Peripheral Circulation and Regulation

Functions of Peripheral Circulation
1. Contain the blood
2. Exchange nutrients, waste products, and gases with tissues
3. Transport
4. Regulate blood pressure, along with cardiac output
5. Control direction of blood flow
6. Participate in thermoregulation

Blood Vessel Structure and Function

Blood vessels – ‘closed system’
• Delivery system of dynamic structures that begins and ends at heart
• Work with lymphatic system to circulate fluids

Arteries - delivery
• Carry blood away from ventricles
• Oxygenated except for pulmonary circulation and umbilical arteries of fetus
• Closer to the heart, greater the pressure artery must tolerate

Capillaries - exchange
• Numerous small vessels = high surface area
• Direct contact with tissue cells; directly serve cellular needs
• ‘Endothelium’ only one layer of squamous cells

Veins - return
• Carry blood toward atria
• Deoxygenated except for pulmonary circulation and umbilical veins of fetus
• Built to tolerate lower blood pressures and prevent backflow
60,000 miles of vessels in average body

 Venous pathways are more interconnected

Arteries run deep, whereas veins are both deep and superficial

Note subdivisions and by-pass vessels
Structure of Blood Vessel Wall

**Tunica intima**
- Smooth, friction-reducing, innermost layer in contact with blood
- Endothelium: simple squamous epithelium lines lumen of all vessels is continuous with endocardium

**Tunica media**
- Middle layer composed mostly of smooth muscle and sheets of elastin
- Sympathetic vasomotor nerve fibers innervate this layer
- Thickest in arteries - responsible for maintaining blood flow and blood pressure

**Tunica externa**
- Outermost layer of wall
- Mostly loose collagen fibers that protect and reinforce wall and anchor it to surrounding structures
- Infiltrated with nerve fibers, lymphatic vessels, and **Vasa vasorum**

**Capillaries**
- Endothelium with sparse basal lamina

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**Vasomotor tone: what's up with that?**
Capillaries

- Functions: exchange between blood and interstitial fluid
- Small diameter vessels force RBCs to pass in single file
  - Slows flow and promotes exchange
- Thin tunica intima; in smallest vessels, one cell forms entire circumference
- Supply almost every cell, except for cartilage, epithelia, cornea, and lens of eye

Continuous Capillaries:

- Abundant in skin, muscles, lungs, and CNS.
- Often have associated pericytes.
- Pinocytotic vesicles ferry fluid across the endothelial cell.
- Brain capillary endothelial cells lack intercellular clefts and have tight junctions around their entire perimeter.

Fenestrated Capillary:

- Occur in areas of active filtration (e.g., kidney) or absorption (e.g., small intestine), and areas of endocrine hormone secretion.

- Fenestrations are Swiss cheese-like holes that tunnel through endothelial cells.
  - Usually covered by a very thin diaphragm.
  - Readily allows solute and fluid movement.
- In some digestive tract organs, the number of fenestrations in capillaries increases during active absorption of nutrients.
Sinusoidal Capillaries:

- Occur in liver, bone marrow, spleen, and adrenal medulla.
- Have large intercellular clefs as well as fenestrations; few tight junctions; incomplete basement membranes.
- Are irregularly shaped and have larger lumens than other capillaries.

- Allow large molecules and even cells to pass across their walls.
- Blood flows slowly through their channels.
- Macrophages may extend processes through the clefs to catch "prey" or, in liver, form part of the sinusoid wall.

Anatomy of a capillary bed.

- Capillary bed: interwoven network of capillaries between arterioles and venules
- Microcirculation: flow of blood through bed

Capillary beds vessels
1. Vascular shunt: channel that connects arteriole directly with venules (metarteriole—thoroughfare channel)
2. True capillaries: actual vessels involved in exchange

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

Total area (cm²) of the vascular bed

Velocity of blood flow (cm/s)
Venules
• postcapillary venules consist of endothelium and a few pericytes
  – Very porous; allow fluids and WBCs into tissues
• Larger venules have one or two layers of smooth muscle cells

Veins
• Have all tunics
• Large lumen and thin walls make veins good storage vessels
• Blood pressure lower than in arteries, so adaptations ensure return of blood to heart
  • Large-diameter lumens offer little resistance
  • Venous valves
    • Prevent backflow of blood
    • Most abundant in veins of limbs
  • ‘filling’ effect

Relative proportion of blood volume throughout the cardiovascular system.

Venous reservoir provides a source of blood to fill dilating arteries upon initiation of exercise – compensation to maintain blood pressure

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 Out of Capillaries

Capillary pressures
• 35 mm Hg at beginning of capillary bed
• ∼17 mm Hg at the end of the bed
• Low capillary pressure is desirable

• Fluid is forced out clefts of capillaries at arterial end, and most returns to blood at venous end
• 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

Hydrostatic pressure (HP)
• Capillary hydrostatic pressure (HP_c)
• Interstitial fluid hydrostatic pressure (HP_if): assumed to be zero because lymphatic vessels drain interstitial fluid

Capillary colloid osmotic pressure (oncotic pressure, OP_c)
• Remember the presence of plasma proteins

Interstitial fluid colloid osmotic pressure (OP_if)
• inconsequential

Hydrostatic-osmotic pressure interactions
• Net filtration pressure (NFP):
  • NFP = (HP_c + 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

How do the pressures drive fluid flow across a capillary?

Net filtration occurs at the arteriole end of a capillary.

Osmotic pressure (OP_if) in interstitial fluid “pulls” fluid out of capillary.

Hydrostatic pressure in capillary (HP_c) “pushes” fluid out of capillary.

Osmotic pressure (OP_c) in capillary “pulls” fluid into capillary.

As a result, fluid moves from the capillary into the interstitial space.
Net reabsorption occurs at the venous end of a capillary.

Arterial side NFP = 10; venous side NFP = -8
Capillary bed NFP is therefore 10 - 8 = 2 mm Hg

2 mm Hg pressure causes a net fluid loss from bed to tissues.

Control Over Blood Pressure and Flow

Blood pressure (BP)
- Expressed in mm Hg, systolic over diastolic
- Measured as systemic arterial BP in large arteries at same level as heart
- Pressure gradient provides driving force that keeps blood moving from higher- to lower-pressure areas

Blood flow
- Measured in ml/min
- Overall is relatively constant when at rest, varies at individual organ level, based on needs

Resistance (peripheral resistance)
- Measurement of amount of friction blood encounters with vessel walls, generally in peripheral/systemic circulation
- Three important sources of resistance
  - Blood viscosity
  - Total blood vessel length
  - Blood vessel diameter
• **Blood viscosity**
  - The thickness or “stickiness” of blood due to formed elements and plasma proteins
  - Increased viscosity equals increased resistance
  - Increasing hematocrit increases viscosity

• **Total blood vessel length**
  - The longer the vessel, the greater the resistance encountered
  - Essentially remains constant once adulthood is reached

• Goal of blood pressure regulation is to keep blood pressure high enough to provide adequate tissue perfusion, but not so high that blood vessels are damaged
  - Example: If BP to brain is too low, perfusion is inadequate, and person loses consciousness
  - If BP to brain is too high, person could have stroke

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**Arterial Blood Pressure**

• Pulse pressure and MAP both decline with increasing distance from heart
  - With increasing distance, flow is nonpulsatile with a steady MAP pressure

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**Diagram:**

- Pulse Pressure = 120 - 80 mmHg
- Systolic pressure
- Mean pressure
- Diastolic pressure
- Pumping action of heart generates blood flow
- Pressure results when flow is opposed by resistance
- Systemic pressure is highest in aorta and declines throughout pathway
- Steepest drop occurs in arterioles

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**Graph:**

- Blood pressure (mm Hg)
- Aorta, Arteries, Arterioles, Capillaries, Veins, Vena cavae
- **Mean pressure**
- **Pulse pressure**
- **Diastolic pressure**
Measuring Arterial Blood Pressure using auscultatory methods and a sphygmomanometer

1. Wrap cuff around arm superior to elbow
2. Increase pressure in cuff until it exceeds systolic pressure in brachial artery
3. Pressure is released slowly, and examiner listens for sounds of Korotkoff with a stethoscope

Venous Blood Pressure

• Small pressure gradient, only about 15 mm Hg
• Factors aiding venous return
  1. Backflow prevention
  2. Muscular pump
  3. Respiratory pump
  4. Sympathetic vеноconstriction

The muscular pump.
Regulation of Blood Pressure

• Maintaining blood pressure requires cooperation of heart, blood vessels, and kidneys
  • All supervised by brain
• Three main factors regulating blood pressure
  • Cardiac output (CO)
  • Peripheral resistance (PR or just R)
  • Blood volume
• Blood pressure varies directly with CO, PR, and blood volume

Poiseuille’s Law

Simplifying: \[ \text{Flow} = \frac{\pi \Delta P r^4}{8 v l} \]

\[ \Delta P = P_1 - P_2 \text{ or the change in pressure over the length of the vessel} \]
\[ v \text{ is the viscosity of the blood} \]
\[ l \text{ is the length of the blood vessel from } P_1 \text{ to } P_2 \]
\[ r \text{ is the radius of the blood vessel (diameter } = 2r) \]
\[ \pi \text{ is a constant} \]

1. Resistance to flow is caused by viscosity, vessel length, and vessel radius
   1. Once mature, length of vessel fairly constant – no impact
   2. Viscosity and flow are inversely proportional – Homeostatic mechanisms control viscosity
   3. Small changes in radius or diameter (vasoconstriction/dilation) significantly impact flow

2. Minimum pressure differential required - no difference, no flow
   a) Must maintain pressure above critical closing pressure
   b) Heart as the generator of pressure can compensate

Regulation of Blood Pressure

\[ \text{MAP} = \text{SV} \times \text{HR} \times R \]

• Anything that increases SV, HR, or R will also increase MAP
  • SV is affected by venous return (EDV)
  • HR is maintained by medullary centers
  • R is affected mostly by vessel diameter
Regulation of Blood Pressure

• Factors can be affected by:
  • Short-term regulation: neural controls
    • Neural controls operate via reflex arcs that involve:
      • Cardiovascular center of medulla
      • Baroreceptors
      • Chemoreceptors
      • Higher brain centers
  • Short-term regulation: hormonal controls
  • Long-term regulation: renal controls

Baroreceptor reflex

Short-Term Regulation: Neural Controls (cont.)

• Chemoreceptor reflexes
  • Aortic arch and large arteries of neck detect increase in CO₂, or drop in pH or O₂
  • Cause increased blood pressure by:
    • Signaling cardioacceleratory center to increase CO
    • Signaling vasomotor center to increase vasoconstriction

• Influence of higher brain centers
  • Reflexes that regulate BP are found in medulla
  • Hypothalamus and cerebral cortex can modify arterial pressure via relays to medulla
    • Increases blood pressure during stress
    • Mediates redistribution of blood flow during exercise and changes in body temperature
Short-Term Mechanisms: Hormonal Controls

- Hormones regulate BP in short term via changes in peripheral resistance or long term via changes in blood volume
- Adrenal medulla hormones
  - Epinephrine and norepinephrine from adrenal gland increase CO and vasoconstriction
- Angiotensin II stimulates vasoconstriction
- ADH (or vasopressin): high levels can cause vasoconstriction
- Atrial natriuretic peptide decreases BP by antagonizing aldosterone, causing decreased blood volume

### Table 9.2 Effects of Selected Hormones on Blood Pressure

<table>
<thead>
<tr>
<th>Hormone</th>
<th>Action on BP</th>
<th>Blood Volume</th>
<th>Mean Arterial Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epinephrine and norepinephrine (NE)</td>
<td>心输出量增加</td>
<td>阻力血管收缩</td>
<td>阻力血管收缩</td>
</tr>
<tr>
<td>Angiotensin II</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Atrial natriuretic peptide (ANP)</td>
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<tr>
<td>Aldosterone</td>
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</tbody>
</table>

Long-Term Mechanisms: Renal Regulation

Summary of Factors that Increase MAP
Control of Blood Flow

Tissue perfusion: blood flow through body tissues; involved in:
1. Delivery of O₂ 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 blood flow is controlled by extrinsic and intrinsic factors
  • Extrinsic control: sympathetic nervous system and hormones control blood flow through whole body
  • 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
    - Metabolic controls – smooth muscle response to metabolic wastes
    - Myogenic controls – smooth muscle response to increasing and decreasing MAP
    - Long-term autoregulation – angiogenesis and vessel enlargement

Intrinsic and extrinsic control of arteriolar smooth muscle in the systemic circulation

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

Metabolic
- Prostaglandins
- Adenosine
- Nitric oxide

Hormonal
- Atrial natriuretic peptide

Sympathetic tone
- Vasoconstrictors

Myogenic
- Stretch
- Metabolic
- Endothelins

Neural
- Sympathetic tone
- Norepinephrine
- Epinephrine
- Antidiuretic hormone
- Angiotensin II

Vasodilators
- Brain
- Heart
- Skeletal muscles
- Skin
- Kidneys
- Abdomen
- Other

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