THE CARDIOVASCULAR SYSTEM: 
PERIPHERAL CIRCULATION AND REGULATION

**Hemodynamics** - A study of the force involved in circulating blood throughout the body.

<table>
<thead>
<tr>
<th>Blood</th>
<th>-Life line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart</td>
<td>-Pumps</td>
</tr>
<tr>
<td>Vessels</td>
<td>-Direct/distribute</td>
</tr>
</tbody>
</table>

**GENERAL FEATURES OF BLOOD VESSEL STRUCTURE**

(Blood vessels form a **Network** (Closed System) of tubes that carry blood away from the heart, transport it to the tissues of the body, and then return it to the heart.)

**Arteries** - Vessels that carry blood from the heart to the tissues.

**Arterioles** - Smallest branches of arteries. (Medium-sized arteries divide into smaller arteries, which, in turn divide into smaller arteries called arterioles.)

**Capillaries** - countless microscopic vessels formed as branches of Arterioles as they enter a tissue.

**Venules** - small veins formed as groups of capillaries reunite before leaving the tissue.

**Veins** - blood vessels that convey blood from the tissues back to the heart.

(Formed by merged venules results to progressively larger tubes called veins).

*Vasa Vasorum* - Blood vessels on the walls of blood vessels. (Blood vessels require oxygen and nutrients just like other tissues of the body.)
ARTERIES

Structure

1) Found empty at death, were thought to contain only air.  

**Lumen** - Is the hollow center through which blood flows.

2.) **Three coats or tunics:**

a) **Tunica Intima** - Inner Coat - simple squamous epithelium  
   1) Endothelium  
   2) Basement Membrane  
   3) Internal Elastic Lamina

b) **Tunica Media** - Middle coat  
   1) External elastic lamina  
   2) Smooth muscle

c) **Tunica Adventitia** - Outer coat  
   1) Elastic fiber  
   2) Collagen fiber

The smooth muscle of arteries is arranged circularly around the lumen.

Usually, when there is an increase in sympathetic stimulation, the smooth muscle contracts, squeezes the wall around the lumen, and narrows the vessel.

**Vasoconstriction** - Is a decrease in the size of arterial lumen due to contraction (of the smooth muscle in Tunica Media)

**Vasodilation** - an increase in size of arterial lumen due to relaxation (of the smooth muscle)

*The contractility of arteries also serves a function in stopping bleeding.*
Types:

1. **Elastic (Conducting) Arteria** - Large arteries, serve as a pressure reservoir.
   - Aorta and Brachiocephalic
   - Common Carotid
   - Subclavian
   - Vertebral
   - Common Iliac

2. **Muscular (Distributing) Arteries** - Medium-sized arteries, are capable of greater vasoconstriction.
   - axillary - mesenteric
   - brachial - femoral
   - radial - popliteal
   - intercostal - tibial
   - splenic

*Anastomosis* - Is the union of the branch of two or more arteries supplying the same body region.

(Most parts of the body receive branches from more than one artery. In such areas the distal ends of the vessels unite,)

-(Anastomoses between arteries provide alternate routes by which blood can reach a tissue or organ --if a vessel is occluded by disease, injury, or surgery.)

*Collateral Circulation* - the alternate route of blood to a body part through an anastomosis.

**End Arteries** - arteries that do not anastomose.
(Occlusion (obstruction) of an end artery interrupts the blood supply to whole segment of an organ, producing necrosis (death) of that segment.)

**ARTERIOLES**

- A very small, almost microscopic artery, delivers blood to capillaries.

- Arterioles closest to the arteries have *tunica intima*, *tunica media*, and *tunica adventitia* like those of arteries.

- Closest to Capillaries consist larger of endothelium and are smaller.

- Play a key role in regulating blood flow from arteries into capillaries.

**CAPILLARIES**

- Are microscopic vessels that usually connect arterioles and venules.

  **Microcirculation** - Is the flow of blood from arterioles to venules through capillaries.

  **Primary function** is to permit the exchange of nutrients and wastes between the blood and tissue cells.

  *Form networks that increase the surface area for diffusion and filtration and thereby allow a rapid exchange of large quantities of materials.

  *Vessels with smooth muscle in their walls regulate the flow of blood through capillaries.

**Capillary Network:**

a)  **Metarteriole** - a vessel that emerges from an arteriole, passes
through the capillary network, and empties into the venule. (have smooth muscles- the proximal end)

b) **Thoroughfare Channel** - the distal portion of Metarteriole with no smooth muscle fibers.
   - Serves as a low-resistance channel that increases blood flow.

c) **True capillaries** - emerge from arterioles or metarterioles and are not on the direct flow route from arteriole to venule.

d) **Precapillary Sphincter** - a ring of smooth muscle fibers at the site of origins of true capillaries.
   - Regulates blood flow through capillaries.
   - Controls flow of blood entering a true capillary.

(Blood usually does not flow in a continuous manner through capillary networks. Rather, it flows intermittently, because of contraction and relaxation of the smooth muscle of metarterioles and the precapillary sphincters of true capillaries).

**Vasomotion** is the intermittent contraction and relaxation.

**Types of Capillaries:**

(a) **Continuous capillaries**

Form a continuous, uninterrupted ring around the capillary;

Except for **intercellular clefts**, which are gaps between neighboring endothelial cells.

Found in skeletal and smooth muscles, connective tissues, and the lungs.

(b) **Fenestrated capillaries**

Differ from continuous capillaries in that their endothelial cells have many fenestrations (pores) in the plasma membrane.
Found in the kidneys, villi of the small intestine, choroid plexuses of the ventricles in the brain, ciliary processes of the eyes, and endocrine glands.

(c) **Sinusoids**

Are wider than other capillaries and more winding

Instead of the usual endothelial lining, contain spaces between endothelial cells, and basement membrane is incomplete or absent.

Found in the liver.

**Substances enter and leave capillaries through four basic routes:**

1) Through junctions that anchor endothelial cells;
2) Via pinocytic vesicles;
3) Directly across capillary membranes; and
4) Through fenestration (surgical opening) - pores

**VENULES**

- Are small veins formed by unification of several capillaries.
- Collect blood from capillaries and drain it into veins.

**VEINS**

Veins consist of the same three tunics (tunica intima, tunica media, and tunica adventitia) as arteries, but variation in their relative thickness.

Have less elastic tissue and smooth muscle.

Do not contain the **external** or **internal elastic laminae** found in arteries.
They contain valves to prevent back flow of blood, especially those in the limbs.

Weak valves can lead to varicose vein or hemorrhoids.

**Vascular (venous) sinus** - is vein with a thin endothelial wall that has no smooth muscle to alter its diameter.

**BLOOD DISTRIBUTION**

*Systemic veins and venules contain so much of the blood (60%) and are called Blood Reservoirs.*

They serve as storage depots for blood, which can be diverted quickly to other vessels if the need arises.

**Blood Reservoirs** - Systemic Veins are collectively called blood reservoirs. (Veins, venules, and venous sinuses contain about 60% of the blood in the system.)

- They store blood, which through vasoconstriction can move to the other parts of the body if the need arises.

- Among the principal reservoirs are the veins of the abdominal organs (liver and spleen) and skin.

**CIRCULATORY ROUTES**

Shows the circulatory routes for blood flow.

Two basic routes are

(1) **Pulmonary Circulation**;
(2) **Systemic Circulation (Arteries and Veins)**
PULMONARY CIRCULATION

Takes deoxygenated blood from the right ventricle to the air sacs of the lungs and returns oxygenated blood from the lungs to the left atrium.

It allows blood to be oxygenated for systemic circulation.

Right pulmonary artery extends into the right lung.

Left pulmonary artery extends into the left lung.

SYSTEMIC CIRCULATION

Systemic Circulation - Includes all the oxygenated blood that leaves the left ventricle through the Aorta and reaches all systemic capillaries and the deoxygenated to all the organs including the nutrient arteries to the lungs.

1. The systemic circulation takes oxygenated blood from the left ventricle through the aorta to all parts of the body, including lung tissue (but does not supply the air sacs of the lungs) and returns the deoxygenated blood to the right atria.

2. The Aorta is divided into the ascending aorta, the arch of the aorta, and the descending aorta. Each section gives off arteries that branch to supply the whole body.

3. Blood is returned to the heart through the systemic veins. All the veins of the systemic circulation flow into either the superior or inferior vena cavae or the coronary sinus. They in turn empty into the right atrium.
Three of the many subdivisions of the Systemic Circulation:

(a). **Coronary (Cardiac) Circulation** - supplies the myocardium of the heart

(b). **Hepatic Portal Circulation** - runs from gastrointestinal tract to the liver

(c). **Cerebral circulation** - which supplies the brain

(Blood leaving the Aorta and traveling through the systemic arteries is a bright red color. As it moves through capillaries, it loses some of its oxygen and takes on carbon dioxide, so that blood in systemic veins is a dark red color.)

**Cerebral Circulation**

Cerebral arterial circle, or circle of Willis - circulation in the brain.

**Hepatic Portal Circulation**

The hepatic portal circulation detours blood from the gastrointestinal organs (pancreas, spleen, stomach, intestines, gallbladder), and spleen through the liver before it returns to the heart.

A Portal system carries blood between two capillary networks, from one location in the body to another without passing through the heart, in this case from capillaries of the gastrointestinal tract to sinusoids of the liver.

After a meal, hepatic portal blood is rich with absorbed substances. The liver stores some and modifies others before they pass into the general circulation.

**Example**: The liver converts glucose into glycogen for storage, thereby helping to restore blood sugar homeostasis.

It also modifies other digested substances so they may be
used by cells,

**Detoxifies** harmful substances that have been absorbed by the gastrointestinal organs, and

**Destroys** bacteria by phagocytosis.

**Anatomy of the Hepatic Portal Vein**

**Hepatic portal vein** is formed by the union of

(1) Superior mesentric vein, and
(2) Spenic vein.

(1) **Superior mesentric vein** drains blood from:

(a) Small intestine
(b) Portions of the large intestine
(c) Stomach
(d) Pancreas

Through the followings veins (networks):

(a) Jejunal
(b) Ileal
(c) Ileocolic
(d) Right colic
(e) Middle colic
(f) Pancreaticoduodenal
(g) Right gastroepiploic

(2) **Splenic Vein** drains blood from:

(a) Stomach
(b) Pancreas
(c) Portions of the large intestine

Through the following veins (networks):

(a) Short gastric
(b) Left gastroepiploic
(c) Pancreatic
(d) Inferior mesentric

Inferior mesentric vein passes into Splenic vein, drains blood from:

(a) Portions of the large intestine

Through the following veins (networks):
(a) Superior rectal
(b) Sigmoidal
(c) Left colic

Left and Right Gastric veins open directly into the Hepatic portal vein, drain blood from:

(a) Stomach

Cystic vein opens directly into the Hepatic portal vein, drains blood from:

(a) Gallbladder

Note: Liver receives deoxygenated blood via the hepatic portal system and oxygenated blood via the hepatic artery (a branch of celiac artery), at the same time.

Blood leaves liver through hepatic veins, which drain into the inferior vena cava.

**DYNAMICS OF BLOOD CIRCULATION**

The interrelationships between pressure, flow, resistance, and the control mechanisms that regulate blood and blood flow through vessels play a critical role in the function of the circulatory system.
Laminar Flow – Is a streamlined fashion in which fluid, including blood, tends to flow through long, smooth-walled tubes.

Fluid behaves as if it were composed of a large number of concentric layers.

- The layer nearest to the tube experiences the greatest resistance to flow because it moves against the stationary wall.

- The innermost layers slip over the surface of the outermost layer and experience less resistance to movement.

(Thus, flow in a vessel consists of movement of concentric layers, with the outermost layer moving slowest and the layer at the center moving fastest).

Note: Laminar flow is interrupted and becomes turbulent flow when the rate of flow exceeds a critical velocity or when the fluid passes a constriction, a sharp turn, or a rough surface.

Note: Turbulent flow of blood through vessels occurs primarily in the heart and to lesser extent where arteries branch.

BLOOD PRESSURE

Blood Pressure - Is a measure of the force blood exerts against blood vessel walls.

Mercury (Hg) Manometer is the standard instrument for measuring blood pressure.

Can be measured by inserting a cannula (or tube) into blood vessels or auscultatory method (using a Sphygmomanometer).

The blood flow is turbulent and produces vibrations in the blood and surrounding tissues that can be heard through the stethoscope.
Blood Pressure (BP) - Refers to the pressure in arteries exerted by the left ventricle when it undergoes systole and the pressure remaining in the arteries when the ventricle is in diastole.

- Usually taken in the left brachial artery.

Sphygmomanometer (sfig-mo-ma-NOM-e-ter) - Is the instrument for measuring blood pressure. Usually on the left brachial artery.

The normal Blood Pressure of a young adult male is about 120 mm Hg Systolic and 80 mm Hg Diastolic (120/80).

In young adult females, the pressures are 8 to 10 mm Hg less.

People who exercise regularly and are in good physical condition also tend to have a lower blood pressure.

Systolic Blood Pressure (SBP) - the force with which blood is pushing against arterial walls during ventricular contraction.

- A reading on the mercury column when the first sound is heard.

Diastolic Blood Pressure (DBP) - corresponds to the lowest force of blood in arteries during ventricular relaxation.

- Recorded on the mercury column when the sounds suddenly become faint.

- Provides information for systemic vascular resistance.

Korotkoff sounds - The various sounds that are heard while taking blood pressure.

Systolic pressure – Is the pressure at which a Korotkoff sound is first heard.
Diastolic pressure – Is the pressure at which continuous laminar flow is reestablished.

**BLOOD FLOW**

Rate at which blood or any other liquid flows through a tube can be expressed as the volume that passes a specific point per unit of time.

When a person is resting, the cardiac output of the heart is approximately 5 L/min; thus blood flow through the aorta is approximately 5 L/min.

**Note:** Blood flow in a vessel is proportional to the pressure difference in that vessel.

Example:

(1) If the pressure at point 1 (P1) and point 2 (P2) in a vessel are the same, no flow occurs.

(2) If the pressure at P1 is greater than at P2, flow proceeds from P1 toward P2.

**Note:** The greater the pressure difference the greater is the flow rate. Pressure always occurs from a higher to a lower pressure.

The flow of blood resulting from a pressure difference in a vessel is opposed by a resistance to blood flow.

**Note:** As resistance increases, blood flow decreases, and as resistance decreases, blood flow increases.

\[
\text{Flow} = \frac{P1-P2}{R}
\]

**Poiseuille’s Law** – According to Poiseuille’s law, flow decreases when resistance increases.
Resistance to flow dramatically decreases when blood vessel diameter increases.

**VISCOSITY**

**Viscosity** – Is a measure of the resistance of a liquid to flow.

As viscosity of a liquid increases, the pressure required to force it to flow increases.

**Note:** Viscosity of blood is influenced largely by **hematocrit**, which is the percentage of the total blood volume composed of red blood cells.

- Plasma proteins have a minor effect on the viscosity of blood

- Dehydration or uncontrolled production of erythrocytes can increase hematocrit and the viscosity of blood substantially.

**CRITICAL CLOSING PRESSURE AND LAPLACE’S LAW**

**Critical closing pressure** – Is the pressure below which the vessel collapses and blood flow through the vessels stops.

**Laplace’s Law** – States that the force that stretches the vascular wall is proportional to the diameter of the vessel times the blood pressure.

- Helps explain the critical closing pressure.

**Note:** As the pressure in a vessel decreases, the force that stretches the vessel wall also decreases. Some minimum force is required to keep the vessel open. If the pressure decreases so that the force is blow that minimum requirement, the vessel will close.

Laplace’s Law expressed:

\[ F = D \times P \]
According to Laplace’s Law, as the diameter of a vessel increases, the force applied to the vessel wall increases, even if the pressure remains constant. If a part of an arterial wall becomes weakened so that a bulge forms in it, the force applied to the weakened part is greater than at other points along the blood vessel because its diameter is greater. The greater force causes the weakened vessel wall to bulge even more, further increasing the force applied to it.

Note: As the bulges in weakened blood vessel walls, called aneurysms, enlarge, the danger of their rupturing increases.

VASCULAR COMPLIANCE

Compliance – Is the tendency for blood vessel volume to increase as the blood pressure increases.

The more easily the vessel wall stretches, the smaller is its compliance.

Note: Venous compliance is approximately 24 times greater than the compliance of arteries.

As venous pressure increases, the volume of the veins increases greatly. Consequently, veins act as storage areas, or reservoirs, for blood because their large compliance allows them to hold much more blood than other areas of the vascular system.

PHYSIOLOGY OF SYSTEMIC CIRCULATION

Approximately 84% of the total blood volume is contained in the systemic circulatory system.

- Most of the blood volume is in the vein, which are the vessels with the
greatest compliance.
- Smaller volumes of blood are in the arteries and capillaries.

**Cross-Sectional Area of Blood Vessels**

One aorta exists and has a cross-sectional area of 5 square centimeters.

Millions of capillaries exist, and each has a small cross-section area, but total cross-sectional area of all capillaries is 2500 square centimeters. This is much greater than the cross-sectional area of aorta.

*Note:* The velocity of blood flow is greater in the aorta, but the total cross-sectional area is small. In contrast, the total cross-sectional area for the capillaries is large, but the velocity of blood flow is low.

**Pressure and Resistance**

Because the pumping action of the heart is pulsatile, the aortic pressure fluctuates between a systolic pressure of 120 mm Hg and a diastolic pressure of 80 mm Hg.

Within the arterioles, the resistance to flow is higher than in any other part of the systemic circulation, and at their ends, the average pressure is only approximately 30 mm Hg.

The blood pressure at the arterial end of the capillaries is approximately 30 mm Hg, and it decreases to approximately 10 mm Hg at the venous end.

Resistance to blood flow in the veins is low because of their relatively large diameter; by the time the blood reaches the right atrium in the venous system, the average pressure has decreased from 10 mm Hg to approximately 0 mm Hg.
Pulse pressure

**Pulse Pressure** – Is the difference between systolic and diastolic pressures.

Healthy adult at rest:

\[
\begin{align*}
\text{Systolic pressure} &= 120 \text{ mm Hg} \\
\text{Diastolic pressure} &= 80 \text{ mm Hg} \\
\text{Pulse pressure} &= 40 \text{ mm Hg (Systolic – Diastolic)}
\end{align*}
\]

**Note**: When stroke volume decreases, pulse pressure also decrease; and when stroke volume increases, pulse pressure increase.

The pulse in monitored frequently, especially in the radial artery, where it’s called the **radial pulse**.

**Note**: Weak pulses usually indicate a decreased stroke volume or increased constriction of the arteries as a result of intense sympathetic stimulation of the arteries.

**CAPILLARY EXCHANGE AND REGULATION OF INTERSTITIAL FLUID VOLUME**

**Capillary Exchange** – Is the movement of substances into and out of capillaries.

- It is a process by which cells receive everything they need to survive and to eliminate metabolic waste products.

**Diffusion** is by far the most important means by which capillary exchange occurs.

Lipid-soluble molecules cross capillary walls by diffusing through the plasma membrane of the endothelial cells of the capillaries.
Substances enter and leave capillaries in three basic ways:

1) Diffusion
2) Vesicular transport (Endocytosis and Exocytosis)
3) Bulk flow (Filtration and Absorption)

1. **Diffusion**

   **Simple diffusion** is the most important method of capillary exchange.

   Substances such as Oxygen, Carbon Dioxide, glucose, amino acids, hormones, and others diffuse through capillary walls down their concentration gradients.

   **All plasma solutes**, except larger proteins, pass freely across most capillary walls.

   **Lipid-soluble materials**, such as CO₂, O₂, and steroid hormones, may pass directly through the phospholipid bilayer of the endothelial plasma membranes.

   **Water-soluble substances**, such as glucose and amino acid, pass either through fenestrations or intercellular clefts. (Because like dissolves like).

   How about the brain where the endothelial cells in most regions are nonfenestrated and sealed together by tight junctions? Problems for the water-soluble substances.

2. **Vesicular Transport**

   Small material crosses capillary membranes.

   **Endocytosis** - substances in blood plasma cells become enclosed within tiny vesicles and enter cells.

   **Exocytosis** - substances enclosed within tiny vesicles exit cells into capillaries.
*Important for large lipid insoluble materials that cannot cross capillary walls in any other way.

3. **Bulk Flow (Filtration and Reabsorption)**

Diffusion is more important for solute exchange between plasma and interstitial fluid, but

**Bulk flow** is more important for regulation of the relative volumes of blood and interstitial fluid.

*Some forces* push fluid out of capillaries into the surrounding interstitial (tissue) spaces, resulting in **filtration of fluid**.

(To prevent fluid from moving in one direction only and accumulating in interstitial spaces).

**Opposing forces** push fluid from interstitial spaces into blood capillaries, resulting in **reabsorption of fluid**.

Bulk flow (Filtration and Reabsorption) is a passive process that involves the movement of large numbers of ions, molecules, or particles in the same direction.

Bulk flow occurs because some pressures promote filtration of water and solutes from capillaries into the surrounding interstitial (tissue) spaces.

**Note:** A small amount of fluid moves out capillaries at their arterial ends, and most, but not all, of that fluid reenters capillaries at their venous end. (See Figure 21.32, Page 747).

The remaining of fluid enters lymphatic vessels, which eventually return it to the venous circulation.

**Edema** is as a result of alterations in the forces affecting fluid movement across capillary walls.
**Net Filtration Pressure (NFP)** – Is the force responsible for moving fluid across capillary walls. It is the difference between net hydrostatic pressure and net osmotic pressure.

\[
\text{NFP} = \text{Net Hydrostatic Pressure} - \text{Net Osmotic Pressure}
\]

**Net Hydrostatic Pressure** – Is the difference in pressure between the blood and interstitial fluid.

**Blood pressure (BP)** at the arterial end of capillary is about 30 mm Hg.

**Interstitial Fluid Pressure (IFP)** – Is the pressure of interstitial fluid within the tissue spaces.

- It is –3 mm Hg.

**Note**: IFP is a negative number because of the suction effect produced by the lymphatic vessels as they pump excess fluid from the tissue spaces.

**Note**: At the arterial end of capillaries, the net hydrostatic pressure that moves fluid across capillary walls into the tissue spaces is the difference between BP and IFP.

\[
\text{Net Hydrostatic Pressure} = BP - IFP = 30 - (-3) = 33 \text{ mm Hg}
\]

**Net Osmotic Pressure** – Is the difference in osmotic pressure between the blood and the interstitial fluid.

(a) **Blood Colloid Osmotic Pressure (BCOP)** – Is the osmotic pressure caused by the plasma proteins.

(b) **Interstitial Colloid Osmotic Pressure (ICOP)** – Is the osmotic pressure caused by proteins in the interstitial fluid.

**Note**: The BCOP (28 mm Hg) is several times larger than the ICOP (8
mm Hg) because of presence of albumin and other proteins in the plasma.

\[ \text{Net Osmotic Pressure} = BCOP – ICOP \]
\[ = 28 – 8 \]
\[ = 20 \text{ mm Hg} \]

**Note:** The greater the Osmotic pressure of the fluid, the greater is the tendency for water to move into the fluid. The Net Osmotic pressure results in the osmosis of water into the capillary because there is greater tendency for water to move into the blood than into the interstitial fluid.

Net Filtration Pressure at the arterial end of the capillary is equal to the Net Hydrostatic Pressure, which moves fluid out of the capillary, minus the net osmotic pressure, which moves fluid into the capillary

\[ \text{NFP} = \text{Net Hydrostatic Pressure} – \text{Net Osmotic Pressure} \]
\[ = 33 – 20 \]
\[ = 13 \text{ mm Hg} \]

Between the arterial ends of capillaries and their venous ends, the blood pressure decreases from about 30 mm Hg to 10 mm Hg, which reduces the net hydrostatic pressure moving fluid out of the venous end of the capillary.

\[ \text{Net Hydrostatic Pressure} = BP – IFP \]
\[ = 10 – (-3) \]
\[ = 13 \text{ mm Hg} \]

At the Venous end of Capillaries the NFP now causes fluid to reenter the capillaries.

\[ \text{NFP} = \text{Net Hydrostatic Pressure} – \text{Net Osmotic Pressure} \]
\[ = 13 – 20 \]
\[ = -7 \text{ mm Hg} \]
Venous return is the volume of blood flowing back to the heart from the systemic veins.

It depends on the pressure difference from venules (averaging about 16 mm Hg) to the right ventricle (0 mm Hg).

If pressure increases in the right atrium, however, venous return will decrease.

Two Other Mechanisms, beside the Heart, that act as Pumps to boost venous return:

1. **Skeletal Muscle Pump**
   - Contraction of skeletal muscles open valves in veins - drives blood towards the heart action called "milking"
   - Relaxation closes the valves and prevents backflow.

2. **Respiratory Pump**
   
   During inspiration, the diaphragm moves downward. This causes a decrease in pressure in the thoracic (chest) cavity, and increase in pressure in the abdominal cavity. As a result, a greater volume of blood moves from the abdominal veins into the thoracic veins. When the pressure reverse during expiration, blood in the vein is prevented from back flowing by the valves.
Varicose Veins

The result of back-pressure overloads the vein and pushes its wall outward. After repeated overloading, the walls lose their elasticity and become stretched and flabby. They maybe due to heredity, mechanical factors - prolonged standing and pregnancy, or aging.

CONTROL OF BLOOD PRESSURE AND BLOOD FLOW

Several interconnected negative feedback systems control blood pressure by:

- Adjusting heart rate
- Stroke volume
- Systemic vascular resistance
- Blood volume

Some systems allow rapid adjustment of blood pressure to cope with sudden changes such as the drop in blood pressure that occurs when we get out of bed.

Others act more slowly to provide long-term regulation of blood pressure.

During exercise a greater percentage of blood is diverted to organs directly involved in exercise;

No matter what the level of exercise, blood flow to the brain remains nearly constant.

The Cardiovascular Center in the Medulla, by its influence on the sympathetic and parasympathetic divisions of the autonomic nervous system (ANS), contributes to regulation of heart rate and stroke volume.
Cardiovascular Center

Cardiovascular (CV) Center in the Medulla Oblongata is the main region for nervous system regulation of the heart and blood vessels.

A. Input to Cardiovascular Center - from
   (1) Higher Brain region - cerebral cortex, limbic system, hypothalamus
   (2) Sensory Receptors - Two types:
      (a). Barareceptors - A pressure-sensitive sensory neurons - monitor stretching of the walls of blood vessels and the atria (monitor blood pressure)
      (b). Chemoreceptors - monitor blood acidity, carbon dioxide level, and oxygen level.

B. Output from Cardiovascular Center - to the Heart

Flows along sympathetic and parasympathetic fibers of the autonomic nervous system (ANS).

   (1). Parasympathetic Stimulation - decreases heart rate.
       - conveyed along the vagus (X) nerves.
   (2). Sympathetic Stimulation - increases heart rate and contractility.
       - conveyed along the cardiac accelerator nerves.

Vasomotor Nerves - Another sympathetic fiber through which cardiovascular (CV) Center sends impulses to smooth muscle in Blood vessel walls.

Result to:
   (a) Vasodilation - an increase in the size of the lumen of blood vessel caused by relaxation of the smooth muscle in the wall of
the vessel.

(b) **Vasoconstriction** - a decrease in the size of the lumen of blood vessel caused by contraction of the smooth muscle in the wall of the vessel.

*Autonomic control of the heart is the result of opposing **sympathetic (stimulatory)** and **parasympathetic (inhibitory)** influences.

**Neural Regulation of Blood Pressure**

Regulation of blood pressure by the nervous system depends on receptors in the periphery that monitor blood pressure (**baroreceptors**) and blood chemistry (**chemereceptors**) and provide input to the cardiovascular center.

1. **Baroreceptors** - nerve cells capable of responding to changes in pressure or stretch.

   (Baroreceptors in the walls of the arteries, veins, and right atrium monitor blood pressure and participate in several negative feedback systems that contribute to blood pressure control.)

   Three most important negative feedback systems that Baroreceptors participate in are:

   a. **Carotid Sinus Reflex** - concerned with maintaining normal blood pressure in the brain and is initiated by baroreceptor in the wall of the carotid sinus.

   b. **Carotid Sinus** - is a small widening of the internal carotid artery just above the point where it branches from the common carotid artery.

      - Any increase in blood pressure stretches the wall of the Aorta and Carotid sinus, and stretching stimulates the baroreceptors.
(c). **Aortic Reflex** - is concerned with general systemic blood pressure and is initiated by baroreceptors in the wall of the arch of the aorta or attached to the arch.

Impulses from baroreceptors in the Arch of the Aorta reach the Cardiovascular (CV) Center via *Sensory (Afferent)* fibers of the Vagus (X) nerves.

(*Sensory (Afferent)* - conveying or conducting toward CV)

Cardiovascular (CV) Center responds by:

a. Putting out *more Parasympathetic impulses* (inhibitory - decrease heart ate) via motor (Efferent) fibers of the Vagus (X) nerve to the heart;

b. Putting out *fewer sympathetic impulses* (Stimulatory - increase heart rate) via cardiac accelerator nerves to the heart.

The resulting decrease in heart rate and force of contraction lower cardiac output.  
Also results to vasodilation, lowers systemic vascular resistance (SVR). (CV Center sends out decreased sympathetic impulses along vasomotor fibers that normally cause vasoconstriction- results in vasodilation.)

**If blood pressure (controlled condition) falls,** on the other hand,  
**Baroreceptor (receptors) are stretched less**

That is, they send nerve impulses (input) at a slower rate to the cardiovascular center (control center).

**In response,**

(i) the cardiovascular (CV) center calls for increased sympathetic impulses;

(ii) decreased parasympathetic impulses;  and
(iii) increased secretion of epinephrine and norepinephrine (NE) by the adrenal medulla (output).

(Result to Negative feedback regulation of blood pressure via Baroreceptor reflexes).

Marey’s Law of the Heart is the relationship between heart rate and blood pressure.

(2). **Chemoreceptors** - receptors sensitive to chemicals or receptors that monitor blood chemicals.

(a). **Carotid Bodies** - chemoreceptors located close to the baroreceptors of the Carotid Sinus in small structures.

(b). **Aortic Bodies** - chemoreceptors located close to the arch of the Aorta in small structures.

Chemoreceptors detect changes in the blood level of $O_2$, $CO_2$, and $H_2$ ion.

If there is a severe deficiency of oxygen (hyoxia), an increase in hydrogen ion (increased acidity or acidosis), or an excess of carbon dioxide (hypercapnia), the chemoreceptors are stimulated and send impulses to the CV center.

In response,

(i) The CV Center increases **sympathetic stimulation** (increased heart rate) to arterioles and veins;

(ii) Brings about vasoconstriction and increase in blood pressure.
Several hormones affect blood pressure and blood flow by three mechanisms:

1. **Renin-angiotensin-aldosterone (RNA) system.** When blood volume falls or blood flow to the kidney decreases, juxtaglomerular cells in the kidney release increased amount of an enzyme called rennin into the bloodstream.

   *Renin* acts on angiotensinogen to form **angiotensin I.** As this molecule passes through capillaries in the lungs, **angiotensin converting enzyme (ACE)** changes it into **angitensin II.**

   **Angiotensin II** helps to raise blood pressure in two ways:
   
   (i) It is a potent vasoconstrictor and thus raises total systemic resistance.

   (ii) It stimulates secretion of **aldosterone,** which increases sodium ion (Na⁺) and water absorption by the kidneys. This action increases total blood volume and thus increase blood pressure.

2. **Epinephrine and Norepinephrine (NE)** - Produced by the Adrenal Medulla.
   
   * Increases Cardiac Output (rate and force of heart contraction)
   * Bring about vasoconstriction of abdominal and cutaneous arterioles and veins.
   * Bring about vasodilation of cardiac and skeletal muscle arterioles

3. **Antidiuretic Hormone (ADH)** - Produced by the hypothalamus and released from the posterior pituitary gland. Causes vasoconstriction if there is a severe loss of blood due to
hemorrhage. ADH is also called vasopressin. (Alcohol inhibits release of ADH and has inhibitory effect on the Vasomotor center of the Medulla.) * This effects bring about Vasodilation, which lowers blood pressure.

4. **Atrial Natriuretic Peptide (ANP)** - Released by cells in the atria of the heart.
   - Lowers blood pressure by causing vasodilation
   - By promoting loss of salt and water in the urine, which reduces blood volume.

5. **Parathyroid hormone (PTH) and Calcitriol** - Two hormones, which regulate the circulating levels of calcium ions (Ca\(^+\)) and phosphate ions (HPO\(_4\)\(^{2-}\)) in the blood, also influence vascular smooth muscle. PTH causes vasodilation, which tends to decrease blood pressure. On the other hand, Calcitriol, the active form of vitamin D, causes vasoconstriction, which increases blood pressure.

**Autoregulation of Blood Pressure**

**Autoregulation** refers to a local, automatic adjustment of blood flow in a given region of the body to match the particular needs of the tissue.

Is important in meeting the oxygen and nutritional demands of active tissues (e.g. heart, muscle tissue...)

**Two general types of stimuli that cause autoregulatory changes in Blood Flow:**

- **Physical and Chemical**
  - **(a). Physical changes**
    - Warming promotes vasodilation
    - Cooling causes vasoconstriction
  - **(b). Chemical Mediators**
Cells in blood (white blood cells and platelets), cells near blood vessels (smooth muscle fibers, microphages, and endothelial cells) Synthesize and release a wide variety of Vasoactive Factors.

**Vasoactive Factors** are chemicals that alter blood vessel diameter.

**Vasodilators** - Widen blood vessels, results in an increased flow of blood into the tissue, which restores oxygen level to normal.

1. Endothelium - derived relaxation factor (EDRF), now known to be Nitric Oxide.
2. Ions (K⁺ and H⁺)
3. Lactic Acid (Lactate)
4. Adenosine (from ATP)

**Vasoconstrictors** - Have the opposite effects.

**CLINICAL APPLICATION**

**Syncope**, or faint, refers to a sudden, temporary loss of consciousness followed by spontaneous recovery.

- Due to cerebral ischemia (lack of sufficient blood flow)

**CHECKING CIRCULATION**

A. **Pulse** - The alternate expansion and elastic recoil of the wall of artery with each systole and diastole of the left ventricle.

- Pulse is strongest in the arteries closest to the heart; disappears altogether in the capillaries.
Arteries that maybe used for determining pulse

1. **Radial artery** - at the wrist (the most commonly used)
2. **Temporal artery** - lateral to the orbit of the eye.
3. **Facial artery** - at the lower jawbone on a line with corners of the mouth.
4. **Common Carotid artery** - lateral to the larynx (voice box)
5. **Brachial artery** - along the medial side of the biceps brachii muscle.
6. **Femoral artery** - inferior to the inguinal ligament.
7. **Popliteal artery** - behind the knee
8. **Posterior tibial artery** - posterior to the medial malleolus of the tibia.
9. **Dorsalis pedi artery** - superior to the instep of the foot.

*Pulse rate is the same as the heart rate and averages between 70 and 80 beats per minute in the resting stage.*

**Tachycardia** - is applied to rapid heart or pulse rate (over 100/min).

**Bradycardia** - indicates a slow heart or pulse rate (under 60/min).

**FETAL CIRCULATION**

The exchange of materials between fetus and mother.

Lungs, kidneys, and gastrointestinal tract of a fetus are nonfunctional.

The fetus derives its oxygen and nutrients, and eliminates its carbon dioxide and wastes through the maternal blood supply by means of a structure called the **placenta**.

All exchanges occurs through capillary walls by diffusion.

Normally, there is no direct mixing of maternal and fetal blood.
At birth, when pulmonary (lung), digestive, and liver functions are established, the special structures of fetal circulation are no longer needed.

**Following vascular changes occur:**

1. When the **umbilical cord** is tied off, no blood flows through the umbilical arteries, they fill with connective tissue, and the distal portions of the umbilical arteries become the **medial umbilical ligaments**.

2. Tying the umbilical cord results in the conversion of the umbilical vein into the **ligamentum tere (round ligament)**, a structure that attaches the umbilical to the liver.

3. The placenta is expelled as the "**afterbirth.**"

4. The **ductus venosus** collapses as blood stops flowing through the umbilical vein and becomes the **ligamentum venosum**, a fibrous cord on the inferior surface of the liver.

5. The **foramen ovale** normally closes shortly after birth to become the **fossa ovalis**, a depression in the interatrial septum.

6. The **ductus arteriosus** closes by vasoconstriction, atrophies, and becomes the **ligamentum arteriosum**.

---

**AGING AND THE CARDIOVASCULAR SYSTEM**

1. General changes include loss of elasticity of blood vessels, reduction in cardiac muscle size, and reduced cardiac output.

2. Total blood cholesterol and low-density lipoprotein (LDL) tend to increase with age, while high-density lipoprotein (HDL) tends to decrease.
3. The incidence of Coronary artery disease (CAD), congestive heart failure (CHF), and atherosclerosis increases with age.

EXERCISE AND THE CARDIOVASCULAR SYSTEM

1. Aerobic exercises provide useful benefit for the cardiovascular system. (At least 20 min., 3-5 sessions a week)

   Example of Aerobic Exercise - Brisk walking, Running, bicycling, cross-country skiing, and swimming.

2. Among the benefits are increased cardiac output, increased delivery of oxygen to tissue, reduced systolic blood pressure, increased high-density lipoprotein (HDL), weight control, and increased ability to dissolve blood clots.

DEVELOPMENTAL ANATOMY OF BLOOD AND BLOOD VESSELS

1. Blood vessels develop from isolated masses of mesenchyme in mesoderm called blood islands.

2. Blood is produced by the endothelium of blood vessels.

CLINICAL FOCUS – SHOCK

(See page 760 – 761)
1. **Hypertension**, or high blood pressure.

   a. **Primary hypertension** (Essential hypertension) - is a persistently elevated blood pressure that cannot be attributed to any particular organic cause.

   b. **Secondary Hypertension** has an identifiable underlying cause such as kidney disease and adrenal by preservation.

2. **Aneurysm** - is a thin, weakened section of the wall of an artery or a vein that bulges outward, forming a balloon like sac of the blood vessel. Blood vessel defect, trauma etc.