**Blood Vessels & Circulation – Ch. 21**

*vital functions of cardiovascular system depend entirely on events at capillary level*
*all chemical & gaseous exchange between blood & interstitial fluid takes place across capillary walls*
*tissue cells rely on capillary diffusion to obtain nutrients & oxygen & to remove metabolic wastes*
*continuous movement of water out of capillaries, through peripheral tissues, then back to bloodstream via lymphatic system has four important functions:
*ensures that plasma & interstitial fluid, 2 major components of extracellular fluid, are in constant communication*
*accelerates distribution of nutrients, hormones, & dissolved gases throughout tissue*
*assists in transport of insoluble lipids & tissue proteins that cannot enter circulation by crossing capillary walls*
*has flushing action that carries bacterial toxins & other chemical stimuli to lymphoid tissues & organs responsible for providing immunity from disease*
*arterioles: smallest arterial branches; from which blood moves into capillaries*

**Anatomy of Blood Vessels**

*Structure of Vessel Walls*
*tunica interna: innermost layer of blood vessel*
*layer includes endothelial lining & underlying layer of connective tissue with variable number of elastic fibers*
*in arteries outer margin of interna contains thick layer of elastic fibers called **internal elastic membrane***
*tunica media: middle layer containing concentric layers of smooth muscle tissue in framework of connective tissue*
*collagen fibers bind media to interna & externa*
*commonly thickest layer in wall of small artery*
*separated from surrounding externa by **external elastic membrane**: thin band of elastic fibers*
*smooth muscle cells encircle endothelium lining of lumen of vessel*
*vessel diameter decreases when cells contract, & increases when cells relax*
*tunica externa: outermost layer of vessel & forms connective tissue sheath around vessel*
*in arteries, this layer contains collagen fibers with scattered bands of elastic fibers*
*in veins, which is generally thicker than media, contains networks of elastic fibers & bundles of smooth muscle cells*
*help to stabilize & anchor vessel*
*layers give veins & arteries considerable strength*
*muscular & elastic components also permit controlled alterations in diameter as blood pressure or blood volume changes*
*walls in veins & arteries are too thick to allow diffusion between bloodstream & surrounding tissues*

**Differences between Arteries & Veins**
*typically lie side by side in same region*
*in general, walls of arteries are thicker than veins*
*tunica media of artery contains more smooth muscle & elastic fibers → these contractile & elastic components resist pressure generated by heart as it forces blood into circuit*
*when not opposed by blood pressure, elastic fibers in arterial walls recoil, constricting lumen → so arterial walls on slide look smaller than veins, but they retain circular shape*
*veins’ shapes on slides look distorted because they do not retain circular shape
*endothelial lining of artery cannot contract, its endothelium, is thrown into folds that give arterial sections a pleated appearance → lining of vein lacks these folds
*arteries & veins can generally be distinguished, in gross dissection, because:
  *thicker walls of artery can be felt when vessel is compressed
  *arteries usually retain cylindrical shape, whereas veins often collapse
  *arteries are more resilient
  *veins typically contain valves, which prevent backflow of blood toward capillaries

**Arteries**
*relatively thick walls make them elastic & contractile
*elasticity permits passive changes in vessel diameter in response to alterations in blood pressure
*allows arteries to absorb pressure pulses that accompany contractions of ventricles
*contractility gives ability to change in diameter actively, primarily under control of sympathetic division of ANS
*vasoconstriction: when stimulated, arterial smooth muscles contract & thereby constrict artery
*vasodilation: relaxation in smooth muscles causes increase in diameter of lumen
*both process affect:
  *afterload of heart
  *peripheral blood pressure
  *capillary blood flow

**Elastic arteries**: conducting arteries
*large vessels that transport large volumes of blood away from heart → aortic & pulmonary trunks
*walls are extremely resilient
  *tunica media contains high density of elastic fibers & relatively few smooth muscle cells
  *able to tolerate pressure changes that occur during cardiac cycle
  *elasticity of arterial system dampens pressure peaks & valleys that accompany heartbeat

**Muscular arteries**: medium-sized arteries or distribution arteries
*distribute blood to body’s skeletal muscle & internal organs
*characterized by thick tunica media that contains more smooth muscle cells than does media of elastic arteries
*ex: external carotid arteries of neck, brachial arteries of arms

**Arterioles**: “resistance vessels”
*poorly defined tunica externa, & media of larger arterioles consists of one or two smooth muscle cells
*diameters change in response to local conditions or to sympathetic or endocrine stimulation
*changes in their diameter affect amount of force required to push blood around cardiovascular system
*resistance (R): force opposing blood flow (arterioles)

**Capillaries**
*only blood vessels whose walls permit exchange between blood & surrounding interstitial fluids
*diffusion distances are small & exchange can occur quickly because of thin walls
*blood flows through capillaries relatively slow, allowing sufficient time for diffusion or active transport of materials across walls
*typical capillary consists of endothelial tube inside delicate basement membrane
*has neither tunica media nor externa
**Continuous capillaries**
*supplies most regions of body with blood
*endothelium is complete lining
*located in all tissues except epithelia & cartilage
*permit diffusion of water, small solutes, & lipid-soluble materials into surrounding interstitial fluid
through movement of vesicles that form at inner endothelial surface
*have very restricted permeability characteristics \(\rightarrow\) blood-brain barrier

*fenestrated capillaries
*capillaries that contain “windows” or pores that span endothelial lining
*pores permit rapid exchange of water & solutes as large as small peptides between plasma & interstitial fluid
*sinusoids: specialized fenestrated capillaries that are flattened & irregular
*commonly have gaps between adjacent endothelial cells, & basement membrane may be incomplete or absent \(\rightarrow\) permit free exchange of water & solutes as large as plasma proteins
*blood moves through sinusoids relatively slowly, maximizing time available for absorption & secretion across sinusoidal walls
*occur in liver, bone marrow, adrenal glands

capillary beds: interconnected network of capillaries
*precapillary sphincter: band of smooth muscle that guards entrance to each capillary
*relaxation of sphincter dilates opening, allowing blood to enter capillary at faster rate
*preferred channels: within capillary bed; provides direct means of communication between arterioles & venules
*metarteriole: arteriolar segment of channel that contains smooth muscles capable of altering its diameter
*thoroughfare channel: rest of preferred channel
*single capillary bed may receive blood from more than one artery
*collaterals: multiple arteries
*enter region & fuse before giving rise to arterioles
*arterial anastomosis: fusion of 2 collateral arteries that supply capillary bed
*arteriovenous anastomoses: direct connection between arterioles & venules
*when dilated, blood will bypass capillary bed & flow directly into venous circulation
*pattern of blood flow is regulated primarily by sympathetic innervation under control of cardiovascular centers of medulla oblongata
*vasomotion: cycling of contraction & relaxation of smooth muscles that causes alteration of blood flow through capillary beds
*flow within each capillary is quite variable
*controlled at local level by changes in concentration of chemicals & dissolved gases within interstitial fluids

*Veins
*collect blood from all tissues & organs & return it to heart
*walls are thinner than those of corresponding arteries \(\rightarrow\) blood pressure in veins is lower
*classified on basis of their size; generally veins are larger in diameter than corresponding arteries
*venules
*collect blood from capillary beds
*vary widely in size & character
*large veins
*include superior & inferior venae cavae & their tributaries within abdominopelvic & thoracic cavities
*all tunica layers are present
*slender tunica media is surrounded by thick externa composed of mixture of elastic & collagen fibers
*venous valves
*blood pressure in venules & medium-sized veins is so low that it cannot oppose force of gravity
*contain valves: which are folds of tunica interna that project from vessel wall & point in direction of blood flow
permit blood flow in one direction & prevent backflow of blood toward capillaries
*contractions of surrounding muscles help push blood against gravity toward heart

**Distribution of Blood**
*total blood volume is unevenly distributed among arteries, veins, & capillaries
*heart, arteries, & capillaries usually contain about 30-35% of blood volume
*venous system normally contains other 65-70%
*because walls are thinner & contain lower proportion of smooth muscle, veins are much more
distensible than arteries
*capacitance of blood vessel is relationship between volume of blood it contains & blood pressure
*capacitance vessels: name for veins because they are easily distensible, & large changes in blood
volume have little effect on blood pressure
*if serious hemorrhaging occurs, vasomotor centers of medulla oblongata stimulate sympathetic nerves
that innervate smooth muscle cells in walls of medium-sized veins; has 2 major effects:
*venoconstriction: systemic veins constrict & reduce volume of venous system
  *this maintains volume within arterial system & capillaries at near-normal levels despite
  significant blood loss
*constriction of veins in liver, skin, & lungs redistributes significant proportion of total blood
volume
*as result, blood flow to delicate organs, such as brain, & to active skeletal muscles can be
  increased or maintained after blood loss
*venous reserve: amount of blood shifted from these organs to general circulation; normally
  accounts for 20% of total blood volume

**Cardiovascular Physiology**
*goal of cardiovascular regulation is maintenance of adequate blood flow through peripheral tissues &
organs
*normally, blood flow equals cardiac output
*afterload of heart is determined by interplay between pressure & resistance in circulatory network
*if there were no resistance to blood flow in cardiovascular system, heart would not have to generate
pressure to force blood around pulmonary & systemic circuits

*Pressure  $\Delta P \sim CO \times R$
*hydrostatic pressure (HP): force exerted against liquid that is conducted in all directions
  *usually pushes liquid from area of higher pressure to one of lower pressure
  *flow rate is directly proportional to pressure gradient
*circulatory pressure: pressure gradient in systemic circuit of cardiovascular system; pressure
difference between base of ascending aorta & entrance to right atrium
*blood pressure (BP): used when referring to arterial pressure → distinguishes it from total
circulatory pressure
  *capillary blood flow is directly proportional to blood pressure, which is closely regulated by
  combination of neural & hormonal mechanisms
  *capillary pressure: pressure within capillary beds
*venous pressure: pressure within venous system, which is quite low

*Resistance  $R \sim (\Delta P \times r^4) / (L \times \text{viscosity})$
*any force that opposes movement
*greater resistance, slower blood flow
*total peripheral resistance: resistance of entire cardiovascular system that pressure gradient must be
great enough to overcome for circulation to occur
* peripheral resistance (PR): resistance of arterial system that pressure gradient must be great enough to overcome in order for blood to flow into peripheral capillaries
* flow is directly proportional to pressure gradient & indirectly proportional to resistance
* sources of peripheral resistance are:
  * vascular resistance: resistance of blood vessels
    * largest component of PR
    * most important factor in vascular resistance is friction between blood & vessel walls
    * amount of friction depends on length & diameter of vessel
    * vessel length – increasing length of vessel increases friction
      * the longer the vessel, the more surface area in contact with blood
      * not much significant effects on resistance; usually constant
    * directly related
    * vessel diameter – friction affects blood primarily in narrow zone closest to vessel wall
    * resistance in small diameter vessel will be relatively high due to friction from walls
    * differences in diameter have more significant effects on resistance than do differences in length
      * 2 vessels of equal length, but one is twice in diameter than other, narrower one will offer 16 times as much resistance to blood flow
    * vessel diameter changes → due to muscle contractions or relaxations
    * indirectly related (x^4)
  * viscosity: resistance to flow caused by interactions among molecules & suspended materials in liquids
    * blood has viscosity about 5 times that of water, owing to presence of plasma proteins & blood cells
    * directly related
  * turbulence: phenomenon where high flow rates, irregular surfaces, & sudden changes in vessel diameter upset flow of blood, creating eddies & swirls
    * slows rate of flow & increases resistance
    * normally occurs when blood flows between atria & ventricles & between ventricles & aortic & pulmonary trunks
    * seldom occurs in smaller vessels unless their walls are damaged

* Arterial Blood Pressure
  * arterial pressures overcome peripheral resistance & maintain blood flow through capillary beds
  * not stable – rises during ventricular systole & falls during ventricular diastole
    * systolic pressure: peak blood pressure measured during ventricular systole
    * diastolic pressure: minimum blood pressure at end of ventricular diastole
  * pulse: rhythmic pressure oscillation that accompanies each heartbeat
  * pulse pressure: difference between systolic & diastolic pressures
  * mean arterial pressure (MAP): used to report single blood pressure
    * mean pressure over time of cycle
    * $\text{MAP} = P_{\text{dia}} + \frac{1}{3} \text{(PP)}$
  * elastic rebound: phenomenon where arterial recoil pushes blood toward capillaries because aortic semilunar valve prevents return of blood to heart; maintains pressure during diastole
  * pressures in small arteries & arterioles
    * mean arterial pressure & pulse pressure become smaller as distance from heart increases:
      * MAP declines as arterial branches become smaller & more numerous
      * blood pressure decreases as it produces blood flow & overcomes friction
      * pulse pressure fades as result of cumulative effects of elastic rebound
      * each arterial segment reduces magnitude of pressure change that’s experienced by its downstream neighbors
by time blood reaches precapillary sphincter, there are no pressure oscillations & blood pressure remains steady at approximately 35 mm Hg.

**Capillary Exchange**

capillary walls are very thin & delicate – consist of single squamous endothelial cell, generally supported by basement membrane

this arrangement minimizes distance between blood & interstitial fluid, facilitating rapid diffusion or transport of materials into or out of circulation

most important processes involved in movement of materials across typical capillary walls are:

diffusion: net movement of ions or molecules from area of higher concentration to area of lower concentration

occurs most rapidly when (1) distances are small, (2) concentration gradient is large, & (3) ions or molecules involved are small

can occur by several different routes:

between adjacent endothelial cells or through pores of fenestrated capillaries – water, ions, & small molecules like glucose & amino acids

across endothelial cells while passing through channels in cell membrane – ions such as Na⁺, K⁺, Ca²⁺

large water-soluble compounds are unable to enter or leave circulation except at fenestrated capillaries

cross capillary walls by diffusion through endothelial cell membranes – lipids like fatty acids & steroids

plasma proteins are normally unable to cross endothelial lining anywhere except in sinusoids, such as those of liver, where plasma proteins enter circulation

**filtration**

driving force is hydrostatic pressure; in this case blood hydrostatic pressure

in capillary filtration, water is forced across capillary wall & small solute molecules travel with water

**reabsorption**: occurs as result of osmosis: diffusion of water across selectively permeable membrane separating 2 solutions of differing solute concentrations → tend to diffuse to area of higher solute concentration

*osmotic pressure (OP): indication of force of water movement resulting from its solute concentration

*blood colloid osmotic pressure (BCOP): osmotic pressure of blood

*interplay between filtration & reabsorption

rates of filtration & reabsorption gradually change as blood passes along length of capillary

*net hydrostatic pressure: tends to push water & solutes into interstitial fluid; +35 mm Hg

is difference between:

*blood hydrostatic pressure (BHP): which ranges from 35 mm Hg; at arterial end of capillary to 18 mm Hg at venous end; pushes out

*hydrostatic pressure of interstitial fluid (IHP): measurements of IHP have yielded very small values that differ from tissue to tissue; 0 mm Hg; pushes in

*positive IHP oppose BHP, & tissue hydrostatic pressure must be overcome before fluid can move out of capillary

*negative IHP assists BHP, & additional fluid must be pulled out of capillary

*net colloid osmotic pressure: tends to pull water & solutes into capillary; difference between:

*blood colloid osmotic pressure (BCOP): roughly about 25 mm Hg; pulls water into vessel

*interstitial fluid colloid osmotic pressure (ICOP): is as variable & low as IHP, because interstitial fluid in most tissues contains negligible quantities of suspended proteins
*net filtration pressure (NFP): difference between net hydrostatic pressure & net osmotic pressure; +10 mm Hg at arterial end (fluid moves out)
*when NFP is positive, fluid will tend to move out of capillary at venous end & into interstitial fluid
*when NFP is negative, there is net movement of fluid into capillary \(\rightarrow\) reabsorption occurs
*any condition that affects hydrostatic or osmotic pressure in blood or tissues will shift balance between hydrostatic & osmotic forces

*Venous Pressure & Venous Return
*venous pressure, although low, determines venous return, which has direct impact on cardiac output & peripheral blood flow
*interstitial fluid enters lymphatic capillary; known as lymph
*two factors cooperate to assist relatively low venous pressures in propelling blood toward heart:
  *muscular compression
    *contractions of skeletal muscles near vein compress it, helping push blood toward heart
  *valves in small & medium-sized veins ensure that blood flow occurs in one direction only
  *reduction in venous return leads to fall in cardiac output, which reduces blood supply to brain \(\rightarrow\) fainting: temporary loss of consciousness
  *respiratory pump:
    *during exhalation, thoracic cavity decreases in size; internal pressures rise, forcing air out of your lungs & pushing venous blood into right atrium \(\rightarrow\) respiratory pump

**Cardiovascular Regulation**

*homeostatic mechanisms regulate cardiovascular activity to ensure that tissue blood flow, also known as tissue perfusion, meets demand for oxygen & nutrients
*three variable factors include cardiac output, peripheral resistance, & blood pressure
*goal of cardiovascular regulation is to ensure that blood flow changes occur:
  *at appropriate time
  *in right area
  *without drastically altering blood pressure & blood flow to any vital organ
*factors involved in regulation of cardiovascular function include:
  *local factors – change pattern of blood flow within capillary beds in response to chemical changes in interstitial fluids \(\rightarrow\) example of autoregulation at tissue level \(\rightarrow\) causes immediate localized homeostatic adjustments
  *central mechanisms – respond to changes in arterial pressure or blood gas levels at specific sites
  *endocrine factors – endocrine system releases hormones that enhance shot-term adjustments & direct long-term changes in cardiovascular performance
*Autoregulation of Blood Flow within Tissues
*under normal resting conditions, cardiac output remains stable, & peripheral resistance within individual tissue is adjusted to control local blood flow
*local vasodilators: produced at tissue level & accelerate blood flow through tissue of origin
  *vasodilators: factors that promote dilation of precapillary sphincters
  *examples include:
    *decreased tissue oxygen levels or increases CO₂ levels
    *generation of lactic acid or other acids by tissue cells
    *elevated local temperatures
  *these factors work by stimulating relaxation of smooth muscle cells of precapillary sphincters
*local vasoconstrictors: produce compounds that stimulate constriction of precapillary sphincters
  *examples include:
*prostaglandins & thromboxanes released by activated platelets & white blood cells & endothelins released by damaged endothelial cells
*both local vasoconstrictors & vasodilators control blood flow within single capillary bed

**Neural Control of Blood Pressure & Blood Flow**
*nervous system is responsible for adjusting cardiac output & peripheral resistance to maintain adequate blood flow to vital tissues & organs
*centers responsible for these regulatory activities include cardiac centers & vasomotor centers of medulla oblongata
*often considered to form complex cardiovascular (CV) centers; however often the two centers act independently of each other
*vasomotor centers contain two populations of neurons:
*very large group responsible for widespread vasoconstriction
*relatively small group responsible for vasodilation of arterioles in skeletal muscle & brain
*vasomotor centers exert their effects by controlling activity of sympathetic motor neurons:
*control of vasoconstriction
*neurons innervating peripheral blood vessels in most tissues are adrenergic, releasing norepinephrine
*response to NE release is stimulation of smooth muscle in walls of arterioles, producing vasoconstriction
*control of vasodilation
*vasodilator neurons innervate blood vessels in skeletal muscles & in brain
*stimulation of these neurons will relax smooth muscle cells in walls of arterioles, producing vasodilation

**Vasomotor Tone**: produced when sympathetic vasoconstrictor nerves are chronically active
*vasoconstriction activity is normally sufficient to keep arterioles partially constricted
*because blood pressure varies directly with peripheral resistance, vasomotor centers can provide effective control over arterial blood pressure by making modest adjustments in vessel diameter

**Reflex Control of Cardiovascular Function**
*cardiovascular centers detect changes in tissue demand by monitoring arterial blood, with particular attention to blood pressure & to pH & dissolved gas concentrations
*reflexes are regulated through negative feedback loop
*baroreceptor reflexes: specialized receptors that monitor degree of stretch in walls of expandable organs; respond to changes in blood pressure
*located in walls of:
*carotid sinuses: expanded chambers near bases of internal carotid arteries of neck
*aortic sinuses: pockets in walls of ascending aorta adjacent to heart
*wall of right atrium
*adjust cardiac output & peripheral resistance to maintain normal arterial pressure
*aortic reflex: adjusts blood pressure in response to changes in pressure at ascending aorta
*goal is to maintain adequate blood pressure & blood flow through systemic circuit
*blood flow to brain must remain constant, & carotid sinuses receptors are extremely sensitive
*when blood pressure climbs, increased output from baroreceptors alters activity in CV centers & produces two major effects:
*decrease in cardiac output
*widespread peripheral vasodilation
*opposite effects occur when blood pressure falls
*chemoreceptor reflexes: monitor changes in chemical composition of arterial blood
*located in:
*carotid bodies: situated in neck near carotid sinuses
*aortic bodies: near arch of aorta
**Special Circulation**
*term refers to circulation through organs where blood flow is controlled by separate mechanisms
*brain – has very high demand for oxygen & receives substantial supply of blood
  *about 12% of cardiac output sent to brain
  *total blood flow to brain is relatively constant; however, circulation to specific parts of brain changes from moment to moment
  *changes occur in response to local changes in interstitial fluid composition that accompany neural activity
*heart
  *normal cardiac muscle cells can tolerate brief circulatory interruptions because they have substantial oxygen reserves
*lungs – contain roughly 300 million alveoli, delicate epithelial pockets where gas exchange occurs
  *blood flow through lungs is regulated primarily by local responses to levels of oxygen within individual alveoli
  *when alveolus contains oxygen in abundance, associated vessels dilate, & blood flow increases → this increase promotes absorption of oxygen from alveolar air

**CNS Activities & Cardiovascular Centers**
*output of CV centers can also be influenced by activities in other areas of brain
*activation of either division of ANS will affect output from CV centers:
  *cardioacceleratory centers & vasomotor centers are stimulated when general sympathetic activation occurs → result is increase in cardiac output & blood pressure
  *when parasympathetic division is activated, cardioinhibitory centers are stimulated, producing reduction in cardiac output

**Hormones & CV Regulation**
*E & NE stimulate cardiac output & peripheral vasoconstriction
*other hormones important in regulating CV function include:
*Antidiuretic Hormone
  *released in response to decrease in blood volume or increase in osmotic concentration of plasma or, secondarily in response to release of angiotensin II
  *immediate result is peripheral vasoconstriction that elevates blood pressure
*Angiotensin II
  *appears in blood following release of rennin by specialized kidney cells in response to fall in renal blood pressure
  *has two short-term effects:
    *an extremely powerful vasoconstriction that elevates blood pressure
    *positive inotropic action on heart, which elevates cardiac output
  *has two long-term effects:
    *stimulates secretion of ADH & aldosterone
    *stimulates thirst
*Erythropoietin
  *released if blood pressure declines or if oxygen content of blood becomes abnormally low
  *stimulates RBC production & maturation, elevating blood volume & improving oxygen-carrying capacity of blood
*Atrial Natriuretic Peptide
  *produced by cardiac muscle cells in wall of right atrium in response to excessive stretching during diastole
  *reduces blood volume & blood pressure by:
    *increasing sodium ion excretion at kidneys
    *promoting water losses by increasing volume of urine produced
    *reducing thirst
*blocking release of ADH, aldosterone, E, & NE
*stimulating peripheral vasodilation

**Patterns of Cardiovascular Response**

*Exercise & the Cardiovascular System
*both pattern of blood distribution & cardiac output change markedly during exercise than at rest
*Light Exercise
*three interrelated changes occur:
  *extensive vasodilation occurs as rate of skeletal muscle oxygen consumption increases
  *peripheral resistance drops, blood flow through capillaries increases, & blood enters venous system at accelerated rate
  *venous return increases, as skeletal muscle contractions squeeze blood along peripheral veins & increased breathing rate pulls blood into venae cavae via respiratory pump
  *cardiac output rises, primarily in response to (1) rise in venous return, & (2) atrial stretching
*regulation by venous feedback produces gradual increase in cardiac output to about double resting levels
*increased blood flow to skin occurs in response to rise in body temperature
*Heavy Exercise
*cardiac output increases toward maximum levels, & major changes occur in peripheral distribution of blood, facilitating blood flow to active skeletal muscles
*only blood supply to brain remains unaffected
*Exercise, Cardiovascular Fitness, & Health
*cardiovascular performance improves significantly with training
*Exercise & Cardiovascular Disease
*regular moderate exercise routine can lower total blood cholesterol levels, may cut incidence of heart attack almost in half
*also beneficial in accelerating recovery after heart attack
*Cardiovascular Response to Hemorrhaging
*when hemostasis fails to prevent significant blood loss, entire CV system begins making adjustments to maintain blood pressure & restore blood volume
*immediate problem is maintenance of adequate blood pressure & peripheral blood flow
*long-term problem is restoration of normal blood volume
*Short-term Elevation of Blood Pressure
*neural – maintains pressure
*carotid & aortic reflexes increase cardiac output & cause peripheral vasoconstriction
*with blood volume reduced, cardiac output is maintained by increasing heart rate
*sympathetic activation provides assistance by increasing vasomotor tone, constricting arterioles, & elevating blood pressure
*at same time, small muscle arteries, arterioles, & veins decrease in diameter
*venoconstriction demanded by vasomotor center mobilizes venous reserve & quickly improve venous return
*hormonal adjustments occur:
*sympathetic activation causes secretion of E & NE by adrenal medulla, increasing cardiac output & extending peripheral vasoconstriction
*release of ADH & production of angiotensin II enhance vasoconstriction while participating in long-term response
*above combination of adjustments elevates blood pressure & improves peripheral blood flow
**Long-term Restoration of Blood Volume**
- hormonal – restores blood volume
- decline in capillary blood pressure triggers recall of fluids from interstitial spaces
- ADH & aldosterone promote fluid retention & reabsorption at kidneys, preventing further reductions in blood volume
- thirst increases & additional water is obtained by absorption across digestive tract
  - intake of fluid elevates plasma volume & ultimately replaces interstitial fluids “borrowed” at capillaries
- erythropoietin targets bone marrow, stimulating maturation of RBCs, which increase blood volume & improve oxygen delivery to peripheral tissues

**Shock**
- an acute circulatory crisis marked by low blood pressure & inadequate peripheral blood flow
- common causes of shock are (1) drop in cardiac output after hemorrhaging or other fluid losses, (2) damage to heart, (3) external pressure on heart, & (4) extensive peripheral vasodilation

**Circulatory Shock**
- severe reduction of blood volume produces symptoms of circulatory shock
  - symptoms appear after fluid losses of about 30% of total blood volume
  - divided into stages:
    - **compensated stage**: homeostatic adjustments can cope with situation
      - during this period, peripheral blood flow is reduced but remains within tolerable levels
    - **progressive stage**: homeostatic mechanisms are now unable to cope with situation
      - blood pressure remains abnormally low, venous return is reduced, & cardiac output is inadequate
      - blood flow to brain will decrease
      - sympathetic output causes sustained & maximal vasoconstriction called **central ischemic response**, which reduces peripheral circulation to an absolute minimum
      - 
    - **irreversible stage**: conditions in heart, liver, kidneys, & CNS are rapidly deteriorating to point at which death will occur, even with medical treatment
      - begins when conditions in tissues become so abnormal that arteriolar smooth muscles & precapillary sphincters become unable to contract → result is widespread peripheral vasodilation & immediate & fatal decline in blood pressure called **circulatory collapse**

**Blood Vessels**
- peripheral distributions of arteries & veins on left & right sides are generally identical except for near heart
- single vessel may have several different names as it crosses specific anatomical boundaries, making accurate anatomical descriptions possible when vessel extends far into periphery

**Pulmonary Circulation**
- relatively short when compared to systemic circuit
- arteries carry deoxygenated blood (different from systemic circuit)
- as it curves over superior border of heart, pulmonary trunk gives rise to left & right pulmonary arteries
  - enter lungs before branching repeatedly, giving rise to smaller & smaller arteries
  - smallest branch, pulmonary arterioles, provide blood to capillary networks that surround alveoli
- as oxygenated blood leaves alveolar capillaries, it enters venules that in turn unite to form larger vessels carrying blood toward pulmonary veins

**Systemic Circulation**
- supplies capillary beds in all parts of body not serviced by pulmonary circuit
- contains about 84% of total blood volume
*Systemic Arteries*

*Ascending Aorta* – begins at aortic semilunar valve of left ventricle
*left & right coronary arteries originate at base of ascending aorta, just superior to aortic semilunar valve

*Aortic Arch* – curves like cane handle across superior surface of heart, connecting ascending & descending aorta
*three elastic arteries, which deliver blood to head, neck, shoulders, & upper limbs originate along aortic arch:
*brachiocephalic – branches to form right subclavian artery & right common carotid artery
*left common carotid
*left subclavian

*Subclavian Arteries*
*supply blood to arms, chest walls, shoulders, back, & CNS
*before subclavian artery leaves thoracic cavity it branches into:
*thyrocervical: provides blood to muscles & other tissues of neck, shoulders, & upper back
*internal thoracic artery: supplying pericardium & anterior wall of chest
*vertebral artery: provides blood to brain & spinal cord
*after leaving thoracic cavity & passing across superior border of first rib, subclavian is called axillary artery – crosses axilla to enter arm, where it becomes brachial artery
*brachial artery supplies blood to upper extremity; divides into radial artery (follow radius) & ulnar artery (follows ulna to wrist) → these supply blood to forearm
*at wrist, they anastomose to form superficial palmar arch & deep palmar arch which supply blood to hand & to digital arteries of thumb & fingers

*Carotid Artery & Blood Supply to Brain*
*common carotid arteries descend deep in tissues of neck
*each one divides into external carotid artery (supply blood to structures of neck, esophagus, pharynx, larynx, lower jaw, & face) & internal carotid artery (enter skull through carotid canals of temporal bones, delivering blood to brain)
*internal carotids ascend to level of optic nerves, where each divides into three branches:
*ophthalmic artery: supplies to eyes
*anterior cerebral artery: supplies to frontal & parietal lobes of brain
*middle cerebral artery: supplies to mesencephalon & lateral surfaces of cerebral hemispheres
*normally supply arteries of anterior half of cerebrum, & rest of brain receives blood from vertebral arteries
*brain is extremely sensitive to changes in circulatory supply
*vertebral arteries arise from subclavian arteries & enter cranium at foramen magnum where they fuse along ventral surface of medulla oblongata to form basilar artery, which divides into posterior cerebral arteries, which branch off to form posterior communicating arteries
*internal carotids & basilar artery are interconnected in ring-shape anastomosis called cerebral arterial circle, or circle of Willis, which encircles infundibulum of pituitary gland

*Descending Aorta* – continuous with aortic arch; divided into:
*superior Thoracic aorta* – travels within mediastinum, on dorsal thoracic wall, slightly left of vertebral column
*supplies blood to branches servicing tissues & organs of mediastinum, muscles of chest & diaphragm, & thoracic spinal cord
*branches are anatomically grouped as either:
*visceral branches – which supply organs of chest
*bronchial arteries – supply nonrespiratory tissues of lungs
*pericardial arteries – supply pericardium
*esophageal arteries – supply esophagus
*mediastinal arteries – supply tissues of mediastinum
*parietal branches – supply chest wall
*intercostal arteries – supply chest muscles & vertebral column area
*superior phrenic arteries – deliver blood to superior surface of diaphragm, which separates thoracic & abdominopelvic cavities

**inferior Abdominal Aorta** – begins immediately inferior to diaphragm; continuation of thoracic aorta
*commonly surrounded by adipose tissue
*splits into 2 major arteries – left & right common iliac arteries – that supply deep pelvic structures & lower limbs
*region where aorta splits is called terminal segment of aorta
*delivers blood to all abdominopelvic organs & structures
*major branches to visceral organs are unpaired, & they arise on anterior surface of abdominal aorta & extend into mesenteries
*branches to body wall, kidneys, urinary bladder, & other structures outside abdominopelvic cavity are paired
*gives rise to three unpaired arteries:
  *celiac artery: delivers blood to liver, stomach, & spleen; divides into 3 branches:
    *left gastric artery: supplies blood to stomach & interior portion of esophagus
    *splenic artery: supplies spleen & arteries to stomach & pancreas
    *common hepatic artery: supplies arteries to liver, stomach, gallbladder, & duodenal area
  *superior mesenteric artery: supplies arteries to pancreas & duodenum, small intestine, & most of large intestine
*inferior mesenteric artery: delivers blood to terminal portions of colon & rectum
*gives rise to five paired arteries:
  *inferior phrenics: which supply inferior surface of diaphragm
  *suprarenal arteries: each supplies one of adrenal glands that cap superior portions of kidneys
  *renal arteries
  *gonadal arteries: called testicular arteries in males & are long thin arteries that supply blood to testes & scrotum; called ovarian arteries in women & supply blood to ovaries, uterine tubes, & uterus
  *lumbar arteries: supply vertebrae, spinal cord, & abdominal wall

**Arteries of Pelvis & Lower Limbs**
*terminal segment of ascending aorta divides to form pair of elastic arteries called right & left common iliac arteries – carry blood to pelvis & lower limbs
*these arteries then divide to form:
  *internal iliac artery: supply urinary bladder, internal & external walls of pelvis, external genitalia, medial side of thigh, & in females, uterus & vagina
  *external iliac artery: supply blood to lower limbs; much larger in diameter than internal iliac arteries

**Arteries of Thigh & Leg**
*external iliac artery emerges in anteromedial surface of thigh as femoral artery, which then branches off to form deep femoral artery: gives rise to medial & lateral circumflex arteries; supplies blood to ventral & lateral regions of skin & deep muscles of thigh
*femoral artery continues inferiorly & posterior to femur; at knee, it becomes popliteal artery, which branches to form posterior & anterior tibial arteries
*posterior tibial artery gives rise to peroneal artery & continues inferiorly along posterior surface of tibia
*anterior descend down leg, supplying blood to skin & muscle of anterior portion of leg
*Arteries of Foot*
*as anterior tibial artery reaches ankle it becomes doralis pedis artery, which repeatedly branches to supply ankle & dorsal portion of foot*
*as posterior tibial artery reaches ankle, it divides to form medial & lateral plantar arteries, which supply blood to plantar surface of foot*
*connected to doralis pedis artery through pair of anastomoses producing dorsal arch & plantar arch*

*Systemic Veins*
*branching pattern of peripheral veins is much more variable than that of arteries*
*differs mainly from arteries in distribution of major veins in neck & limbs*
*neck & limbs generally have two sets of peripheral veins, one superficial & one deep*
*dual venous drainage is important for controlling body temperature*

*Superior Vena Cava*
*receives blood from tissues & organs of head, neck, chest, shoulders, & upper limbs*

*Venous Return from Cranium*
*superficial cerebral veins & small veins of brain stem empty into network of dural sinuses*
*superior sagittal sinus: largest sinus; in falx cerebri*
*internal cerebral veins: majority collect inside brain to form great cerebral vein, which collects blood from interior of cerebral hemispheres & choroids plexus & delivers it to straight sinus*
*other cerebral veins drain into cavernous sinus*
*blood leaves skull via internal jugular vein*
*vertebral veins drain cervical spinal cord & posterior surface of skull; empty into brachiocephalic veins of chest*

*Superficial Veins of Head & Neck*
*superficial veins of head collect to form temporal, facial, & maxillary veins*
*temporal & maxillary veins drain into external jugular vein*
*facial vein drains into internal jugular vein*

*Venous Return from Upper Limbs*
*digital veins empty into superficial & deep palmar veins of hand, which are interconnected to form palmar venous arches*
*superficial arch empties into cephalic vein which ascends along radial side of forearm, median antebrachial vein, & basilic vein, which ascends on ulnar side*
*superficial median cubital vein: runs anterior to elbow*
*deep palmar veins drain into radial vein & ulnar vein, which fuse together to form brachial vein as it continues toward trunk, it receives blood from basilic vein before entering axilla as axillary vein*

*Formation of Superior Vena Cava*
*cephalic vein joins axillary vein on lateral side of first rib, forming subclavian vein, which continues into chest*
*vein meets & merges with external & internal jugular veins of that side → this fusion creates brachiocephalic vein, or innominate vein, which penetrates body wall & enters thoracic cavity*
*each brachiocephalic vein receives blood from vertebral vein of same side, which drains back of skull & spinal cord*
*internal thoracic vein empties into brachiocephalic vein*
*azygous vein: major tributary of superior vena cava; on left side, it receives blood from smaller hemiazygos vein*
*both called chief collecting vessels of thorax*
*receive blood from:
*numerous intercostals veins, which receive blood from chest muscles*
*esophageal veins, which drain blood from esophagus*
*smaller veins draining other mediastinal structures

*Inferior Vena Cava
*collects most of venous blood from organs inferior to diaphragm

*Veins Draining Lower Limb
*blood leaving capillaries in sole of each foot collects into network of **plantar veins**, which supply **plantar venous arch**
*plantar network provides blood to deep veins of leg: **anterior tibial vein**, **posterior tibial vein**, & **peroneal vein**
*dorsal venous arch** collects blood from capillaries on superior surface of foot & digital veins of toes
*arch is drained by 2 superficial veins:  
  * **great saphenous vein**: drains into **femoral vein** near hip joint  
  * **small saphenous vein**: enters popliteal fossa, where it meets popliteal vein, formed by union of tibial & peroneal veins  
*once it reaches femur, popliteal vein becomes femoral vein, which receives blood from great saphenous vein & deep femoral vein, which collects blood from thigh
*femoral vein then penetrates body wall & emerges in pelvic cavity as **external iliac vein**

*Veins Draining Pelvis
*external iliac veins receive blood from lower limbs, pelvis, & lower abdomen
*internal iliac veins (which drain pelvic organs) join right & left external iliac veins across inner surface of ilium
*common iliac vein: union of external & internal iliac veins

*Veins Draining Abdomen
*collects blood from six major veins:  
  * **lumbar veins**: drain lumbar portion of abdomen, including spinal cord & body wall muscles  
  * **gonadal veins**: drain ovaries or testes; right usually empties into inferior vena cava & left generally drains in left renal vein  
  * **hepatic veins**: leave liver & empty into inferior vena cava  
  * **renal veins**: collect blood from kidneys; largest tributaries of inferior vena cava  
  * **suprarenal veins**: drain adrenal glands; generally only right suprarenal vein drains into inferior vena cava, & left drains into left renal vein  
  * **phrenic veins**: drain diaphragm; only right phrenic vein drains into inferior vena cava; left drains into left renal vein

*Hepatic Portal System
*liver is only digestive organ drained by inferior vena cava
*hepatic portal system: system where blood leaving capillaries supplied by celiac, superior, & inferior mesenteric arteries flow into
*portal vessel: blood vessel connecting 2 capillary beds
*hepatic portal vessels contain substances absorbed by stomach & intestines
*system delivers these substances directly to liver for storage, metabolic conversion, or excretion
*tributaries of hepatic portal vein:  
  * **inferior mesenteric vein**: collects blood from capillaries along lower portion of large intestine  
    * its tributaries include **left colic vein** & **superior rectal veins** which drain descending colon, sigmoid colon, & rectum  
  * **splenic vein**: formed by union of inferior mesenteric vein & veins from spleen, lateral border of stomach, & pancreas  
  * **superior mesenteric vein**: collects blood from veins draining stomach, small intestine, & two-thirds of large intestine
*hepatic portal veins forms through fusion of superior mesenteric vein (normally contributes greater volume & most nutrients) & splenic veins
*as it proceeds toward liver, portal receives blood from **gastric veins**, which drain medial border of stomach, & **cystic vein** from gallbladder

**Fetal Circulation**
*all embryonic nutritional & respiratory needs are provided by diffusion across placenta

**Placental Blood Supply**
*umbilical arteries: provides blood flow to placenta; arises from internal iliac arteries & enter umbilical cord
*umbilical vein: returns blood from placenta, bringing oxygen & nutrients to developing fetus
*drains into **ductus venosus**, which is connected to intricate network of veins within developing liver; also collects blood from veins of liver & from umbilical vein & empties into inferior vena cava

**Aging & Cardiovascular System**

*age-related changes in blood
*decreased hematocrit
*constriction or blockage of peripheral veins by thrombus
*pooling of blood in veins of legs because valves are not working properly

*aging heart
*reduction in maximum cardiac output
*changes in activities of nodal & conducting cells
*reduction in elasticity of fibrous skeleton
*progressive atherosclerosis that can restrict coronary circulation
*replacement of damaged cardiac muscle cells by scar tissue

*aging & blood vessels
*inelastic walls of arteries become less tolerant of sudden pressure increases
*calcium salts can be deposited on weakened vascular walls, increasing risk of stroke or myocardial infarction
*thrombi can form at atherosclerotic plaques