Cardiovascular System

Blood Vessels

- Delivery system of dynamic structures
- Closed system
  - Arteries
    - Carry blood away from the heart
  - Capillaries
    - Contact tissue cells and directly serve cellular needs
  - Veins
    - Carry blood toward the heart

Blood Vessel Structure

- Tissue layers
  - Tunica intima
  - Tunica media
  - Tunica externa
Blood Vessel Structure

Arteries of the head and trunk
- Internal carotid artery
- External carotid artery
- Common carotid arteries
- Vertebral artery
- Subclavian artery
- Brachiocephalic trunk
- Aortic arch
- Ascending aorta
- Coronary artery
- Thoracic aorta (above diaphragm)
- Celiac trunk
- Abdominal aorta
- Superior mesenteric artery
- Renal artery
- Gonadal artery
- Common iliac artery
- Inferior mesenteric artery
- Internal iliac artery

(b) Illustration, anterior view

Arteries that supply the upper limb
- Subclavian artery
- Axillary artery
- Brachial artery
- Radial artery
- Ulnar artery
- Deep palmar arch
- Superficial palmar arch

Arteries that supply the lower limb
- External iliac artery
- Femoral artery
- Popliteal artery
- Anterior tibial artery
- Posterior tibial artery
- Arterioles

Table 19.1 (1 of 2)

**Arteries**

- Transport blood from left ventricle to body tissues
  - High pressure
- Three groups
  - Elastic (conducting)
  - Muscular (distributing)
  - Arterioles (resistance)

**Arteries**

- Elastic arteries
  - Near the heart
    - Aorta and major branches
  - Conducting arteries
    - Conduct blood from the heart to medium-sized arteries
    - Large and thick-walled
    - Large lumen = low resistance
  - Highly elastic
    - Expand during systole & recoil during diastole
Arteries

- Muscular arteries
  - Distributing arteries
    - Distal to elastic arteries
    - Deliver blood to body organs
  - Thick tunica media with more smooth muscle
  - Active in vasoconstriction
  - Examples
    - Radial, femoral, brachial

- Resistance arteries
  - Smallest arterial vessels (arterioles)
  - Lead to capillary beds
  - Control valves to capillary beds
  - Site of most vasodilation and vasoconstriction

Capillaries

- Exchange vessels
- Exceedingly thin walls – just a tunica intima
- Capillary beds
  - Microcirculation between arterioles and venules

- Two types
  1. Continuous
    - Open junctions between adjacent endothelial cells
    - Most common
    - In skin & muscles
  2. Fenestrated
    - Pores = permeable
    - Intestines, endocrine organs, kidneys

Capillaries

- Precapillary sphincters
  - Cuff of smooth muscle fibers
  - Acts as a valve to control blood flow into the capillary
  - Responds to local chemical conditions
  - Vasomotor nerves (sympathetic)
Continuous Capillaries

- Abundant in the skin and muscles
  - Tight junctions connect endothelial cells
  - Intercellular clefts allow the passage of fluids and small solutes

Continuous Capillaries

- Continuous capillaries of the brain
  - Tight junctions are complete, forming the blood-brain barrier

(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).
Capillaries

- **Functions**
  - Exchange area for blood and interstitial fluid compartment
  - Diffusion
    - O₂ and nutrients from the blood to tissues
    - CO₂ and metabolic wastes from tissues to the blood

Veins

- **Functions**
  - Collect blood from capillary beds
  - “Drain” organs and tissues of blood
  - Become larger as they come closer to the heart

Venules

- **Functions**
  - Formed when capillary beds unite
  - Very porous
    - Allow fluids and WBC’s into tissues
Veins

- Thinner walls, larger lumens than arteries
- Blood pressure is lower than in arteries
- Thin tunica media and a thick tunica externa
- Capacitance vessels (blood reservoirs)
  - Contain up to 60% of the blood supply

Venous Blood Pressure

- Low pressure
  - Due to cumulative effects of peripheral resistance
- Working against gravity
  - Valves
  - Skeletal muscle action
  - Thoracic pressure changes

Blood Vessel Matching

1. Pump
2. Resistance vessels, site of most vasodilation and vasoconstriction
3. Exchange sites
4. Pressure reservoirs, conducting vessels
5. Blood reservoirs
6. Distributing vessels

- Veins
- Arterioles
- Capillaries
- Heart
- Elastic arteries
- Muscular arteries

Venous Valves

Venous Blood Pressure

- Low pressure
  - Due to cumulative effects of peripheral resistance
- Working against gravity
  - Valves
  - Skeletal muscle action
  - Thoracic pressure changes
Varicose Veins

- Incompetent valves
  - Pregnancy
  - Obesity
  - Long periods of standing
  - Hemorrhoids

Blood Flow

- Blood flow is involved in
  - $O_2$ delivery
  - Removal of wastes
  - Gas exchange (lungs)
  - Absorption of nutrients (digestive tract)
  - Urine formation (kidneys)

Blood Flow

- Perfusion
  - Rate of blood flow per given volume of tissue
- Blood flow (F)
  - Volume of blood flowing through a vessel, an organ, or tissue in a given period
  - Measured as ml/min
  - Varies widely through individual organs
    - Based on needs

Blood Flow

- $F= \frac{\Delta P}{R}$
  - $F$ = Blood flow
  - $\Delta P$ = Difference in pressure between two points
  - $R$ = Resistance

Blood Flow

- Blood pressure (BP)
  - Force per unit area exerted on the wall blood vessel by the blood
  - Expressed as the height of a column of mercury (mmHg)
  - $P = H \times D$
    - $P$ = pressure
    - $H$ = height of column
    - $D$ = density of material in the column
Blood Pressure

- Factors influencing blood pressure
  - Cardiac output (CO)
  - Peripheral resistance (PR)
  - Blood volume

Blood Pressure

- Systolic pressure
  - Pressure exerted during ventricular contraction
    - Top number
- Diastolic pressure
  - Lowest level of arterial pressure
    - Bottom number
- Average value = 120/80
- Pulse pressure
  - Difference between systolic and diastolic pressure

Arterial Blood Pressure

- Reflects two factors of the arteries close to the heart
  - Elasticity
  - Volume of blood forced into them at any time
- Blood pressure near the heart is pulsatile

Arterial Blood Pressure

- Mean arterial blood pressure (MABP)
  - Pressure that propels blood to tissues
  - Represents average blood pressure

\[ \text{MABP} = \text{diastolic pressure} + \frac{1}{3} \text{pulse pressure} \]

_Pulse pressure and MABP both decline with increasing distance from the heart_
Hypertension

- “Silent Killer”
  - Resting systolic >140 mmHg and/or diastolic >90 mmHg
- Causes
  - Loss of flexibility in vessel walls
- Results
  - Heart failure
  - Renal failure
  - Stroke
  - Increased risk of aneurysm

Capillary Blood Pressure

- Not pulsatile
- Low capillary pressure is desirable
  - High BP would rupture fragile, thin-walled capillaries
  - Most are very permeable, so low pressure forces filtrate into interstitial spaces

Peripheral Resistance

- The opposition to blood flow exerted by vessel walls
  - The result of friction
- Influenced by 3 factors
  - Blood viscosity
  - Blood vessel length
  - Blood vessel radius

Peripheral Resistance

- Viscosity = a fluid’s resistance to flow
- Blood viscosity influenced by...
  - Albumin
  - Erythrocytes

Peripheral Resistance

- Vessel length
  - The farther fluid travels = more cumulative friction

Peripheral Resistance

- Vessel radius
  - Most significant factor
  - Vasoconstriction and vasodilation
  - Flow is proportional to fourth power of radius
    - Alteration of radius profoundly affects blood flow
Poiseuille’s Law

• Formula representing the factors influencing flow

\[ F = \frac{\Delta P \pi r^4}{8 nL} \]

- \( F \) = flow
- \( \Delta P \) = pressure gradient
- \( r^4 \) = vessel radius
- \( n \) = viscosity
- \( L \) = vessel length

Poiseuille’s Law

• Blood flow is directly proportional to pressure gradient and vessel radius

\[ F = \frac{\Delta P \pi r^4}{8 nL} \]

Poiseuille’s Law

• Blood flow is inversely proportional to vessel length and blood viscosity

\[ F = \frac{\Delta P \pi r^4}{8 nL} \]

Regulation of Peripheral Resistance

• Local control
  - Arterioles vary diameters = autoregulation
  - A response to the chemical composition of the blood
    - Faster flow = faster removal of wastes

Regulation of Peripheral Resistance

• Local control
  - Precapillary sphincters
    - Respond to local stimuli and vasoactive hormones
  - Endothelial cells & platelets
    - Vasodilators
      - NO, prostacyclin
    - Vasconstrictors
      - Endothelins, serotonin, thromboxane A₂
**Figure 19.15**

**Metabolic controls**
- Sympathetic α receptors
- β receptors
- Epinephrine, norepinephrine
- Angiotensin II
- Antidiuretic hormone (ADH)
- Atrial natriuretic peptide (ANP)
- Dilates
- Prostaglandins
- Adenosine
- Nitric oxide
- Endothelins
- Stretch

**Amounts of:**
- O2
- CO2
- K+

**Myogenic controls**
- Nerves
- Hormones

**Intrinsic mechanisms (autoregulation)**
- Distribute blood flow to individual organs and tissues as needed

**Extrinsic mechanisms**
- Maintain mean arterial pressure (MAP)
- Redistribute blood during exercise and thermoregulation

**Peripheral Resistance**

- Example of autoregulation
  - Blood flow to skeletal muscles
    - During muscle activity, blood flow increases in direct proportion to the metabolic activity
    - Blood flow can increase 10× or more during physical activity

- Neural control
  - Directed by ANS via sympathetic innervation
    - Vascular smooth muscle lacks parasympathetic input

- Baroreflex
  - Baroreceptors (pressure receptors) in
    - Carotid sinuses
    - Aortic arch
  - Example: Blood pressure increases
    - Inhibitory signals are sent to the vasomotor center
    - Stimulatory signals are sent to the cardioinhibitory center (which acts through which nerve?)
Baroreceptors in carotid sinuses and aortic arch are stimulated. Impulses from baroreceptors stimulate cardioinhibitory center and inhibit vasomotor center.

Rate of vasomotor impulses allows vasodilation, causing R. Sympathetic impulses to heart cause HR, contractility, and CO.

Stimulus: Blood pressure (arterial blood pressure rises above normal range).

Homeostasis: Blood pressure in normal range. CO and R return blood pressure to homeostatic range.

Baroreceptors in carotid sinuses and aortic arch are inhibited. Impulses from baroreceptors stimulate cardioacceleratory center and stimulate vasomotor center. Vasomotor fibers stimulate vasoconstriction, causing R. Sympathetic impulses to heart cause HR, contractility, and CO.

CO and R return blood pressure to homeostatic range.

Peripheral Resistance

• Chemoreflex
  – Excitatory or inhibitory signals to vasomotor center
  – Chemoreceptors detect low blood pH and high CO₂ levels
  – Chemoreceptors are located in the
    • Carotid bifurcation
    • Aortic arch
    • Large arteries of the neck

Peripheral Resistance

• Medullary Ischemic Reflex
  – Triggered by low perfusion of the medulla
  
  Hypoxia and hypercapnia (high blood CO₂) of the brain
  
  Vasoconstriction in extremities

Midline ischemic haplotyping
  Blood flow directed to head and upper body

Peripheral Resistance

• Hormonal controls
  – Angiotensin II
    • Generated by kidney release of renin
    • Causes vasoconstriction
  – Atrial natriuretic peptide/factor
    • Causes blood volume and blood pressure to decline
    • Causes generalized vasodilation

Peripheral Resistance

• Hormonal controls cont.
  – Antidiuretic hormone (ADH, vasopressin)
    • Causes intense vasoconstriction in cases of extremely low BP
  – Epinephrine
    • Causes generalized vasoconstriction and increases cardiac output

Peripheral Resistance

Hormonal controls cont.

Antidiuretic hormone (ADH, vasopressin)
  • Causes intense vasoconstriction in cases of extremely low BP

Epinephrine
  • Causes generalized vasoconstriction and increases cardiac output
Fluid Shifts Between Capillaries and Tissue

- Capillaries allow plasma and solutes to pass into interstitial space (interstitial or extracellular fluid (ECF))
  - Dynamic equilibrium
  - Facilitates exchange of resources & wastes between cells & plasma
  - Imbalances?
  - Exceptions?

Regulation of ECF Movement

- Hydrostatic and osmotic pressure
  - Hydrostatic "pushes" and osmotic "sucks"
  - 4 types
    - Capillary hydrostatic pressure
    - Interstitial osmotic pressure
    - Interstitial hydrostatic pressure
    - Capillary osmotic pressure

Regulation of ECF Movement

- Osmotic
  - Interstitial fluid osmotic pressure (OPif)
    - The osmotic pressure force created by interstitial solutes
    - Low (~1 mm Hg), due to low protein content
  - Capillary colloid osmotic pressure (OPo)
    - Created by non-diffusible plasma proteins, which draw water toward themselves
    - ~26 mm Hg
Regulation of ECF Movement
• The movement of fluid between the extracellular compartments is driven by a pressure gradient
  – Most influenced by capillary hydrostatic pressure

Regulation of ECF Movement
• Net Filtration Pressure (NFP)
  – Comprises all the forces acting on a capillary bed
  \[ \text{NFP} = (\text{HP}_\text{c} - \text{HP}_\text{if}) - (\text{OP}_\text{c} - \text{OP}_\text{if}) \]

Regulation of ECF Movement
• Arterial NFP
  – Arterial end of a capillary bed = hydrostatic forces dominate
  • Fluid moves out
  • \[ \text{NFP} = (35 - 0) - (26 - 1) = 10 \text{ mm Hg} \]

Regulation of ECF Movement
• Venous NFP
  – Venous end of a capillary bed = osmotic forces dominate
  • Fluid moves in
  • \[ \text{NFP} = (17 - 0) - (26 - 1) = -8 \text{ mm Hg} \]

Regulation of ECF Movement
• Excess fluid
  – Returned to the blood via the lymphatic system

Edema
• Occurs when filtration greatly exceeds reabsorption
  – Abnormal increase in interstitial fluid volume
Venous Blood Pressure
• Changes little during the cardiac cycle
• Low pressure due to cumulative effects of peripheral resistance
• Central venous pressure
  — Pressure at the point where vena cava enter heart
  — Average = 4.6 mm Hg

Venous Return
• Venous hydrostatic pressure relatively low
• Returning blood to heart requires adaptations

Mechanisms of Venous Return
1. Thoracic pump
   • Pressure changes created during breathing move blood toward the heart by squeezing abdominal veins as thoracic veins expand
2. Cardiac Suction
   • During atrial systole, movement of AV valves enlarges atria = lower pressure = increasing pressure gradient between vena cava
3. Muscular pump
   • Contraction of skeletal muscles “milk” blood toward the heart and valves prevent backflow
4. Gravity
   • Helps with return of blood from superior regions

Types and Causes of LVR Shock
1. Hypovolemic shock
   — Most common form of shock
   — Result of blood loss
     • Direct losses: hemorrhage, trauma, burns, bleeding ulcers
     • Indirect losses: fluids other than blood lost
       — Burns and dehydration
Types and Causes of LVR Shock

2. Vascular shock
   - Body retains normal blood volume but blood accumulates in extremities
     a) Neurogenic shock
        • Usually follows spinal cord trauma, widespread vasodilation
     b) Septic shock
        • Bacterial endotoxin simulates vasodilation
     c) Anaphylactic shock
        • Following allergic reaction
        • Sudden release of histamine, massive vasodilation and permeability changes

Pathways of Blood Circulation

• Complete circuits begin and end at heart
• A double pump with 2 pathways
  — Pulmonary circulation
  — Systemic circulation

Systemic Circulation

• Carries oxygen rich blood to all parts of the body
• Subdivisions
  — Coronary circulation
    • Supplies myocardium
  — Hepatic-portal circulation
    • Directs blood from spleen, stomach, pancreas, gallbladder, and intestines to the liver via portal vein
    • Organs of digestion and recycling — materials are substantially metabolized in the liver before reaching general circulation
      • Jaundice
    • Portal systems
      • 2 capillary beds

Pulmonary Circulation

• Carries oxygen poor blood from heart to alveolar surface of lungs and oxygen rich blood back to the heart
Fetal Circulation

- Oxygen and nutrients obtained from maternal blood
  - Respiratory and digestive systems not yet functional
  - Blood oxygenated in placenta
    - Attached to uterine wall by cotyledons (contain placental villi)
    - Waste carried from fetus by umbilical arteries
    - Extensions of the internal iliac arteries
  - Nutrient rich blood enters fetal circulation by umbilical vein

Fetal Circulation

- Ductus venosus
  - Continuation of the umbilical vein under liver
  - Drains into inferior vena cava
  - Allows blood to bypass the liver
  - Functionally closes minutes after birth
  - Structurally closes in term infants in 3-7 days

Fetal Circulation

- Foramen ovale
  - Opening between right and left atria bypasses fetal lungs
  - Blood routed to aorta

Fetal Circulation

- Foramen ovale
  - First breath after birth decreases pulmonary pressure
  - Left atrial pressure exceeds right and forces foramen ovale closed
  - May remain open
    - Patent foramen ovale or ASD
    - "Hole in the heart"
    - May be surgically closed

Fetal Circulation

- Ductus arteriosis
  - Connects pulmonary artery with descending thoracic aorta
  - Also aids in bypassing lungs

Fetal Circulation

- Ductus arteriosis
  - Failure to close at birth = patent ductus arteriosis
  - Leads to pulmonary hypertension and congestive heart failure
  - NSAIDs are administered to force closure
    - Why NSAIDs MUST be avoided in late pregnancy
Hypertension

- “Silent Killer”
  - Produces few symptoms
- Major cause of heart failure, stroke & kidney failure
- Resting systolic above?
- Resting diastolic above?

| Categories for Blood Pressure Levels in Adults (Ages 18 Years and Older) |
|---------------------------------|----------------|
| Category                        | Blood Pressure Level (mmHg) |
| Normal                          | Systolic $< 120$ and Diastolic $< 80$ |
| Prehypertension                 | 120–139 or 80–89 |
| High Blood Pressure             | Stage 1 Hypertension 140–159 or 90–99 |
|                                 | Stage 2 Hypertension 160 or 100 |

Hypertension

- Arteries are stretched
  - Tears endothelium = exposes muscle = focal point for atherosclerosis = worsens hypertension
- Remember atherosclerosis?
  - Emboli may lodge in narrowed vessel
  - Clots may form on roughened endothelium
  - Long-standing belief that high lipid, high cholesterol diets contribute are being called into question

Renal Hypertension

- Blood flow to kidneys is reduced
  - Leads to thickening of arterioles respond as though BP were reduced Angiotensin II produced aldosterone released
- Increases blood volume and BP
  - Worsens existing hypertension kidney failure may result
Hypertension

- Primary hypertension
  - 90% of hypertensive conditions
  - Cause unknown
  - Contributing factors include
    - Genetics
    - Obesity
      - Adipose tissue extensively vascularized
      - 10 miles per pound!!
      - Means increased peripheral vascular resistance
    - Smoking
      - Nicotine = coronary vasoconstrictor
    - Diet
      - Salt = water retention ➔ higher blood volume
      - Mineral deficiencies (Mg, K, Ca)

- Secondary hypertension
  - 10% of cases
  - Due to identifiable disorders
    - Kidney disease
    - Atherosclerosis
    - Endocrine disorders
      - Hyperthyroidism
      - Cushing’s disease
      - Polycythemia

Deep venous thrombosis (DVT)
- Affects mainly the veins in the lower leg and the thigh
- It involves the formation of a clot (thrombus) in the larger veins of the area

- Can be caused by any condition that restricts venous return in the lower extremities
- Cause in 1/3 of cases is unknown

This picture shows a red and swollen thigh and leg caused by a blood clot (thrombus) in the deep veins in the groin which prevents normal return of blood from the leg to the heart.