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

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
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

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

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

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

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**

- 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

**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
- 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 ($\Delta P$) between two points in the circulation
  - If $\Delta P$ increases, blood flow speeds up; if $\Delta P$ decreases, blood flow declines
- Blood flow is inversely proportional to resistance (R)
  - If R increases, blood flow decreases
- R is more important than $\Delta P$ 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

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)

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

**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

**Cardiac Output (CO)**
- Under stress, the cardioacceleratory center increases heart rate and stroke volume
  - The end systolic volume (ESV) decreases and MAP increases
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 (O₂, CO₂, 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: 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 perfusion 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**

- Decreased arterial pressure
- Baroreceptors
- Decreased renal perfusion pressure
- Increased sodium intake
- Increased ADH release
- Increased aldosterone release
- Increased renal sodium reabsorption
- Increased arterial pressure
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

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

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
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: 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
Capillary Exchange: Fluid Movements

- Direction of movement depends upon the difference between:
  - Capillary hydrostatic pressure ($H_P$)
  - Capillary colloid osmotic pressure ($O_P$)
- $H_P$ – 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
- $O_P$ – created by nondiffusible plasma proteins, which draw water toward themselves

Net Filtration Pressure (NFP)

- NFP – considers all the forces acting on a capillary bed
- $NFP = (H_P - H_d) - (O_P - O_d)$
- 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)

- 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

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<th>Arteries</th>
<th>Veins</th>
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<tbody>
<tr>
<td>Delivery</td>
<td>Blood pumped into single systemic artery – the aorta</td>
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<tr>
<td></td>
<td>Blood returns via superior and inferior venae caveae and the coronary sinus</td>
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<tr>
<td>Location</td>
<td>Deep, and protected by tissue</td>
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<tr>
<td></td>
<td>Both deep and superficial</td>
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<tr>
<td>Pathways</td>
<td>Flat, clear, and defined</td>
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<td>Supply/Drainage</td>
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