Blood Vessels and Circulation

Chapter 21

Five General Classes of Blood Vessels

• Arteries, which carry blood away from the heart
• Aterioles, the smallest arterial branches, that communicate with
• Capillaries, where diffusion (exchange) between blood and interstitial fluids occurs
• Venules, which carry blood from the capillary beds
• Veins, larger vessels that return blood to the heart

Anatomy of Blood Vessels

• The walls of arteries and veins contain 3 distinct layers
  – The tunica intima, or tunica interna, consists of the innermost endothelial layer and an underlying layer of connective tissue
  – The tunica media, contains concentric sheets of smooth muscle in a framework of loose connective tissues, commonly the thickest layer in arteries
  – Tunica externa, or tunica adventitia, is the outermost layer and forms a connective tissue sheath around the vessel, that stabilizes and anchors the blood vessel

Differences between Arteries and Veins

• In general, the walls of arteries are thicker than those of veins, principally due to the thickness of the smooth muscle and elastic fibers in the tunica media
• When not opposed by blood pressure, the walls of arteries constrict the lumen to a narrow diameter. Veins, on the other hand, tend to collapse and appear flattened in cross section
• The endothelial lining of an artery folds when an artery contracts, veins do not form folds

Arteries

• The contractile nature of the arterial wall gives arteries the ability to actively change diameter
• These changes in diameter are primarily under the control of the sympathetic division of the autonomic nervous system
• Vasoconstriction is the process by which the smooth muscle in arteries contract when stimulated and the diameter of the blood vessel decreases
• Vasodilation increases the diameter of the lumen and results from relaxation of the smooth muscle layer
### Arteries

- Vasoconstriction and vasodilation affect
  - The afterload of the heart
  - Peripheral blood pressure
  - & capillary blood flow
- Arteries are classified, based on size, as either: elastic (aka conducting), up to 2.5 cm in diameter, or muscular (aka distribution or medium sized arteries) with a diameter of 0.5 to 4.0 mm
- Small arteries (generally with an internal diameter of 30 µm or less) are called arterioles
- See fig 21-2 on p711

### Capillaries

- Structurally capillaries are an endothelial tube inside a basal lamina
- Capillaries are the only blood vessels permitting exchange between blood and surrounding tissues
  - Surround muscle fibers
  - Radiate through connective tissue
  - & weave throughout all active tissues
- There are two major types of capillaries
  - Continuous capillaries with a complete endothelial lining
  - Fenestrated capillaries which contain pores spanning the endothelial lining
    - These pores (fenestrations) allow for much more rapid movement of water and solutes between blood plasma and the interstitial fluids
    - Sinusoids are a type of fenestrated capillary with flattened and irregular gaps between endothelial cells permitting a free exchange of water and solutes as large as plasma proteins

### Capillary Beds

- Capillary beds are an interconnected network of vessels consisting of
  - The collateral arteries feeding an arteriole
  - Metarterioles (capable of contraction)
  - Capillaries
  - Arteriovenous anastomoses (joining of artery & vein)
  - Venules
**Capillary Beds**

- Each capillary bed
  - connects one arteriole to one venule
  - & contains precapillary sphincters that regulates blood flow through the bed

**Veins**

- Veins collect blood from all tissues and organs and return it to the heart
- Veins are also classified according to size
  - Venules - collect from capillary beds
  - Medium-sized veins
  - Large veins
- Venules and medium-sized veins contain valves which prevent the backflow of blood
The Distribution of Blood

- Our blood volume is unevenly distributed among arteries, veins, and capillaries.
- The heart, arteries, and capillaries normally contain about 30-35% of the blood volume.
- The venous system contains the rest.
- Veins, with their thinner walls, are much more distensible than arteries, as a result veins act as a reservoir for blood volume and are termed capacitance vessels (arteries, with their contractile muscular walls are considered a reserve of pressure).

Cardiovascular Physiology

- The goal of cardiovascular regulation is the maintenance of adequate blood flow through the capillary beds in peripheral tissues and organs.
- Under normal circumstances, this means that blood flow is equal to cardiac output.
- When cardiac output increases, so does blood flow through the capillary beds...and vice versa.
- Factors affecting blood flow and cardiac output fall under the broad topic: cardiovascular physiology.

Blood flow

- Blood flow is determined by the interplay between pressure (P) and resistance (R) in the cardiovascular network.
- In order for blood to flow the heart must generate sufficient pressure to overcome the peripheral resistance in the pulmonary and systemic circuits.
- As pressure (P) increases flow increases and as resistance (R) decreases flow increases.

Blood flow

- Absolute pressure (the size of the number) is less important than the pressure gradient – the difference in pressure from one end of the vessel to the other.
- In other words, blood will flow as long as the pressure is greater at one end of the vessel versus the other.
Cardiovascular Physiology

- In order to understand cardiovascular physiology we must understand circulatory pressure and resistance, as well as the mechanisms of capillary exchange that ultimately provide part of the feedback that regulates pressure and resistance.

Circulatory Pressure

- Circulatory pressure can be divided into three components
  - Blood pressure (BP), really arterial pressure, around 100mm Hg at aorta to 35mm at capillary bed
  - Capillary hydrostatic pressure, pressure within the capillary beds 35-18 mm Hg
  - Venous pressure around 18 mm Hg

Resistance (R)

- Resistance of the cardiovascular system opposes the movement of blood
- For blood to flow, the circulatory pressure must overcome total peripheral resistance; the resistance of the entire cardiovascular system

Peripheral Resistance

- Peripheral resistance has three major components
  - Vascular resistance: the resistance of the blood vessels is the largest component of peripheral resistance, it is dependent upon the length and diameter of the blood vessels
  - Viscosity is resistance to flow caused by blood components, blood viscosity is generally stable excepting specific disorders
  - Turbulence seldom occurs in the smallest vessels and has little affect on resistance in larger vessels

Figure 21-9 Factors Affecting Friction and Vascular Resistance p719

- Factors Affecting Friction and Vascular Resistance
- Resistance to flow
- Flow
- Internal surface area
- Resistance to flow
- Flow
- Diameter
- Resistance to flow
- Flow
- Turbulence
- Plaque deposit
- Turbulence
Arterial blood pressure

- Arterial blood pressure
  - Maintains blood flow through capillary beds
  - Rises during ventricular systole and falls during ventricular diastole
- Pulse is a rhythmic pressure oscillation that accompanies each heartbeat
  - Pulse pressure = difference between systolic and diastolic pressures
- Mean Arterial Pressure (MAP) is a weighted average of pulse pressure and diastolic pressure

Venous Pressure and Venous Return

- Venous pressure, though low, determines venous return
- Venous pressures in the vena cavae are around 2 mm Hg
- Both muscular compression and the respiratory pump assist in propelling blood toward the heart

Muscular Compression

- The contraction of skeletal muscles near a vein compress it, helping push blood toward the heart
- Valves in the veins insure that blood flows in one direction only
- Normal standing and walking causes cycles of muscle contraction that assist venous return

Respiratory Pump

- As you inhale, the increase in thoracic cavity volume decreases pressure within the pleural cavity and pulls air into the lungs and also blood into the inferior vena cava and right atrium
- As you exhale, the increasing pressure pushes blood into the right atrium from the vena cavae
- This respiratory pump is important during heavy exercise when respiration is deep and frequent

Capillary Exchange
Capillary Exchange

- Capillary exchange is the flow of water and solutes from capillaries to interstitial space.
- Most of this material is reabsorbed, but some enters the lymphatic system, which then returns it to the bloodstream.
- The most important processes that move materials across capillary walls are diffusion, filtration, and reabsorption.

Diffusion

- Diffusion is the passive movement of ions or compounds from a region of high concentration to a region of low concentration.
- Water, ions, and small organic molecules readily diffuse across capillary boundaries.
- Plasma proteins and blood cells are normally unable to cross the capillary boundaries except at sinusoids, where large gaps exist.

Filtration

- Filtration is the removal of solutes as a solution flows across a porous membrane (fenestrated capillaries).
- The driving force in filtration is Capillary Hydrostatic Pressure (CHP) which forces water and small ions across the capillary walls.
- This leaves larger solutes, blood cells, and plasma proteins behind within the vessel where they maintain the osmotic potential (blood colloidal osmotic pressure) to drive reabsorption.

Reabsorption

- Reabsorption occurs as a result of blood colloidal osmotic pressure which draws water back into the capillaries via osmosis.
- Remember:
  - Hydrostatic pressure forces water and solutes out of the blood vessel via filtration.
  - Reabsorption pulls water back into the blood vessel driven by the osmotic pressure of blood cells and plasma proteins remaining in the blood vessel.

In Summary

- Blood entering the capillary bed has a capillary hydrostatic pressure (CHP) of 35 mm Hg.
- The blood colloid osmotic pressure (pulling water back into the blood vessel) is a constant across the capillary bed at 25 mm Hg.
- Blood leaving capillary bed has a CHP of 18 mm Hg.
- So what does that all mean?
Cardiovascular Regulation

- Homeostatic mechanisms regulate cardiovascular activity to ensure that blood flow through tissues (perfusion) meets the demands for oxygen and nutrients
- Regulation of cardiovascular function is accomplished via autoregulation, neural mechanisms, and endocrine mechanisms
- Section 20.4 in openstax, Figure 21-12 in Martini (section 21-3)

Autoregulation

- The pattern of blood flow within capillary beds changes in response to chemical changes in interstitial fluids
- Autoregulation causes immediate, localized homeostatic adjustments
- If autoregulation fails to return the system to homeostasis, neural and endocrine factors are activated

Neural Mechanisms

- Neural mechanisms respond to changes in arterial pressure (baroreceptors) or blood gas levels (chemoreceptors) at specific sites
- Cardiovascular centers of the autonomic nervous system adjust cardiac output and peripheral resistance to maintain blood pressure and ensure adequate bloodflow

Endocrine Mechanisms

- Endocrine mechanisms cause the release of hormones to enhance short term adjustments or direct long-term changes
- E, NE, ADH, Angiotensin II, Erythropoetin, and atrial natriuretic peptide are important in cardiovascular regulation
Exercise and the Cardiovascular System

- Light exercise results in
  - Extensive vasodilation as oxygen consumption increases
  - Increased venous return through the action of muscle contraction and respiratory pump
  - A rise in cardiac output in response to increased venous return and atrial pressure

- Heavy exercise results in
  - Increased blood flow to skeletal muscles
  - Restriction of blood flow to nonessential organs

Cardiovascular response to hemorrhaging: short term

- Carotid and aortic reflexes increase cardiac output and peripheral vasoconstriction
- Sympathetic nervous system elevates blood pressure
- E and NE increase cardiac output and ADH enhances vasoconstriction

Cardiovascular response to hemorrhaging: long term

- Decline in capillary blood pressure recalls fluids from interstitial spaces
- Aldosterone and ADH promote fluid retention
- Increased thirst promotes water absorption across the digestive tract
- Erythropoietin ultimately increases blood volume and improves O₂ delivery

<table>
<thead>
<tr>
<th>Table 21-2</th>
<th>Effects of Training on Cardiovascular Performance</th>
</tr>
</thead>
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<tr>
<td>Impact</td>
<td>Rest (Hemodynamic)</td>
</tr>
<tr>
<td>Rest (Hemodynamic)</td>
<td></td>
</tr>
<tr>
<td>Exercise (Max)</td>
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<tr>
<td>Heart rate (bpm)</td>
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<tr>
<td>Stroke volume (mL)</td>
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<tr>
<td>Cardiac output (L/min)</td>
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<tr>
<td>Blood pressure (mmHg)</td>
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</tr>
</tbody>
</table>

*Rest values were recorded during normal activity and training activity increased.*

- Trained athletes have bigger hearts and greater stroke volumes than non-athletes
- An athlete’s cardiac output can be half again that of a non-athlete during exercise
- Regular moderate exercise can cut the risk of heart attack in half
- Only around 8% of US adults exercise at recommended levels
Circulatory Shock

- Circulatory shock is marked by low blood pressure and inadequate peripheral bloodflow.
- Symptoms appear after a loss of about 30% of total blood volume.
- In mild cases, homeostatic mechanisms can cope with the situation.
- When blood volume drops by more than 35%, homeostatic mechanisms cannot cope and low cardiac output results in damage to the myocardium.
- In the absence of treatment, damage becomes irreversible and death ensues.

Special circulation

- The brain
  - The brain has a very high oxygen demand and normally receives about 12% of cardiac output.
  - Four arteries anastomose inside the cranium, insuring constant blood flow.
- The heart
  - Coronary arteries arise from the ascending aorta.
- The lungs
  - Pulmonary circuit, regulated by local responses to O₂ levels within the alveoli.
  - The pulmonary circuit responds differently than other tissues in that a decline in O₂ levels causes vasoconstriction in the lung tissues and blood is shunted to the alveoli.

The distribution of blood: General functional patterns

- Peripheral distribution of arteries and veins is generally symmetrical, except near the heart where the largest vessels connect to the atria or ventricles.
- Single vessels may have several names as they cross anatomical boundaries.
- Arteries and corresponding veins usually travel together.

Pulmonary circuit consists of pulmonary vessels

- The pulmonary trunk gives rise to the right and left pulmonary arteries which deliver blood to the lungs.
- Capillary networks in the lungs surround alveoli where gas exchange occurs.
- Four pulmonary veins, two from each lung deliver blood to the left atrium.

The Systemic Circuit

- The systemic circuit supplies and drains the capillary beds in parts of the body not serviced by the pulmonary circuit.
- The systemic circuit begins at the left ventricle and ends at the right atrium.
**Ascending Aorta And Aortic Arch**

- The right and left coronary arteries originate from base of aortic sinus at the base of the aortic arch
- The aortic arch connects the ascending and descending aortas
- Three elastic arteries branch from the aortic arch; the brachiocephalic, left common carotid, and left subclavian
- The brachiocephalic ascending then branches to form the right subclavian and right common carotid arteries

**Descending Aorta**

- The descending aorta is continuous with the aortic arch and is divided into the superior thoracic aorta and inferior abdominal aorta by the diaphragm
Systemic Veins

- The superior vena cava drains blood from the head and neck
- The inferior vena cava drains blood from the remainder of the body
Figure 21-29a  Major Veins of the Head, Neck, and Brain

Cerebral veins

Cavernous sinus

Pt l i

Superior sagittal, sinus (cut)

An inferior view of the brain, showing the venous distribution. For the relationship of these veins to meningeal layers, see Figure 14-3, p. 453.

Occipital sinus

Straight sinus

Transverse sinus

Cerebellar veins

Sigmoid sinus

Internal jugular

Petrosa

l

s

i

n

Figure 21-29c  Major Veins of the Head, Neck, and Brain

Superior sagittal sinus

Superficial cerebral veins

Inferior sagittal sinus

Great cerebral

Straight sinus

Petrosal sinuses

Right transverse sinus

Occipital sinus

Sigmoid sinus

Figure 21-30  The Venous Drainage of the Abdomen and Chest

Adrenal veins

Phrenic veins

Basilic

INFERIOR VENA CAVA

Intercostal veins

Hemiazygos

Accessory hemiazygos

Cephalic

Axillary

Brachiocephalic

Highest intercostal

Subclavian

External jugular

Internal jugular

Vertebral

Lumbar

Gonadal

veins

Renal veins

Hepatic

veins

Internal thoracic

Azygos

Esophageal

veins

Mediastinal

veins

SUPERIOR VENA CAVA

Brachial

Palmar venous

arches

Digital veins

Ulnar

Median antebrachial

Radial

Cephalic

Anterior crural

interosseous

Medial

Sacral

Basilic

MDI BIBI

Adrenal

Figure 21-32  Venous Drainage from the Lower Limb

External iliac

Common iliac

Internal iliac

Gluteal

Internal pudendal

Lateral sacral

Obturator

Femoral

Femoral circumflex

Deep femoral

Femoral

Great saphenous

Popliteal

Small saphenous

Anterior tibial

Posterior tibial

Fibular

Dorsal venous arch

Plantar venous arch

Digital

An anterior view A posterior view

KEY

Superficial veins

Deep veins

Collects blood from the superficial veins of the lower limb

Collects blood from the thigh

Collects blood from superficial veins of the leg and foot
The Hepatic Portal System

- Blood leaving capillaries supplied by the celiac, superior, and inferior mesenteric arteries flows into the hepatic portal system.
- This blood contains substances absorbed by the stomach and intestines.
- At the liver these compounds are stored, metabolized into other compounds or excreted.
- After flowing through the sinusoids of the liver, blood collects in the hepatic portal vein and is discharged into the inferior vena cava.

Fetal Bloodflow

- Fetal blood flow to the placenta is supplied via paired umbilical arteries.
- A single umbilical vein drains from the placenta to the ductus venosus, which collects blood from both the umbilical vein and liver and empties into the inferior vena cava.

Fetal Circulation of the Heart and Great Vessels

- There is no need for pulmonary function in the fetus.
- Two shunts bypass the pulmonary circuit:
  - Foramen ovale or interatrial opening allows blood to flow from the right to left atrium.
  - Ductus arteriosus connects the pulmonary and aortic trunks.

Cardiovascular Changes at Birth

- At birth the lungs and pulmonary vessels expand.
- The ductus arteriosus constricts and becomes ligamentum arteriosum.
- A valvular flap closes the foramen ovale.
Figure 21-34a  Fetal Circulation

- Aorta
- Foramen ovale (open)
- Ductus arteriosus (open)
- Pulmonary trunk
- Placenta
- Inferior vena cava
- Ductus venosus
- Umbilical cord
- Liver
- Umbilical arteries

Blood flow to and from the placenta in full-term fetus (before birth)

Figure 21-34b  Fetal Circulation

- Right atrium
- Foramen ovale (closed)
- Left atrium
- Pulmonary trunk
- Ductus arteriosus (closed)
- Right atrium
- Left ventricle
- Right ventricle
- Inferior vena cava
- Ductus venosus

Blood flow through the neonatal (newborn) heart after delivery