Chapter 19: Physiology of the Cardiovascular System

Now that students have gained an understanding of the anatomy of the cardiovascular system through Chapters 17 and 18, they will recognize that its vital role in maintaining homeostasis depends on the continuous and controlled movement of blood through the thousands of miles of capillaries that permeate every tissue to reach every cell in the body. It is in the microscopic capillaries that blood performs its ultimate transport function. Nutrients and other essential materials pass from capillary blood into fluids surrounding the cells as waste products are removed. Blood not only must be kept moving through the closed circuit of vessels by the pumping of the heart, but also must be directed and delivered to those capillary beds surrounding cells that need it most. Regulation of blood pressure and flow must change in response to cellular activity.

The chapter introduces students to the physiology of the heart and control of circulation by tracing a cardiac impulse through the conduction system of the heart. Control of circulation is explained in light of hemodynamics, control of arterial blood pressure, venous return to the heart, and minute volume of blood. Finally, the focus moves into the means of measuring and evaluating blood pressure, velocity of blood, and the pulse.

Objectives
After students have completed this chapter, they should be able to:

1. Trace a cardiac impulse through the conduction system of the heart.
2. Discuss normal ECG deflections and intervals and their relationship to mechanical contraction.
3. Discuss the major events of the cardiac cycle.
4. Discuss the physical principles that govern fluid flow and circulation.
5. Discuss how arterial blood pressure is influenced by cardiac output, stroke volume, peripheral resistance, vasomotor pressoreflex, and chemoreflex control mechanisms.
6. Compare the results of parasympathetic and sympathetic stimulation on the heart and explain the mechanism involved in both types of autonomic control.
7. Discuss several factors that influence heart rate.
8. Explain the main determinants of peripheral resistance.
9. Identify and discuss the most important factors influencing venous return to the heart.
11. Discuss measurement of arterial blood pressure.
12. Explain how the blood pressure gradient and peripheral resistance are related to the minute volume of blood.
13. Define pulse and identify the factors most responsible for its existence.
14. Identify those body areas where the pulse can be felt and those areas where pressure may be applied to stop arterial bleeding.

Lecture Outline
I. Introduction (p. 593)
   A. Materials exchange occurs in the capillaries
   B. Blood must be delivered to where materials exchange is needed

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C. Control mechanisms regulate the location of blood delivery

II. Hemodynamics (p. 594)
A. The study of the regulation of blood flow
B. Involves maintaining circulation to all cells
C. Necessitates varying the volume and distribution of circulating blood

III. The Heart as a Pump (p. 594)
A. Conduction system of the heart (Fig. 19-1)
   1. Sinoatrial (SA) node
      a. Located in the right atrium, just below the superior vena cava
      b. Intrinsic rhythm—natural pacemaker of heart
         1) Has the fastest rhythm
      c. Interatrial bundle to muscle fibers of both atria
      d. Signal to AV node conducted by internodal bundles
   2. Atrioventricular (AV) node
      a. Slows conduction for about 0.1 sec.
      b. Impulse passed to AV bundle, which crosses the fibrous base
   3. AV bundle
      a. Increase in conduction velocity
      b. Forms right and left bundle branches in interventricular septum
      c. Impulse passed to Purkinje system
   4. Purkinje system
      a. Impulse conduction throughout both ventricles
   5. Artificial pacemaker
   6. Ectopic pacemakers
      a. An abnormal area of myocardium, which becomes the pacemaker

B. Electrocardiogram (ECG) (p. 597)
   1. A recording of the electrical activity of the heart (Fig. 19-2)
   2. Electrocardiograph = a machine used to record heart electrical activity
      a. Gives a meaningful recording of electrical conduction across the heart
      b. Theory of electrocardiography (Fig. 19-3)
         1) Electrodes record current on sarcolemma of muscle fiber
         2) Electrodes attached to a voltmeter
         3) One electrode is positive; one is negative

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4) As an action potential moves across the sarcolemma, it reaches one electrode first

5) The result is a different voltage at each electrode

6) This causes the voltmeter needle to move; a pen at the end of the needle marks the paper, and an electrocardiogram is produced

3. ECG waves (Fig. 19-4)
   a. P wave—depolarization of atria (Fig 19-4, A–C)
   b. QRS complex—depolarization of ventricles (Fig. 19-4, E–F)
      1) Recording electrodes on sarcolemma of muscle fiber
      2) Action potential's movement on sarcolemma
   c. T wave—repolarization of ventricles (Fig. 19-4, F–G)
   d. U wave—repolarization of Purkinje fibers in papillary muscle

4. ECG intervals (Fig. 19-2)
   a. Used to diagnose myocardial damage
   b. Include a wave form
      1) P-R interval (also called the P-Q interval)—from the beginning of the P wave to the beginning of the Q wave
      2) Q-T interval—from the beginning of the Q wave to the end of the T wave
   c. Segments between wave forms
      1) S-T segment—between the end of the S wave and the start of the T wave

C. Cardiac cycle—about 0.8 sec. (Figs. 19-5, 19-6)
   1. Starts with SA node discharge (p. 602)
   2. Atrial systole—0.1 sec.
   3. AV node discharge
   4. Ventricular systole—0.3 sec.
      a. Isovolumetric ventricular contraction (occurs first)
      b. Ejection of blood into the pulmonary artery and aorta
   5. Ventricular diastole—0.5 sec.
      a. Isovolumetric ventricular relaxation
      b. Passive ventricular filling (at end is atrial systole)
      c. Overlaps atrial systole by 0.1 sec.

D. Heart sounds (Fig. 19-5)
   1. First sound
      a. Contraction of ventricles
      b. Vibrations of closing AV valves
2. Second sound  
a. Vibration of closing semilunar valves

3. Heart murmur  
a. Caused by blood rushing around an irregularity, such as a leaking valve or a stenosis

IV. Primary Principle of Circulation (Fig. 19-7)  
A. Fluid flowing from greater pressure to lesser pressure  
B. Progressive fall in pressure as blood flows from the left ventricle to the right atrium

V. Arterial Blood Pressure (Fig. 19-7)  
A. Cardiac output (Fig. 19-8)  
1. Cardiac output (CO) = stroke volume (SV) X heart rate (HR)  
a. Increase in cardiac output (CO) increases arterial blood volume  
b. Increase in arterial blood volume increases blood pressure

2. Factors that affect stroke volume  
a. Starling’s law of the heart (Fig. 19-9)  
   1) Within limits, the more stretched the heart muscle at the start of contraction, the stronger the contraction  
   2) Increased venous return increases stroke volume  
   3) Starling’s law ensures that the heart pumps out all of the blood returning to it (prevents pooling in veins)

3. Factors that affect heart rate (p. 606)  
a. Influenced by the ratio of sympathetic and parasympathetic system stimulation  
   1) Parasympathetic (vagal) stimulation slows the heart as a result of the release of acetylcholine  
   2) Sympathetic stimulation speeds the heart as a result of the release of norepinephrine

b. Cardiac pressoreflexes (Fig. 19-10)  
1) Aortic baroreceptors located in the aortic arch  
2) Carotid baroreceptors located in the carotid sinus in the internal carotid artery  
3) Impulses sent by both baroreceptors to the cardiac center in the medulla  
4) Integrated in cardiac control center in medulla  
a) Carotid sinus reflex for high pressure (Fig. 19-11)  
   (1) Runs from carotid sinus nerve to glossopharyngeal nerve to cardiac control center, out vagus nerve to heart

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(2) Slowing of heart; drop in pressure
b) Aortic reflex for high pressure (Fig. 19-11)
   (1) Runs from vagus nerve to cardiac control center in medulla, out vagus nerve to heart
   (2) Slowing of heart; drop in pressure
c. Other reflexes that influence heart rate (p. 607)
   1) Operate from cerebrum through the hypothalamus
      a) Emotions—may speed heart (anger, fear, anxiety)
      b) Emotions—may slow heart (grief)
      c) Exercise—accelerates heart
      d) Temperature increase—speeds heart
      e) Temperature decrease—slows heart; sometimes used in surgery
      f) Stimulation of pain receptors—slows heart; may cause fainting
   2) Increases in heart rate and strength of contraction frequently caused by sympathetic nervous system releasing norepinephrine

B. Peripheral resistance (p. 608)
   1. How resistance influences blood pressure
      a. Viscosity = resistance to flow
         1) Increased viscosity due to increased number of RBCs
            a) Polycythemic blood more viscous (thicker)
         2) Protein level in blood increased, resulting in some increase in viscosity
      b. Diameter of blood vessels
         1) The smaller the diameter, the greater the resistance to flow
         2) Thus, distribution of blood regulated by diameter of arterioles
   2. Vasomotor control mechanism (Figs. 19-14, 19-15)
      a. Vasomotor center in medulla
         1) Sends impulses through sympathetic fibers
         2) Causes constriction of arterioles, venules, and veins
         3) Maintains general blood pressure
         4) Distributes blood to areas of need (Fig. 19-13)
            a) Greater vasoconstriction, less blood flow through the vessel; blood flows to less constricted vessels

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b) Thus, blood distribution controlled

5) Blood reservoirs in the skin and abdominal veins

b. Vasomotor pressoreflexes (Fig. 19-14)
1) Increased blood pressure in the carotid sinus and aortic arch, causing impulses to the vasomotor center resulting in:
   a) Parasympathetic stimulation and decreased heart rate and, thus, decreased blood pressure
   b) Inhibition of sympathetic vasoconstriction and, therefore, vasodilation and decreased blood pressure
2) Decreased blood pressure in the carotid sinus and aortic arch, causing impulses to the vasomotor center results in:
   a) Sympathetic stimulation, increased heart rate, and increased pressure
   b) Sympathetic stimulation of blood vessels and vasoconstriction, causing increased pressure

c. Vasomotor chemoreflexes (Fig. 19-15)
1) Located in aortic and carotid bodies
   a) Sensitive to hypercapnia, hypoxia, and lower pH
2) Send impulses to medullary vasomotor center
3) Vasoconstriction of arterioles and venous reservoirs, which increases the blood flow

d. Medullary ischemic reflex
1) If excess carbon dioxide and insufficient oxygen to the medulla, then hypercapnia causes vasoconstriction, thus increasing the flow

e. Vasomotor control by higher brain centers
1) Signals from the cerebral cortex to hypothalamus to vasomotor center
2) Linked to intense emotions of fear or anger

3. Local control of arterioles
   a. Stimulated by locally produced substances when there is a lack of oxygen or too much carbon dioxide
   b. Results in local vasodilation (reactive hyperemia)

VI. Venous Return to Heart (p. 612)
A. Venous pumps (Figs. 19-16, 19-17)
   1. Valves in the veins keep the blood moving in one direction
2. Two pumps:
   a. Inspiration (respiratory pump)
   b. Skeletal muscle contractions (booster pumps for the heart)

B. Total blood volume
   1. Capillary exchange and total blood volume
      a. Starling's law of the capillaries (Fig. 19-18)
         1) A balance of forces determines whether fluid will enter or leave a capillary
           a) Colloidal osmotic pressure inside and outside the capillary
           b) Hydrostatic pressure inside (blood pressure) and outside (tissue fluid pressure) the capillary
         2) The hydrostatic pressure of the blood is greater at the arteriole end of the capillary, and fluid leaks out; the colloidal osmotic pressure inside the capillary is great enough to pull fluids back into the capillary at the venous end
         3) About 10% of fluid is lost from the capillaries; this fluid is returned to the blood via the lymphatics

2. Changes in total blood volume (Fig. 19-19)
   a. ADH mechanism results in more water reabsorption from kidneys; therefore blood volume is maintained
   b. Renin-angiotensin mechanism triggers aldosterone secretion; aldosterone causes increased sodium retention, with water following the sodium; thus blood volume is maintained (Fig. 16-23)
   c. ANH is released in response to increased blood volume, resulting in increased sodium being lost in the urine and more water following the sodium; thus blood volume and blood pressure are decreased

VII. Measuring Blood Pressure (Fig. 19-20)
   A. Arterial blood pressure (p. 615)
      1. Sphygmomanometer
      2. Korotkoff sounds
      3. Systolic and diastolic pressure
      4. Pulse pressure (systolic pressure minus diastolic pressure)

   B. Blood pressure and arterial versus venous bleeding

VIII. Minute Volume of Blood (Fig. 19-21)
   A. Poiseuille's law
      1. Volume of blood circulated

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IX. Velocity of Blood Flow (Fig. 19-22)
A. Larger cross-sectional area decreases flow velocity (e.g., capillaries)
   1. The total-cross sectional area of all of the capillaries is much greater than that of the arteries; thus flow is slower in capillaries and faster in arteries
B. Smaller cross-sectional area increases flow velocity (e.g., aorta).

X. Pulse (p. 619)
A. Mechanism
   1. Alternate expansion and recoil of an artery
   2. Causes
      a. Intermittent injections of blood from the heart
      b. Elasticity of arterial walls
B. Pulse wave (Fig. 19-23)
   1. Increase in pressure from ventricular systole
   2. Dicrotic notch occurring when aortic semilunar valve closes
   3. Decrease in pressure during ventricular diastole
   4. Functions to conserve energy and keep blood moving
C. Where pulse can be felt
   1. Pulse points (Fig. 19-24)
      a. Radial artery
      b. Temporal artery
      c. Common carotid artery
      d. Facial artery
      e. Brachial artery
      f. Popliteal artery
      g. Posterior tibial artery
      h. Dorsalis pedis artery
   2. Pressure points
      a. Temporal artery
      b. Facial artery
      c. Common carotid artery
      d. Subclavian artery
      e. Brachial artery
      f. Femoral artery
D. Venous pulse
1. Detectable only in large veins near heart because of atria systole and diastole

XI. Cycle of Life: Cardiovascular Physiology (p. 621)
   A. Blood pressure higher with age
   B. Heart rate much more variable in children

XII. The Big Picture: Blood Flow and the Whole Body (p. 621)
   A. Important homeostatic mechanism
      1. Maintains constancy of internal fluids
      2. Maintains body temperature
      3. Maintains filtering requirement for kidney

XIII. Mechanisms of Disease: Disorders of Cardiovascular Physiology (p. 622)
   A. Hypertension (Fig. 19-25)
      1. Primary essential (idiopathic)—unknown cause
      2. Secondary—kidney disease, hormonal problems, pregnancy, etc.
      3. Risk factors
         a. Genetics
         b. Sex
         c. Race
         d. Age
         e. Stress
         f. Obesity
         g. High alcohol and caffeine intake
         h. Smoking
         i. Lack of exercise
   B. Heart failure
      1. Cardiomyopathy
      2. Congestive heart failure (CHF)
   C. Circulatory shock
      1. Cardiogenic shock
      2. Hypovolemic shock
      3. Neurogenic shock
      4. Anaphylactic shock
      5. Septic shock