CHAPTER 52: CIRCULATION

CHAPTER SYNOPSIS

Simple, small organisms transport nutrients and gases directly across the membrane of each cell. Other organisms are too large and complex for such exchange and need a circulatory system to transport nutrients, gases, and other materials to their cells and remove waste materials from those cells to disposal organs. In open systems there is no distinction between the circulating fluid and the body fluid. In a closed system the circulating fluid is restricted to tubular vessels throughout the animal. In vertebrates, oxygen diffuses into the blood in the gills or lungs, accumulates in the erythrocytes and is carried to all tissues. Waste carbon dioxide is collected at metabolizing tissues and transported back to the gills or lungs for release. Nutrients enter the circulation through the wall of the small intestine and are transported to the liver. The blood transports nutrients to the tissues while metabolic wastes are collected from them and carried to the kidneys for removal. Hormones are also transported through the circulatory system to various target tissues. Heat produced in body tissues is distributed through the bodies of homeothermic birds and mammals.

Blood is composed of various metabolites, waste, salts, ions, and proteins in solution in the plasma. Circulating cells include erythrocytes, granular and non-granular leukocytes, and platelets. Arteries carry blood away from the heart; veins carry it back. Capillaries lie between the two and are the location of exchange with individual cells since they have only a single thin layer if endothelial cells. The walls of all other blood vessels are composed of four layers, an innermost endothelium, a layer of elastic fibers, a layer of smooth muscle, and an outer layer of connective tissue. The muscle layer of arteries and arterioles is thicker than that in venules and veins. As a result the resistance and flow of blood in these vessels changes through vasoconstriction or vasodilation. The velocity of the blood in the capillaries is less than in the arteries due to differences in overall vessel area coupled with a constant flow rate. The lymphatic vessels constitute an open system to collect blood fluid lost to the tissues and return it to the closed circulation.

The vertebrate heart originated as a simple peristaltic pump in early chordates. Fish evolved the first true heart composed of four consecutive chambers that pumped blood from the heart to the gills to the body and back to the heart. The first separation of systemic and pulmonary circulation is seen in amphibians and reptiles. A complete two-cycle pump evolved independently in birds and mammals. The right side of the heart pumps deoxygenated blood to the lungs while the left side pumps oxygenated blood to the body tissues. The sinoatrial (SA) node, a remnant of the sinus venosus, is the heart's pacemaker. The wave of depolarization passes through cardiac cell gap junctions. There is a slight delay between atrial and ventricular contractions as the wave of depolarization cannot pass through the connective tissue between the chambers. The wave is conducted via the atrioventricular (AV) node and across both ventricles through the bundle of His and through Purkinje fibers. Cardiac performance is monitored by recording the wave of depolarization in an electrocardiogram. Cardiac output, the volume of blood pumped by each ventricle per minute increases greatly with exercise, the rate at which the heart fills and empties is increased and the ventricles contract more strongly and empty more completely.

Blood flow, pressure, and blood volume are regulated by several homeostatic systems. Baroreceptors are located in the walls of the aortic arch and carotid artery. Their rate of firing decreases when blood pressure falls, which increases sympathetic activity, decreases parasympathetic activity, and restores normal pressure and cardiac output. Blood volume is also regulated by three homeostatic endocrine systems. Antidiuretic hormone (ADH) secreted by the posterior pituitary reduces the amount of water lost in the urine, increasing blood volume. The renin-angiotensin-aldosterone system stimulates contraction of blood vessel smooth muscle (vasoconstriction) and increases body sodium, both which serve to increase blood volume and pressure. Atrial natriuretic hormone production increases when the atrium is stretched by high blood volume. This increases the excretion of sodium and water in the urine, lowering blood volume. Nitric oxide (NO) produced by blood vessel endothelial cells causes vessel muscles to relax, dilating the blood vessel. Nitroglycerine causes the release of NO gas.

CHAPTER OBJECTIVES

- ä Compare the anatomy and efficiency of open and closed circulatory systems.
- ä Understand the three primary functions of the vertebrate circulatory system.
- ä Identify and describe the function(s) of each of the cellular and non-cellular components of blood.
- ä Describe the anatomy of the major kinds of blood vessels.
- ä Explain the relationship between blood vessel diameter and flow resistance including the effects resistance has on the efficient operation of a closed circulatory system.
- ä Describe the vertebrate lymphatic system and indicate its importance.
- ä Understand the evolution of the vertebrate heart from primitive fish to amphibians and reptiles through birds and mammals in terms of structure and overall circulatory efficiency.
- ä Describe the structure of a human heart and the flow of blood through it.
- ä Explain how the mammalian heart contracts.
- ä Understand how the heart's performance is monitored.
- ä Explain how exercise affects cardiac output.
- ä Describe how blood flow, pressure, and volume are regulated.

KEY TERMS

albumin
angina pectoris
aorta
aortic valve
arteriole
arteriosclerosis
artery
atherosclerosis
atrioventricular (AV) valve
atrioventricular bundle
atrioventricular (AV) node
atrium
baroreceptor
basophil
bicuspid (mitral) valve
bundle of His
capillary
cardiac output
cardiac cycle
closed circulatory system
conus arteriosus
coronary artery
countercurrent heat exchange
cutaneous respiration
depolarization
diastole
electrocardiogram (ECG/EKG)
endotherm
eosinophil
erythrocyte (red blood cell)
fibrin
globulin
granular leukocyte
heart
hemolymph
inferior vena cava
interstitial fluid
leukocyte (white blood cell)
lymph
lymph heart
lymph vessels
lymphatic system
lymphocyte
monocyte
neutrophil
nongranular leukocyte
open circulatory system
pacemaker
plasma
platelet
precapillary sphincter
pulmonary artery
pulmonary circulation
pulmonary valve
pulmonary vein
Purkinje fibers
semilunar valve
serum
sinoatrial (SA) node
sinus venosus
stroke
superior vena cava
systemic circulation
systole
vasoconstriction
vasodilation
vein
venous valve
ventricle
venule

CHAPTER OUTLINE

52.0 Introduction

I. BLOOD AND BLOOD VESSELS COMPRISE THE CIRCULATORY SYSTEM fig 52.1

A. Blood Is Analogous to Trucks Carrying Food to Market

B. Blood Vessels Are Analogous to Highways

52.1 The circulatory systems of animals may be open or closed

I. OPEN AND CLOSED CIRCULATORY SYSTEMS

A. All Organisms Capture Nutrients and Gases from the Environment
1. Simple organisms transport materials across membrane of each cell fig 52.2a
    a. Examples: *Hydra* (cnidarian) and *Dugesia* (flatworm)
    b. Only 2 cell layers, in direct contact with outside or gastrovascular cavity
2. Interior of large organisms cannot communicate with environment
    a. Fluids within body cavity facilitate movement of materials
    b. Circulation: Transport of materials through an internal fluid

B. Types of Circulatory Systems
1. Open system: No distinction between circulating fluid and body fluid
    a. Mollusks and arthropods have open system fig 52.2b
    b. Fluid called hemolymph
    c. Muscular tube in body cavity pumps fluid through network of channels
    d. Fluid drains back into central cavity
2. Closed system: Blood enclosed within vessels
    a. Blood transported via actions of a pump, the heart
    b. Annelids have a closed system fig 52.2c
        1) Dorsal artery contracts rhythmically, functions as pump
        2) Five connecting arteries also function as pumps
        3) Ventral artery pumps blood posteriorly
        4) Blood eventually reenters dorsal artery
        5) Smaller vessels branch from arteries to supply all tissues

C. The Functions of Vertebrate Circulatory Systems
1. Blood vessels form tubular network
    a. Arteries: Direct blood away from heart
    b. Veins: Carry blood back to heart
    c. Capillaries: Transition from arteries to veins
2. Pressure of blood forces some blood plasma out of capillaries
    a. Interstitial fluid passes into surrounding tissues
    b. Some fluid returns directly to capillaries
    c. Some fluid enters lymph vessels in connective tissues around blood vessels
        1) Fluid called lymph
        2) Returned to venous blood at certain points
3. Transportation
    a. Respiratory
        1) Erythrocytes transport oxygen to tissue cells
        2) Oxygen diffuses into capillaries in lungs or gills
        3) Oxygen attaches to hemoglobin of red blood cells
        4) Transported to cells for aerobic respiration

        5) Carbon dioxide, a metabolic product, is released by cells into blood
        6) Carbon dioxide carried back to gills or lungs and released
    b. Nutritive
        1) Digestive system breaks down food
        2) Nutrients enter blood through wall of intestine
        3) Carried through liver and to all body cells
    c. Excretory
        1) Metabolic wastes, water, ions carried to kidney for removal
        2) Filtered through capillaries
        3) Excreted in urine
4. Regulation
    a. Hormone transport
        1) Body activities coordinated by hormones produced in endocrine glands
        2) Hormones transported to target tissues throughout body
    b. Temperature regulation
        1) Warm-blooded vertebrates are endotherms
        2) Maintain constant body temperature
        3) Heat distributed by circulating blood
        4) Temperature adjusted by directing flow to interior or extremities
            a) Decrease body temperature by dissipating heat to environment — fig 52.3
            b) Retain heat by directing blood from extremities to interior
        5) Some animals use countercurrent heat exchange system — fig 52.4
            a) Vessels lie adjacent to one another
            b) One carries warm blood from interior
            c) Other carries cold blood from body surface
            d) Warm blood heats cold blood, so it isn't cold when it reaches interior
5. Protection
    a. Blood clotting
        1) Protects against blood loss when vessels are damaged
        2) Involves proteins in plasma and platelets
    b. Immune defense
        1) Leukocytes, white blood cells, provide immunity against disease agents
        2) Are phagocytic, produce antibodies or have other actions

52.2 A network of vessels transports blood through the body

I. THE BLOOD PLASMA

A. Composition of Blood — fig 52.5
1. Fluid plasma
2. Several kinds of cells
    a. Platelets are not complete cells
    b. Are fragments of cells found in bone marrow
3. Blood plasma contains three primary solutes
    a. Metabolites, wastes, and hormones
        1) Dissolved within are glucose, amino acids, vitamins
        2) Also includes wastes, nitrogenous compounds, carbon dioxide (as bicarbonate)
        3) Also contains hormones that regulate cell activities
    b. Ions
        1) Plasma is a dilute salt solution
        2) Primarily sodium, chloride, and bicarbonate
        3) Trace amounts of calcium, magnesium, potassium, and metallic ions
        4) Similar to sea water with slightly lower total ion concentration

c. Proteins
   1) Liver produces most plasma proteins, including albumin
   2) Alpha and beta globulins are carriers of lipids and steroid hormones
   3) Fibrinogen associated with blood clotting
   4) Serum is blood fluid minus the fibrinogen

II. THE BLOOD CELLS

fig 52.5

A. Erythrocytes and Oxygen Transport
1. Each milliliter of blood contains 5 million erythrocytes or red blood cells
2. Hematocrit: Volume of blood composed of red blood cells, 45% of blood volume
3. Structure of a red cell
   a. Donut-shaped disk with a central depression (not hole)
   b. Contain hemoglobin, function in oxygen transport
   c. Plasma lacks hemoglobin
   d. Many invertebrates also have pigment in plasma
4. Cells produced in bone marrow during erythropoiesis
   a. Develop from unspecialized stem cells
   b. Occurs in response to decrease in plasma oxygen concentration
   c. Process stimulated by erythropoietin hormone
   d. Produced in kidneys from a plasma protein
5. Mammal red cells are non-nucleated, lost during maturation process
6. All other vertebrates have nucleated cells
7. Red cells removed by phagocytic cells of spleen, bone marrow, liver

B. Leukocytes Defend the Body
1. Less than 1% of total blood cells
2. Larger than red cells, possess nuclei
3. Circulate in blood, present also in interstitial fluid
4. Function to defend body against microbes and foreign substances
   a. Colorless, lack hemoglobin, difficult to see without staining
   b. Granular leukocytes include neutrophils, basophils, eosinophils
   c. Nongranular leukocytes include monocytes and lymphocytes
   d. Most → neutrophils, lymphocytes, monocytes, eosinophils, basophils → least

C. Platelets Help Blood to Clot
1. Platelets are cell fragments that pinch off from megakaryocytes
2. Play important role in blood clotting
   a. Ruptured vessel constricts due to contraction of smooth muscle in wall
   b. Platelets accumulate and form plug by sticking to tissues and each other
   c. Fibrin protein reinforces plug — fig 52.6
   d. Plug of platelets, fibrin, and trapped red cells constitutes a blood clot

III. CHARACTERISTICS OF BLOOD VESSELS

A. Kinds of Blood Vessels
1. Arteries: Direct blood away from heart
2. Arterioles: Large network of microscopic vessels of arterial tree
3. Capillaries: Fine network of thin-walled tubes
4. Venules: Small vessels that collect blood from capillaries
5. Veins: Large vessels carry blood back to heart

B. Anatomy of a Blood Vessel
  1. Similar structures found in arteries, arterioles, veins, and venules fig 52.7
  2. Walls are composed of four layers of tissue
     a. Innermost endothelium: Epithelial sheet of cells
     b. Thin layer of elastic fibers
     c. Layer of smooth muscle
     d. Encased in connective tissue
  3. Walls too thick to permit exchange of materials
  4. Exchange occurs in capillaries, have only endothelium
     a. Molecules and ions leave blood plasma by filtration
     b. Travel through pores in capillary walls
     c. Transported through endothelial cells
     d. Exchange gases and metabolites with cells of body

C. Arteries and Arterioles
  1. Elastic fibers allow large artery to expand and recoil when receiving blood from heart
  2. Smaller arteries and arterioles are less elastic, but have thicker smooth muscle
  3. Network of small vessels provides frictional resistance to flow fig 52.3
     a. Inversely proportional to radius of the tube to the fourth power
     b. Small diameter arteries and arterioles cause greatest resistance to blood flow
     c. Contraction of smooth muscle causes vasoconstriction
        1) Increases resistance
        2) Decreases flow
     d. Relaxation of smooth muscle causes vasodilation
        1) Decreases resistance
        2) Increases flow
     e. Blood around some organs regulated by precapillary sphincters fig 52.8
        1) Rings of smooth muscle around arterioles where they empty into capillaries
        2) Close off specific capillary beds to all blood flow
        3) Close beds in skin to limit heat loss in cold environments

D. Exchange in the Capillaries
  1. Heart provides sufficient pressure to pump against resistance of arterial tree and into capillaries
  2. Every cell within 100 μm of a capillary
  3. Average capillary 1 mm long, 8 μm wide, just larger than red blood cell
  4. Capillaries have greatest cross-sectional area of all types of vessels
     a. Blood velocity decreases in capillary beds
     b. Provides greater time for exchange of materials with extracellular fluid
     c. Blood releases oxygen and nutrients, picks up carbon dioxide and wastes
     d. Blood pressure greatly reduced when blood enters veins

E. Venules and Veins
  1. Blood flows from venules to larger vessels to heart
  2. Veins and venules have thinner layer of smooth muscle than arteries
  3. Pressure one-tenth that of arteries
     a. Most blood in body held in veins
     b. Can expand to hold greater quantities
  4. Venous pressure not sufficient to return blood to heart from feet and legs
     a. Aided by contraction of skeletal muscles
     b. One-way venous valves direct flow toward heart fig 52.9
     c. Varicose veins produced when valves don't work, blood pools in veins

IV. THE LYMPHATIC SYSTEM

A. The Lymphatic System Recovers Lost Fluid
1. Circulatory system open to diffusion through capillary walls
   a. Filtration driven by pressure of blood, supplies cells with oxygen and nutrients
   b. Most fluid returned by osmosis due to concentration of protein in blood
   c. Difference in protein concentration called osmotic pressure — fig 52.10
2. High capillary blood pressure causes production of too much interstitial fluid
   a. Commonly occurs in pregnant women
      1) Fetus compresses veins, increases blood pressure in mother's lower limbs
      2) Causes swelling, edema, in tissues of feet
   b. Edema also results when plasma protein concentration is too low
      1) May be caused by liver disease, liver produces most plasma protein
      2) May be caused by protein malnutrition
3. Open lymphatic system collects rest of fluid and returns it to blood
   a. Composed of lymphatic capillaries, lymphatic vessels, lymph nodes and lymphatic organs like spleen and thymus
   b. Fluid in tissues drains into blind-ended lymph capillaries
   c. Lymph passes into progressively larger vessels
   d. Lymphatic vessels are vein-like and contain one-way valves — fig 52.11
   e. Major lymphatic ducts drain into veins on sides of neck
4. Lymph fluid movement assisted by movement of muscles
   a. Some lymph vessels contract rhythmically
   b. Many fish, all amphibians and reptiles, some birds have lymph hearts
5. Lymph modified by phagocytic cells in nodes and lymphatic organs
   a. Contain germinal centers for production of lymphocytes
   b. Important role in immune system

52.3 The vertebrate heart has undergone progressive evolutionary change

I. THE FISH HEART

A. The Early Chordates Had Simple Tubular Hearts
1. Peristaltic contractions of muscular wall of ventral artery
2. Pumps in direction of wave
   a. Uncontracted portion of vessel has larger diameter
   b. Provides less resistance to blood flow

B. Fish Developed a True Chamber-Pump Heart
1. Development of gills required more efficient pump
2. Four consecutive chambers — fig 52.12a
   a. Two collection chambers: Sinus venosus and atrium
   b. Two pumping chambers: Ventricle and conus arteriosus
3. Heartbeat sequence: Sinus venosus, atrium, ventricle, conus arteriosus
   a. Pattern maintained in all vertebrates
   b. Impulse initiated in sinus venosus (or its equivalent)
4. Blood delivered to body tissues is fully oxygenated
5. Flow: Heart gills tissues heart — fig 52.12b
6. Circulation to body is sluggish due to resistance in gill capillaries

II. AMPHIBIAN AND REPTILE CIRCULATION

A. Amphibian and Reptile Hearts Reflect the Evolution of Pulmonary Circulation

1. Blood pumped from heart to pulmonary arteries to lungs
   a. Blood does not go directly to body tissues
   b. Returns to heart via pulmonary veins
2. Creation of two circulations
   a. Pulmonary circulation: Heart to lungs and back to heart
   b. Systemic circulation: Heart to body and back
   c. Without this structural change, oxygenated blood mixed with deoxygenated blood
3. Structure of the amphibian heart reduces mixing — fig 52.13
   a. Atrium divided into right and left chambers
      1) Right atrium gets deoxygenated blood from systemic circulation
      2) Left atrium gets oxygenated blood from lungs
   b. Conus arteriosus partially separated by a septum
   c. Imperfect separation of blood flow into pulmonary and systemic circulations
   d. Deficiency partly compensated for by cutaneous respiration
4. Structure of the reptile heart reduces mixing even better
   a. Have two separate atria
   b. Ventricle partially divided by a septum
   c. Greater separation of oxygenated/deoxygenated blood, greater efficiency
   d. Complete separation into two ventricles in crocodiles
   e. Conus arteriosus incorporated into arteries leaving heart

III. MAMMALIAN AND BIRD HEARTS

A. Mammals and Birds Have Four-Chambered Hearts

1. Two separate atria, two separate ventricles — fig 52.14
2. Advent of a double circulatory system
   a. Right atrium gets deoxygenated blood from body
   b. Delivers it to right ventricle, pumped to lungs
   c. Left atrium gets oxygenated blood from lungs
   d. Delivers it to left ventricle, pumped to body
3. Produces a two-cycle pump
   a. Both atria fill and contract simultaneously
   b. Ventricles contract at same time
4. Evolution of double pump related to development of endothermy
   a. Requires more efficient circulation
   b. Needed to support high metabolic rate
5. Same volume of blood moves through each circuit
   a. Left ventricle pumps blood through higher resistance pathway than right
   b. Left ventricle is more muscular and generates more pressure than right one

B. The Pacemaker Is a Remnant of the Sinus Venosus

1. Sinus venosus served as collection chamber and pacemaker in early vertebrates
2. Remaining tissue is site of origin of the heartbeat in mammals and birds
   a. Located in wall of right atrium
   b. Called sinoatrial node (SA node)

52.4 The cardiac cycle drives the cardiovascular system

I. THE CARDIAC CYCLE

A. Double Pump System Operates within a Single Organ
1. Right side sends blood to lungs
2. Left side sends blood to rest of body

B. Circulation through the Heart
1. Heart has two pairs of valves
   a. Atrioventricular (AV) valves lie between atria and ventricles
      1) AV valve on right side is called the tricuspid valve
      2) AV valve on left side is the bicuspid or mitral valve
   b. Semilunar valves lie between ventricles and main arteries
      1) Pulmonary valve is at exit of right ventricle
      2) Aortic valve is at exit of left ventricle
2. Cardiac cycle: Complete journey of blood through body and heart
   a. Diastole is rest cycle
   b. Systole is contraction cycle
   c. Lub-dub heart sounds produced by closing of valves
3. Blood returns to resting heart, into left and right atria
   a. Atria fill, increase pressure, AV valves open
   b. Blood flows from atrium to opening in left ventricle
   c. Ventricle about 80% full
   d. Contraction of right atrium produces final 20% of blood volume to ventricle
   e. Occurs while ventricles are relaxing, period called ventricular diastole
4. Ventricles contract, called ventricular systole
   a. Blood forced out of ventricles
   b. AV valves close forcefully (“lub”), prevents backflow into atria
   c. Ventricular pressure forces semilunar valves open
   d. Blood flows through arterial system
   e. Ventricles relax, semilunar valves close (“dub”)
5. Pulmonary arteries deliver oxygen-depleted blood to lungs
   a. Return blood via pulmonary veins
   b. Blood collects in left atrium
6. Systemic arteries include aorta and its branches — fig 52.15
   a. Carry oxygen-rich blood from left ventricle to body
   b. Coronary arteries branch off aorta first, supply heart muscle with blood
   c. Systemic arteries branch from aorta to all body organs
   d. Blood returns to heart via systemic veins, has less oxygen
7. Systemic veins empty into two major veins
   a. Superior vena cava drains upper body
   b. Inferior vena cava drains lower body
   c. Vena cava empty into right atrium

C. Measuring Arterial Blood Pressure
1. Pressure generated in body arteries as ventricles contract
   a. Felt as pulse at wrist, neck
   b. Strong enough to push blood through capillaries, but not damage arterioles
2. Measure blood pressure to determine how hard heart works
   a. Sphygmomanometer measures pressure at brachial artery — fig 52.15
      1) Cuff tightened to stop flow of blood into lower arm
      2) As cuff loosened, blood begins to pulse through artery
      3) Detected with stethoscope

- b. Two measurements recorded
  - 1) Systolic pressure is peak pressure during ventricular contraction
  - 2) Diastolic pressure is minimum pressure between heartbeats
  - 3) Written as diastolic/systolic, typical 120/75 mm Hg
- c. Hypertension is high blood pressure
  - 1) Ventricles contract very strongly
  - 2) Systolic pressure above 150
  - 3) Diastolic pressure above 90

II. ELECTRICAL EXCITATION AND CONTRACTION OF THE HEART

A. How the Heart Is Stimulated to Contract — fig 52.16

1. Caused by membrane depolarization, reversal of electrical polarity
2. Contraction triggered by sinoatrial (SA) node, not nervous system
   - a. Derived from sinus venosus
   - b. SA node is pacemaker
   - c. Membrane of cells depolarize spontaneously with regular rhythm
3. Depolarization passes from one cardiac muscle cell to another
4. Spreads because cardiac cells are electrically coupled by gap junctions
5. Ventricular wave of depolarization delayed by nearly 0.1 second
   - a. Atria and ventricles separated by connective tissue
   - b. Connective tissue cannot propagate depolarization
   - c. Wave passes via atrioventricular (AV) node
   - d. Delay permits atria to completely empty before ventricles contract
6. Depolarization conducted over both ventricles at same time
   - a. Carried over network of fibers called atrioventricular bundle
   - b. Also called bundle of His
7. Transmitted by Purkinje fibers that stimulate ventricle myocardial cells
8. Right and left ventricles contract almost simultaneously
9. Rate can be increased or decreased
   - a. Caused by neural regulation
   - b. Increased by hormone epinephrine

B. Monitoring the Heart's Performance

1. Depolarization in heart generates electrical signals that spread throughout body
2. Monitor electrocardiogram (ECG/EKG) that records waves of depolarization
   - a. Depolarization causes contraction of heart
   - b. Repolarization causes relaxation
3. Meaning of ECG tracing
   - a. First peak (P): Depolarization associated with atrial contraction, atrial systole
   - b. Second peak (QRS): Depolarization of ventricles, ventricular systole
   - c. Last peak (T): Ventricular repolarization, ventricles begin diastole

III. BLOOD FLOW AND BLOOD PRESSURE

A. Cardiac Output

1. Output is the volume pumped by each ventricle per minute
2. Calculated by: Rate of heart beat x stroke volume (volume of blood ejected)
3. Cardiac output is increased with exercise
   - a. Heart rate and stroke volume increase
   - b. Skeletal muscles squeeze on veins, returning blood to heart more rapidly
   - c. Increases rate at which heart fills and ejects blood
   - d. Ventricles contract more strongly, empty more completely

4. Cardiac output may increase fivefold
    a. Not all organs receive same increase in blood flow
    b. Arterioles in some organs constrict, those to other organs dilate
        1) Decrease flow to digestive system
        2) Increases blood flow to heart and skeletal muscles

B. Blood Pressure and the Baroreceptor Reflex
1. Arterial blood pressure depends on two factors
    a. Cardiac output, how much blood ventricles pump
    b. Resistance to flow
2. Increased blood pressure caused by
    a. Increased heart rate or blood volume (both increase cardiac output)
    b. Vasoconstriction (increases resistance to flow)
3. Blood pressure will fall if
    a. Heart rate slows
    b. Blood volume reduced, by dehydration or hemorrhage
4. Baroreceptors respond to changes in systemic arterial blood pressure
    a. Located in walls of aortic arch and carotic arteries
    b. Connected to cardiovascular control center in medulla
5. When baroreceptors detect decrease in blood pressure
    a. Stimulate neurons to blood vessels in skin and viscera to constrict
    b. Raises blood pressure
    c. Negative feedback loop that restores normal pressure and cardiac output

C. Blood Volume Reflexes
1. Blood pressure depends partly on blood volume
2. Lower blood volume means lower blood pressure
3. Volume regulation via three hormones
    a. Antidiuretic hormone (ADH)
    b. Aldosterone system
    c. Atrial natriuretic hormone
4. Antidiuretic hormone (ADH) system (also called vasopressin)
    a. Secreted by posterior pituitary with increased osmotic concentration of blood
    b. Example: Dehydration decreases volume, increases plasma concentration
    c. Stimulates osmoreceptors in brain hypothalamus
    d. Promote thirst and stimulate ADH secretion
    e. ADH stimulates kidneys to reduce amount of water lost in urine
    f. Individual drinks more and urinates less, increasing blood volume
5. Aldosterone
    a. When blood flow through kidney is decreased, cells secrete angiotensin II
    b. Angiotensin II has two effects
        1) Promotes vasoconstriction (raises blood pressure)
        2) Stimulates production of aldosterone by adrenal cortex
    c. Aldosterone increases total body Na^+, reduces water loss
    d. Animal without aldosterone dies, blood volume lost in urine
6. Atrial natriuretic hormone
    a. Body responds to need to excrete Na^+ and lower blood volume
    b. Inhibits aldosterone secretion
    c. Also secretes atrial natriuretic hormone
        1) Secreted by endocrine cells in atrial walls
        2) Occurs when atrium is stretched by high blood volume
    d. More Na^+ excreted in urine, water follows, blood volume and pressure lowered

7. Nitric Oxide (NO)
   a. Gas that acts as hormone in vertebrates
   b. Regulates blood pressure and blood flow
      1) Paracrine hormone is produced in one cell, alters activities of neighbor cells
      2) NO produced by blood vessel surface endothelial cells
      3) Passes inward through vessel cell layers
      4) Causes vessel muscles to relax, vessel dilates
   c. Nitroglycerine causes release of NO gas

D. Cardiovascular Diseases
1. Leading cause of death in U.S.
2. Heart attack
   a. Accounts for 1/5 of all deaths
   b. Insufficient supply of blood reaches heart muscle, myocardial cells die
      1) May be caused by blood clot in coronary artery
      2) May occur if coronary artery blocked by atherosclerosis
   c. Recovery possible if small portion damaged
      1) Other coronary vessels enlarge capacity
      2) Resupply damaged tissue
   d. Angina pectoris (chest pain)
      1) Similar to heart attack, but not as severe
      2) Pain in heart, left shoulder, and arm
      3) Warning sign of inadequate blood supply to heart, no myocardial death
3. Stroke
   a. Interference with blood supply to brain
      1) Blood vessel may burst
      2) Blood flow blocked by clot (thrombus) or atherosclerosis
   b. Effects dependent on severity and location of damage
4. Atherosclerosis fig 52.17
   a. Blockage of arteries
      1) Deposits of fatty materials, cholesterol, fibrin, cellular debris
      2) Also caused by abnormal amount of smooth muscle
   b. Causes reduction in blood flow, may completely block artery
   c. Promoted by several factors
      1) Genetics, smoking, high blood pressure
      2) Also high blood cholesterol
   d. Reduce risk factor
      1) Lower cholesterol and saturated fat in diet
      2) Therapy for hypertension
      3) Quit smoking
5. Arteriosclerosis
   a. Hardening of arteries when calcium is deposited in walls
      1) Occurs when atherosclerosis is severe
      2) Blood flow restricted in arteries
   b. Arteries also lack ability to expand when volume of blood is pumped from heart
   c. Heart must work harder to accommodate inflexibility

INSTRUCTIONAL STRATEGY

PRESENTATION ASSISTANCE:

Compare the countercurrent analogy with a heat pump. If very cold air meets very warm air a lot of exchange will occur, but only over a short distance.

Most students are relatively familiar with the circulatory system and shouldn't have much difficulty with this chapter. The most confusing thing is which ventricle pumps blood to the lungs (the right side) and which pumps to the rest of the body (the left side). Since the left ventricle pumps blood through the systemic circulation, it is the largest chamber of the mammalian heart.

Stress that circulation is not directional with respect to individual organs, with the exception of circulation to the lungs and from the small intestine to the liver. Blood flows throughout the body reaching every cell in its own good time, like riding a circular subway system. You can't get from point a to point c without going through point b. Once you've passed b, you have to go around the entire circuit again to get back to it.

Stress why a two-cycle pump is more effective for terrestrial circulation than a one-cycle pump.

VISUAL RESOURCES:

Obtain a fresh heart from a butcher or a slaughter house to demonstrate the various anatomical structures. The bigger the better so try for a cow or an ox. As last resort, purchase a preserved heart from a biological supply company.

Construct a transparent circulatory system with plastic chambers and tygon tubing. Alternately, purchase and assemble one of the many kits available. Most kits, though, rely on only a single pump to push the "blood" through both systemic and pulmonary circulations.