CHAPTER 19

The Cardiovascular System: Blood Vessels
Blood Vessels

- Closed system
  - begins and ends with heart

- The three major types of vessels are:
  - **Arteries**
    - Carry blood away from the heart; oxygenated except for pulmonary circulation and umbilical vessels of fetus
  - **Veins**
    - Carry blood toward the heart; deoxygenated except in pulmonary circulation
  - **Capillaries**
    - Contact tissue cells and directly serve cellular needs
Structure of Blood Vessel Walls

- Arteries & veins
  - Tunica intima, tunica media, tunica externa
- Lumen
  - Central blood-containing space
- Capillaries
  - Mostly endothelium
Structure of Blood Vessels

- **Tunica intima**
  - Endothelium
  - Subendothelial layer
- Internal elastic lamina
- **Tunica media**
  - (smooth muscle and elastic fibers)
- External elastic lamina
- **Tunica externa**
  - (collagen fibers)

**Artery**
- Lumen
- Capillary network
- Basement membrane
- Endothelial cells

**Vein**
- Lumen
- Valve

**Capillary**
Tunics of Blood Vessels

- **Tunica intima** (deepest)
  - endothelium lines the lumen

- **Tunica media** (middle)
  - Smooth muscle & sheets of elastin
  - Sympathetic nerve fibers control vasoconstriction & vasodilation of vessels

- **Tunica externa** (tunica adventitia – superficial)
  - Collagen fibers protect & reinforce
  - Larger vessels also contain vasa vasorum to nourish this external layer
# Blood Vessel Anatomy

## Table 19.1 Summary of Blood Vessel Anatomy

<table>
<thead>
<tr>
<th>Vessel Type/Illustration*</th>
<th>Average Lumen Diameter (D) and Wall Thickness (T)</th>
<th>Relative Tissue Makeup</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Elastic artery</strong></td>
<td>D: 1.5 cm T: 1.0 mm</td>
<td>Endothelium, Elastic Tissues, Smooth Muscles</td>
</tr>
<tr>
<td><strong>Muscular artery</strong></td>
<td>D: 6.0 mm T: 1.0 mm</td>
<td>Endothelium, Elastic Tissues, Smooth Muscles</td>
</tr>
<tr>
<td><strong>Arteriole</strong></td>
<td>D: 37.0 μm T: 6.0 μm</td>
<td>Endothelium, Elastic Tissues, Smooth Muscles, Fibrous (Collagenous) Tissues</td>
</tr>
</tbody>
</table>

*Size relationships are not proportional. Smaller vessels are drawn relatively larger so detail can be seen. See column 2 for actual dimensions.
Arterial system

The arteries of the body can be divided into three divisions based on size and function:

- Elastic (conducting) arteries
- Muscular (distributing) arteries
- Arterioles (resistance vessels)
Elastic (Conducting) Arteries

- Large thick-walled arteries with elastin in all 3 tunics
- Includes aorta and its major branches
- Large lumen allow low-resistance conduction of blood
- Act as pressure reservoirs – expand and constrict as blood is ejected from heart
Muscular (Distributing) Arteries and Arterioles

- **Muscular arteries**
  - Diverge from elastic arteries; deliver blood to body organs
  - Have thick tunica media with more smooth muscle
  - Active in vasoconstriction

- **Arterioles**
  - Smallest arteries; lead to capillary beds
  - Control blood flow into capillary beds via vasodilation and vasoconstriction
Capillaries

- Smallest blood vessels (microscopic)
- Walls consisting of thin tunica intima, one cell thickness
- Pericytes: cells on the outer surface stabilize capillary walls & control permeability
- Diameter only allows a single RBC to pass at a time
- Function: exchanges of gases, nutrients, and metabolic wastes between tissue and blood
Vascular Components

- Venous system
  - Large veins
  - Venous capillaries
- Arterial system
  - Elastic arteries (conducting vessels)
  - Muscular arteries (distributing vessels)
- Lymphatic system
  - Lymph nodes
- Arteriovenous anastomosis
- Lymphatic capillary
- Postcapillary venule
- Sinusoid
- Capillaries (exchange vessels)
- Precapillary sphincter
- Metarteriole
- Thoroughfare channel

(b) Pie chart showing:
  - Pulmonary blood vessels 12%
  - Systemic arteries and arterioles 15%
  - Heart 8%
  - Systemic veins and venules 60%
  - Capillaries 5%
Three Types of Capillaries

- **Continuous capillaries**: abundant in the skin and muscles
  - Endothelial cells with tight junctions provide a continuous lining
  - Intercellular clefts (gaps) allows passage of fluids
    - everywhere but in the brain—blood brain barrier—tight junctions only

- **Fenestrated capillaries**
  - oval-shaped pores (fenestrations) that permit greater absorption and filtration (i.e. more permeable)
    - Found in small intestines and kidneys

- **Sinusoidal capillaries** (sinusoids)
  - Fewer tight junctions, large intracellular clefts, large lumens
  - Usually fenestrated; allows passage of large molecules & blood
    - Found in liver (lined with phagocytes), bone marrow, spleen
Continuous Capillaries

(a) **Continuous capillary.** Least permeable, and most common (e.g., skin, muscle).
(b) **Fenestrated capillary.** Large fenestrations (pores) increase permeability. Occurs in special locations (e.g., kidney, small intestine).
Sinusoids

(c) Sinusoidal capillary. Most permeable. Occurs in special locations (e.g., liver, bone marrow, spleen).
Capillary Beds

- Interwoven networks of capillaries form the microcirculation between arterioles & venules
- Consist of two types of vessels:
  - **Vascular shunts**
    - Aka: metarteriole; thoroughfare channel
    - Directly connects arteriole with a postcapillary venule
  - **True capillaries**
    - 10 to 100 exchange vessels per capillary bed
    - branch off the metarteriole or terminal arteriole
    - Flow of blood through these vessels is regulated by precapillary sphincters (muscle)
Capillary Beds

Sphincters when constricted divert blood flow through the vascular shunt:

Ex. Sphincters are closed in the intestines when not digesting food.

(a) Sphincters open—blood flows through true capillaries.

(b) Sphincters closed—blood flows through metarteriole—thoroughfare channel and bypasses true capillaries.
Venous System

- Blood returns to the heart via veins
- There are typically two types of venous vessels:
  - Venules
    - Very porous; allows fluids & WBCs into tissues
    - Smallest originate as postcapillary venules with single endothelial layer and occasional pericytes; larger venules have 1 or 2 layers of smooth muscle
  - Veins
    - Formed when venules converge; BP lower than in arteries
    - Called capacitance vessels (blood reservoirs)
    - 3 tunics; externa is thickest
Venous System: Veins

- Lower blood pressure than arteries
- Special adaptations to ensure return blood:
  - Large-diameter lumens: offer little resistance to blood flow
  - Valves prevent backflow of blood
    - Varicose veins and hemorrhoids are the result of incompetent valves (valve failure)
- Venous sinuses: flattened veins with extremely thin walls (coronary sinus of heart & dural sinus of brain)
Factors Aiding Venous Return

- Valve (open)
- Contracted skeletal muscle
- Valve (closed)
- Vein
- Direction of blood flow
Valve failure in veins

- Varicose veins
- Hemorrhoids
Physiology of Circulation: Terms

- Blood Flow
- Blood Pressure
  - Systemic blood pressure
  - Arterial blood pressure
  - Capillary blood pressure
  - Venous blood pressure
- Resistance (peripheral resistance)
- Cardiac output
Physiology of Circulation: Blood Flow

- Volume of blood flowing through a vessel, organ, or the entire circulation at a given period
  - Measured in mL per min
  - Equivalent to cardiac output (CO) for entire vascular system
  - Relatively constant when at rest
  - Varies through individual organs – based on needs
Blood Flow Through Body Tissues

- Blood flow (tissue perfusion) is involved in:
  - Delivery of O2 & nutrients, waste removal from tissues and cells; Gas exchange (lungs); GI absorption; urine formation

- Rate of flow is precisely correct to provide proper function:
  - Slowest in capillaries – allows adequate time for exchange between blood and tissues
  - Fastest in the aorta – as blood exits left ventricle to body

![Diagram showing blood flow rates in different body parts]
Velocity of Blood Flow

Velocity of blood flow (cm/s)

Aorta, Arteries, Arterioles, Capillaries, Venules, Veins, Venae cavae
Autoregulation: automatic adjustment of blood flow to each tissue in proportion to tissue’s requirements (intrinsic)

Regulated by local conditions (independent of systemic conditions)

- **Metabolic controls:** based on O2 and nutrients
  - Major ones: Nitric oxide – vasodilator; Endothelins- vasoconstrictors

- **Myogenic controls:** through vascular smooth muscle
  - Resist/permit stretch within vessel

- **Angiogenesis:** inc # or size of blood vessels (long-term)
Blood Flow in Special Areas

- **Skeletal muscle**
  - blood is shunted to muscles as needed

- **Brain**
  - very sensitive to H+ and CO2 concentration
    - High CO2 normally causes constriction in Blood vessels - this does not happen in the brain– vasodilation to ensure perfusion

- **Skin**
  - blood flow provides nutrients & O2, regulates temperature
    - When body temp increases > blood flow to skin increases to get rid of excess heat
    - When body temp decreases > blood flow to skin decreases diverting blood to more vital organs
Physiology of Circulation: Blood Pressure (BP)

- Force per unit area exerted on the wall of a blood vessel by blood
  - Expressed in millimeters of mercury (mm Hg)
    - Based on original methods for measuring BP
  - Typically describes the arterial systemic BP in large arteries near the heart
- Blood moves from higher to lower pressure areas (pressure gradient)
Physiology of Circulation: Arterial Blood Pressure

- Reflects 2 factors of the arteries close to the heart
  - Elasticity
  - Volume of blood forced into arteries at any time
- Systolic pressure
  - Exerted during ventricular contraction
- Diastolic pressure
  - Lowest level of arterial pressure
- Pulse pressure
  - Difference between systolic & diastolic
- Mean Arterial Pressure (MAP): pressure that propels blood through tissues (diastolic + 1/3 pulse pressure)
Blood Pressure (BP)

systolic pressure (ventricular systole) = 120mmHg
Diastolic pressure (ventricular diastole) = 80 mmHg
Physiology of Circulation:
Pulse & Pulse Pressure

- **Pulse**
  - # of cardiac cycles/min
  - Palpitating the systolic pressure surges

- **Pulse pressure**
  - systolic pressure minus diastolic pressure
  - chronic increase can indicate arteriosclerosis
    - Hardening of arteries
Physiology of Circulation: Resistance

- Resistance (peripheral resistance- PR)
  - opposition to flow (amount of friction blood encounters)
  - Encountered in the peripheral systemic circulation

- The three important sources of resistance:
  - blood viscosity: remains relatively constant; “stickiness”
  - total blood vessel length: remains relatively constant
    - longer length = longer resistance encountered
  - blood vessel diameter: changes with dilation/constriction
    - Small-diameter arterioles are major determinant of PR
      - plaque build up decreases diameter
      - sympathetic nervous system activation dec. diameter also (constriction)
Relationship of BP, CO and PR

- **BP = CO x PR** (know these equations)
  - **CO = (HR x SV)**

- Keep in mind anything that affects CO or PR will affect BP
  - Increase CO or PR ... BP will increase
  - Decrease CO or PR ... BP will decrease
Systemic Blood Pressure

Highest in aorta

Declines throughout pathway

Largest drop in blood pressure is in the arterioles
Physiology of Circulation: Capillary Blood Pressure

- Blood pressure entering the capillaries
  - Ranges from 15-35 mmHg
  - Low is desirable
    - High BP would rupture capillaries

- Low BP is sufficient to force filtrate out into interstitial space and distribute nutrients, gases, and hormones between blood and tissues

- Increases in pressure can result in permanent damage—renal failure for example
Maintaining Blood Pressure

- Requires:
  - Cooperation of the heart, blood vessels, and kidneys
  - Supervision by the brain

- The main factors influencing blood pressure are:
  - Cardiac output \( (CO) = SV \times HR \)
  - Peripheral resistance \( (PR) \)
    - anything that increases friction and opposes flow
    - Blood pressure \( (BP) = CO \times PR \)
  - Blood volume
    - typically, the amount of water in the blood
    - ↑ volume will ↑ BP
Control of Blood Pressure

- **Goal**: Maintain BP for adequate perfusion of organs

- **Accomplished through:**
  - **Short-term neural and hormonal control**
    - Counteract fluctuations in BP by altering peripheral resistance
      - Neural
        - Cardiovascular center .......... cardiac + vasomotor (vessels)
        - Baroreceptor reflexes (stretch receptors)
        - Chemoreceptor reflexes (oxygen, pH, carbon dioxide)
  - **Long-term renal regulation**
    - Counteract fluctuations in BP by altering blood volume
Short-term Control of BP: Role of Vasomotor Center

- Cardiovascular Center = Cardiac centers + vasomotor center
  - Control blood pressure by altering cardiac output and blood vessel diameter
- Vasomotor center (cluster of sympathetic neurons)
  - Located in the medulla; controls blood vessel diameter
  - Uses sympathetic nervous system to maintain blood vessel tone (vasomotor tone) by innervating smooth muscles of blood vessels, especially arterioles
    - Sympathetic activity causes: Vasoconstriction, BP to decline if decreased
  - Vasomotor activity is modified by:
    - Baroreceptors (pressure-sensitive), chemoreceptors (O2, CO2, and H+ sensitive), higher brain centers, blood borne chemicals, and hormones
Baroreceptors are located in:
- Carotid sinuses
- Aortic arch
- Walls of large arteries of the neck and thorax

Respond to stretch from inc. pressure

Inc BP > stimulates baroreceptors to increase input to vasomotor and cardioinhibitory center> inc vessel diameter & dec HR
Baroreceptor modification of the vasomotor center and the cardiac centers (cardiovascular center)
1. **Stimulus:**
   - **Blood pressure** (arterial blood pressure rises above normal range).

2. **Baroreceptors in carotid sinuses and aortic arch are stimulated.**

3. **Impulses from baroreceptors stimulate cardioinhibitory center (and inhibit cardioacceleratory center) and inhibit vasomotor center.**

4. **Sympathetic impulses to heart cause \( \downarrow \) HR, \( \downarrow \) contractility, and \( \downarrow \) CO.**
   - **Rate of vasomotor impulses allows vasodilation, causing \( \downarrow R \).**

5. **CO and \( \downarrow \) R return blood pressure to homeostatic range.**

**Homeostasis:** Blood pressure in normal range.
Homeostasis: Blood pressure in normal range

1. Stimulus: Blood pressure (arterial blood pressure falls below normal range).

2. Baroreceptors in carotid sinuses and aortic arch are inhibited.

3. Impulses from baroreceptors stimulate cardioacceleratory center (and inhibit cardioinhibitory center) and stimulate vasomotor center.

4a. Sympathetic impulses to heart cause ↑ HR, ↑ contractility, and ↑ CO.

4b. Vasomotor fibers stimulate vasoconstriction, causing ↑ R.

5. ↑ CO and ↑ R return blood pressure to homeostatic range.
Short Term Control of BP: Chemoreceptors

- Located in:
  - carotid sinus
  - aortic arch (aortic bodies)
  - large arteries of neck

- sensitive to rise in CO2, drop in pH or O2

- Transmit impulses to cardioacceleratory center > inc CO; also to vasomotor center > vasoconstriction; >> increase BP to speed return of blood to heart

- Discuss regulation of CO2 & O2 and pH more in Respiratory Chapter 22
Control of BP: Hormonal Controls

- **Adrenal medulla hormones**: released in times of stress
  - NE and Epi increase vasoconstriction and heart rate >> inc BP

- **Atrial Natriuretic Peptide (ANP)**: released by atria
  - dec. aldosterone and renin secretion and vasodilation >> dec. blood volume & dec. BP

- **Antidiuretic hormone (ADH)**: released when BP falls very low
  - causes intense vasoconstriction >> inc BP
  - Also stimulates kidneys to conserve water

- **Angiotensin II**: released in low renal perfusion
  - kidney are stimulated to release of renin which generates angiotensin II
    - Initially creates vasoconstriction (short term) >> inc BP
    - long term >> stim aldosterone & ADH release >> inc blood volume >> inc BP
Control of BP:

Hormonal (Chemical) Controls

- **Nicotine**: Vasoconstrictor >> inc BP

- **Endothelium-derived factors**
  - endothelin (Ca entry into smooth muscle) and prostaglandin-derived growth factor (PDGF) are both vasoconstrictors (local)

- **Nitric oxide (NO)**: is a brief, but potent vasodilator

- **Inflammatory chemicals**: ex. histamine, potent vasodilators

- **Alcohol**: inhibiting ADH >> depresses vasomotor center >> vasodilatation (esp. in skin) >> causes BP to drop
<table>
<thead>
<tr>
<th>HORMONE</th>
<th>EFFECT ON BP</th>
<th>EFFECT ON VARIABLE</th>
<th>SITE OF ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epinephrine and norepinephrine (NE)</td>
<td>↑</td>
<td>↑ CO (HR and contractility)</td>
<td>Heart (β₁ receptors)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>↑ Peripheral resistance (vasoconstriction)</td>
<td>Arterioles (α receptors)</td>
</tr>
<tr>
<td>Angiotensin II</td>
<td>↑</td>
<td>↑ Peripheral resistance (vasoconstriction)</td>
<td>Arterioles</td>
</tr>
<tr>
<td>Atrial natriuretic peptide (ANP)</td>
<td>↓</td>
<td>↓ Peripheral resistance (vasodilation)</td>
<td>Arterioles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>↓ Blood volume (↑ water and salt loss)</td>
<td>Kidney tubule cells</td>
</tr>
<tr>
<td>Antidiuretic hormone (ADH)</td>
<td>↑</td>
<td>↑ Peripheral resistance (vasoconstriction)</td>
<td>Arterioles</td>
</tr>
<tr>
<td>Aldosterone</td>
<td>↑</td>
<td>↑ Blood volume (↓ water and salt loss)</td>
<td>Kidney tubule cells</td>
</tr>
<tr>
<td>Cortisol</td>
<td>↑</td>
<td>↑ Blood volume (↓ water and salt loss)</td>
<td>Kidney tubule cells</td>
</tr>
</tbody>
</table>

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Long-Term Control of BP: Renal Regulation

- Mechanisms control BP by altering blood volume
  - Note: Baroreceptors are great for short term control but they soon adapt to chronic high or low BP

- Long term regulation of BP is by the kidneys
  - Direct renal mechanism
    - alters blood volume by varying reabsorption capabilities
      - Increased BP stimulates the kidneys to eliminate water, thus reducing BP
      - Decreased BP stimulates the kidneys to increase blood volume and BP
  - Indirect mechanism (renin-angiotensin)
Long Term Control of BP: Indirect Renal Regulation

- Renin-angiotensin mechanism
  - ↓Arterial blood pressure > release of renin
  - Renin > production of angiotensin II
    - Angiotensin II is a potent vasoconstrictor
  - Angiotensin II > aldosterone secretion
    - Aldosterone > renal reabsorption of Na+ and ↓urine formation
  - Angiotensin II stimulates ADH release
↓ Arterial pressure

Direct renal mechanism

Indirect renal mechanism (hormonal)

Baroreceptors

Sympathetic stimulation promotes renin release

Kidney

Renin release

Angiotensin II

↓ Filtration

ADH release by posterior pituitary

Aldosterone secretion by adrenal cortex

↑ Water reabsorption by kidneys

↑ Sodium reabsorption by kidneys

↑ Blood volume

Vasoconstriction (↓ diameter of blood vessels)

↑ Arterial pressure

Initial stimulus

Physiological response

Result

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Maintaining Systemic Blood Pressure

- **Activity of muscular pump and respiratory pump**: ↑
- **Release of ANP**: ↓
- **Fluid loss from hemorrhage, excessive sweating**: ↓
- **Crisis stressors: exercise, trauma, ↑ body temperature**: ↓
- **Bloodborne chemicals: epinephrine, NE, ADH, angiotensin II; ↓ ANP release**: ↓
- **Dehydration, high hematocrit**: ↓
- **Body size**: ↑

**Conservation of Na⁺ and water by kidney**: ↑

**Blood volume**: ↓

**Blood pressure**: ↓

**Blood pH, ↓ O₂, ↑ CO₂**: ↓

**Baroreceptors**: ↓

**Chemoreceptors**: ↓

**Activation of vasomotor and cardiac acceleration centers in brain stem**: ↓

**Venous return**: ↑

**Stroke volume**: ↑

**Heart rate**: ↑

**Diameter of blood vessels**: ↓

**Blood viscosity**: ↑

**Blood vessel length**: ↑

**Peripheral resistance**: ↑

**Cardiac output**: ↑

**Mean systemic arterial blood pressure**: ↑

Legend:
- Initial stimulus
- Physiological response
- Result
Alterations in Blood Pressure

- **Hypotension**: low blood pressure
  - Systolic below 100 mm Hg
  - Promotes long life & cardiovascular health

- **Hypertension**: high blood pressure
  - Sustained 140/90 or higher
  - May be transient - caused by fever, physical exertion, and emotional upset
Homeostatic Imbalance: Hypotension

- **Orthostatic hypotension**
  - drop when changing position; common in elderly
  - sympathetic NS responds slower to posture change

- **Chronic hypotension**
  - poor nutrition
  - Addison’s disease (adrenal cortex function), hypothyroidism

- **Acute hypotension**
  - important sign of circulatory shock
  - threat to patients undergoing surgery and those in intensive care units
Homeostatic Imbalances: Hypertension

- Chronic elevation is a major cause of heart failure, vascular disease, renal failure, and stroke

- **Primary** or **Essential hypertension**
  - 90% of cases
  - Due to several risk factors: heredity, diet, obesity, age, stress, diabetes mellitus, smoking

- **Secondary hypertension**
  - Less common
  - Due to identifiable disorders: kidney disease, arteriosclerosis, endocrine disorders (hyperthyroidism, Cushing’s syndrome)
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 (low blood volume)
    - results from large-scale blood loss
  - Vascular shock
    - poor circulation resulting from extreme vasodilation
  - Cardiogenic shock (pump failure)
    - the heart cannot sustain adequate circulation
Hypovolemic shock

Acute bleeding (or other events that cause blood volume loss) leads to:
1. Inadequate tissue perfusion resulting in ↓ O₂ and nutrients to cells
2. Anaerobic metabolism by cells, so lactic acid accumulates
3. Movement of interstitial fluid into blood, so tissues dehydrate

Chemoreceptors activated (by ↓ in blood pH)
- Activation of respiratory centers
- ↑ Heart rate
- ↑ Rate and depth of breathing
- CO₂ blown off; blood pH rises
- Tachycardia, weak, thready pulse

Baroreceptor firing reduced (by ↓ blood volume and pressure)
- Cardioacceleratory and vasomotor centers activated
- Intense vasoconstriction (only heart and brain spared)
- Renal blood flow ↓
- Renin released
- Aldosterone released
- Kidneys retain salt and water
- Water retention
- ↓ Urine output
- Thirst
- Restlessness (early sign)
- Coma (late sign)

Hypothalamus activated (by ↓ pH and ↓ blood pressure)
- Sympathetic nervous system activated
- ADH released
- Kidneys retain salt and water
- Water retention
- Thirst
- Restlessness (early sign)
- Coma (late sign)

Brain
- Neurons depressed by ↓ pH
- Central nervous system depressed