monitors
    - Respond to volume changes
  - Baroreceptor output is directly proportional to vessel stretch
    - Negative feedback system, so greater stretch causes venodilation and decreased heart rate and contractility.
Peripheral Receptors: Chemoreceptors

- Located in aortic arch and carotid sinus
- Respond to changes in blood chemistry.
  - Decreased PaO$_2$ provides strong stimulus
  - Low pH and high PaCO$_2$
- Major CV response to their increased output is vasoconstriction and increased heart rate.
  - Occur only when CV system is overtaxed, so generally will have little affect.
Response to Changes in Volume

- Best noted under abnormal conditions
  - Hemorrhage sets up this sequelae.
    - 10% blood volume loss decreases CVP.
    - 50% decrease in baroreceptor discharge
      - ↑ Sympathetic discharge increases HR.
    - ADH begins to rise.
    - Normal BP is maintained.
  - Blood loss approaches 30%, BP starts to fall
    - Aortic baroreceptors now increase output.
    - IF no further blood loss, BP still maintained.
Events of the Cardiac Cycle

- Figure 9-14 provides a visual summary of mechanical, electrical, and auditory events as they occur during the cardiac cycle.

- Understanding of the cause and effect of each event will help you attain mastery of this important cycle.
Events of the Cardiac Cycle (cont.)