

Blood Vessels and Circulation

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Cardiovascular System

- The cardiovascular system is divided into
 - (1) the heart and
 - (2) the blood vessels.
- The heart is the muscular pump that pumps blood, and blood vessels function as
 - (1) the pathways for distribution of the blood and
 - (2) the sites of exchange.

Cardiovascular System

- According to the direction of blood flow in reference to the heart, blood flows through
 - arteries,
 - arterioles,
 - capillaries,
 - venules, and
 - veins (which return to the heart).

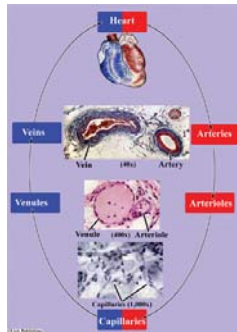


Fig. 24.1

Arteries

- Arteries carry blood **away** from the heart. Typically, arteries are described as vessels that have the **highest blood pressure** and have the thick walls.
- All arteries carry oxygen-rich blood, except those of the **pulmonary arterial circuit**.
- Arteries are divided into
 - (1) elastic arteries, and
 - (2) muscular arteries.

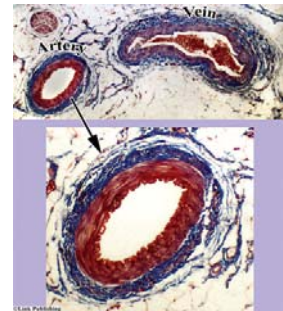


Fig. 24.2

Elastic Arteries

- Elastic arteries contain abundant **elastic fibers** in the middle and outer layers of their wall.
- Often called **conducting arteries**, the elastic arteries expand to **accommodate the volume of blood ejected by the heart**.
- When the heart enters its resting period, the elastic fibers recoil and provide the **force which continues to push blood through the vascular system**.

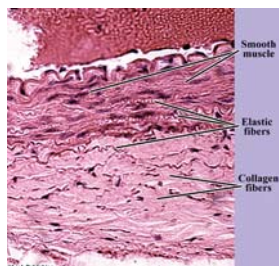


Fig. 24.3

Muscular Arteries

- Muscular arteries contain abundant **smooth muscle** in their middle wall layer.
- Often called **distribution arteries**, muscular arteries function by **vasoconstriction and vasodilation** to route blood to the body's organs and skeletal muscles.

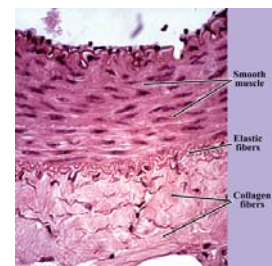


Fig. 24.4

Arterioles

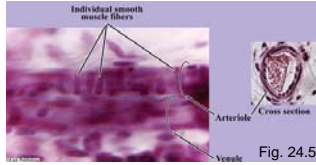


Fig. 24.5

- Arterioles contain a high percentage of **smooth muscle** that functions in **regulation of arteriole resistance by vasoconstriction and vasodilation**.
- **Vasoconstriction** is a major factor that increases resistance and reduces blood flow to distal tissues. Increasing resistance and reducing blood flow to the body's peripheral tissues, increases systemic blood pressure.
- **Vasodilation** decreases resistance and increases blood flow to distal tissues. Decreasing resistance and increasing blood flow to the body's peripheral tissues, decreases systemic blood pressure.

Capillaries

- Capillaries are the **sites of exchange** between the blood and surrounding tissues.
- **Diffusion, blood hydrostatic pressure (blood pressure), osmosis, and vesicular transport** are primary mechanisms for movement of substances across the capillary wall.
- Capillaries are divided into
 - (1) **Continuous capillaries,**
 - (2) **Fenestrated capillaries,** and
 - (3) **Sinusoids.**

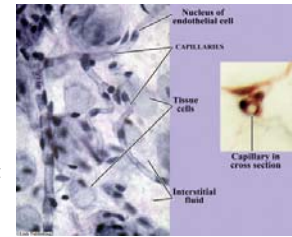


Fig. 24.6

Continuous Capillaries

- Continuous capillaries are characterized by having **tight junctions** between adjacent endothelial cells and the presence of minute clefts (**intercellular clefts**) between the tight junctions.
- Movement of substances across the wall of the capillary is mostly by **diffusion, filtration, osmosis, and vesicular transport**. Diffusion is limited to small substances that diffuse through the intercellular clefts, and substances that are permeable to the plasma membranes of the endothelial cells.
- Driven by **hydrostatic pressure** (blood pressure) filtration also occurs through the intercellular clefts. Filtration occurs as hydrostatic pressure (blood pressure) moves water and substances (solutes) smaller than the size of the intercellular clefts across the capillary wall. **The movement of water back into the capillary is by osmosis.**

Fenestrated Capillaries

- Fenestrated capillaries, like continuous capillaries are characterized by having **tight junctions** between adjacent endothelial cells and the presence of minute clefts (**intercellular clefts**) between the tight junctions.
- Additionally, the endothelial cells of fenestrated capillaries have small **membrane-covered pores called fenestrations that facilitate the movement of water and small substances.**

Sinusoids

- Sinusoids are the **most permeable** of the capillaries and are found in organs (like the liver and bone marrow) that require greater permeability.
- Their endothelial cells typically are **fenestrated, and large intercellular clefts exist between adjacent cells.**

Venules

- Capillaries unite to form small veins called **venules**. Venules are typically thin walled and unite to form veins.
- High power photographs of a small venule (and associated arteriole). Venules are thin walled and contain very little smooth muscle.

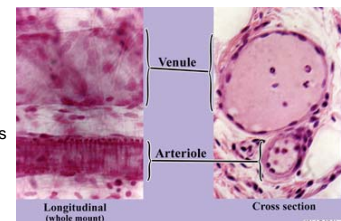


Fig. 24.7

Veins

- Venules merge to form the **veins**, which continue to transport blood toward the heart (right atrium).
- All veins carry oxygen poor blood **except** for the pulmonary venous circuit, which carries oxygen-rich blood from the lungs to the heart (left atrium).

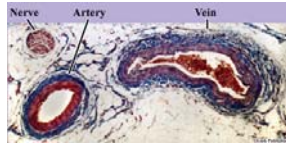


Fig. 24.8

Artery and Vein Structure

- Structurally, arteries and veins are characterized by containing three layers called tunics. From outer to inner the three tunics of the vascular wall are
 - (1) **tunica interna**,
 - (2) **tunica media**, and
 - (3) **tunica externa**.

Tunics of Vessels

- The tunica intima forms the inner lining of blood vessels. It consists of a surface layer of **simple squamous epithelium (endothelium)** and an **underlying layer of loose connective tissue**.
- The tunica media is the middle layer composed mostly of **smooth muscle fibers intermixed with elastic and collagen fibers**.
- The tunica externa is the outer layer that contains **interwoven collagen fibers and elastic fibers**.

Lab Activity 1 – Artery & Vein

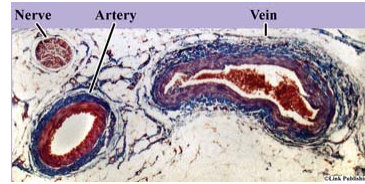


Fig. 24.9

- Scanning power photograph of a preparation of an artery, vein, and nerve, Masson stain. Masson stain dyes the connective tissues (collagen) blue. An artery has a thicker tunica media and a smaller lumen than its companion vein.

Structure of an Artery

- Usually, the artery has a thicker wall than its companion vein.
- It has a thicker tunica media and a smaller internal cavity (lumen).

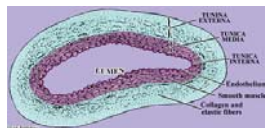


Fig. 24.10

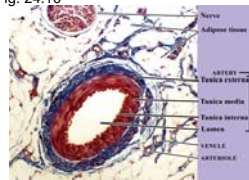


Fig. 24.11

Structure of an Artery

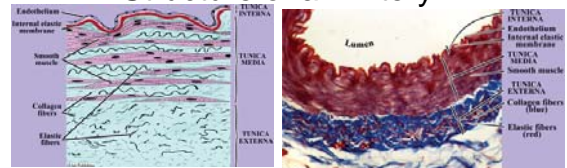


Fig. 24.12

Fig. 24.13

- The **tunica intima** forms the inner lining of the artery. Identify its surface layer, which consists of simple squamous epithelium (endothelium).
- The **tunica media** is the thick middle layer. Identify its circularly arranged smooth muscle. The tunica media of arteries functions in **vasoconstriction, vasodilation**, and in **accommodation for changes in blood volume and pressure by passive expansion and recoil**.
- The tunica adventitia is the outer layer that contains **elastic fibers** and interwoven, lightly stained **collagen fibers**.

Structure of an Artery

- In **elastic arteries**, such as the aorta shown in this photograph, the tunica media has abundant elastic fibers.
- The elastic fibers provide for **expansion** of the artery when blood is ejected from the left ventricle. The **recoil** of the elastic fibers provides the force to continue to drive blood through the vascular system while the heart is in its resting period.

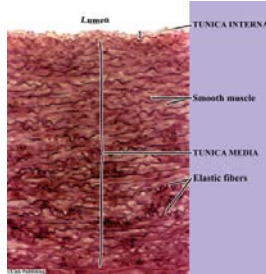


Fig. 24.14

Structure of a Vein

- Usually, the vein has a **thinner wall than its companion artery**.
- It has a **thinner tunica media and a larger internal cavity (lumen)**.

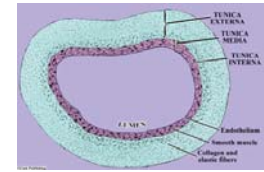


Fig. 24.15

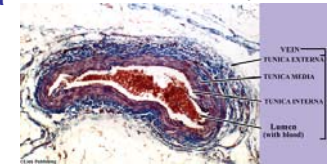


Fig. 24.16

Structure of a Vein

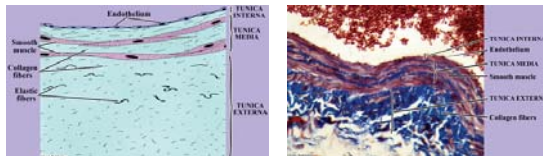


Fig. 24.17

Fig. 24.18

- The **tunica intima** forms the inner lining of the vein. Identify its surface layer, which consists of simple squamous epithelium (endothelium).
- The tunica media is the middle layer that contains a few elastic fibers and circularly arranged smooth muscle.
- The tunica adventitia is the outer layer that contains elastic fibers and interwoven, lightly stained collagen fibers.

VALVES

- Many medium sized veins contain valves that are formed from the tunica intima.
- A venous valve consists of two leaflets that allow blood to flow in only one direction, toward the heart.
- Venous return is increased by the **"skeletal muscle pumping mechanism."**

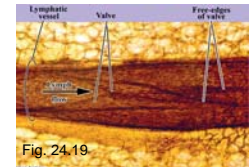


Fig. 24.19

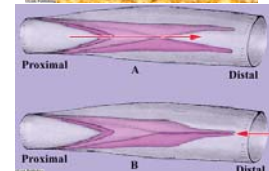


Fig. 24.20

VALVES Skeletal Muscle Pumping Mechanism."

- The contraction of a skeletal muscle squeezes its associated veins resulting in increased pressure of the blood.
- Under increased pressure the proximal valve (toward the capillaries) closes and the distal valve (toward the heart) opens.
- Relaxation of the muscle reduces the pressure in the vein. With reduced pressure, the distal valve closes, preventing back flow of blood, and the proximal valve opens.
- Opening of the proximal valve allows refilling of the vein with blood.

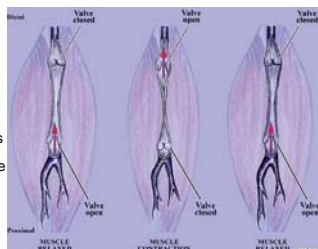


Fig. 24.21

Circulation Pathways

Circulation Pathways

- The arteries, arterioles, capillaries, venules, and veins are interconnected to provide circulation pathways throughout the body. The two major circulation pathways are (1) systemic circuit and the (2) pulmonary circuit.
- Systemic circulation**
 - The systemic circuit delivers oxygen-rich blood throughout the body. It begins with blood flow from the left ventricle into the aorta. It continues through the vascular pathways of the body and terminates with the return of oxygen-poor blood to the right atrium. Systemic circulation is divided into subdivisions that describe the pathways for specific regions. Regional pathways include (1) the coronary (heart), (2) the hepatic portal (digestive tract to liver), and (3) the cerebral circulation.
- Pulmonary circulation**
 - Pulmonary circulation is the pathway for blood flow to and from the lungs for gas exchange. It begins with the delivery of oxygen-poor (and carbon dioxide rich) blood to the lungs by way of the pulmonary arterial circuit, which begins at the right ventricle. Gas exchange occurs across the capillaries and air sacs. Oxygen-rich blood (carbon dioxide poor) is returned to the left atrium of the heart by the pulmonary venous circuit.

Systemic Circulation Overview of Major Arteries

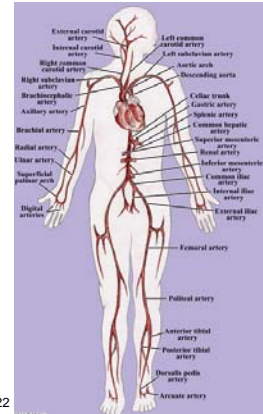


Fig. 24.22

Systemic Circulation Overview of Major Veins

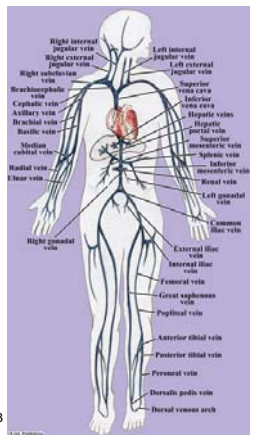


Fig. 24.23

SYSTEMIC BLOOD PRESSURE

Systemic Blood Pressure

- Vascular blood pressure is the force that blood exerts against the walls of blood vessels.**
- Vascular blood pressure is produced by the contraction of the muscles of the heart and the recoil of the walls of elastic vessels.
- The pressure produced by the contraction of the heart's left ventricle ejects blood into the systemic circuit of the body.** The high pressure produced by the contraction of the heart's left ventricle is called **systolic pressure** (contraction phase pressure). As blood surges into the elastic arteries during the contraction event, their walls expand to accommodate the increased volume.
- When the left ventricle relaxes, the aortic (semilunar) valve closes, and the elastic recoil of the arteries produces the pressure that drives the blood onward through the remaining vascular system.** During the recoil of the elastic arteries blood pressure continues to decrease. The lowest pressure in the vascular system while the heart is in its resting period is called the **diastolic pressure** (relaxation phase pressure).

Sphygmomanometer

- A sphygmomanometer is an instrument consisting of an inflatable cuff and a pressure gauge, which is used for measuring arterial blood pressure.
- Arterial blood pressure is measured as the height in millimeters the pressure exerted by the blood will raise a column of mercury (mm Hg.).
- The systolic pressure is written first and the diastolic pressure second. For a blood pressure written as 120/80 mm Hg., the 120 mm Hg. is the **systolic pressure**, and the 80 mm Hg. is the **diastolic pressure**.

Sphygmomanometer

- There are two common types of sphygmomanometers.
 - (1) the mercurial sphygmomanometer (uses the liquid mercury) and
 - (2) the aneroid sphygmomanometer (aneroid means "not using liquid").
- The **mercurial sphygmomanometer** uses a mercury column to measure the blood pressure. Cuff pressure is produced by a rubber bulb pump and is measured by the movement of the column of mercury along a scale calibrated in millimeters of mercury (mm Hg.).
- The **aneroid sphygmomanometer** uses a mechanical type of pressure gauge to measure the blood pressure. Cuff pressure is produced by a rubber bulb pump and is measured by the movement of the gauge's needle along a scale calibrated in mm Hg.

Stethoscope

- The stethoscope is an instrument used to amplify and transmit sounds directly to the ears. The standard stethoscope used in blood pressure determination consists of two ear pieces with tubing attached to a diaphragm. Sounds are picked up by the diaphragm and are transmitted through the tubing to the ears.

Lab Activity 3 Blood Pressure Measurement

- Observe the **arrow** on the cuff for placement in the proper position directly over the brachial artery.
- Place the cuff snugly around the upper arm about an **inch above the bend of the elbow**.
- **Close (clockwise rotation) the exhaust valve** on the rubber bulb pump. Quickly inflate the cuff to about **140 mm Hg**.
- Place the diaphragm of the stethoscope directly **over the front of the elbow (the antecubital fossa)**.
- Carefully loosen the exhaust valve and slowly deflate the cuff at a **constant rate (about 2 to 3 mm Hg. per second)**. As the cuff deflates, **listen carefully for the onset of tapping sounds (Korotkov's sounds)**.
- Record the reading of **systolic pressure** when the Korotkov's sounds first begin.
- Record the reading of **diastolic pressure** at the termination of the Korotkov's sounds

REGULATION OF BLOOD PRESSURE AND FLOW

Regulation of Pressure and Flow

Three major factors that influence blood pressure (BP) and flow are

- (1) **cardiac output,**
- (2) **peripheral resistance, and**
- (3) **blood volume.**

Cardiac Output

- Cardiac output is the volume of blood ejected by each ventricle in one minute.
- Increasing or decreasing cardiac output increases or decreases blood pressure, respectively.
- Cardiac output (CO) is calculated by multiplying stroke volume (SV) by heart rate (HR), or
 - $CO = SV \times HR.$

Stroke Volume

- **Stroke volume** is the volume of blood ejected by each ventricle by a single cardiac cycle, or heart beat.
 - Stroke volume is calculated by subtracting end systolic volume from end diastolic volume, or $SV = EDV - ESV$.
- **End Diastolic Volume**
 - The end diastolic volume is the volume of blood in each ventricle at the end of its relaxation and filling phase, diastole.
- **End Systolic Volume**
 - The end systolic volume is the volume of blood remaining in each ventricle at the end of the contraction phase, systole.
 - Three factors that influence the end systolic volume are (1) preload, (2) contractility, and (3) afterload.

Heart Rate

- Heart rate is primarily controlled by the autonomic nervous system (ANS).
 - The parasympathetic division (the cardioinhibitory center) decreases heart rate, and the
 - sympathetic division (the cardioacceleratory center) increases heart rate.
 - The parasympathetic and sympathetic centers are located in the medulla oblongata. The cardioinhibitory center (parasympathetic) is the dominate control center.
- The normal range for the heart's rate of beat is between 60 - 100 beats per minute, with most people averaging between 70 - 80 beats per minute (bpm). Bradycardia is defined as a slow heart rate, usually less than 60 bpm. Tachycardia is defined as a fast heart rate, usually more than 100 bpm.

Peripheral Resistance

Peripheral Resistance

- Peripheral resistance of blood vessels is the force that opposes the flow of blood, especially through the small blood vessels called the arterioles. Opposition to flow (increased peripheral resistance) results in an increase of blood pressure.
- Among the factors that influence peripheral resistance are
 - (1) blood viscosity,
 - (2) total length of the blood vessels, and
 - (3) blood vessel diameter.

Blood viscosity

- Viscosity is the resistance to flow. A viscous substance is described as sticky and cohesive with a high resistance to flow. Increased pressure is required to move a viscous substance. Normally, blood viscosity remains fairly constant as plasma and formed elements remain within normal ranges.

Total Length of Blood Vessels

- As a fluid moves against a wall, friction occurs at the interface of the fluid and the wall. Thus, as blood flows through the vascular system, the walls of the blood vessels produce resistance to flow.
- The further blood travels through the vascular system, the more resistance blood encounters. The total length of the body's blood vessels can undergo changes, especially if an individual produces or loses tissue.

Regulation of Peripheral Resistance

- Regulation of peripheral resistance by controlling blood vessel diameter is by the **sympathetic vasomotor center** located in medulla oblongata of the brain stem.
- The **vasomotor center** and the cardioinhibitory and cardioacceleratory centers of the medulla oblongata are the cardiovascular center. The cardiac portion of the cardiovascular center functions to control the heart by adjusting its rate and force of contraction, and the **vascular portion functions to control blood vessel diameter promoting vascular smooth muscle contraction (vasoconstriction) or relaxation (vasodilation).**

Blood Vessel Diameter

- Immediate changes to vascular resistance are by regulation of the **diameter of blood vessels**. As blood flows through a vessel, most resistance is produced by friction at the interface of the blood and the vessel's wall.
- **Large blood vessels offer less resistance** because most of their blood volume is within the vessel, not at the blood vessel's wall.
- **Small blood vessels have more resistance** because more of their blood volume is at the vessel's wall. Thus, the small blood vessels that have the capacity to regulate their diameter, the **arterioles**, are considered the vessels that control vascular resistance.

Vasomotor Center

- The activity of the vasomotor center is primarily regulated by
 - (1) pressure receptors (baroreceptors), and
 - (2) chemical receptors (chemoreceptors).

Baroreceptors

- Baroreceptors, or pressoreceptors, are nerve endings (receptors) that function in the reflex mechanism to reduce increased blood pressure.
- Locations of baroreceptors include the walls of the **aortic sinuses, aortic arch, and carotid sinuses**

Baroreceptors - Vasodilation

- Vasodilation
 - Increased stimulation of the baroreceptors (increased blood pressure) inhibits the vasomotor center resulting in vasodilation of the arterioles.

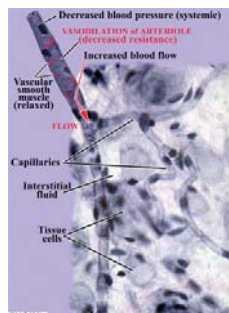


Fig. 24.25

Baroreceptors - Vasoconstriction

- Vasoconstriction
 - Decreased stimulation of the baroreceptors (decreased blood pressure) results in increased stimulation of the vasomotor center, which produces vasoconstriction of the arterioles.

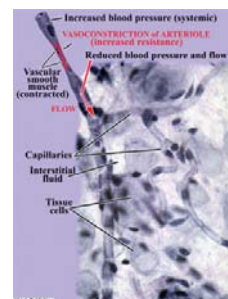


Fig. 24.26

Chemoreceptors

- **Vascular chemoreceptors are nerve endings (receptors) that function in the reflex mechanism of increasing blood pressure.**
- Vascular chemoreceptors are mostly located in the aortic arch (aortic bodies) and the carotid sinus (carotid bodies).
- Chemoreceptors stimulate the vasomotor center and the cardioacceleratory center. Increased stimulation of the vasomotor center results in **vasoconstriction**, which increases blood pressure. Stimulation of the cardioacceleratory center increases heart rate and force of contraction, which also increase blood pressure.
- The vascular chemoreceptors mostly respond to an **increase in pH, increased levels of carbon dioxide, and decreased levels of oxygen**. Increased blood pressure results in removal of the stimuli as more blood is pumped to the lungs for gas exchange and pH adjustment (pH is decreased by removal of CO₂).

Additional Factors Influencing Blood Pressure

Additional Factors Influencing Blood Pressure

- In addition to baroreceptors and chemoreceptors, other factors that influence blood pressure include
- (1) stress,
- (2) atrial natriuretic peptide hormone (ANP),
- (3) antidiuretic hormone (ADH), and
- (4) angiotensin II.

Stress (epinephrine and norepinephrine)

- Stress and the “fight-or-flight” response are mediated through the hypothalamic control of the adrenal medullae. The adrenal medullae release epinephrine and norepinephrine, both of which **increase blood pressure**. Norepinephrine is a powerful vasoconstrictor (increases vascular resistance).

Atrial Natriuretic Peptide (ANP)

- Atrial natriuretic peptide is a hormone produced in the atria of the heart and **functions to decrease blood pressure by reduction of blood volume and by general vasodilation**. Atrial natriuretic peptide reduces blood (water) volume by targeting the kidneys and increasing the secretion of sodium ions from the blood into the forming urine.

Antidiuretic Hormone (ADH)

- Antidiuretic hormone (ADH) is produced by the hypothalamus and released at the posterior pituitary. Antidiuretic hormone is released when the volume of water in the blood decreases. Decreased blood (water) volume results in decreased blood pressure. **Antidiuretic hormone targets the kidneys and promotes the reabsorption of water (into the blood) from the forming urine.**
- Antidiuretic hormone is also a **powerful vasoconstrictor**, hence its other common name of vasopressin.

Angiotensin II

- Angiotensin II is a powerful hormone that is produced as a result of the kidneys releasing the enzyme renin when blood pressure is low. Angiotensin II promotes the release of **aldosterone** from the adrenal cortex. Aldosterone targets the kidneys and promotes the **reabsorption of sodium ions** (into the blood). As sodium moves into the blood, water osmotically follows and **increases blood volume and blood pressure**. Angiotensin II is also a powerful vasoconstrictor.

Fluid Movement at the Capillary

- Capillaries are thin walled blood vessels that function as the sites of exchange between blood and the interstitial fluid.
- Consisting of a layer of simple squamous epithelium and basement membrane, the structure of capillaries provides for the movement of materials through the cells and through intercellular clefts (spaces) between adjacent cells.
- **Substances move by simple diffusion, filtration, and reabsorption.**

Diffusion

- **Diffusion is a process equalization** that involves movement from an area of higher concentration to an area of lower concentration.
- If a substance is permeable to the plasma membrane, has a facilitated membrane carrier, or is small enough to pass through the intercellular clefts, the substance will diffuse from the area of high to the area of low concentration, until equalization occurs.

Filtration

- Filtration is a process of separation by the use of a filter, a porous structure that **separates substances according to size**.
- Filtration requires a force to drive the material through the filter. Capillaries function as filters because their intercellular clefts and pores select what passes into the interstitial fluid.
- The driving force for capillary filtration is hydrostatic pressure. Hydrostatic pressure is the pressure of a fluid against a wall. In the case of capillaries, **hydrostatic pressure is blood pressure, the pressure generated by the contraction of the heart's ventricles**.
- **Hydrostatic pressure (blood pressure) at the capillary is a major driving force for the movement of fluid out of the capillary.**

Reabsorption

- Reabsorption is the uptake of fluid that has been filtered from the capillary. **The process of reabsorption is driven by osmosis.**
- Osmosis is the diffusion of water through a semipermeable membrane, from an area of higher concentration to an area of lower concentration.
- The reason that water has different concentrations is due to its concentration of solutes, substances dissolved in the water. A solution that has a high concentration of water has a low concentration of solutes. Of two solutions, the solution with a lower concentration of solutes is called a **hypotonic solution**. A solution that has a low concentration of water has a high concentration of solutes. Of two solutions, the solution that has a higher concentration of solutes is called a **hypertonic solution**.

Forces at the Arterial End of the Capillary

- At the beginning of the capillary, where the capillary originates from the arteriole, **capillary hydrostatic pressure (blood pressure), is about 35 mm Hg.**
- At the beginning of the capillary, blood osmotic pressure, the pressure that indicates the attraction of the blood for water, **is about 25 mm Hg.**
- The net filtration pressure (NFP) is determined by subtracting the blood osmotic pressure (OP) from the capillary blood pressure (BP). **Using the values, 35 mm (BP) - 25 mm (OP) = 10 mm (NFP).**
- **Thus, blood pressure moves water out of the arterial end of the capillary with a net force of 10 mm Hg.**

Forces at the Venous End of the Capillary

- At the end of the capillary, where the capillary joins with the venule, capillary **hydrostatic pressure** (blood pressure), is about 17 mm Hg.
- At the end of the capillary, blood osmotic pressure, the pressure that indicates the attraction of the blood for water, is (remains) about 25 mm Hg.
- The net filtration pressure (NFP) is determined by subtracting the blood osmotic pressure (OP) from the capillary blood pressure (BP). **Using the values, 17 mm (BP) - 25 mm(OP) = -8 mm (NFP).**
- Thus, **osmosis** moves water into the capillary with a net force of -8 mm Hg.

Fluid Movement at the Capillary

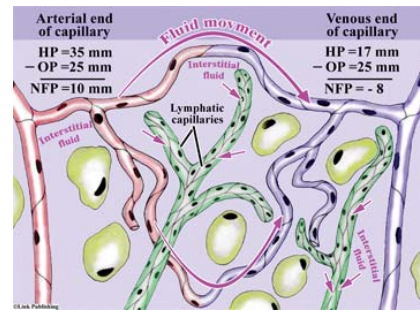


Fig. 24.27