Chapter 18  Part B

The Cardiovascular System: Blood Vessels

PowerPoint® Lecture Slides prepared by
Karen Dunbar Kareiva
Ivy Tech Community College
Homeostatic Imbalances in Blood Pressure

- Transient elevations in BP occur during changes in posture, physical exertion, emotional upset, fever
- Age, sex, weight, race, mood, and posture may also cause BP to vary
Homeostatic Imbalances in Blood Pressure

• **Hypertension**
  – Sustained elevated arterial pressure of 140/90 mm Hg or higher
  – **Prehypertension** if values elevated but not yet in hypertension range
    • May be transient adaptations during fever, physical exertion, and emotional upset
    • Often persistent in obese people
Homeostatic Imbalances in Blood Pressure (cont.)

- Hypertension (cont.)
  - Prolonged hypertension is major cause of heart failure, vascular disease, renal failure, and stroke
    - Heart must work harder; myocardium enlarges, weakens, and becomes flabby
    - Also accelerates atherosclerosis
Homeostatic Imbalances in Blood Pressure (cont.)

- **Primary hypertension**
  - 90% of hypertensive conditions
  - No underlying cause identified
  - Risk factors include heredity, diet, obesity, age, diabetes mellitus, stress, and smoking
  - No cure but can be controlled
    - Restrict salt, fat, cholesterol intake
    - Increase exercise, lose weight, stop smoking
    - Antihypertensive drugs
Homeostatic Imbalances in Blood Pressure (cont.)

– Secondary hypertension

• Less common
• Due to identifiable disorders including obstructed renal arteries, kidney disease, and endocrine disorders such as hyperthyroidism and Cushing’s syndrome
• Treatment focuses on correcting underlying cause
Homeostatic Imbalances in Blood Pressure (cont.)

• Hypotension
  – Low blood pressure below 90/60 mm Hg
  – Usually not a concern unless it causes inadequate blood flow to tissues
  – Often associated with long life and lack of cardiovascular illness
Homeostatic Imbalances in Blood Pressure (cont.)

- **Hypotension (cont.)**
  - *Orthostatic hypotension*: temporary low BP and dizziness when suddenly rising from sitting or reclining position
  - *Chronic hypotension*: hint of poor nutrition and warning sign for Addison’s disease or hypothyroidism
  - *Acute hypotension*: important sign of circulatory shock
Homeostatic Imbalances in Blood Pressure (cont.)

• Circulatory shock
  – Condition where blood vessels inadequately fill and cannot circulate blood normally
    • Inadequate blood flow cannot meet tissue needs
  – Hypovolemic shock results from large-scale blood loss
  – Vascular shock results from extreme vasodilation and decreased peripheral resistance
  – Cardiogenic shock results when an inefficient heart cannot sustain adequate circulation
18.9 Control of Blood Flow

• **Tissue perfusion**: blood flow through body tissues; involved in:
  1. Delivery of $O_2$ and nutrients to, and removal of wastes from, tissue cells
  2. Gas exchange (lungs)
  3. Absorption of nutrients (digestive tract)
  4. Urine formation (kidneys)

• Rate of flow is precisely right amount to provide proper function to that tissue or organ
• Rate of blood flow is controlled by extrinsic and intrinsic factors
  
  – **Extrinsic control**: sympathetic nervous system and hormones control blood flow through whole body
    
    • Act on arteriolar smooth muscle to reduce flow to regions that need it the least
18.9 Control of Blood Flow

– **Intrinsic control: Autoregulation (local) control of blood flow**: blood flow is adjusted locally to meet specific tissue’s requirements

  • Local arterioles that feed capillaries can undergo modification of their diameters
  • Organs regulate own blood flow by varying resistance of own arterioles
Example: redistribution of blood during exercise

- At rest, skeletal muscles receive about 20% of total blood in body, but during exercise, skeletal muscle can receive over 70% of blood
- Intrinsic controls: skeletal muscle arterioles dilate, increasing blood flow to muscle
- Extrinsic controls decrease blood flow to other organs such as kidneys and digestive organs
  - MAP is maintained despite dilation of skeletal muscle arterioles
Figure 18.13 Distribution of blood flow at rest and during strenuous exercise.

- **Total blood flow at rest**: 5800 ml/min
- **Total blood flow during strenuous exercise**: 17,500 ml/min

**Distribution of blood flow**:
- **Brain**: 750 ml/min
- **Heart**: 250 ml/min
- **Skeletal muscles**: 1200 ml/min
- **Skin**: 500 ml/min
- **Kidneys**: 1100 ml/min
- **Abdomen**: 1400 ml/min
- **Other**: 600 ml/min

© 2017 Pearson Education, Inc.
Autoregulation: Intrinsic (Local) Regulation of Blood Flow

- **Autoregulation**: local (intrinsic) conditions that regulate blood flow to that area
  - **Reactive hyperemia**: increased blood flow to an area due to intrinsic factors
- Two types of intrinsic mechanisms both determine final autoregulatory response
  - **Metabolic controls**
  - **Myogenic controls**
Autoregulation: Intrinsic (Local) Regulation of Blood Flow (cont.)

• **Metabolic controls**
  
  – Increase in tissue metabolic activities results in:
    
    • Declining levels of $O_2$
    • Increasing levels of metabolic products ($H^+$, $K^+$, adenosine, and prostaglandins)
  
  – Effects of change in levels of local chemicals
    
    • Cause direct relaxation of arterioles and relaxation of precapillary sphincters
    • Cause release of nitric oxide (NO), a powerful vasodilator, by endothelial cells
Autoregulation: Intrinsic (Local) Regulation of Blood Flow (cont.)

• Metabolic controls (cont.)
  • Endothelins, also released from endothelium, are potent vasoconstrictors
  • NO and endothelins are usually balanced unless blood flow is inadequate, in which case NO wins control, causing vasodilation
    – Inflammatory chemicals can also cause vasodilation
Autoregulation: Intrinsic (Local) Regulation of Blood Flow (cont.)

• **Myogenic controls**
  – **Myogenic responses**: local vascular smooth muscle responds to changes in MAP to keep perfusion constant to avoid damage to tissue
    • Passive stretch: increased MAP stretches vessel wall more than normal
      – Smooth muscle responds by constricting, causing decreased blood flow to tissue
    • Reduced stretch: decreased MAP causes less stretch than normal
      – Smooth muscle responds by dilating, causing increased blood flow to tissue
Autoregulation: Intrinsic (Local) Regulation of Blood Flow (cont.)

- Long-term autoregulation
  - Occurs when short-term autoregulation cannot meet tissue nutrient requirements
    - Long-term autoregulation may take weeks or months to increase blood supply
  - Number of vessels to region increases (*angiogenesis*), and existing vessels enlarge
  - Common in heart when coronary vessel occluded, or throughout body in people in high-altitude areas
Intrinsic and extrinsic control of arteriolar smooth muscle in the systemic circulation.

**Intrinsic controls** (autoregulation)
- Metabolic or myogenic controls
- Distribute blood flow to individual organs and tissues as needed

**Vasoconstrictors**
- Myogenic:
  - Stretch
- Metabolic:
  - Endothelins

**Vasodilators**
- Myogenic:
  - Stretch
- Metabolic:
  - Endothelins

**Extrinsic controls**
- Neural or hormonal controls
- Maintain mean arterial pressure (MAP)
- Redistribute blood during exercise and thermoregulation

**Metabolic**
- ↓O₂
- ↑CO₂
- ↑H⁺
- ↑K⁺
- Prostaglandins
- Adenosine
- Nitric oxide

**Neural**
- ↑Sympathetic tone

**Hormonal**
- Atrial natriuretic peptide
- Angiotensin II
- Antidiuretic hormone
- Epinephrine
- Norepinephrine
Blood Flow in Special Areas

• **Skeletal muscles**
  – Blood flow varies with fiber type and activity
  – At rest, myogenic and neural mechanisms predominate; maintain flow at \( \sim 1 \text{L} / \text{min} \)
  – **Active** or **exercise hyperemia**: during muscle activity, blood flow increases in direct proportion to metabolic activity
    • Local controls override sympathetic vasoconstriction; flow can increase 10\( \times \)
Figure 18.15 Active hyperemia.

Exercise skeletal muscle

↓ O₂, ↑ CO₂, ↑ H⁺, and ↑ other metabolic factors in extracellular fluid

Vasodilation of arterioles (overrides extrinsic sympathetic input)

↑ Muscle blood flow (active hyperemia)
Blood Flow in Special Areas (cont.)

• Brain
  – Blood flow to brain must be constant because neurons are intolerant of ischemia
    • Flow averages ~750 ml/min
  – Control mechanisms
    • Metabolic controls
      – Decreased pH or increased carbon dioxide cause marked vasodilation
        » Very high CO$_2$ levels depress autoregulatory mechanisms
Blood Flow in Special Areas (cont.)

• Brain (cont.)
  – Control mechanisms (cont.)
    • Myogenic controls
      – Decreased MAP causes cerebral vessels to dilate
      – Increased MAP causes cerebral vessels to constrict

• Brain vulnerable under extreme systemic pressure changes
  – MAP below 60 mm Hg can cause syncope (fainting)
  – MAP above 160 mm Hg can result in cerebral edema
Blood Flow in Special Areas (cont.)

• Skin
  – Functions of blood flow through skin
    1. Supplies nutrients to cells
       – Autoregulated in response to O$_2$ needs
    2. Helps regulate body temperature
       – Neurally controlled
       – Important function of skin
    3. Provides a blood reservoir
       – Also neurally controlled
• Skin (cont.)
  – Blood flow through venous plexuses below skin surface regulates body temperature
    • Flow varies from 50 ml/min to 2500 ml/min, depending on body temperature
    • Flow is controlled by sympathetic nervous system reflexes
      – Reflexes initiated by temperature receptors and central nervous system
• Skin (cont.)
  – As temperature rises (e.g., from heat exposure, fever, vigorous exercise)
    • Hypothalamic signals reduce vasomotor stimulation of skin vessels, causing dilation
    • Warm blood flushes into capillary beds
    • Heat radiates from skin
  – As temperature decreases, blood is shunted to deeper, more vital organs
    • Superficial skin vessels constrict strongly
    • Blood in vessels may become trapped
      – Causes rosy cheeks in cold
Lungs

- Pulmonary circuit is unusual; pathway is short
  - Arteries/arterioles are more like veins/venules (thin walled, large lumens)
  - Arterial resistance and pressure are much lower than in systemic circuit
    - Averages ~24/10 mm Hg versus 120/80 mm Hg
- Autoregulatory mechanisms are opposite
  - Low O$_2$ levels cause vasoconstriction, and high levels promote vasodilation
    - Allows blood flow to O$_2$-rich areas of lung
• Heart
  – Blood flow through heart is influenced by aortic pressures and ventricular pumping
  – During ventricular systole, coronary vessels are compressed
    • Myocardial blood flow ceases
    • Stored myoglobin supplies sufficient oxygen
  – During diastole, high aortic pressure forces blood through coronary circulation
Blood Flow in Special Areas (cont.)

• Heart (cont.)
  – At rest, coronary blood flow is \( \sim 250 \text{ ml/min} \)
    • Control is probably via myogenic mechanisms
  – During strenuous exercise, coronary vessels dilate in response to local accumulation of vasodilators
    • Blood flow may increase three to four times
    • Important because cardiac cells use 65% of \( \text{O}_2 \) delivered
      – Other cells use only 25% of delivered \( \text{O}_2 \)
      – Increasing coronary blood flow is only way to provide more \( \text{O}_2 \)
18.10 Capillary Exchange

Velocity of Blood Flow

- Velocity of flow changes as blood travels through systemic circulation
- Fastest in aorta, slowest in capillaries, then increases again in veins
- Speed is inversely related to total cross-sectional area
  - Capillaries have largest area so slowest flow
  - Slow capillary flow allows adequate time for exchange between blood and tissues
Figure 18.16 Blood flow velocity and total cross-sectional area of vessels.

Relative cross-sectional area of different vessels of the vascular bed

Total area $(\text{cm}^2)$ of the vascular bed

Velocity of blood flow $(\text{cm/s})$

- Aorta
- Arteries
- Arterioles
- Capillaries
- Venules
- Veins
- Venae cavae

© 2017 Pearson Education, Inc.
Vasomotion

- **Vasomotion**: intermittent flow of blood through capillaries
  - Due to on/off opening and closing of precapillary sphincters
Capillary Exchange of Respiratory Gases and Nutrients

• Many molecules pass by diffusion between blood and interstitial fluid
  – Move down their concentration gradients
• Molecules use four different routes to cross capillary:
  1. Diffuse directly through endothelial membranes
     • Example: lipid-soluble molecules such as respiratory gases
  2. Pass through clefts
     • Example: water-soluble solutes
Capillary Exchange of Respiratory Gases and Nutrients (cont.)

3. Pass through fenestrations
   • Example: water-soluble solutes

4. Active transport via pinocytotic vesicles or caveolae
   • Example: larger molecules, such as proteins
Figure 18.17-1 Capillary transport mechanisms.

- Pinocytotic vesicles
- Red blood cell in lumen
- Endothelial cell
- Fenestration (pore)
- Endothelial cell nucleus
- Basement membrane
- Tight junction
- Intercellular cleft
Figure 18.17-2 Capillary transport mechanisms.

1. Diffusion through membrane (lipid-soluble substances)
2. Movement through intercellular clefts (water-soluble substances)
3. Movement through fenestrations (water-soluble substances)
4. Transport via vesicles or caveolae (large substances)
Fluid Movements: Bulk Flow

• Fluid is forced out clefts of capillaries at arterial end, and most returns to blood at venous end
  – Extremely important in determining relative fluid volumes in blood and interstitial space

• Bulk fluid flow across capillary walls causes continuous mixing of fluid between plasma and interstitial fluid; maintains interstitial environment.

• Direction and amount of fluid flow depend on two opposing forces
  – Hydrostatic pressures
  – Colloid osmotic pressures
Fluid Movements: Bulk Flow (cont.)

- **Hydrostatic pressures**
  - **Hydrostatic pressure** ($HP$): force exerted by fluid pressing against wall; two types
    - **Capillary hydrostatic pressure** ($HP_c$): capillary blood pressure that tends to force fluids through capillary walls
      - Greater at arterial end (35 mm Hg) of bed than at venule end (17 mm Hg)
    - **Interstitial fluid hydrostatic pressure** ($HP_{if}$): pressure pushing fluid back into vessel; usually assumed to be zero because lymphatic vessels drain interstitial fluid
Fluid Movements: Bulk Flow (cont.)

• Colloid osmotic pressures
  – Capillary colloid osmotic pressure (oncotic pressure, $\text{OP}_c$)
    • “Sucking” pressure created by nondiffusible plasma proteins pulling water back into capillary
    • $\text{OP}_c \sim 26 \text{ mm Hg}$
  – Interstitial fluid colloid osmotic pressure ($\text{OP}_{if}$)
    • Pressure is inconsequential because interstitial fluid has very low protein content
    • $\text{OP}_{if}$ around only 1 mm Hg
Fluid Movements: Bulk Flow (cont.)

- **Hydrostatic-osmotic pressure interactions**
  - Net filtration pressure (NFP): comprises all forces acting on capillary bed
    - \[ \text{NFP} = (HPC + OP_{if}) - (HP_{if} + OP_{c}) \]
  - Net fluid flow out at arterial end (*filtration*)
  - Net fluid flow in at venous end (*reabsorption*)
  - More fluid leaves at arterial end than is returned at venous end
    - Excess interstitial fluid is returned to blood via lymphatic system

© 2017 Pearson Education, Inc.
Focus Figure 18.1-1 Bulk fluid flow across capillary walls causes continuous mixing of fluid between the plasma and the interstitial fluid compartments, and maintains the interstitial environment.

**The big picture**
Each day, 20 L of fluid filters from capillaries at their arteriolar end and flows through the interstitial space. Most (17 L) is reabsorbed at the venous end.

- For all capillary beds, 20 L of fluid is filtered out per day—almost 7 times the total plasma volume!
- 17 L of fluid per day is reabsorbed into the capillaries at the venous end.
- About 3 L per day of fluid (and any leaked proteins) are removed by the lymphatic system (see Chapter 20).

© 2017 Pearson Education, Inc.
Focus Figure 18.1-2 Bulk fluid flow across capillary walls causes continuous mixing of fluid between the plasma and the interstitial fluid compartments, and maintains the interstitial environment.

Recall from Chapter 3 (p. 71) that two kinds of pressure drive fluid movement:

**Hydrostatic pressure (HP)**
- Due to fluid pressing against a boundary (e.g., capillary wall)
- HP “pushes” fluid across the boundary
- In blood vessels, is due to blood pressure

**Osmotic pressure (OP)**
- Due to nondiffusible solutes that cannot cross the boundary
- OP “pulls” fluid across the boundary
- In blood vessels, is due to plasma proteins
Focus Figure 18.1-3 Bulk fluid flow across capillary walls causes continuous mixing of fluid between the plasma and the interstitial fluid compartments, and maintains the interstitial environment.

How do the pressures drive fluid flow across a capillary?

Net filtration occurs at the arteriolar end of a capillary.

**Capillary lumen**

- Hydrostatic pressure in capillary ($HP_c$) “pushes” fluid out of capillary. $HP_c = 35$ mm Hg
- Osmotic pressure in capillary ($OP_c$) “pulls” fluid into capillary. $OP_c = 26$ mm Hg

**Interstitial fluid**

- Hydrostatic pressure in interstitial fluid ($HP_{if}$) “pushes” fluid into capillary. $HP_{if} = 0$ mm Hg
- Osmotic pressure in interstitial fluid ($OP_{if}$) “pulls” fluid out of capillary. $OP_{if} = 1$ mm Hg

Let’s use what we know about pressures to determine the net filtration pressure ($NFP$) at any point. ($NFP$ is the pressure driving fluid out of the capillary.) To do this we calculate the outward pressures ($HP_c$ and $OP_c$) minus the inward pressures ($HP_{if}$ and $OP_{if}$). So,

$$NFP = (HP_c + OP_{if}) - (HP_{if} + OP_c) = (35 + 1) - (0 + 26) = 10$$ mm Hg (net outward pressure)

As a result, fluid moves from the capillary into the interstitial space.
Focus Figure 18.1-4 Bulk fluid flow across capillary walls causes continuous mixing of fluid between the plasma and the interstitial fluid compartments, and maintains the interstitial environment.

**Net reabsorption occurs at the venous end of a capillary.**

*Capillary lumen*

Hydrostatic pressure in capillary "pushes" fluid out of capillary. The pressure has dropped because of resistance encountered along the capillaries.

Hydrostatic pressure in interstitial fluid "pushes" fluid into capillary.

*Interstitial fluid*

Osmotic pressure in capillary "pulls" fluid into capillary.

Osmotic pressure in interstitial fluid "pulls" fluid out of capillary.

Again, we calculate the NFP:

\[
NFP = (HP_c + OP_i) - (HP_if + OP_c)
\]

\[
= (17 + 1) - (0 + 26)
\]

\[
= -8 \text{ mm Hg (net inward pressure)}
\]

Notice that the NFP at the venous end is a negative number. This means that reabsorption, not filtration, is occurring and so fluid moves from the interstitial space into the capillary.

© 2017 Pearson Education, Inc.
Clinical – Homeostatic Imbalance 18.2

• **Edema**: abnormal increase in amount of interstitial fluid

• Caused by either an increase in outward pressure (driving fluid out of the capillaries) or a decrease in inward pressure
  
  – An increase in *capillary hydrostatic pressure* accelerates fluid loss from blood

  • Could result from incompetent venous valves, localized blood vessel blockage, congestive heart failure, or high blood volume
Clinical – Homeostatic Imbalance 18.2

– An increase in *interstitial fluid osmotic pressure* can result from an inflammatory response
  • Inflammation increases capillary permeability and allows proteins to leak into interstitial fluid
  • Causes large amounts of fluid to be pulled into interstitial space

– A decrease in *capillary colloid osmotic pressure* hinders fluid return to blood
  • Can be caused by *hypoproteinemia*, low levels of plasma proteins caused by malnutrition, liver disease, or glomerulonephritis (loss of plasma proteins from kidneys)
Edema also can be caused by decreased drainage of interstitial fluid through lymphatic vessels that have been blocked by disease or surgically removed.

- Excess interstitial fluid in subcutaneous tissues generally causes *pitting edema*.
- Edema can impair tissue function as a result of increased distance for diffusion of gases, nutrients and wastes between blood and cells.
- Slow fluid losses can be compensated for by renal mechanisms, but rapid onset may have serious effects on the circulation.
Figure 18.18 Pitting edema.
Part 3  Circulatory Pathways: Blood Vessels of the Body

• **Vascular system** consists of two main circulations:
  – **Pulmonary circulation**: short loop that runs from heart to lungs and back to heart
  – **Systemic circulation**: long loop to all parts of body and back to heart
Figure 18.19a Pulmonary circulation.

(a) Schematic flowchart.
(b) Illustration. The pulmonary arterial system is shown in blue to indicate that the blood it carries is oxygen-poor. The pulmonary venous drainage is shown in red to indicate that the blood it transports is oxygen-rich.
Figure 18.20 Schematic flowchart showing an overview of the systemic circulation.

- Capillary beds of head and upper limbs
- Superior vena cava
- Common carotid arteries to head and subclavian arteries to upper limbs
- Aortic arch
- Aorta
- Superior vena cava
- Common carotid arteries to head and subclavian arteries to upper limbs
- Aortic arch
- Aorta
- Azygos system
- Thoracic aorta
- Venous drainage
- Arterial blood
- Diaphragm
- Inferior vena cava
- Abdominal aorta
- Capillary beds of mediastinal structures and thorax walls
- Capillary beds of digestive viscera, spleen, pancreas, kidneys
- Capillary beds of gonads, pelvis, and lower limbs
Vascular System

• Important differences between systemic arteries and veins:

1. **Arteries run deep, whereas veins are both deep and superficial**
   • Arteries run deep only, but veins run deep or superficial
     – Deep veins share same name with corresponding artery
     – Superficial veins do not correspond to names of any arteries
Vascular System (cont.)

– Venous pathways are more interconnected
  • Unlike arterial pathways, venous pathways have more interconnections
    – Veins can have more than one name, making venous pathways harder to follow

– The brain and digestive systems have unique venous drainage systems
  • Brain contains *dural venous sinuses*
  • Venous system of the digestive system drains into *hepatic portal system*, which perfuses through liver before returning to heart