Chapter 16

The Cardiovascular System: Blood Vessels and Circulation
Blood Vessels

- Arteries: carry blood away from heart
  1. Elastic: large
  2. Muscular: distribution to organs
  3. Arterioles: distribution to capillaries
     - Their smooth muscle helps regulate blood pressure
- Capillaries: thin-walled for diffusion
- Veins: carry blood back to heart
  1. Venules: from capillaries
  2. Veins from tissues → vena cavae → heart
Blood Vessel Structure: Arteries, Veins

- Three layers (tunica): external, middle, inner
- Arteries: thicker tunica media
  - Elastic tissue and/or muscle
- Arterioles
  - Arterioles: control blood pressure
- Veins
  - Larger lumen, thinner walls
  - Valves to prevent backflow
- Venules
  - Venules: very thin, no valves
Blood Vessel Structure: Arteries, Veins

INNER LAYER:
- Endothelium
- Basement membrane
- Internal elastic lamina

MIDDLE LAYER:
- Smooth muscle

OUTER LAYER

Valve

Lumen
(a) Artery

Lumen
(b) Vein

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Blood Vessel Functions

- Muscular arteries, arterioles regulate flow
  - Sympathetic activity to smooth muscle $\rightarrow$ vasoconstriction (narrowing)
  - Decreased sympathetic activity or NO causes relaxation (dilation)
- Arterioles adjust flow into capillaries
- Capillaries: sites of gas exchange
- Systemic venules and veins serve as blood reservoirs (hold ~64% total blood volume)
Blood Vessel Structure: Arteries, Veins

- Lumen
- Basement membrane
- Endothelium
- Capillary
Capillary Details

- Capillaries composed of endothelium
  - Very thin cells: allows for easy diffuse
  - Cell nuclei protrude into lumen

- Connected from arterioles → venules in networks
  - Sometimes direct route from arteriole to venule

- Capillary filling controlled by small arterioles and precapillary sphincters
  - Autoregulation: ability of a tissue to adjust blood flow into the area according to demands
Capillary Details

Details of a capillary network

From heart

Smooth muscle fiber (cell)
Endothelium
Arteriole

Precapillary sphincters
Capillary

Venule
Endothelium

To heart
Capillary Details

Photomicrograph showing red blood cells squeezing through a blood capillary

LM 900x
Capillary Exchange

- Slowest rate of flow is through capillaries
  - Allows time for exchange through wall
- Blood pressure (BP) (pushes out of capillary)
  - Permits filtration of fluid out of capillary
  - Mostly in first half of capillary network
Capillary Exchange

- Colloid osmotic pressure (pulls into capillary)
  - Plasma proteins create this “pulling” pressure
  - Causes reabsorption of fluid from outside to inside

- Balance of BP and osmosis determines fluid in circulation
  - Excess fluid returned via lymphatic system
  - Local signals can adjust capillary flow (autoregulation)
Capillary Exchange

Blood flow from blood arteriole into capillary

Blood plasma

Lymphatic fluid (lymph) returns to

Tissue cell

Interstitial fluid

Lymphatic capillary

Blood flow from blood capillary into venule

Filtration

Reabsorption

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Venous Return: Two Mechanisms

- Blood enters veins at very low pressure
  - Inadequate to overcome gravity and return blood to heart

- Skeletal muscle contractions
  - Contracting skeletal muscles (especially in lower limbs) squeeze veins emptying them
  - Because of venous valves, flow is → heart
Venous Return: Two Mechanisms

- Respiratory pump has similar action
  - Inhalation decreases thoracic pressure and increases abdominal pressure → blood to heart
  - Exhalation allows refilling of abdominal veins
Venous Return: Two Mechanisms

1. Proximal valve
2. Distal valve
Blood Flow Through Vessels

- From high pressure area to lower pressure area, that is, down pressure gradient
  - Greater gradient → greater flow
    - BP is highest in aorta: 110/70 mm Hg
      - Note pulse in large arteries
    - BP declines as flows through more vessels
      - Arterioles: major drop in BP due to smooth muscle contraction → vasoconstriction
      - Capillary beds ~35-16 mm Hg →
      - 16 mm Hg at venules → 0 at right atrium
Blood Flow Through Vessels

Factors that regulate blood flow and BP

1. Blood volume and ventricular contraction → cardiac output
   - Under control of cardiovascular (CV)
2. Vascular resistance: opposition to flow (depends on lumen diameter and vessel length + blood viscosity)
   - Smaller lumen (with vasoconstriction) → greater resistance
   - Greater vessel length (with weight gain) → greater resistance
   - Higher viscosity (as with high hematocrit) → greater resistance
Cardiovascular Center

- Located in medulla
- Helps regulate
  - Heart rate
  - Stroke volume
  - Blood pressure
  - Blood flow to specific tissues

- Mechanisms
  - By neural mechanisms
  - By hormonal mechanisms
Input to Cardiovascular Center (Medulla)

- To inform brain that BP should be altered
  - Input from different parts of brain
    - Cerebral cortex: thoughts, decisions
    - Limbic system: emotions
    - Hypothalamus: changes in temperature or blood volume $\rightarrow$ blood flow adjusted accordingly
  - Input from sensory receptors and nerves
    - Proprioceptors, baroreceptors, chemoreceptors $\rightarrow$ $\rightarrow$
Input to Cardiovascular Center (Medulla)

- Proprioceptors: monitor movements of joints and muscles
  - Cause ↑ heart rate as exercise begins → ↑ cardiac output (CO) → ↑ BP

- Baroreceptors in aorta and carotid: if BP ↓
  - ↑ sympathetic stimulation → ↑ CO → ↑ BP
  - ↓ parasympathetic → ↑ CO → ↑ BP

- Chemoreceptors in aorta and carotid bodies
  - If low O\(_2\), high CO\(_2\), or high H\(^+\) (acidity) → ↑ resistance by ↑ vasoconstriction → ↑ BP
Input to Cardiovascular Center (Medulla)

INPUT TO CARDIOVASCULAR CENTER (nerve impulses)
- From higher brain centers: cerebral cortex, limbic system, and hypothalamus
- From proprioceptors: monitor joint movements
- From baroreceptors: monitor blood pressure
- From chemoreceptors: monitor blood acidity (H⁺), CO₂, and O₂

OUTPUT TO EFFECTORS (increased frequency of nerve impulses)
- Heart: decreased rate
- Heart: increased rate and contractility
- Blood vessels: vasoconstriction

Cardiovascular (CV) center
- Vagus nerves (parasympathetic)
- Cardiac accelerator nerves (sympathetic)
- Vasomotor nerves (sympathetic)
Output to Cardiovascular Effectors

- **ANS nerves to heart**
  - ↑ Sympathetic → ↑ HR and ↑ force of contraction → ↑ cardiac output (CO) → ↑ BP
  - ↑ Parasympathetic → ↓ HR → ↓ CO → ↓ BP

- **Vasomotor (sympathetic nerves)**
  - To arterioles → contract smooth muscle → ↑ vasomotor tone → ↑ vascular resistance → ↑ BP
  - To veins → contract smooth muscle → move blood to heart → ↑ BP
Hormone Regulation of Blood Flow + BP

- Renin-angiotensin aldosterone (RAA) system
  - Angiotensin II $\rightarrow$ vasoconstriction $\rightarrow$ $\uparrow$ BP
  - $\uparrow$ aldosterone $\rightarrow$ retain Na$^+$+ water $\rightarrow$ $\uparrow$ BP
- Epinephrine + norepinephrine $\rightarrow$ $\uparrow$ CO $\uparrow$ BP
- ADH = vasopressin
  - $\uparrow$ vasoconstriction $\rightarrow$ $\uparrow$ BP
  - Thirst + water retention in kidney $\rightarrow$ $\uparrow$ BP
- ANP from cells in atria
  - Vasodilation, loss of Na$^+$ water in urine $\rightarrow$ $\downarrow$BP
Hormone Regulation of Blood Flow + BP

Some stimulus disrupts homeostasis by decreasing blood pressure.

- **Receptors**: Baroreceptors in arch of aorta and carotid sinus are stretched less.
  - **Input**: Decreased rate of nerve impulses.

- **Control centers**: CV center in medulla oblongata and adrenal medulla.
  - **Output**: Increased sympathetic, decreased parasympathetic stimulation; increased secretion of epinephrine and norepinephrine from adrenal medulla.

- **Effectors**: Increased stroke volume and heart rate lead to increased cardiac output (CO); constriction of blood vessels increases systemic vascular resistance (SVR).
  - **Increased blood pressure**.

Return to homeostasis when increased cardiac output and increased vascular resistance bring blood pressure back to normal.
Checking Circulation: Pulse

- Pulse in arteries = heart rate (HR). Press artery against bone or muscle. Sites used
  - Radial artery (thumb side of wrist)
  - Carotid artery (neck)
  - Brachial artery (arm)
- Tachycardia: rapid resting HR (>100 bpm)
- Bradycardia: slow resting HR (<50 bpm)
Blood Pressure

- Device used: sphygmomanometer
  - Usually on brachial artery
- Inflate cuff to raise pressure > systolic BP
  - Briefly stop blood flow there
- Lower pressure in cuff until flow just starts
  - First sound indicates systolic BP
- Lower pressure further until sound become faint
  - Diastolic BP
- Normal BP values <120 mm Hg for systolic and < 80 mm Hg for diastolic
Circulatory Routes

- Two main routes: systemic + pulmonary

- Systemic circulation
  - Oxygenated blood travels from heart throughout body, deoxygenating as it goes
  - All systemic arteries branch from aorta
  - All systemic veins empty into superior vena cava, inferior vena cava, or the coronary sinus
  - Deoxygenated blood returns to heart
Circulatory Routes
Circulatory Routes: Aorta
Circulatory Routes: Aorta
Circulatory Routes: Aorta

Right posterior cerebral
Basilar
Right internal carotid
Right common carotid
Right subclavian
Right axillary
First rib
Right middle cerebral
Right external carotid
Right common carotid
Right vertebral
Clavicle
Brachiocephalic trunk

Right lateral view of branches of brachiocephalic trunk in neck and head
Circulatory Routes: Aorta

Cerebral arterial circle (circle of Willis):
- Anterior cerebral
- Anterior communicating
- Internal carotid
- Posterior communicating
- Posterior cerebral

ANTERIOR
- Frontal lobe of cerebrum
- Middle cerebral
- Temporal lobe of cerebrum

POSTERIOR
- Pons
- Basilar
- Medulla oblongata
- Vertebral
- Cerebellum

Inferior view of base of brain showing cerebral arterial circle
Circulatory Routes: Pelvis, Lower Limb

(a) Anterior view

(b) Posterior view
Circulatory Routes: Principle Veins
Circulatory Routes: Principle Veins of the Hands and Neck
Circulatory Routes: Principle Veins of the Right Upper Limb

- Right external jugular
- Right subclavian
- Right brachiocephalic
- Right axillary
- Right basilic
- Right cephalic
- Superior vena cava
- Sternum
- Right median cubital
- Right basilic
- Right median antebrachial
- Right palmar venous plexus
- Right internal jugular
- Right subclavian
- Right brachiocephalic
- Right axillary
- Right brachial
- Right radial
- Right ulnar
- Right deep palmar venous arch
- Right superficial palmar venous arch

(b) Anterior view of superficial veins
(c) Anterior view of deep veins

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Circulatory Routes: Principle Veins of the Pelvis and Lower Limbs
Pulmonary Circulation

- Carries blood from right side of heart to lungs to get $O_2$ and eliminate $CO_2$
- Route: (R = right, L = left)
  - Right ventricle (RV) $\rightarrow$ pulmonary trunk $\rightarrow$ R + L pulmonary arteries $\rightarrow$ both lungs $\rightarrow$
  - Carry “blue blood” low $O_2$ in and high in $CO_2$
- Pulmonary capillaries: gas exchange $\rightarrow$
- R and L pulmonary veins $\rightarrow$ L atrium
  - Carry “red blood” (high in $O_2$ in and low in $CO_2$)
Hepatic Portal Circulation

- Portal vein: transports blood from one organ’s capillary bed to another
- GI organs →
- Splenic and superior mesenteric veins →
- Hepatic portal vein (“blue blood”) →
- Sinusoids (“leaky capillaries” in liver) →
  - Mixes “blue blood” with “red blood”
- Hepatic vein → inferior vena cava (IVC)
Hepatic Portal Circulation

Anterior view of veins draining into the hepatic portal vein
Hepatic Portal Circulation

Scheme of principal blood vessels of hepatic portal circulation and arterial supply and venous drainage of liver

- Inferior vena cava
- Hepatic veins
- Proper hepatic artery
- Splenic vein
- Hepatic portal vein
- Superior mesenteric vein
- Tributaries from portions of stomach, pancreas, and portions of large intestine
- Tributaries from small intestine and portions of large intestine, stomach, and pancreas
Fetal Circulation

- Specialized for exchange of materials with maternal blood and bypass of lungs
- Exchange in placenta $\rightarrow$ umbilical vein
- $\rightarrow$ ductus venosus (bypasses liver)
- $\rightarrow$ inferior vena cava $\rightarrow$ R atrium (mixes with deoxygenated blood from lower body)
- $\rightarrow$ foramen ovale $\rightarrow$ L atrium
- Or $\rightarrow$ R Ventricle $\rightarrow$ pulmonary trunk $\rightarrow$ ductus arteriosus $\rightarrow$ aorta $\rightarrow$ internal iliac arteries $\rightarrow$ umbilical arteries $\rightarrow$ placenta
Fetal Circulation

(a) Fetal circulation

(b) Circulation at birth

- Oxygenated blood
- Mixed oxygenated and deoxygenated blood
- Deoxygenated blood
Changes at Birth

- Umbilical arteries $\rightarrow$ medial umbilical ligaments
- Umbilical vein $\rightarrow$ ligamentum teres
- Ductus venosus $\rightarrow$ ligamentum venosum
- Placenta expelled after
- Foramen ovalis closes $\rightarrow$ fossa ovale
- Ductus arteriosus $\rightarrow$ ligamentum arteriosum
Aging

- Stiffening of aorta
- Loss of cardiac muscle strength
  - Reduced CO & increased systolic pressure
- Higher risk for
  - Coronary artery disease (CAD)
  - Congestive heart failure (CHF)
  - Atherosclerosis
End of Chapter 16

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