Welcome to

University of Buea
HSC 205
Physiology by Dr. Salah A. Martin
Faculty of Health Sciences
Health Science Courses

Blood Vessels

- Blood is carried in a closed system of vessels that begins and ends at the heart
- The three major types of vessels are arteries, capillaries, and veins
  - Arteries carry blood away from the heart, veins carry blood toward the heart
  - Capillaries contact tissue cells and directly serve cellular needs

Continuous Capillary Structure

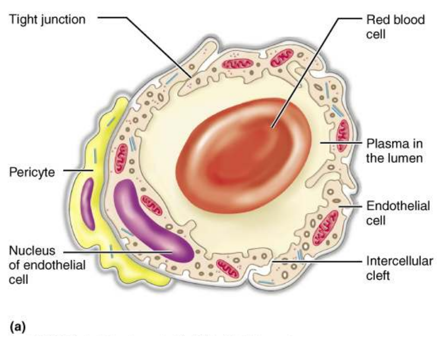


Figure 18.3a

Fenestrated Capillary Structure

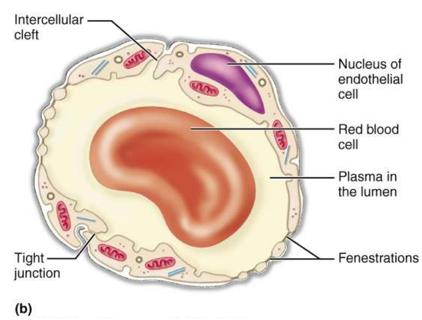


Figure 18.3b

Discontinuous Sinusoidal Capillary Structure

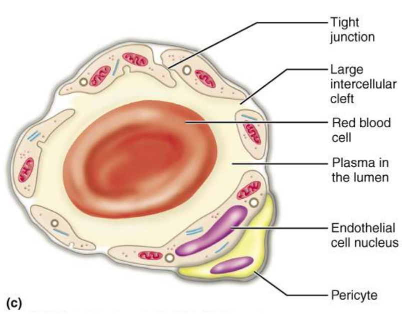


Figure 18.3c

Generalized Structure of Blood Vessels

- Arteries and veins are composed of three tunics – tunica interna, tunica media, and tunica externa
- Capillaries are composed of endothelium with sparse basal lamina
- Lumen – central blood-containing space surrounded by tunics

Generalized Structure of Blood Vessels

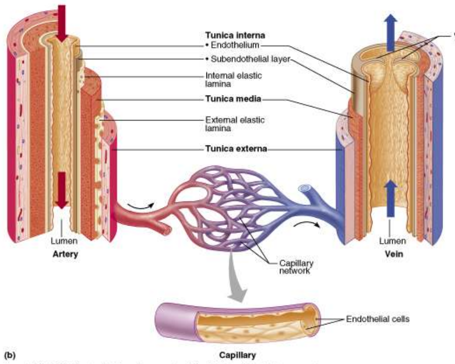


Figure 18.1b

Tunics

- Tunica interna (tunica intima)
  - Endothelial layer that lines the lumen of all vessels
  - In vessels larger than 1 mm, a subendothelial connective tissue basement membrane is present
- Tunica media
  - Smooth muscle and elastic fiber layer, regulated by the sympathetic nervous system
  - Controls vasoconstriction/vasodilation of vessels
- Tunica externa (tunica adventitia)
  - Collagen fibers that protect and reinforce vessels
  - Larger vessels contain vasa vasorum

Elastic (Conducting) Arteries

- Thick-walled arteries near the heart; the aorta and its major branches
  - Large lumen allow low-resistance conduction of blood
  - Contain elastin in all three tunics
  - Withstand and smooth out large blood pressure fluctuations
  - Allow blood to flow fairly continuously through the body

Muscular Arteries and Arterioles

- Muscular arteries – distal to elastic arteries; deliver blood to body organs
  - Have thick tunica media with more smooth muscle and less elastic tissue
  - Active in vasoconstriction
- Arterioles – smallest arteries; lead to capillary beds
  - Control flow into capillary beds via vasodilation and constriction

Capillaries

- Capillaries are the smallest blood vessels
  - Walls consisting of a thin tunica interna, one cell thick
  - Allow only a single RBC to pass at a time
  - Pericytes on the outer surface stabilize their walls
- There are three structural types of capillaries: continuous, fenestrated, and sinusoids

Continuous Capillaries

- Continuous capillaries are abundant in the skin and muscles, and have:
  - Endothelial cells that provide an uninterrupted lining
  - Adjacent cells that are held together with tight junctions
  - Intercellular clefts of unjoined membranes that allow the passage of fluids
- Continuous capillaries of the brain:
  - Have tight junctions completely around the endothelium
  - Constitute the blood-brain barrier

Continuous Capillaries

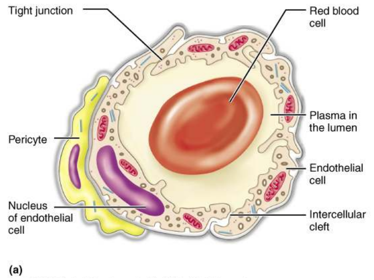


Figure 18.3a

Fenestrated Capillaries

- Found wherever active capillary absorption or filtrate formation occurs (e.g., small intestines, endocrine glands, and kidneys)
- Characterized by:
  - An endothelium riddled with pores (fenestrations)
  - Greater permeability to solutes and fluids than other capillaries

Fenestrated Capillaries

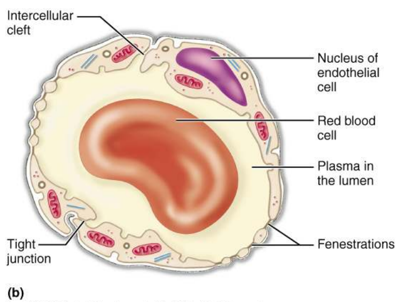


Figure 18.3b

Sinusoids

- Highly modified, leaky, fenestrated capillaries with large lumens
- Found in the liver, bone marrow, lymphoid tissue, and in some endocrine organs
- Allow large molecules (proteins and blood cells) to pass between the blood and surrounding tissues
- Blood flows sluggishly, allowing for modification in various ways

Sinusoids

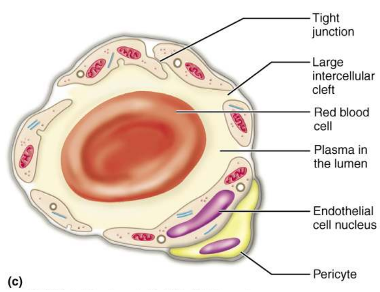
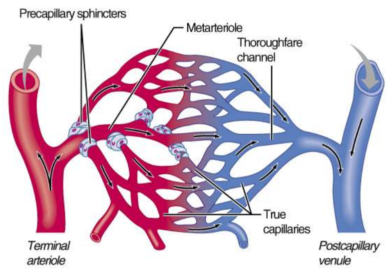


Figure 18.3c

Capillary Beds

- A microcirculation of interwoven networks of capillaries, consisting of:
  - Vascular shunts – metarteriole–thoroughfare channel connecting an arteriole directly with a postcapillary venule
  - True capillaries – 10 to 100 per capillary bed, capillaries branch off the metarteriole and return to the thoroughfare channel at the distal end of the bed

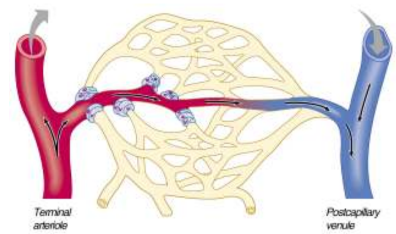
Capillary Beds



(a) Sphincters open

Figure 18.4a

Capillary Beds



(b) Sphincters closed

Figure 18.4b

Blood Flow Through Capillary Beds

- Precapillary sphincter
  - Cuff of smooth muscle that surrounds each true capillary
  - Regulates blood flow into the capillary
- Blood flow is regulated by vasomotor nerves and local chemical conditions, so it can either bypass or flood the capillary bed

Venous System: Venules

- Are formed when capillary beds unite
  - Allow fluids and WBCs to pass from the bloodstream to tissues
- Postcapillary venules – smallest venules, composed of endothelium and a few pericytes
- Large venules have one or two layers of smooth muscle (tunica media)

Venous System: Veins

- Veins are:
  - Formed when venules converge
  - Composed of three tunics, with a thin tunica media and a thick tunica externa consisting of collagen fibers and elastic networks
  - Capacitance vessels (blood reservoirs) that contain 65% of the blood supply

Venous System: Veins

- Veins have much lower blood pressure and thinner walls than arteries
- To return blood to the heart, veins have special adaptations
  - Large-diameter lumens, which offer little resistance to flow
  - Valves (resembling semilunar heart valves), which prevent backflow of blood
- Venous sinuses – specialized, flattened veins with extremely thin walls (e.g., coronary sinus of the heart and dural sinuses of the brain)

Vascular Anastomoses

- Merging blood vessels, more common in veins than arteries
- Arterial anastomoses provide alternate pathways (collateral channels) for blood to reach a given body region
  - If one branch is blocked, the collateral channel can supply the area with adequate blood supply
- Thoroughfare channels are examples of arteriovenous anastomoses

Blood Flow

- Actual volume of blood flowing through a vessel, an organ, or the entire circulation in a given period is:
  - Measured in ml per min
  - Equivalent to cardiac output (CO), considering the entire vascular system
  - Relatively constant when at rest
  - Varies widely through individual organs, according to immediate needs

Blood Pressure (BP)

- Force per unit area exerted on the wall of a blood vessel by its contained blood
  - Expressed in terms of millimeters of mercury (mm Hg)
  - Measured in reference to systemic arterial BP in large arteries near the heart
- The differences in BP within the vascular system provide the driving force that keeps blood moving from higher to lower pressure areas

Resistance

- Resistance – opposition to flow
  - Measure of the amount of friction blood encounters as it passes through vessels
  - Generally encountered in the systemic circulation
  - Referred to as peripheral resistance (PR)
- The three important sources of resistance are blood viscosity, total blood vessel length, and blood vessel diameter

Resistance Factors: Viscosity and Vessel Length

- Resistance factors that remain relatively constant are:
  - Blood viscosity – thickness or "stickiness" of the blood
  - Blood vessel length – the longer the vessel, the greater the resistance encountered

Resistance Factors: Blood Vessel Diameter

- Changes in vessel diameter are frequent and significantly alter peripheral resistance
- Resistance varies inversely with the fourth power of vessel radius (one-half the diameter)
  - For example, if the radius is doubled, the resistance is 1/16 as much
- Small-diameter arterioles are the major determinants of peripheral resistance
- Fatty plaques from atherosclerosis:
  - Cause turbulent blood flow
  - Dramatically increase resistance due to turbulence

Blood Flow, Blood Pressure, and Resistance

- Blood flow (F) is directly proportional to the difference in blood pressure (ΔP) between two points in the circulation
  - If ΔP increases, blood flow speeds up; if ΔP decreases, blood flow declines
- Blood flow is inversely proportional to resistance (R)
  - If R increases, blood flow decreases
- R is more important than ΔP in influencing local blood pressure

Systemic Blood Pressure

- The pumping action of the heart generates blood flow through the vessels along a pressure gradient, always moving from higher- to lower-pressure areas
- Pressure results when flow is opposed by resistance
- Systemic pressure:
  - Is highest in the aorta
  - Declines throughout the length of the pathway
  - Is 0 mm Hg in the right atrium
- The steepest change in blood pressure occurs in the arterioles

Systemic Blood Pressure

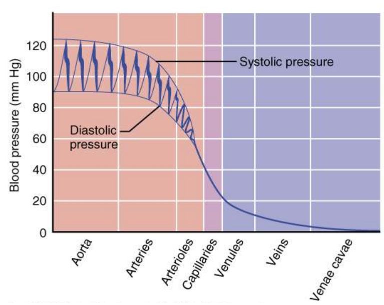


Figure 19.5

Arterial Blood Pressure

- Arterial BP reflects two factors of the arteries close to the heart
  - Their elasticity (compliance, or distensibility)
  - The amount of blood forced into them at any given time
- Blood pressure in elastic arteries near the heart is pulsatile (BP rises and falls)

Arterial Blood Pressure

- Systolic pressure – pressure exerted on arterial walls during ventricular contraction
- Diastolic pressure – lowest level of arterial pressure during a ventricular cycle
- Pulse pressure – the difference between systolic and diastolic pressure
- Mean arterial pressure (MAP) – pressure that propels the blood to the tissues
- MAP = diastolic pressure + 1/3 pulse pressure

Capillary Blood Pressure

- Capillary BP ranges from 20 to 40 mm Hg
- Low capillary pressure is desirable because high BP would rupture fragile, thin-walled capillaries
- Low BP is sufficient to force filtrate out into interstitial space and distribute nutrients, gases, and hormones between blood and tissues

Venous Blood Pressure

- Venous BP is steady and changes little during the cardiac cycle
- The pressure gradient in the venous system is only about 20 mm Hg
- A cut vein has even blood flow; a lacerated artery flows in spurts

Factors Aiding Venous Return

- Venous BP alone is too low to promote adequate blood return and is aided by the:
  - Respiratory pump – pressure changes created during breathing suck blood toward the heart by squeezing local veins
  - Muscular pump – contraction of skeletal muscles “milk” blood toward the heart
- Valves prevent backflow during venous return

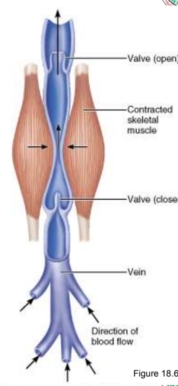


Figure 18.6

Blood Pressure

- Maintaining blood pressure requires:
  - Cooperation of the heart, blood vessels, and kidneys
  - Supervision of the brain
- The main factors influencing blood pressure are:
  - Cardiac output (CO)
  - Peripheral resistance (PR)
  - Blood volume
- Blood pressure = CO x PR
- Blood pressure varies directly with CO, PR, and blood volume

Cardiac Output (CO)

- Cardiac output is determined by venous return and neural and hormonal controls

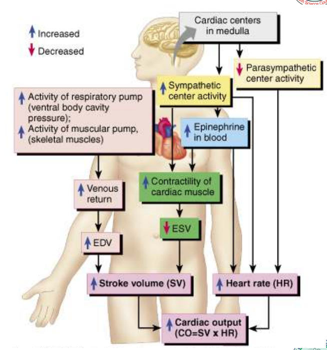


Figure 18

Cardiac Output (CO)

- Resting heart rate is controlled by the cardioinhibitory center via the vagus nerves
  - Stroke volume is controlled by venous return (end diastolic volume, or EDV)

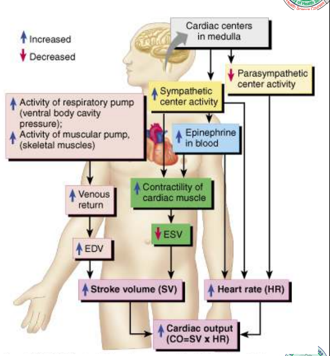


Figure 18

Cardiac Output (CO)

- Under stress, the cardioacceleratory center increases heart rate and stroke volume
  - The end systolic volume (ESV) decreases and MAP increases

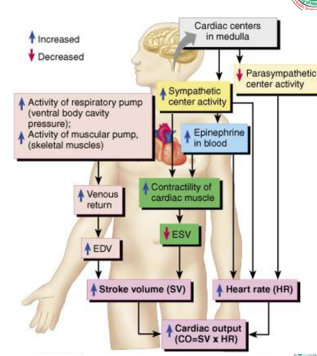


Figure 18

Controls of Blood Pressure

- Short-term controls:
  - Are mediated by the nervous system and bloodborne chemicals
  - Counteract moment-to-moment fluctuations in blood pressure by altering peripheral resistance
- Long-term controls regulate blood volume

Short-Term Mechanisms: Neural Controls

- Neural controls of peripheral resistance:
  - Alter blood distribution to respond to specific demands
  - Maintain MAP by altering blood vessel diameter
- Neural controls operate via reflex arcs, involving:
  - Baroreceptors
  - Vasomotor centers of the medulla and vasomotor fibers
  - Vascular smooth muscle

Short-Term Mechanisms: Vasomotor Center

- Vasomotor center – a cluster of sympathetic neurons in the medulla that oversees changes in blood vessel diameter
  - Maintains blood vessel tone by innervating smooth muscles of blood vessels, especially arterioles
- Cardiovascular center – vasomotor center plus the cardiac centers that integrate blood pressure control by altering cardiac output and blood vessel diameter

Short-Term Mechanisms: Vasomotor Activity

- Sympathetic activity causes:
  - Vasoconstriction and a rise in blood pressure if increased
  - Blood pressure to decline to basal levels if decreased
- Vasomotor activity is modified by:
  - Baroreceptors (pressure-sensitive), chemoreceptors (O_2, CO_2, and H^+ sensitive), higher brain centers, bloodborne chemicals, and hormones

Short-Term Mechanisms: Baroreceptor-Initiated Reflex

- Increased blood pressure stimulates the cardioinhibitory center to:
  - Increase vessel diameter
  - Decrease heart rate, cardiac output, peripheral resistance, and blood pressure
- Declining blood pressure stimulates the cardioacceleratory center to:
  - Increase cardiac output and peripheral resistance
- Low blood pressure also stimulates the vasomotor center to constrict blood vessels

Short-Term Mechanisms: Baroreceptor-Initiated Reflex

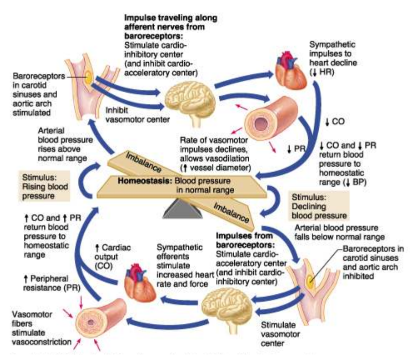


Figure 18.8

Short-Term Mechanisms: Chemical Controls

- Blood pressure is regulated by chemoreceptor reflexes sensitive to oxygen and carbon dioxide
  - Prominent chemoreceptors are the carotid and aortic bodies
  - Reflexes that regulate blood pressure are integrated in the medulla
  - Higher brain centers (cortex and hypothalamus) can modify BP via relays to medullary centers

Chemicals that Increase Blood Pressure

- Adrenal medulla hormones – norepinephrine and epinephrine increase blood pressure
- Antidiuretic hormone (ADH) – causes intense vasoconstriction in cases of extremely low BP
- Angiotensin II – causes intense vasoconstriction when renal profusion is inadequate
- Endothelium-derived factors – endothelin and prostaglandin-derived growth factor (PDGF) are both vasoconstrictors

Chemicals that Decrease Blood Pressure

- Atrial natriuretic peptide (ANP) – causes blood volume and pressure to decline
- Nitric oxide (NO) – has brief but potent vasodilator effects
- Inflammatory chemicals – histamine, prostacyclin, and kinins are potent vasodilators
- Alcohol – causes BP to drop by inhibiting ADH

Long-Term Mechanisms: Renal Regulation

- Baroreceptors adapt to chronic high or low blood pressure
- Kidneys maintain long-term BP by regulating blood volume
  - Increased BP stimulates the kidneys to eliminate water, thus reducing BP
  - Decreased BP stimulates the kidneys to increase blood volume and BP

Kidney Action and Blood Pressure

- Kidneys act directly and indirectly to maintain long-term blood pressure
  - Direct renal mechanism alters blood volume
  - Indirect renal mechanism involves the renin-angiotensin mechanism
    - Declining BP causes the release of renin, which triggers the release of angiotensin II
    - Angiotensin II is a potent vasoconstrictor that stimulates aldosterone secretion
    - Aldosterone enhances renal reabsorption and stimulates ADH release

Kidney Action and Blood Pressure

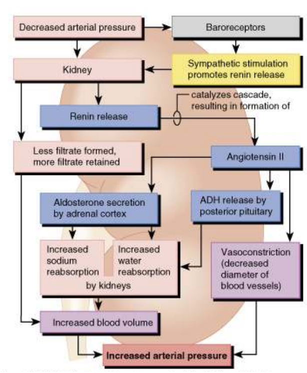


Figure 18.9

Monitoring Circulatory Efficiency

- Efficiency of the circulation can be assessed by taking pulse and blood pressure measurements
- Vital signs – pulse and blood pressure, along with respiratory rate and body temperature
- Pulse – pressure wave caused by the expansion and recoil of elastic arteries
  - Radial pulse (taken on the radial artery at the wrist) is routinely used
  - Varies with health, body position, and activity

Measuring Blood Pressure

- Systemic arterial BP is measured indirectly with the auscultatory method
  - A sphygmomanometer is placed on the arm superior to the elbow
  - Pressure is increased in the cuff until it is greater than systolic pressure in the brachial artery
  - Pressure is released slowly and the examiner listens with a stethoscope
  - The first sounds heard is recorded as the systolic pressure
  - The pressure when sound disappears is recorded as the diastolic pressure

Alterations in Blood Pressure

- Hypotension – low BP in which systolic pressure is below 100 mm Hg
- Hypertension – condition of sustained elevated arterial pressure of 140/90 or higher
  - Transient elevations are normal and can be caused by fever, physical exertion, and emotional upset
  - Chronic elevation is a major cause of heart failure, vascular disease, renal failure, and stroke

Hypotension

- Orthostatic hypotension – temporary low BP and dizziness when suddenly rising from a sitting or reclining position
- Chronic hypotension – hint of poor nutrition and warning sign for Addison's disease
- Acute hypotension – important sign of circulatory shock
  - Threat to patients undergoing surgery and those in intensive care units

Hypertension

- Hypertension – sustained BP of 140/90 or higher:
  - Is the major cause of heart failure, vascular disease, renal failure, and stroke
  - Weakens the heart and ravages the blood vessels
  - Causes tears in vessel endothelium that accelerate atherosclerosis
- Elevated diastolic pressure is more significant than systolic
  - It indicates progressive occlusion and/or hardening of the arterial tree

Hypertension

- Primary or essential hypertension – risk factors in primary hypertension include diet, obesity, age, race, heredity, stress, and smoking
- Secondary hypertension – due to identifiable disorders, including excessive renin secretion, arteriosclerosis, and endocrine disorders

Blood Flow through Tissues

- Blood flow, or tissue perfusion, is involved in:
  - Delivery of oxygen and nutrients to, and removal of wastes from, tissue cells
  - Gas exchange in the lungs
  - Absorption of nutrients from the digestive tract
  - Urine formation by the kidneys
- Blood flow is precisely the right amount to provide proper tissue function

Velocity of Blood Flow

- Blood velocity:
  - Changes as it travels through the systemic circulation
  - Is inversely proportional to the cross-sectional area
- Slow capillary flow allows adequate time for exchange between blood and tissues

Velocity of Blood flow

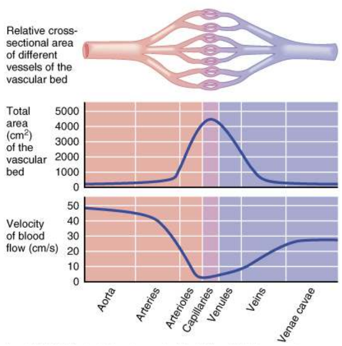


Figure 18.13

Autoregulation: Local Regulation of Blood Flow

- Autoregulation – automatic adjustment of blood flow to each tissue in proportion to its requirements at any given point in time
- Blood flow through an individual organ is intrinsically controlled by modifying the diameter of local arterioles feeding its capillaries
- MAP remains constant, while local demands regulate the amount of blood delivered to various areas according to need

Intrinsic Control of Blood Flow: Metabolic

- Declining tissue nutrient and oxygen levels are stimuli for autoregulation
- Hemoglobin delivers nitric oxide (NO) as well as oxygen to tissues
- Nitric oxide induces vasodilation at the capillaries to help get oxygen to tissue cells
- Other autoregulatory substances include: potassium and hydrogen ions, adenosine, lactic acid, histamines, kinins, and prostaglandins

Intrinsic Control of Blood Flow: Myogenic

- Inadequate blood perfusion or excessively high arterial pressure:
  - Are autoregulatory
  - Provoke myogenic responses – stimulation of vascular smooth muscle
- Vascular muscle responds directly to:
  - Increased vascular pressure with increased tone, which causes vasoconstriction
  - Reduced stretch with vasodilation, which promotes increased blood flow to the tissue

Long-Term Autoregulation

- Is evoked when short-term autoregulation cannot meet tissue nutrient requirements
- May evolve over weeks or months to enrich local blood flow
- Angiogenesis takes place:
  - As the number of vessels to a region increases
  - When existing vessels enlarge
  - When a heart vessel becomes partly occluded
  - Routinely to people in high altitudes, where oxygen content of the air is low

Blood Flow: Skeletal Muscles

- Resting muscle blood flow is regulated by myogenic and general neural mechanisms in response to oxygen and carbon dioxide levels
- When muscles become active, hyperemia is directly proportional to greater metabolic activity of the muscle (active or exercise hyperemia)
- Arterioles in muscles have cholinergic, and alpha (α) and beta (β) adrenergic receptors
- α and β adrenergic receptors bind to epinephrine

Blood Flow: Skeletal Muscle Regulation

- Muscle blood flow can increase tenfold or more during physical activity as vasodilation occurs
  - Low levels of epinephrine bind to β receptors
  - Cholinergic receptors are occupied
- Intense exercise or sympathetic nervous system activation result in high levels of epinephrine
  - High levels of epinephrine bind to α receptors and cause vasoconstriction
    - This is a protective response to prevent muscle oxygen demands from exceeding cardiac pumping ability

Blood Flow: Brain

- Blood flow to the brain is constant, as neurons are intolerant of ischemia
- Metabolic controls – brain tissue is extremely sensitive to declines in pH, and increased carbon dioxide causes marked vasodilation
- Myogenic controls protect the brain from damaging changes in blood pressure
  - Decreases in MAP cause cerebral vessels to dilate to insure adequate perfusion
  - Increases in MAP cause cerebral vessels to constrict

Blood Flow: Brain

- The brain can regulate is own blood flow in certain circumstances, such as ischemia caused by a tumor
- The brain is vulnerable under extreme systemic pressure changes
  - MAP below 60mm Hg can cause syncope (fainting)
  - MAP above 160 can result in cerebral edema

Blood Flow: Skin

- Blood flow through the skin:
  - Supplies nutrients to cells in response to oxygen need
  - Aids in body temperature regulation and provides a blood reservoir
- Blood flow to venous plexuses below the skin surface:
  - Varies from 50 ml/min to 2500 ml/min, depending upon body temperature
  - Is controlled by sympathetic nervous system reflexes initiated by temperature receptors and the central nervous system

Temperature Regulation

- As temperature rises (e.g., heat exposure, fever, vigorous exercise):
  - Hypothalamic signals reduce vasomotor stimulation of the skin vessels
  - Heat radiates from the skin
- Sweat also causes vasodilation via bradykinin in perspiration
  - Bradykinin stimulates the release of NO
- As temperature decreases, blood is shunted to deeper, more vital organs

Blood Flow: Lungs

- Blood flow in the pulmonary circulation is unusual in that:
  - The pathway is short
  - Arteries/arterioles are more like veins/venules (thin-walled, with large lumens)
    - They have a much lower arterial pressure (24/8 mm Hg versus 120/80 mm Hg)
  - The autoregulatory mechanism is exactly opposite of that in most tissues
    - Low oxygen levels cause vasoconstriction; high levels promote vasodilation
    - This allows for proper oxygen loading in the lungs

Blood Flow: Heart

- Small vessel coronary circulation is influenced by:
  - Aortic pressure
  - The pumping activity of the ventricles
- During ventricular systole:
  - Coronary vessels compress
  - Myocardial blood flow ceases
  - Stored myoglobin supplies sufficient oxygen
- During ventricular diastole, oxygen and nutrients are carried to the heart

Capillary Exchange of Respiratory Gases and Nutrients

- Oxygen, carbon dioxide, nutrients, and metabolic wastes diffuse between the blood and interstitial fluid along concentration gradients
  - Oxygen and nutrients pass from the blood to tissues
  - Carbon dioxide and metabolic wastes pass from tissues to the blood
  - Water-soluble solutes pass through clefts and fenestrations
  - Lipid-soluble molecules diffuse directly through endothelial membranes

Capillary Exchange of Respiratory Gases and Nutrients

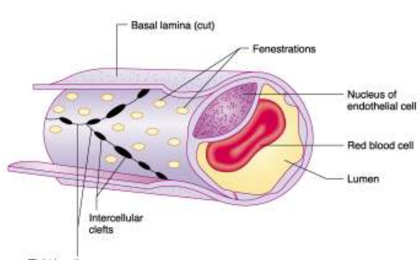


Figure 18.14

Capillary Exchange of Respiratory Gases and Nutrients

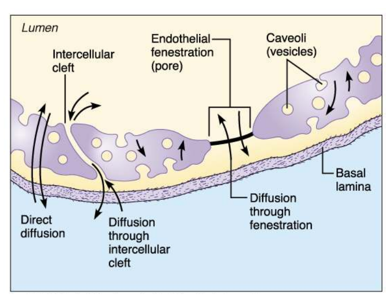


Figure 18.14

Capillary Exchange: Fluid Movements

- Direction of movement depends upon the difference between:
  - Capillary hydrostatic pressure (HP_c)
  - Capillary colloid osmotic pressure (OP_c)
- HP_c – pressure of blood against the capillary walls:
  - Tends to force fluids through the capillary walls
  - Is greater at the arterial end of a bed than at the venule end
- OP_c – created by nondiffusible plasma proteins, which draw water toward themselves

Net Filtration Pressure (NFP)

- NFP – considers all the forces acting on a capillary bed
- $NFP = (HP_c - HP_{if}) - (OP_c - OP_{if})$
- At the arterial end of a bed, hydrostatic forces dominate (fluids flow out)
- At the venous end of a bed, osmotic forces dominate (fluids flow in)
- More fluids enter the tissue beds than return to the blood and the excess fluid is returned to the blood via the lymphatic system

Net Filtration Pressure (NFP)

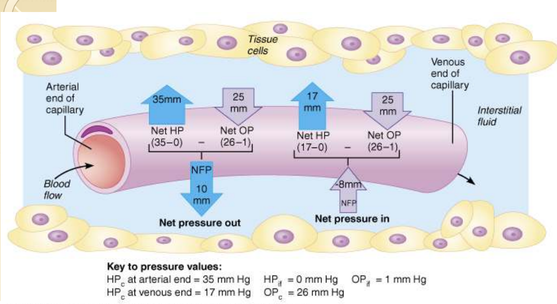


Figure 18.15

Circulatory Shock

- Circulatory shock – any condition in which blood vessels are inadequately filled and blood cannot circulate normally
- Results in inadequate blood flow to meet tissue needs
- Three types include:
  - Hypovolemic shock – results from large-scale blood loss
  - Vascular shock – poor circulation resulting from extreme vasodilation
  - Cardiogenic shock – the heart cannot sustain adequate circulation

Circulatory Pathways

- The vascular system has two distinct circulations
  - Pulmonary circulation – short loop that runs from the heart to the lungs and back to the heart
  - Systemic circulation – routes blood through a long loop to all parts of the body and returns to the heart

Differences Between Arteries and Veins

	Arteries	Veins
Delivery	Blood pumped into single systemic artery – the aorta	Blood returns via superior and inferior venae cavae and the coronary sinus
Location	Deep, and protected by tissue	Both deep and superficial
Pathways	Fair, clear, and defined	Convergent interconnections
Supply/drainage	Predictable supply	Dural sinuses and hepatic portal circulation

Pulmonary Circulation

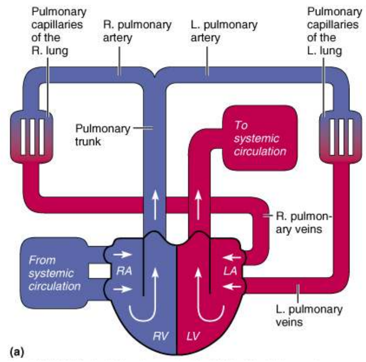


Figure 18.

Pulmonary Circulation

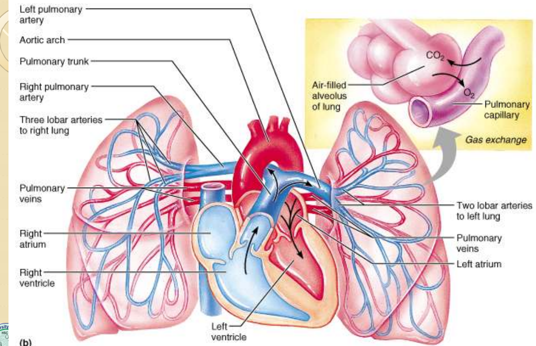


Figure 18.

Systemic Circulation

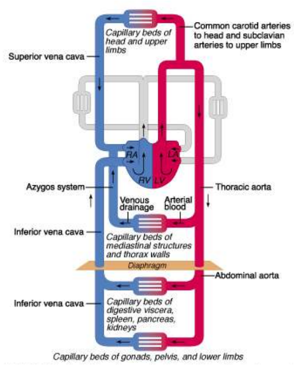


Figure 18.

Aorta and Major Arteries

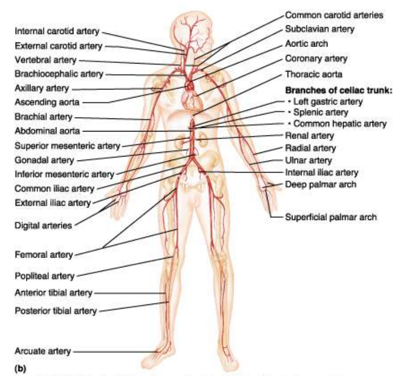


Figure 18.

Arteries of the Head and Neck

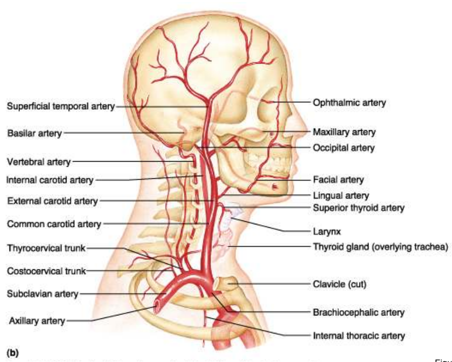


Figure 18.

Arteries of the Brain

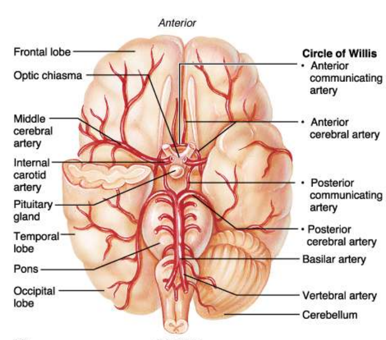


Figure 18.

Arteries of the Upper Limbs and Thorax

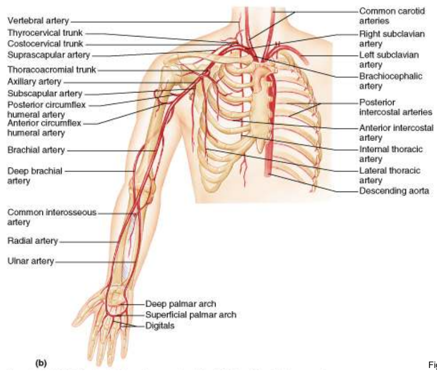


Figure 18.20b

Arteries of the Abdomen

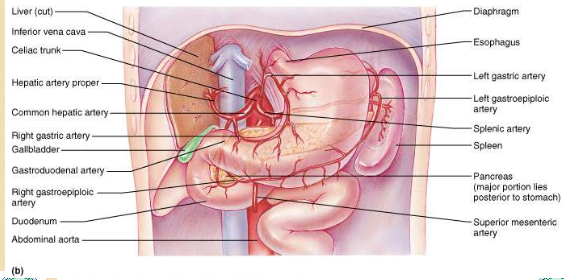


Figure 18.21b

Arteries of the Abdomen

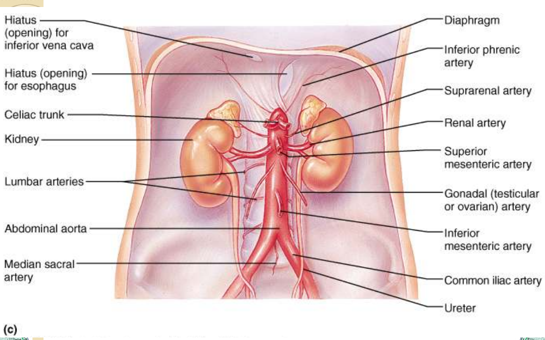


Figure 18.21c

Arteries of the Abdomen

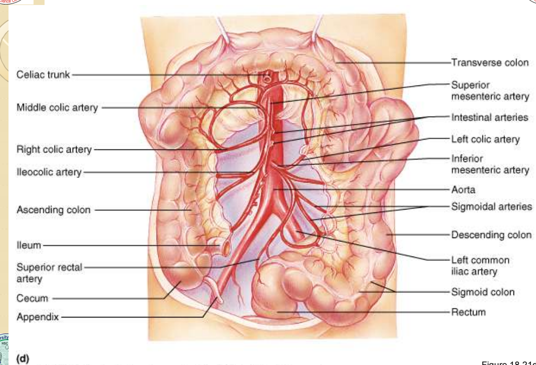


Figure 18.21d

Arteries of the Lower Limbs

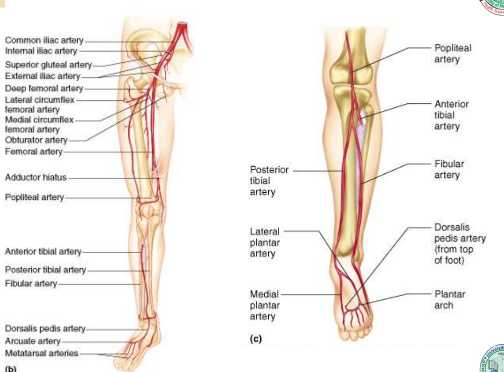


Figure 18.22b, c

Veins of Systemic Circulation

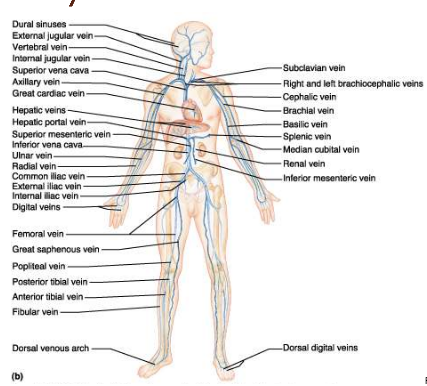


Figure 18.23b

Veins of the Head and Neck

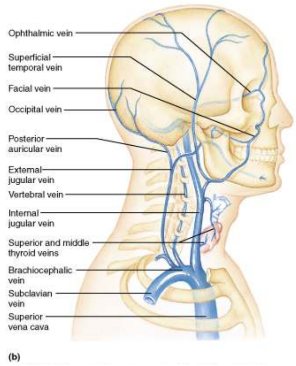


Figure 18.24b

Veins of the Brain

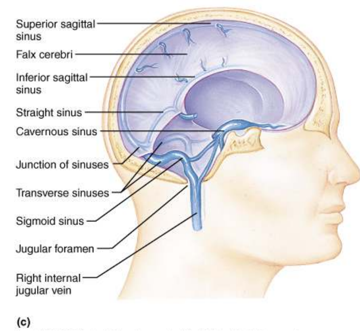


Figure 18.24c

Veins of the Upper Limbs and Thorax

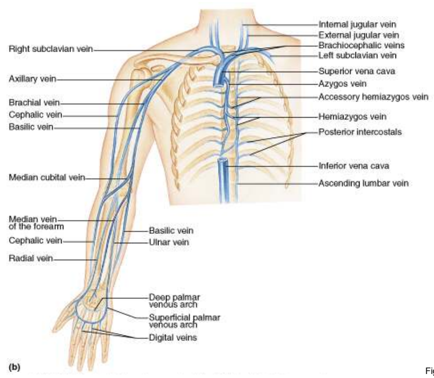


Figure 18.25b

Veins of the Abdomen

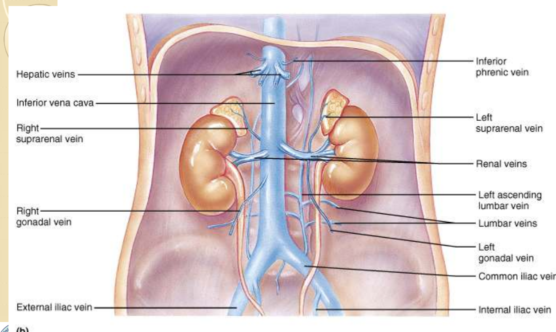


Figure 18.26b

Veins of the Abdomen

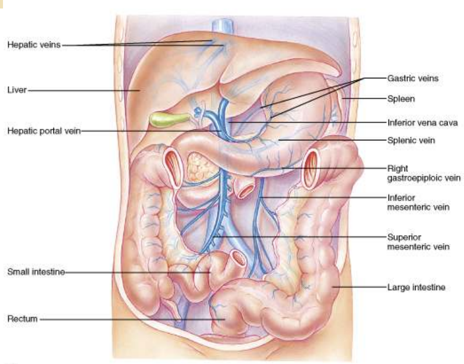


Figure 18.26c

Veins of the Pelvis and Lower Limbs

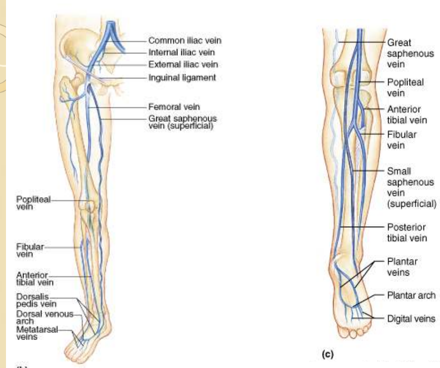


Figure 18.27b, c