Venous System

Veins and Their Functions

- 60% of blood is in veins
- The veins are capable of constricting and enlarging and thereby storing either small or large quantities of blood
- The spleen, liver, large abdominal veins, and the venous plexus also serve as reservoirs

- **Venous Pressures**-Right Atrial Pressure (Central Venous Pressure) and Peripheral Venous Pressures

  - Blood from all the systemic veins flows into the right atrium of the heart; therefore, the pressure in the right atrium is called the **central venous pressure**

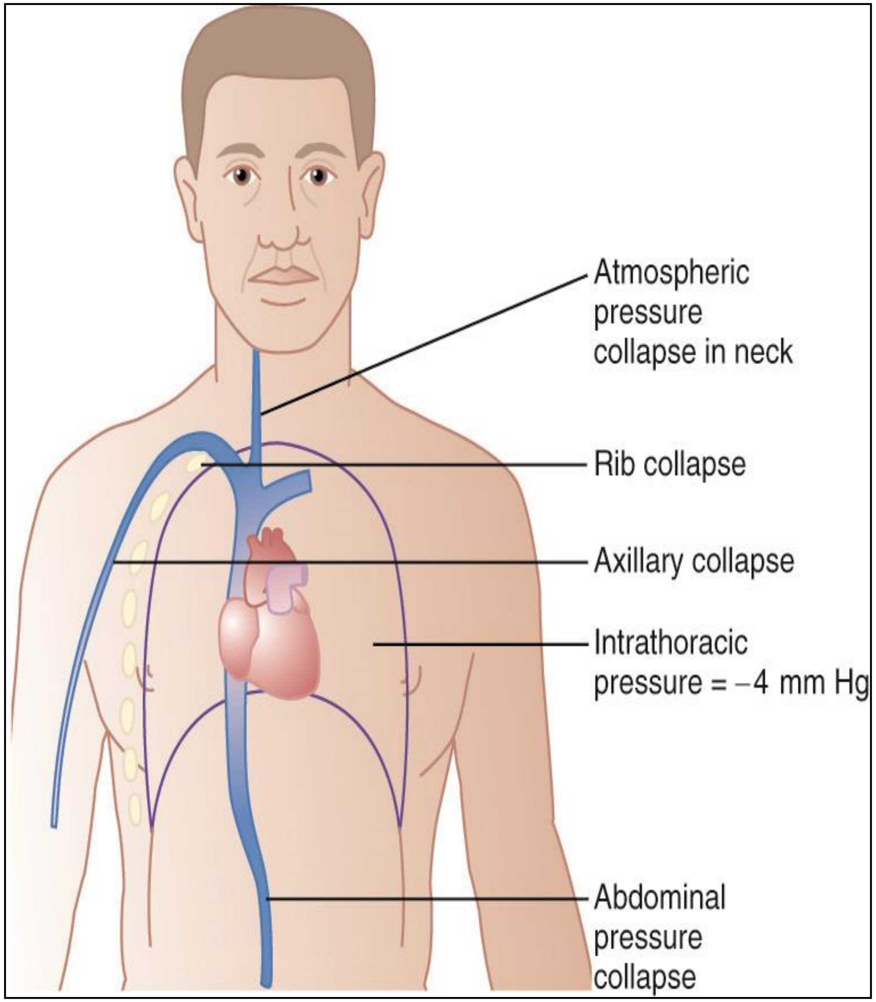
  - **Right atrial pressure** is regulated by a balance between (1) the ability of the heart to pump blood out of the right atrium and ventricle into the lungs and (2) the tendency for blood to flow from the peripheral veins into the right atrium

- **Normal right atrial pressure ~ 0 mm Hg**
  - Right arterial pressure can increase to 20-30 mm Hg due to heart failure or after massive transfusion of blood

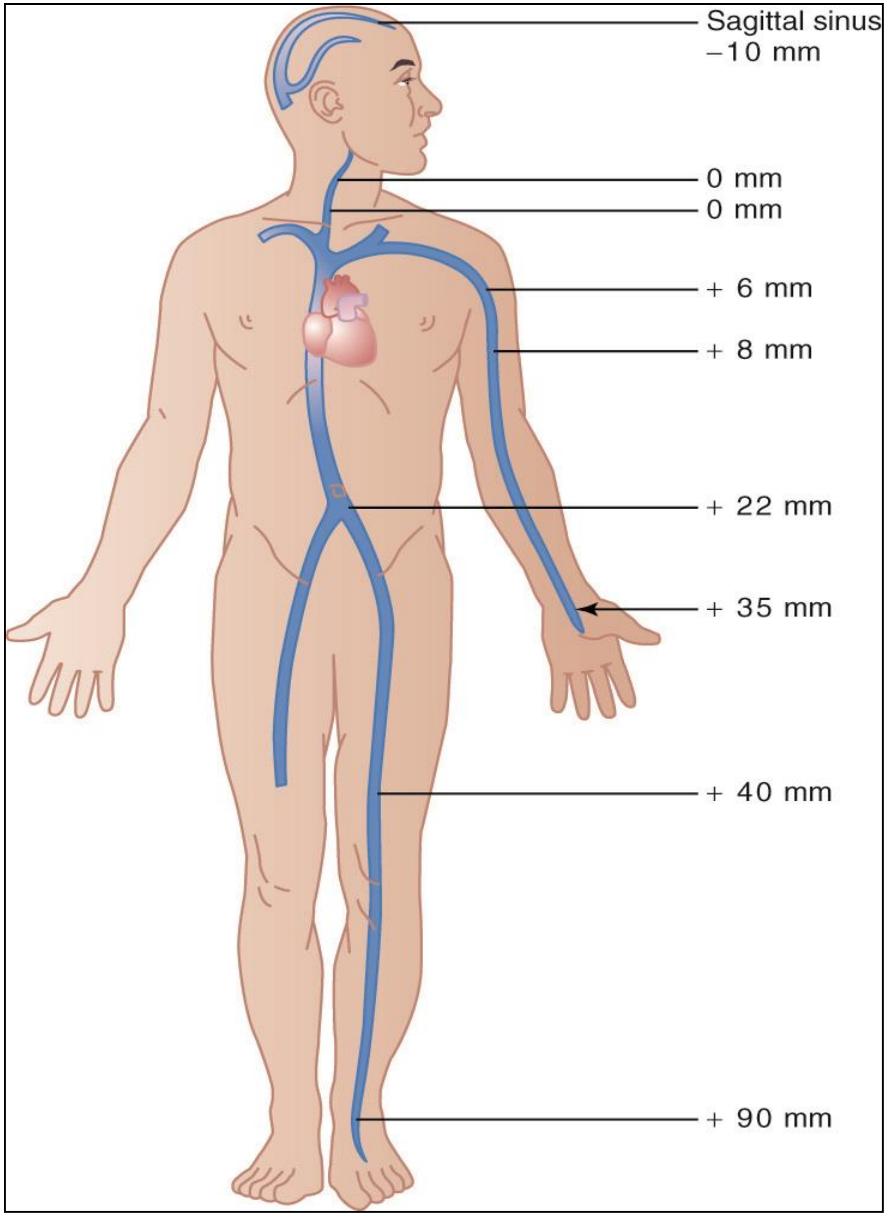
- **Venous return is increased by:**
  - increased blood volume
  - increased large vessel tone and peripheral vessel tone
  - dilatation of arterioles which decreases peripheral resistance and increases blood flow

Venous resistance and peripheral venous pressure

- Large veins have virtually little resistance to blood flow as they are distended
- Many large veins that enter the thorax are compressed at many points by the surrounding tissue
- Venous pressure is slightly higher (4-6 mm Hg) compared with PRA (Right atrial pressure) since otherwise it may collapse.

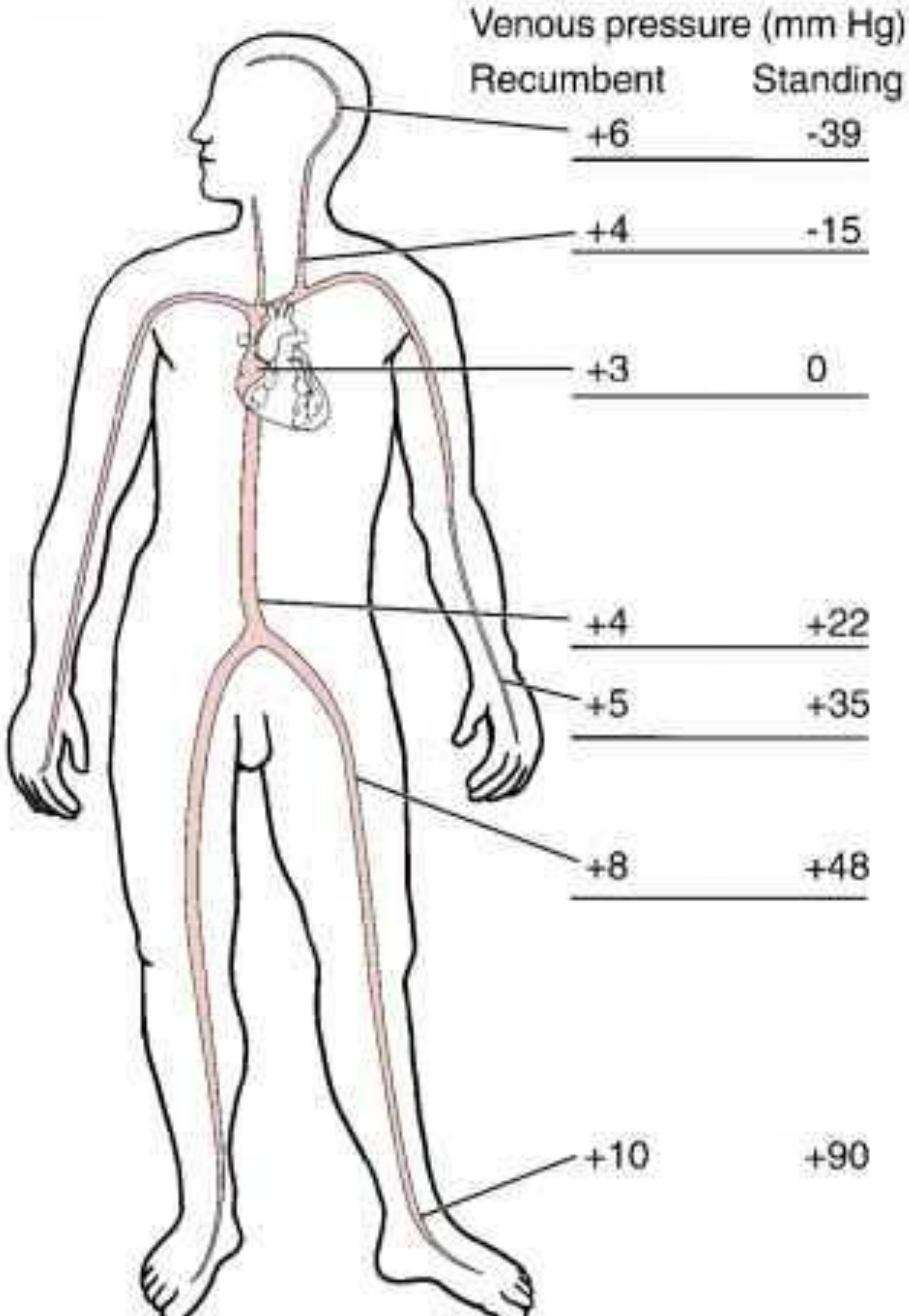


Effect of Gravitational Pressure on Venous Pressure

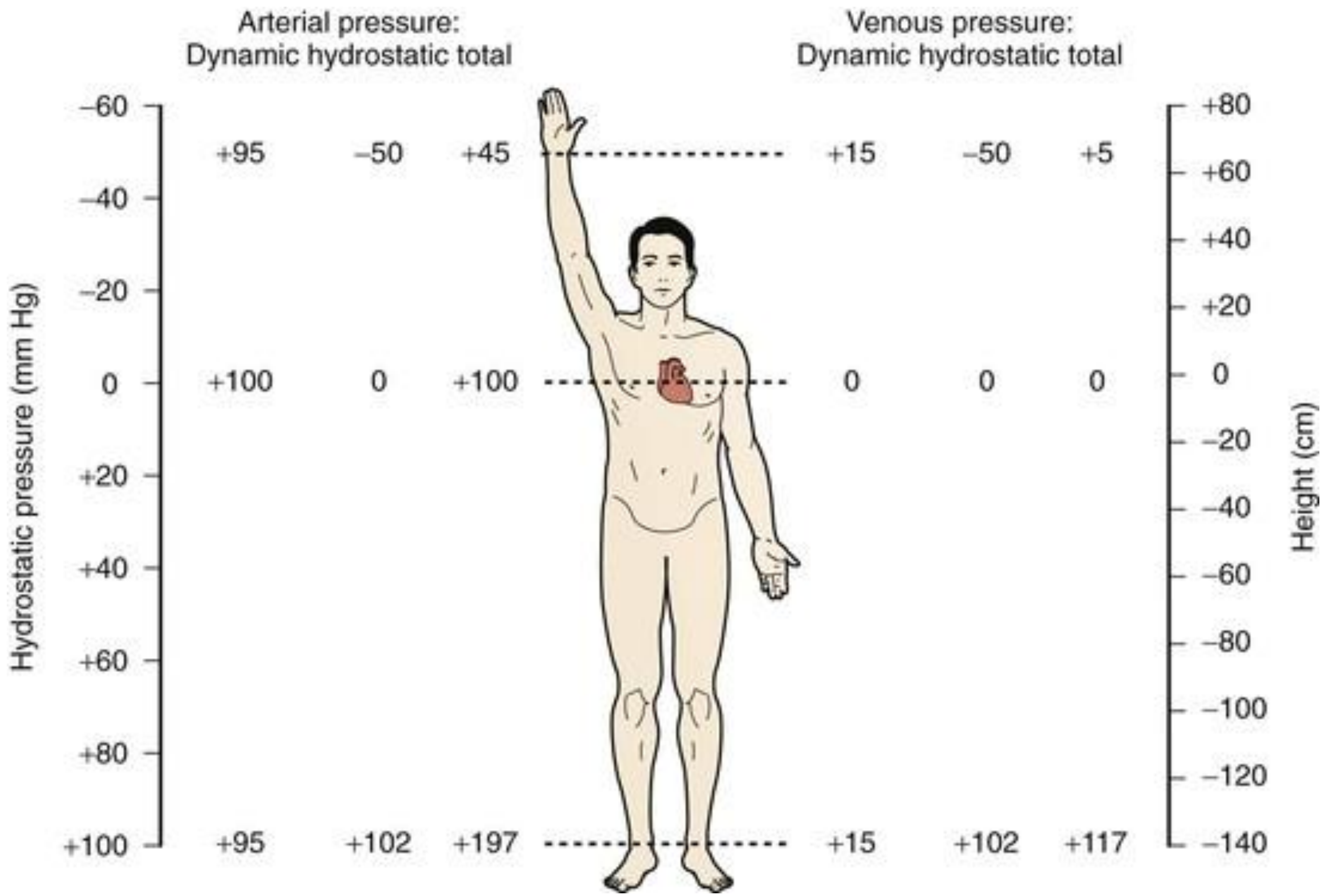


- Gravitational pressure occurs in the vascular system of the human being because of weight of the blood in the vessels
- When a person is standing, the pressure in the right atrium remains about 0 mm Hg because the heart pumps into the arteries any excess blood that attempts to accumulate at this point.
- The venous pressures at other levels of the body are proportionately between 0 and 90 mm Hg.

Figure 15-10; Effect of gravitational pressure on the venous pressures through- out the body in the standing person.



Venous pressure (mm Hg)
Recumbent
Standing
+6
-39
+4
-15
+3
0
+4
+22
+5
+35
+8
+48
+10
+90



Effect of upright position on venous and arterial pressure. Pressure at the right atrial level is 0. In the supine position, hydrostatic pressure is essentially 0, so total intravascular pressure closely approximates dynamic pressure.

Effect of Intra-abdominal Pressure on Venous Pressures of the Leg

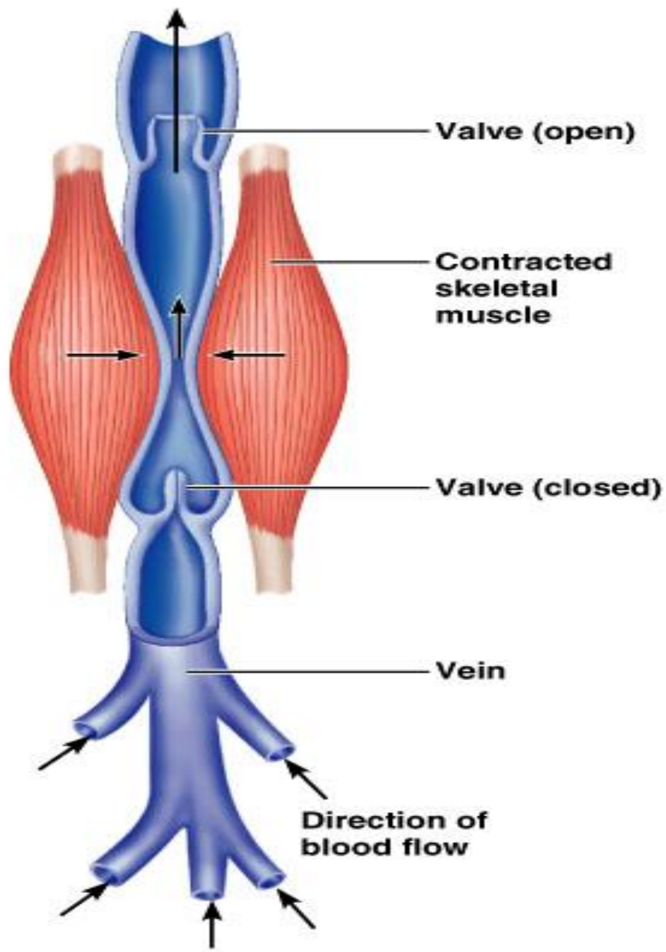
- The pressure in the abdominal cavity normally averages about ***6 mm Hg***,
- It can rise to 15 to 30 mm Hg as a result of **pregnancy, large tumors, or excessive fluid** in the abdominal cavity
- When the intra-abdominal pressure rises, the pressure in the veins of the legs must rise *above* the abdominal pressure before the abdominal veins will open and allow the blood to flow from the legs to the heart

▪ Venous Valves and the "Venous Pump": Their Effects on Venous Pressure

- Leg muscle contractions squeezes veins and pumps blood toward the heart, lowering venous pressure to less than 20 mm Hg in a walking person

- Valves prevent backflow during venous return

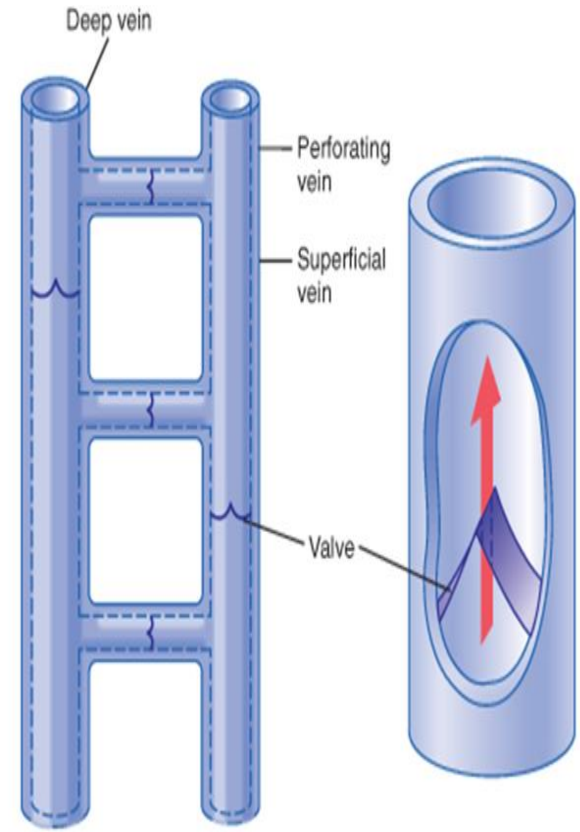
- This pumping system is known as the "***venous pump" or "muscle pump,"***



- In a person standing or sitting for long period of time “venous pump” does not work, pressure rises to full gravitational values of up to +90 mm Hg.

- Fluid leaks from the circulation system to tissues spaces, the legs swell, and blood volume diminishes, risk of blood clots develops

- Thus, the person develops "**varicose veins**," which are characterized by large protrusions of the veins beneath the skin of the entire leg, particularly the lower leg.



▪ Blood Reservoir Function of the Veins

- more than 60 per cent of all the blood in the circulatory system is usually in the veins. For this reason and also because the veins are so compliant, it is said that the venous system serves as a blood reservoir for the circulation.

Specific Blood Reservoirs.

① spleen which sometimes can decrease in size sufficiently to release as much as 100 milliliters of blood into other areas of the circulation;

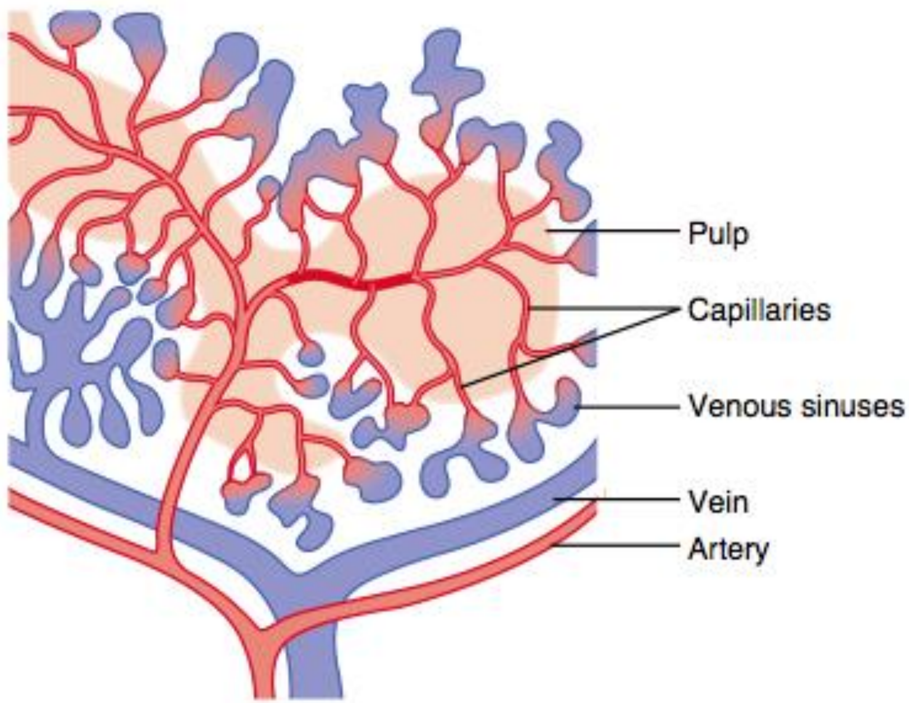


Figure 15–13

Functional structures of the spleen. (Courtesy of Dr. Don W. Fawcett, Montana.)

② the liver, the sinuses of which can release several hundred milliliters of blood into the remainder of the circulation

③ the large abdominal veins, which can contribute as much as 300 milliliters

④ the venous plexus beneath the skin, which also can contribute several hundred milliliters

The Spleen as a Reservoir for Storing Red Blood Cells

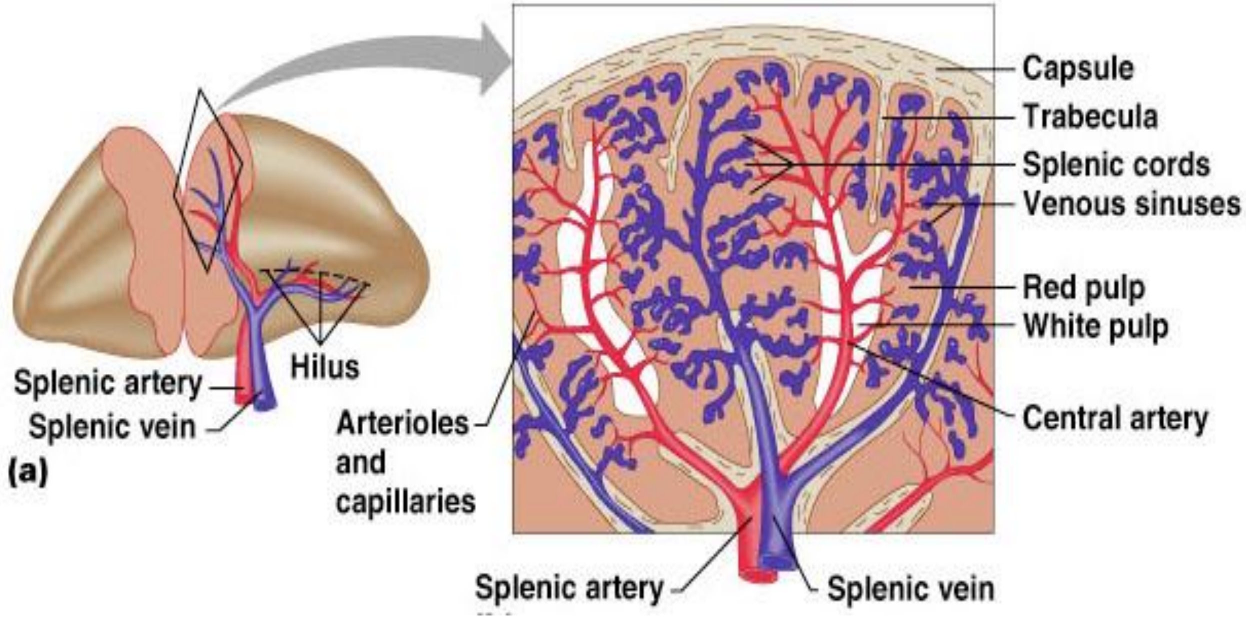
- **the spleen has two separate areas for storing blood:**

1. **the *venous sinuses***
2. **the *pulp***

- The sinuses can swell the same as any other part of the venous system and store whole blood

- In the splenic pulp, the capillaries are so permeable that whole blood, oozes through the capillary walls into a trabecular mesh, forming the *red pulp*

- The red cells are trapped by the trabeculae, while the plasma flows on into the venous sinuses and then into the general circulation.



- The red pulp of the spleen is a ***special reservoir that contains large quantities of concentrated red blood cells***
- These can then be expelled into the general circulation whenever the sympathetic nervous system becomes excited and causes the spleen and its vessels to contract
- In other areas of the splenic pulp are islands of white blood cells, which collectively are called the *white pulp*
- Lymphoid cells are manufactured , they are part of the body's immune system.

Blood-Cleansing Function of the Spleen-Removal of Old Cells

- Many of the red blood cells destroyed in the body have their final demise in the spleen.
- After the cells rupture, the released hemoglobin and the cell stroma are digested by the reticuloendothelial cells of the spleen
- the products of digestion are mainly reused by the body as nutrients, often for making new blood cells

- Reticuloendothelial Cells of the Spleen

- Reticuloendothelial cells function as part of a cleansing system for the blood
- When the blood is invaded by infectious agents, the reticuloendothelial cells of the spleen rapidly remove debris, bacteria, parasites, and so forth.
- Also, in many chronic infectious processes, the spleen enlarges in the same manner that lymph nodes enlarge and then performs its cleansing function even more avidly.

Spleen function

- Reservoir of blood in the venous sinuses
- Fitration of the blood
- Reservoir of red and white cells in the red and white pulp
- Immunity for the body
- Blood cleanser
- Iron recycling

Cardiac Output

- Cardiac output is the quantity of blood pumped into the aorta each minute by the heart. This is also the quantity of blood that flows through the circulation.
- Venous return is the quantity of blood flowing from the veins into the right atrium each minute.

The venous return and the cardiac output must equal each other except for a few heartbeats at a time when blood is temporarily stored in or removed from the heart and lungs.

factors directly affect cardiac output:

(1) the basic level of body metabolism,
(2) whether the person is exercising,
(3) the person's age,
(4) size of the body.

- Effect of Age on Cardiac Output.

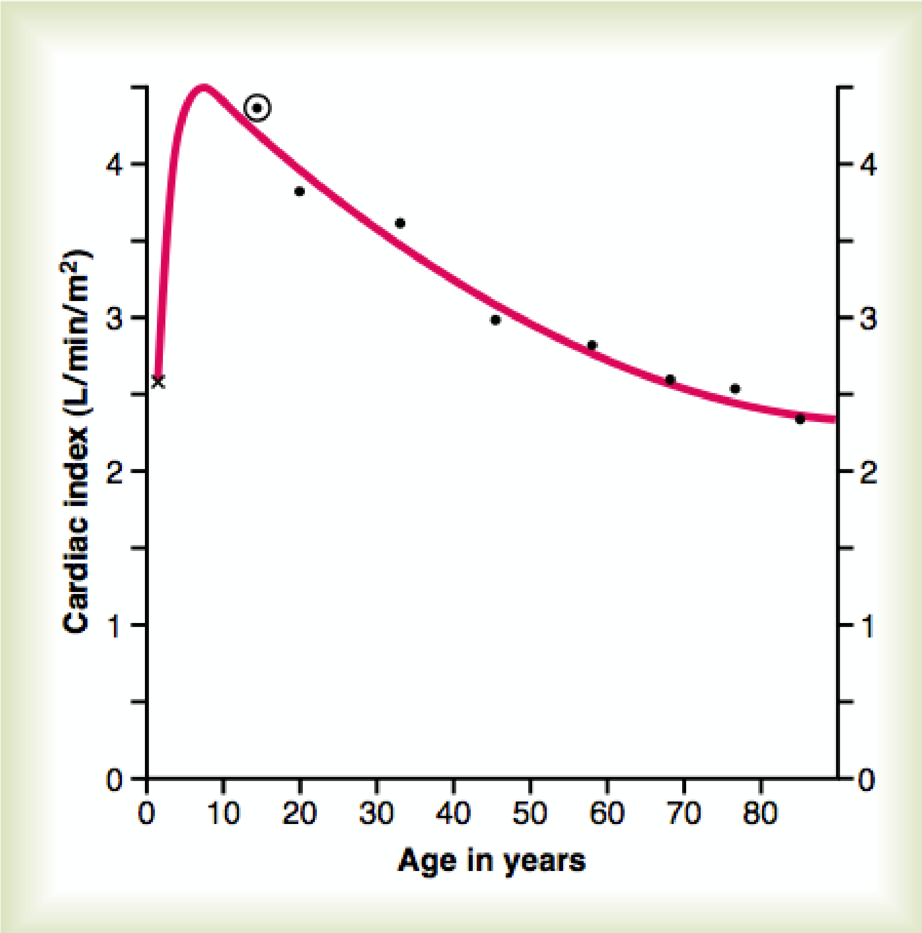


Figure 20–1

Cardiac index for the human being (cardiac output per square meter of surface area) at different ages. (Redrawn from Guyton AC, Jones CE, Coleman TB: Circulatory Physiology: Cardiac Output and Its Regulation. 2nd ed. Philadelphia: WB Saunders Co, 1973.)

Cardiac Index

- cardiac output increases approximately in proportion to the surface area of the body. Therefore, cardiac output is frequently stated in terms of the cardiac index, which is the cardiac output per square meter of body surface area.
- The normal human being weighing 70 kilograms has a body surface area of about 1.7 square meters, which means that the normal average cardiac index for adults is about 3 $L/min/m^2$ of body surface area.

$$CI = \frac{CO}{BSA} = \frac{SV \times HR}{BSA}$$

▪ Effect of Exercising on Cardiac Output.

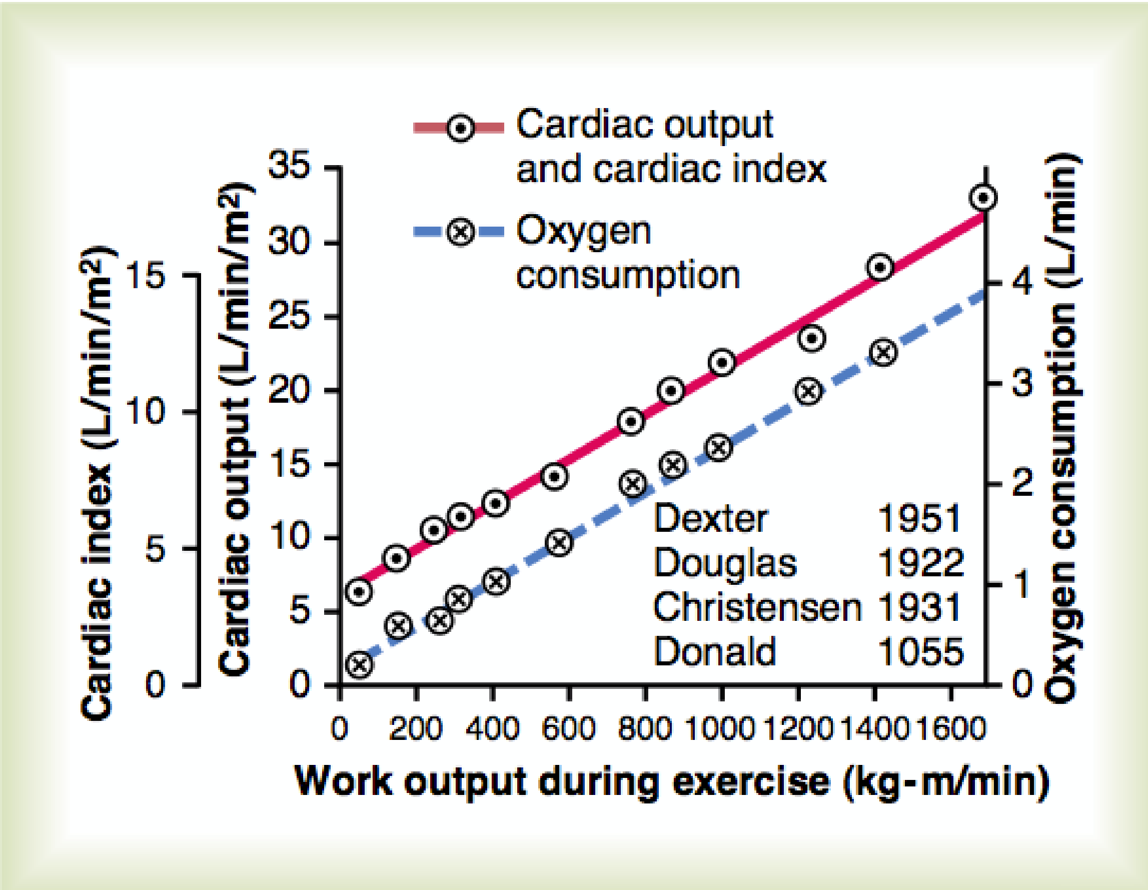


Figure 20–2

Effect of increasing levels of exercise to increase cardiac output *(red solid line)* and oxygen consumption *(blue dashed line)*. (Redrawn from Guyton AC, Jones CE, Coleman TB: Circulatory Physiology: Cardiac Output and Its Regulation. 2nd ed. Philadelphia: WB Saunders Co, 1973.)

- local blood flow almost always increases when tissue oxygen consumption increases

- each peripheral tissue of the body controls its own local blood flow, and all the local tissue flows combine and return by way of the veins to the right atrium. The heart, in turn, automatically pumps this incoming blood into the arteries, so that it can flow around the circuit again.
- **intrinsic ability** of the heart to adapt to increasing volumes of inflowing blood is called the *Frank- Starling mechanism* of the heart.

Effect of Total Peripheral Resistance on the Long-Term Cardiac Output

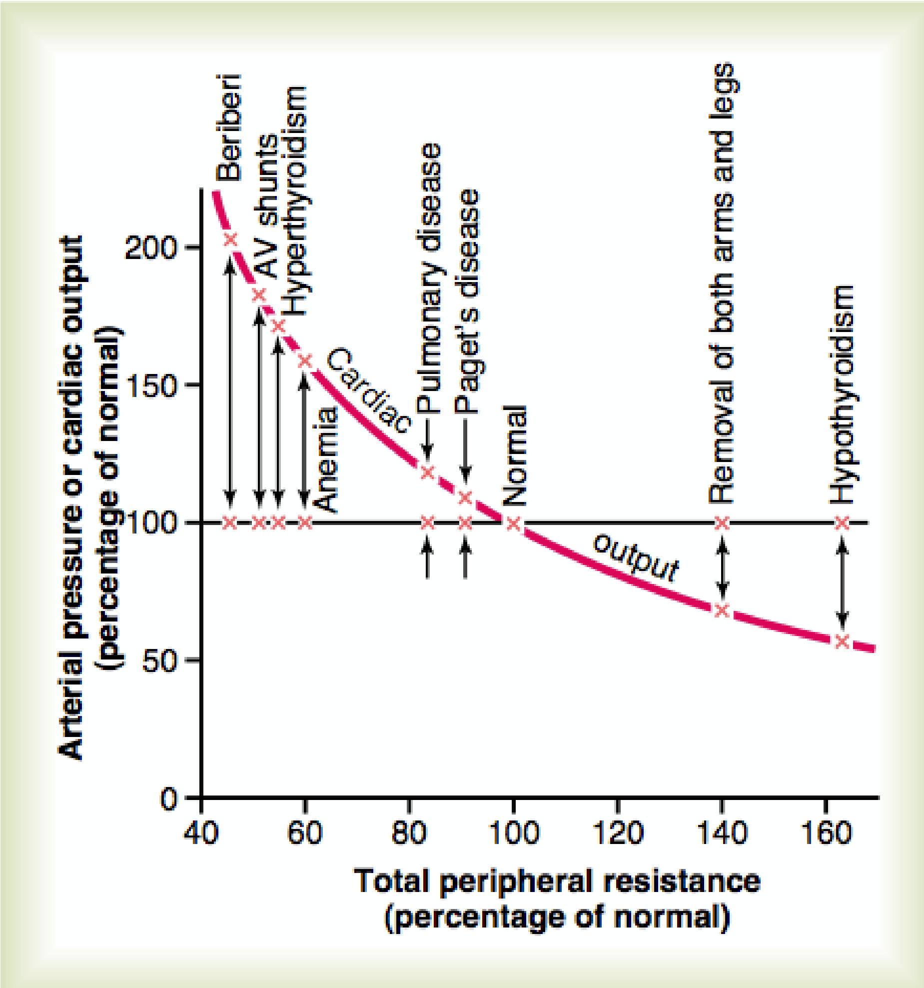


Figure 20–3

Chronic effect of different levels of total peripheral resistance on cardiac output, showing a reciprocal relationship between total peripheral resistance and cardiac output. (Redrawn from Guyton AC: Arterial Pressure and Hypertension. Philadelphia: WB Saunders Co, 1980.)

- when the total peripheral resistance is exactly normal (at the 100 per cent mark in the figure), the cardiac output is also normal. Then, when the total peripheral resistance increases above normal, the cardiac output falls; conversely, when the total peripheral resistance decreases, the cardiac output increases.

$$\text{Cardiac Output} = \frac{\text{Arterial Pressure}}{\text{Total Peripheral Resistance}}$$

Cardiac Output Curves

- There are definite limits to the amount of blood that the heart can pump, which can be expressed quantitatively in the form of *cardiac output curves.*

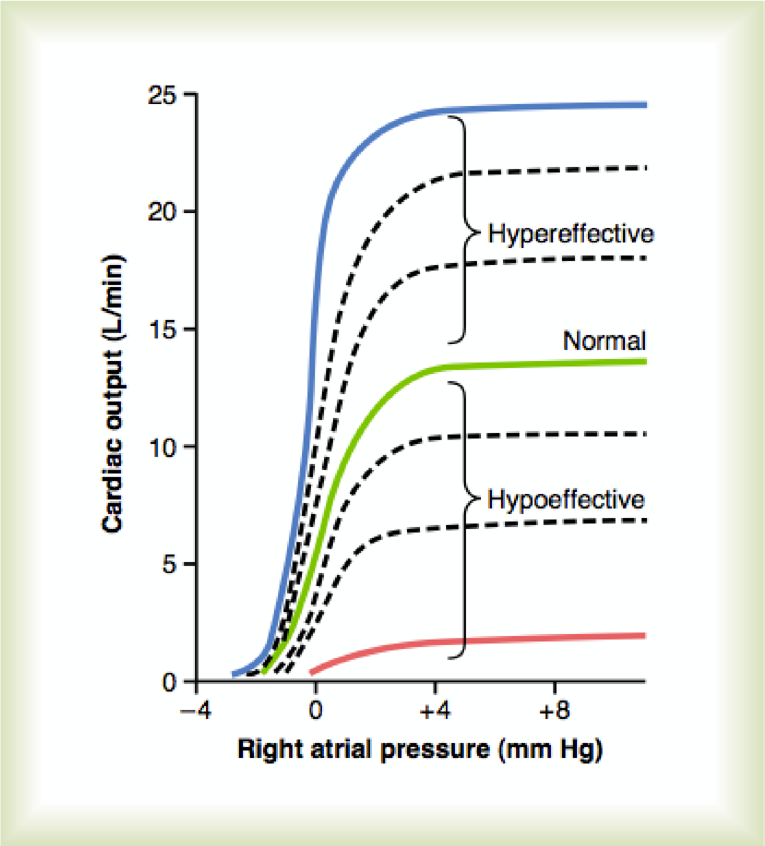


Figure 20–4

Cardiac output curves for the normal heart and for hypoeffective and hypereffective hearts. (Redrawn from Guyton AC, Jones CE, Coleman TB: Circulatory Physiology: Cardiac Output and Its Regulation. 2nd ed. Philadelphia: WB Saunders Co, 1973.)

- ➢ Note that the plateau level of this normal cardiac output curve is about 13 L/min, 2.5 times the normal cardiac output of about 5 L/min.
- ➢ This means that the normal human heart, functioning <u>without</u> any special stimulation, can pump an amount of venous return up to about 2.5 times the normal venous return before the heart becomes a limiting factor in the control of cardiac output.

▪ Factors causing Hypereffective Hearth

(1) nervous stimulation
(2) hypertrophy of the heart muscle

➢ nervous stimulation

- For given levels of input atrial pressure, the amount of blood pumped each minute (cardiac output) often can be increased more than 100 per cent by sympathetic stimulation. By contrast, the output can be decreased to as low as zero or almost zero by vagal (parasympathetic) stimulation.

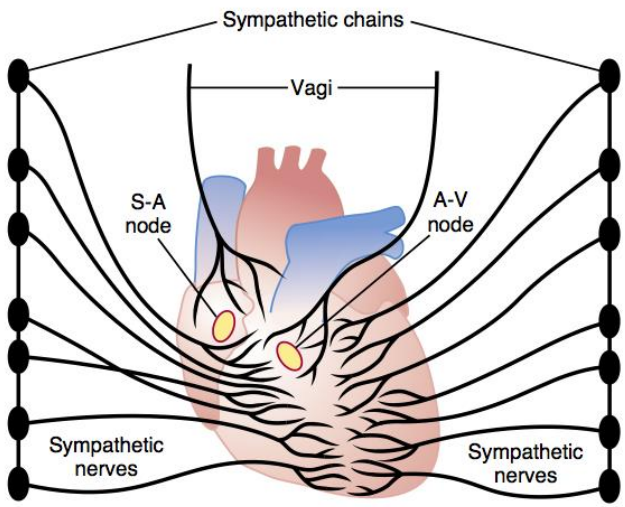


Figure 9–10

Cardiac *sympathetic* and *parasympathetic* nerves. (The vagus nerves to the heart are parasympathetic nerves.)

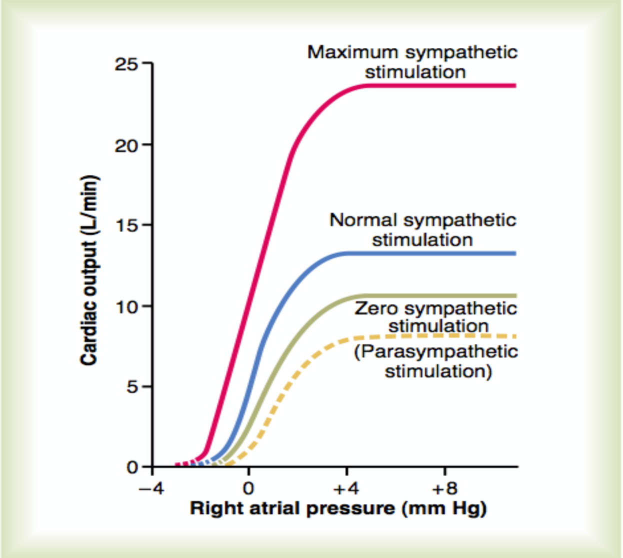


Figure 9–11

Effect on the cardiac output curve of different degrees of sympathetic or parasympathetic stimulation.

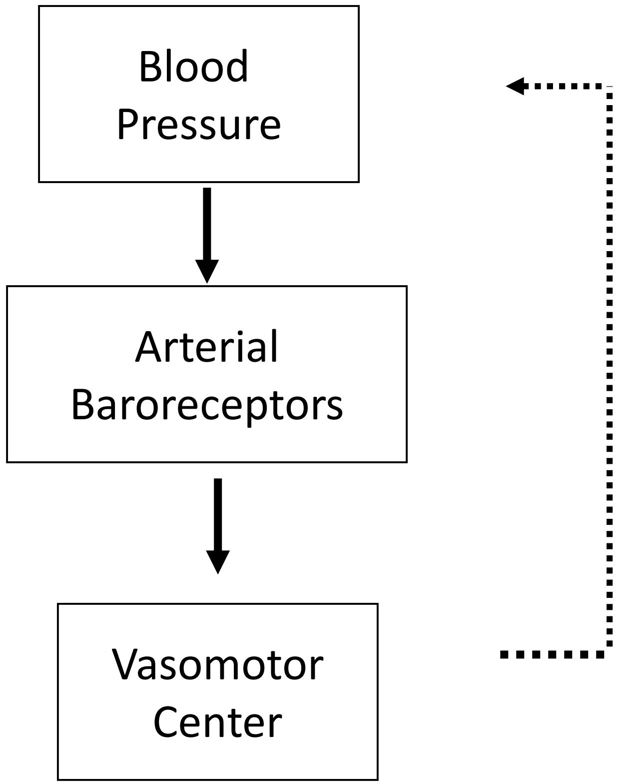
- hypertrophy of the heart muscle

A long-term increased workload, but not so much excess load that it damages the heart, causes the heart muscle to increase in mass and contractile strength in the same way that heavy exercise causes skeletal muscles to hypertrophy.

Factors That Cause a Hypoeffective Heart

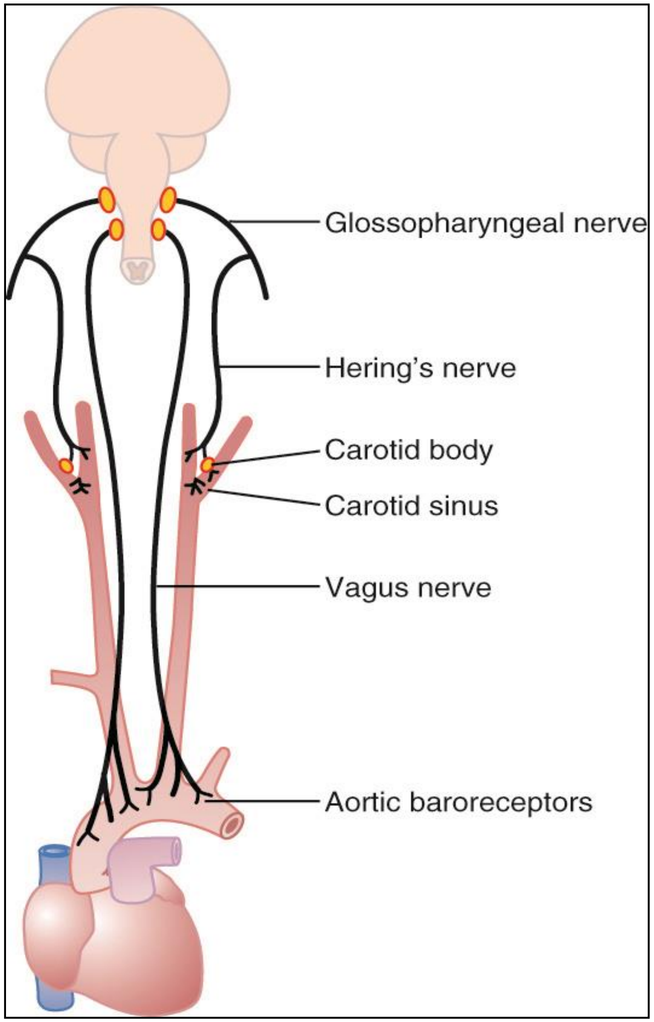
- Any factor that decreases the heart’s ability to pump blood causes hypoeffectivity. Some of the factors that can do this are :
- Coronary artery blockage, causing a “heart attack”
- Inhibition of nervous excitation of the heart
- Pathological factors that cause abnormal heart rhythm or rate of heartbeat
- Valvular heart disease
- Congenital heart disease

Arterial Baroreceptor Reflex



- A rise in arterial pressure stretches the baroreceptors and causes them to transmit signals into the central nervous system. "Feedback" signals are then sent back through the autonomic nervous system to the circulation to reduce arterial pressure downward toward the normal level.

▪ Anatomy of the Baroreceptors



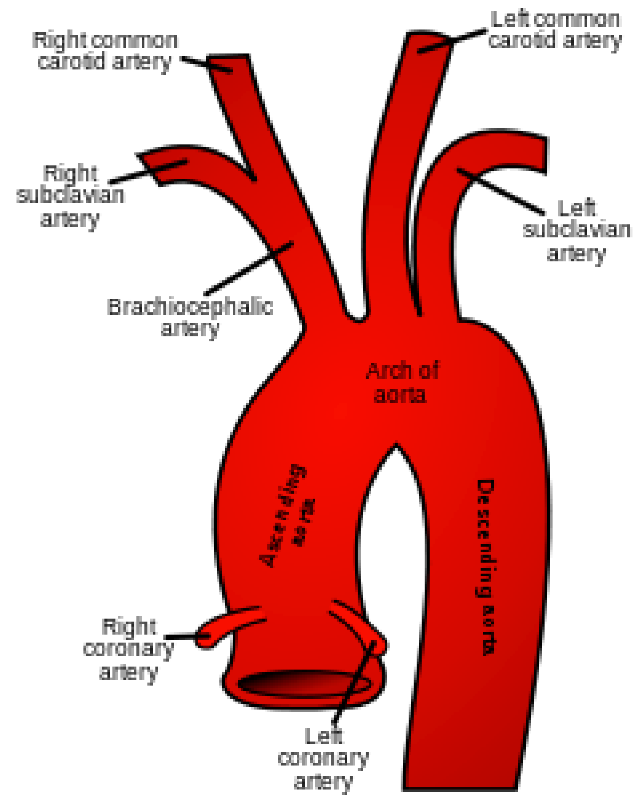
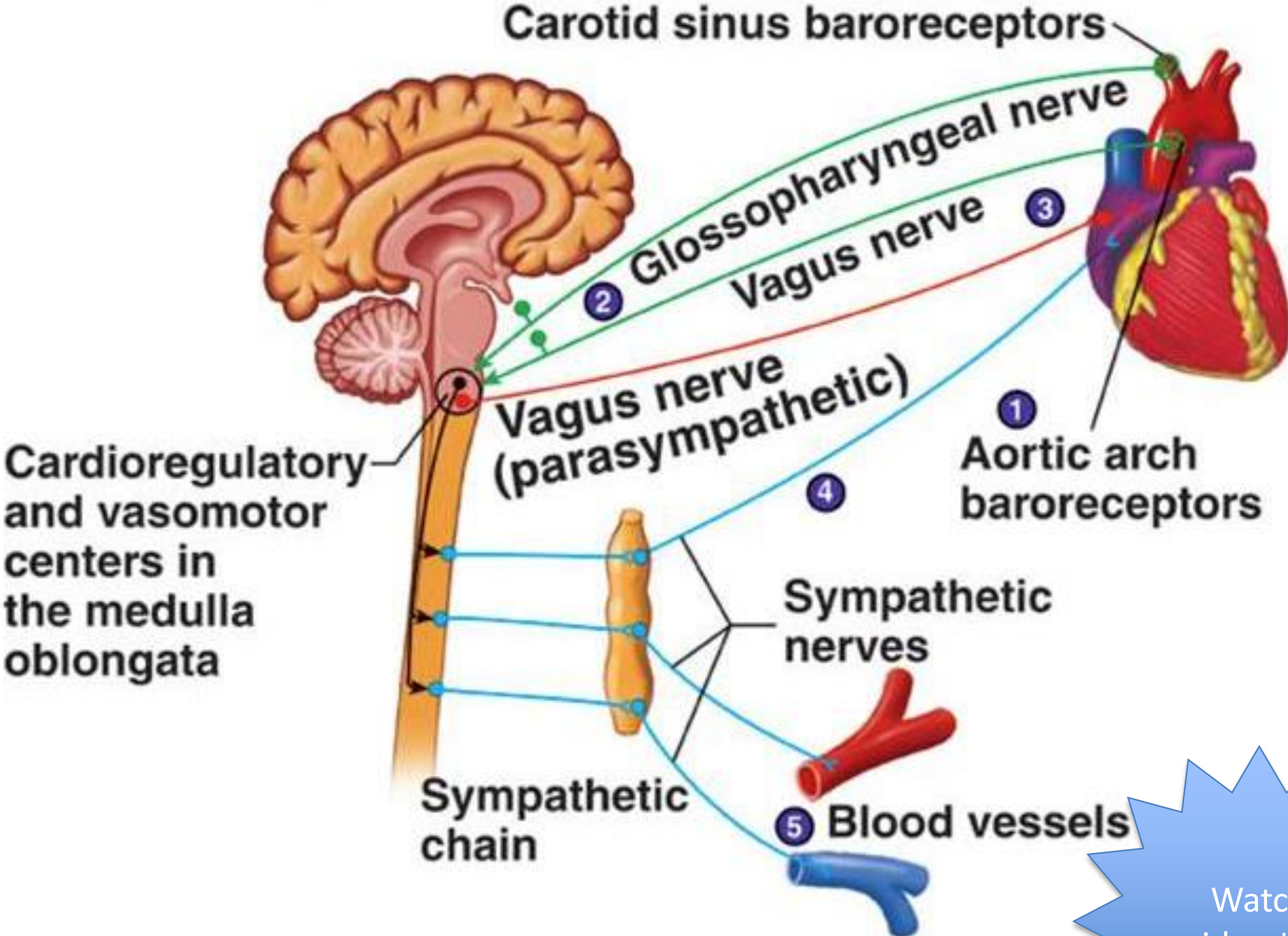


Figure 18-5; The baroreceptor system for controlling arterial pressure.



Watch video #17

Response of the Baroreceptors to Arterial Pressure- (cont.)

Constrict Common Carotids → ↓ Pressure at Carotid Sinuses → ↑ Arterial Pressure

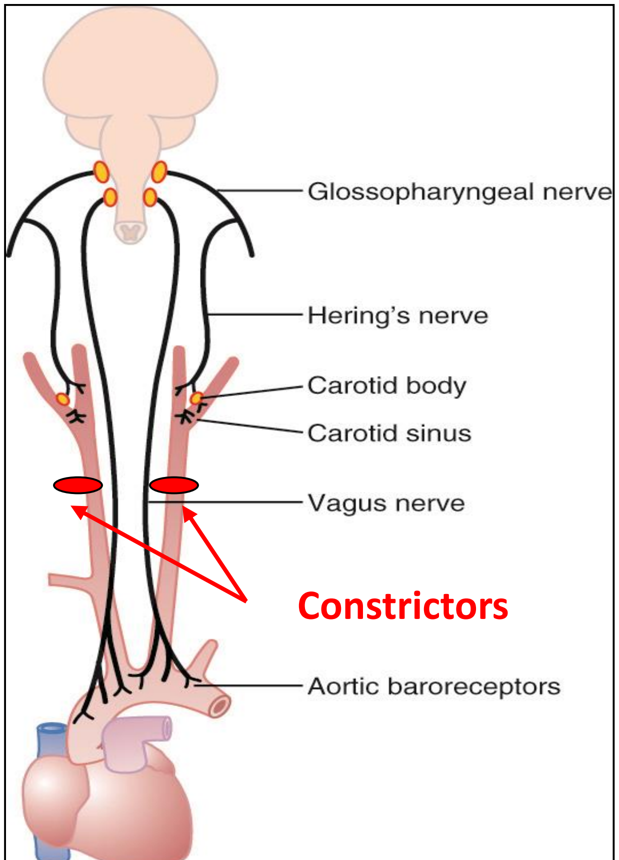


Figure 18-5; Guyton and Hall

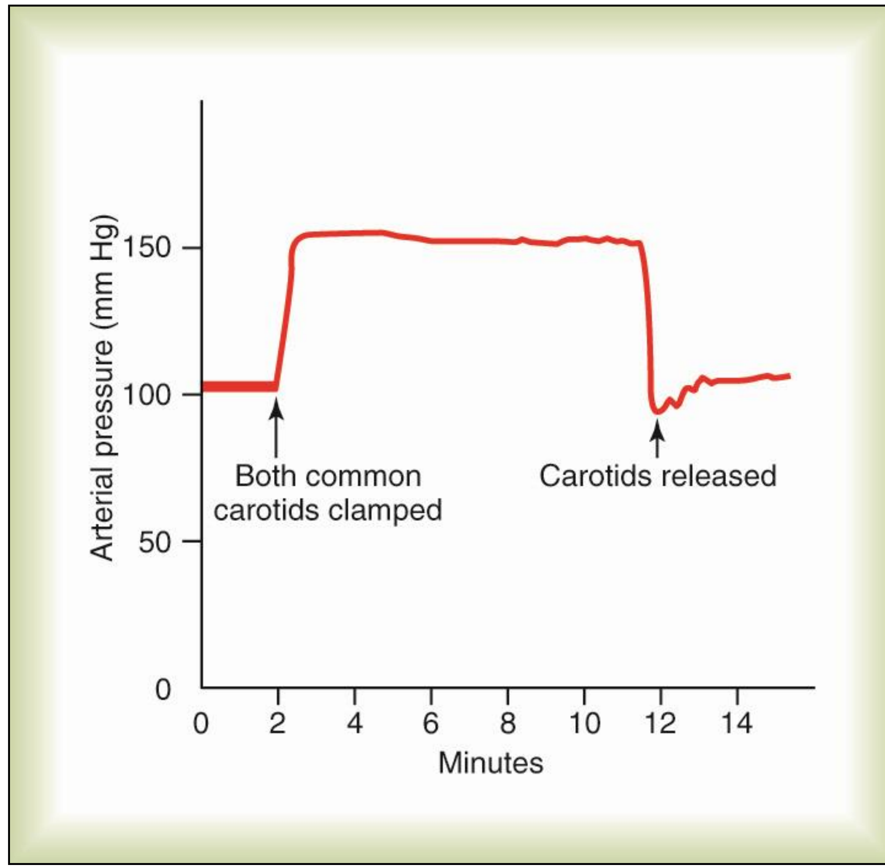
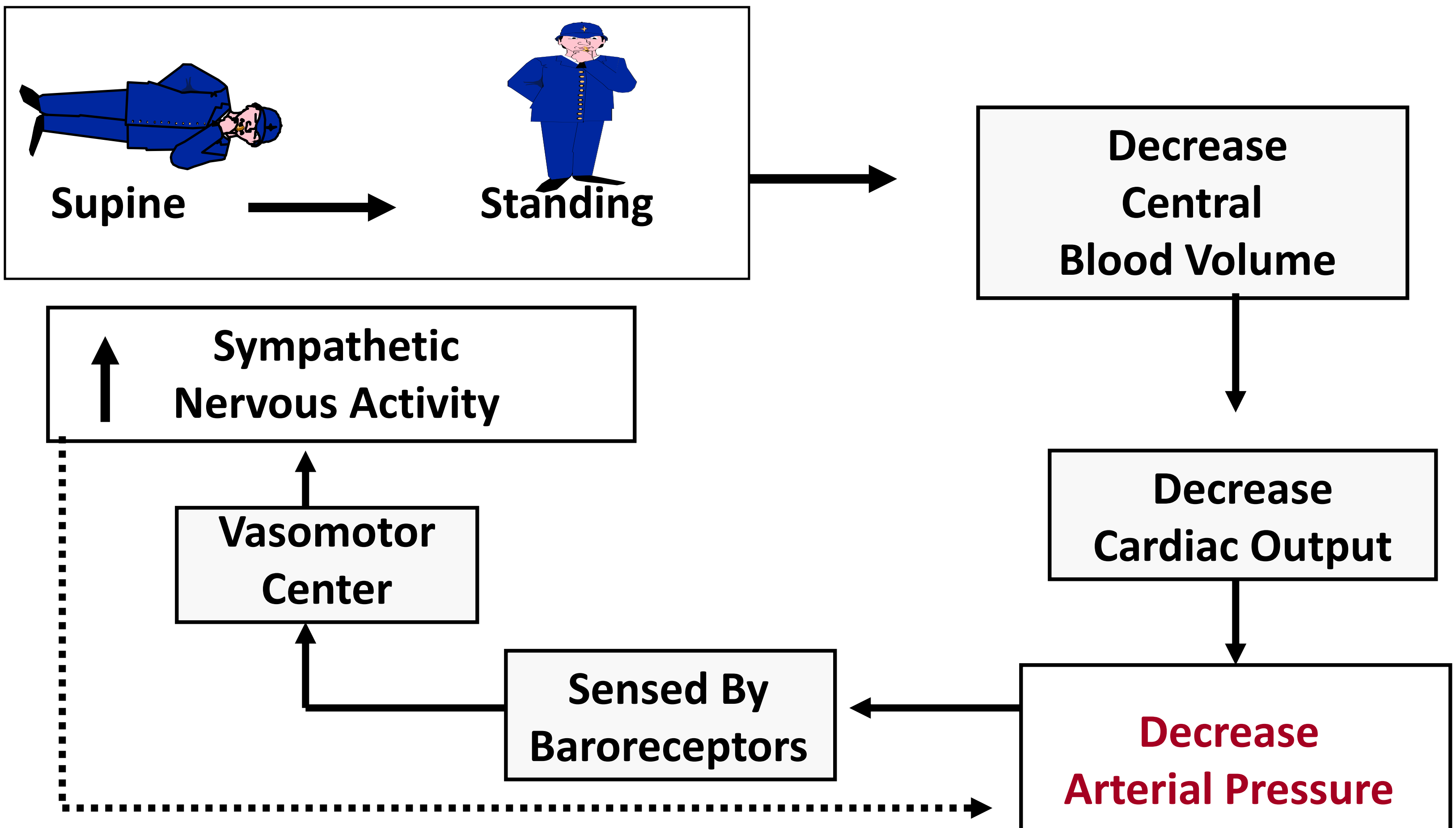


Figure 18-7; Typical carotid sinus reflex effect on aortic arterial pressure caused by clamping both common carotids (after the two vagus nerves have been cut).

Functions of the Baroreceptors

- Maintains relatively constant pressure despite changes in body posture.



▪ Carotid and Aortic Chemoreceptors

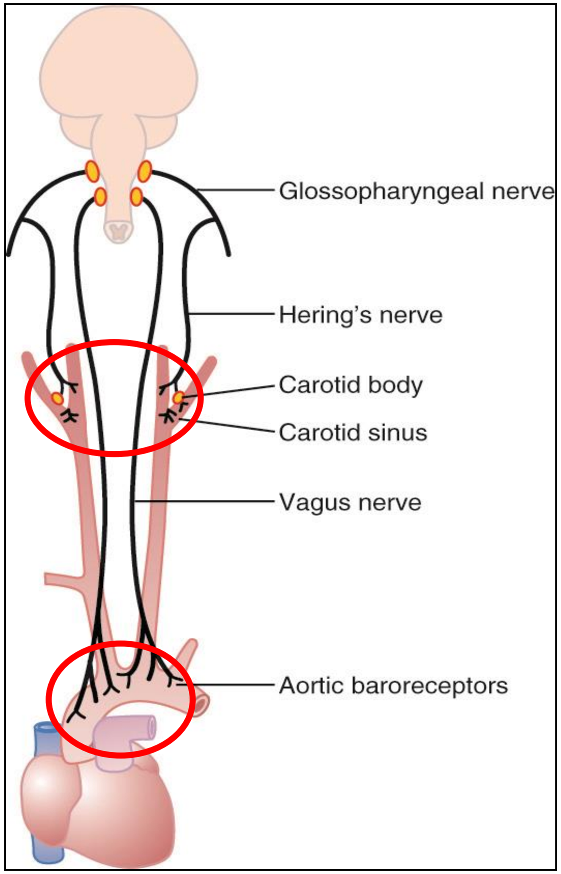


Figure 18-5; Guyton and Hall

Watch video #18

↓ **O2** ↑ **CO2** ↓ **pH** → Chemoreceptors → **VMC** → ↑ Sympathetic activity → ↑ **BP**

Red Blood Cells (Erythrocytes)

- The major function of red blood cells, also known as erythrocytes, is to transport hemoglobin, which in turn carries oxygen from the lungs to the tissues.

Concentration of Red Blood Cells in the Blood

In normal men, the average number of red blood cells per cubic millimeter is 5,200,000 (±300,000); in normal women, it is 4,700,000 (±300,000).

Quantity of Hemoglobin in the Cells.

Red blood cells have the ability to concentrate hemoglobin in the cell fluid up to about 34 grams in each 100 milliliters of cells.

- in a normal man, a maximum of about 20 milliliters of oxygen can be carried in combination with hemoglobin in each 100 milliliters of blood, and in a normal woman, 19 milliliters of oxygen can be carried.

▪ Production of Red Blood Cells

In the early weeks of embryonic life, primitive, nucleated red blood cells are produced in the *yolk sac*. During the middle trimester of gestation, the *liver* is the main organ for production of red blood cells, but reasonable numbers are also produced in the *spleen* and *lymph nodes*. Then, during the last month or so of gestation and after birth, red blood cells are produced exclusively in the *bone marrow*

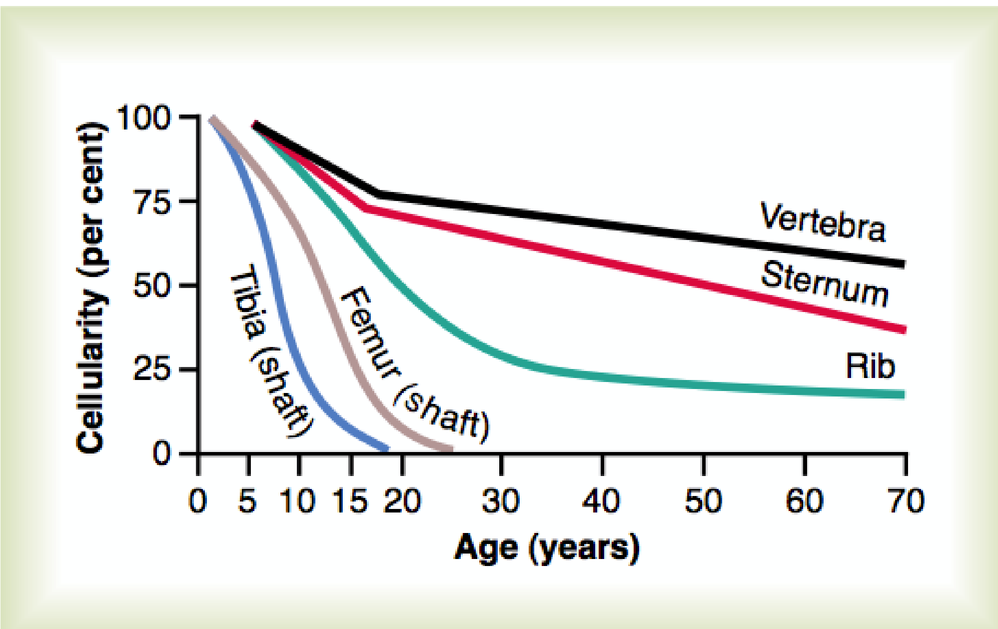


Figure 32–1

Relative rates of red blood cell production in the bone marrow of different bones at different ages.

- the bone marrow of essentially all bones produces red blood cells until a person is 5 years old

Genesis of Blood Cells

The blood cells begin their lives in the bone marrow from a single type of cell called the *pluripotential hematopoietic stem cell*, from which all the cells of the circulating blood are eventually derived.

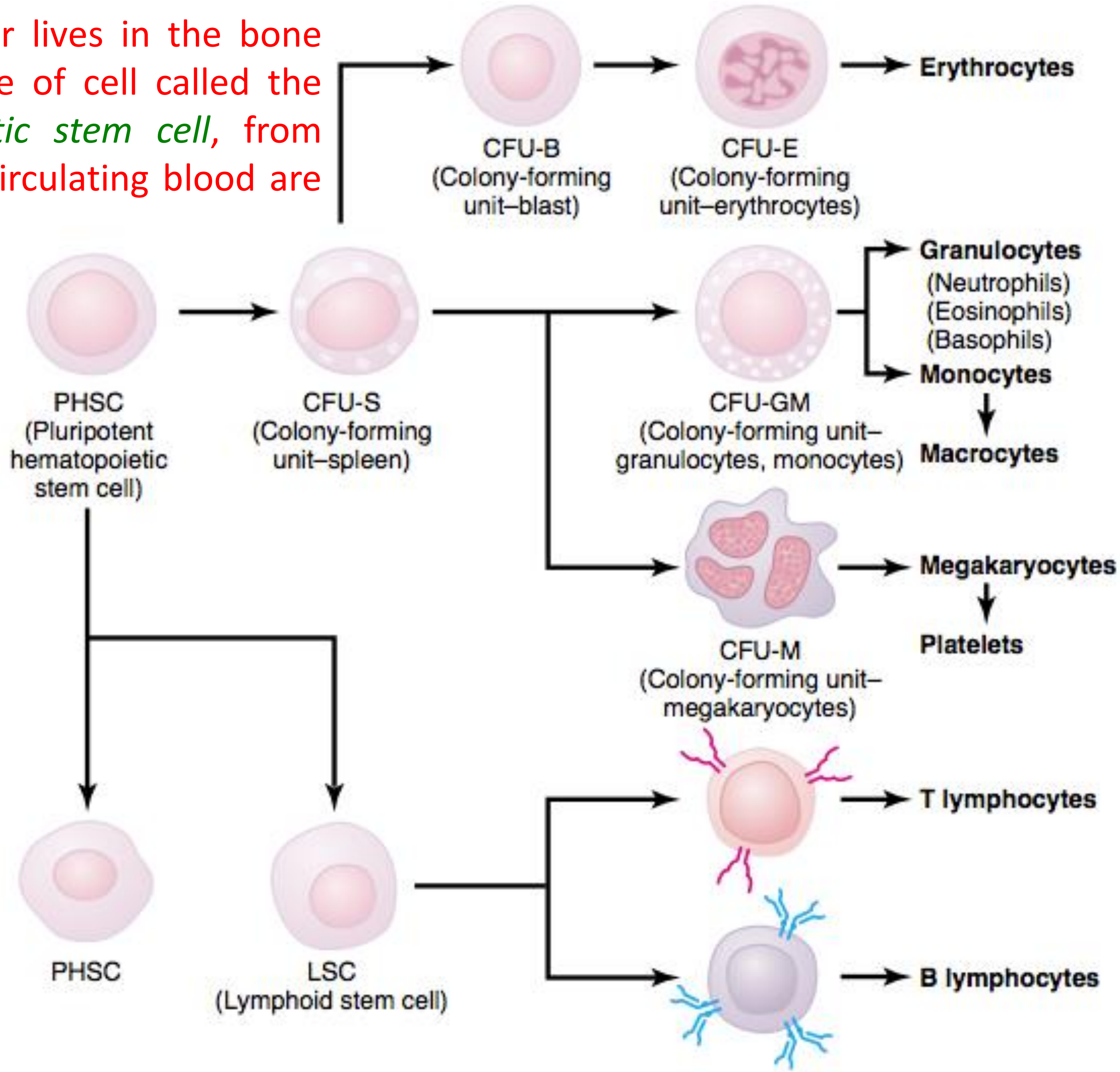


Figure 32–2

Formation of the multiple different blood cells from the original *pluripotent hematopoietic stem cell* (PHSC) in the bone marrow.

Formation of Hemoglobin

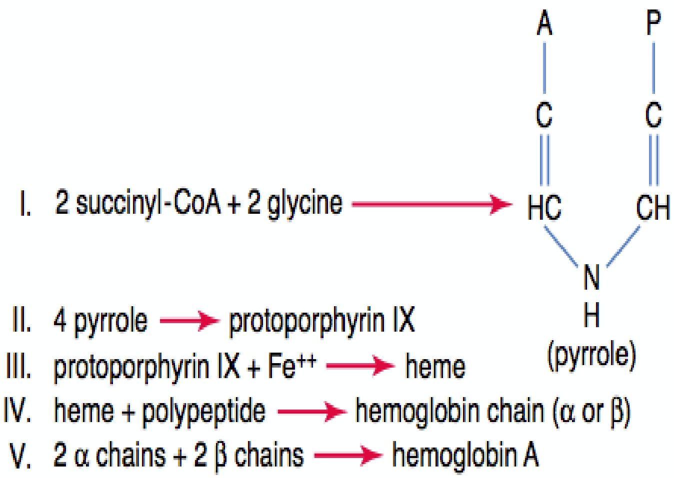


Figure 32–5
Formation of hemoglobin.

The most important feature of the hemoglobin molecule is its ability to combine loosely and reversibly with oxygen.

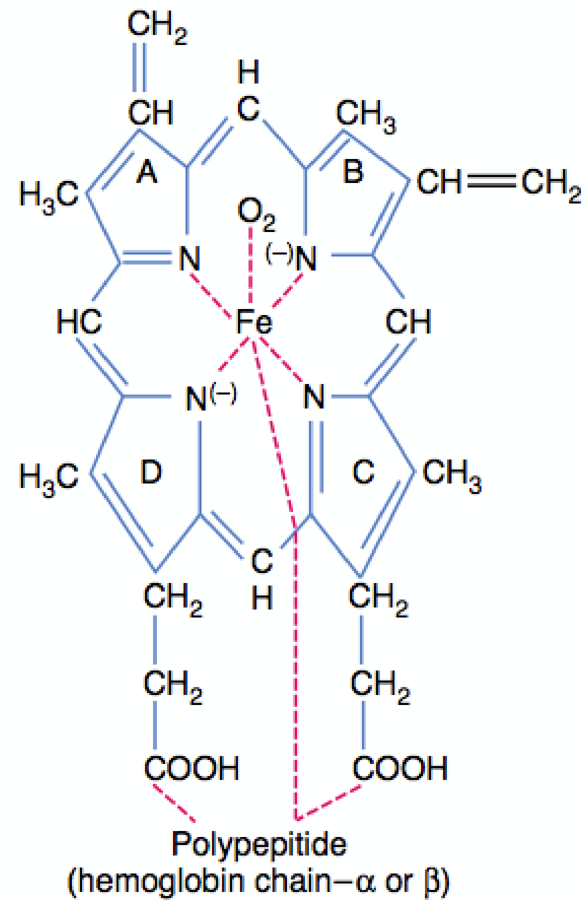


Figure 32–6

Basic structure of the hemoglobin molecule, showing one of the four heme chains that bind together to form the hemoglobin molecule.

▪ Iron

The total quantity of iron in the body averages 4 to 5 grams, about 65 per cent of which is in the form of hemoglobin.

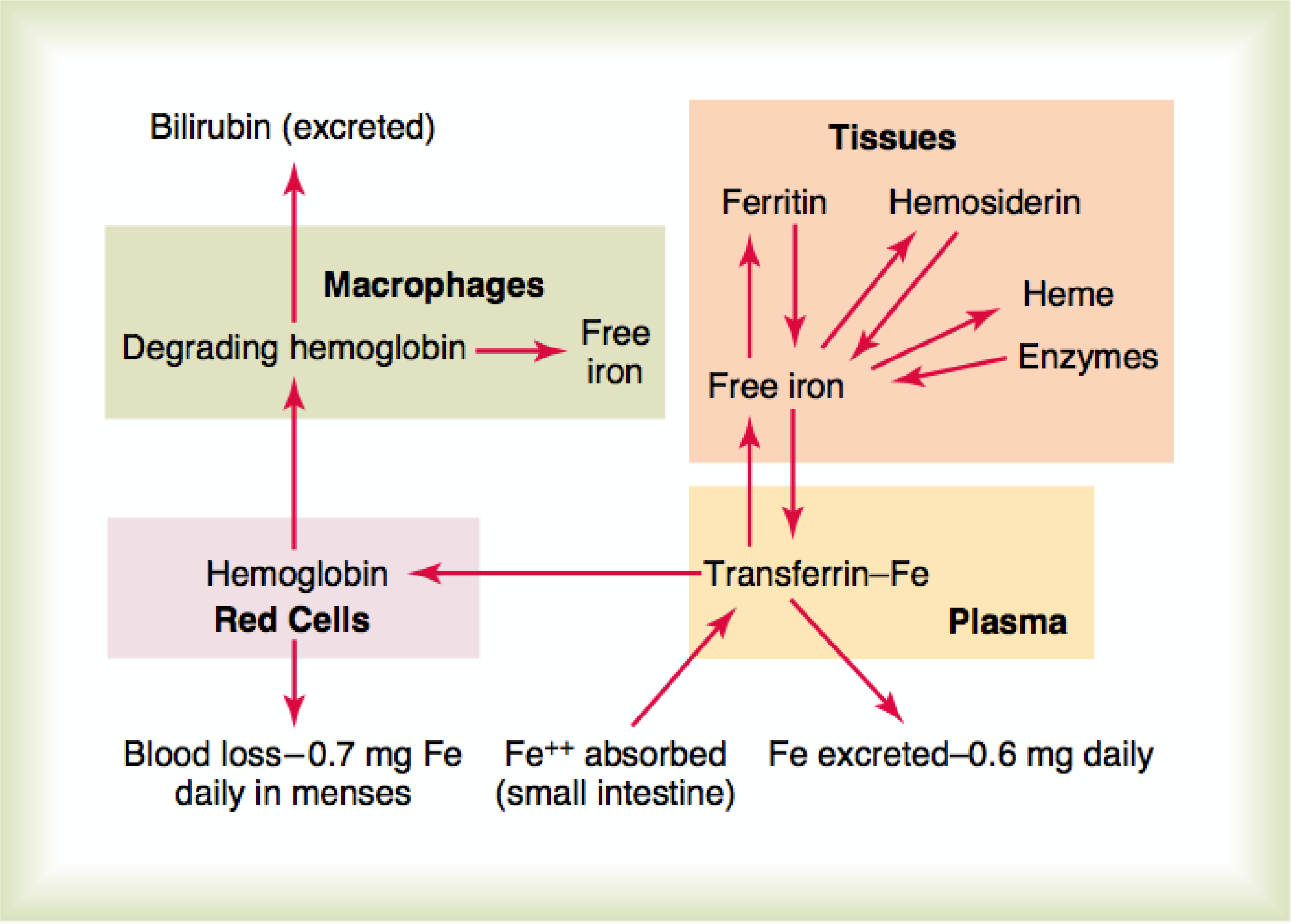


Figure 32–7

Iron transport and metabolism.

Resistance of the Body to Infection

- Our bodies have a special system for combating the different infectious and toxic agents. This is comprised of blood leukocytes (white blood cells) and tissue cells derived from leukocytes. These cells work together in two ways to prevent disease:

(1)destroying invading bacteria or viruses by phagocytosis
(2)forming antibodies and sensitized lymphocytes

▪ Leukocytes (White Blood Cells)

The leukocytes, also called white blood cells, are the mobile units of the body’s protective system. They are formed partially in the bone marrow (granulocytes and monocytes and a few lymphocytes) and partially in the lymph tissue (lymphocytes and plasma cells). After formation, they are transported in the blood to different parts of the body where they are needed.

➢ Types of White Blood Cells.

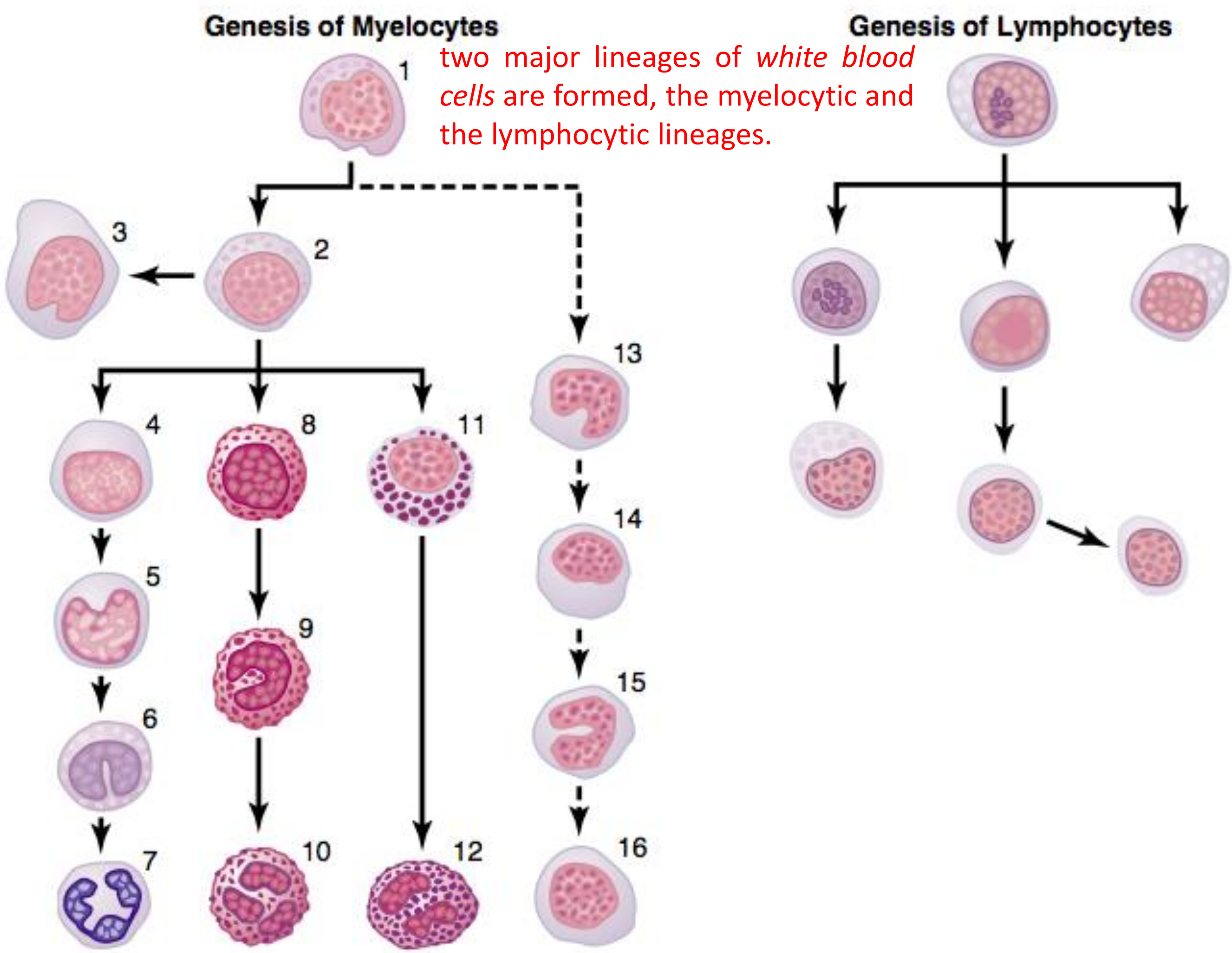
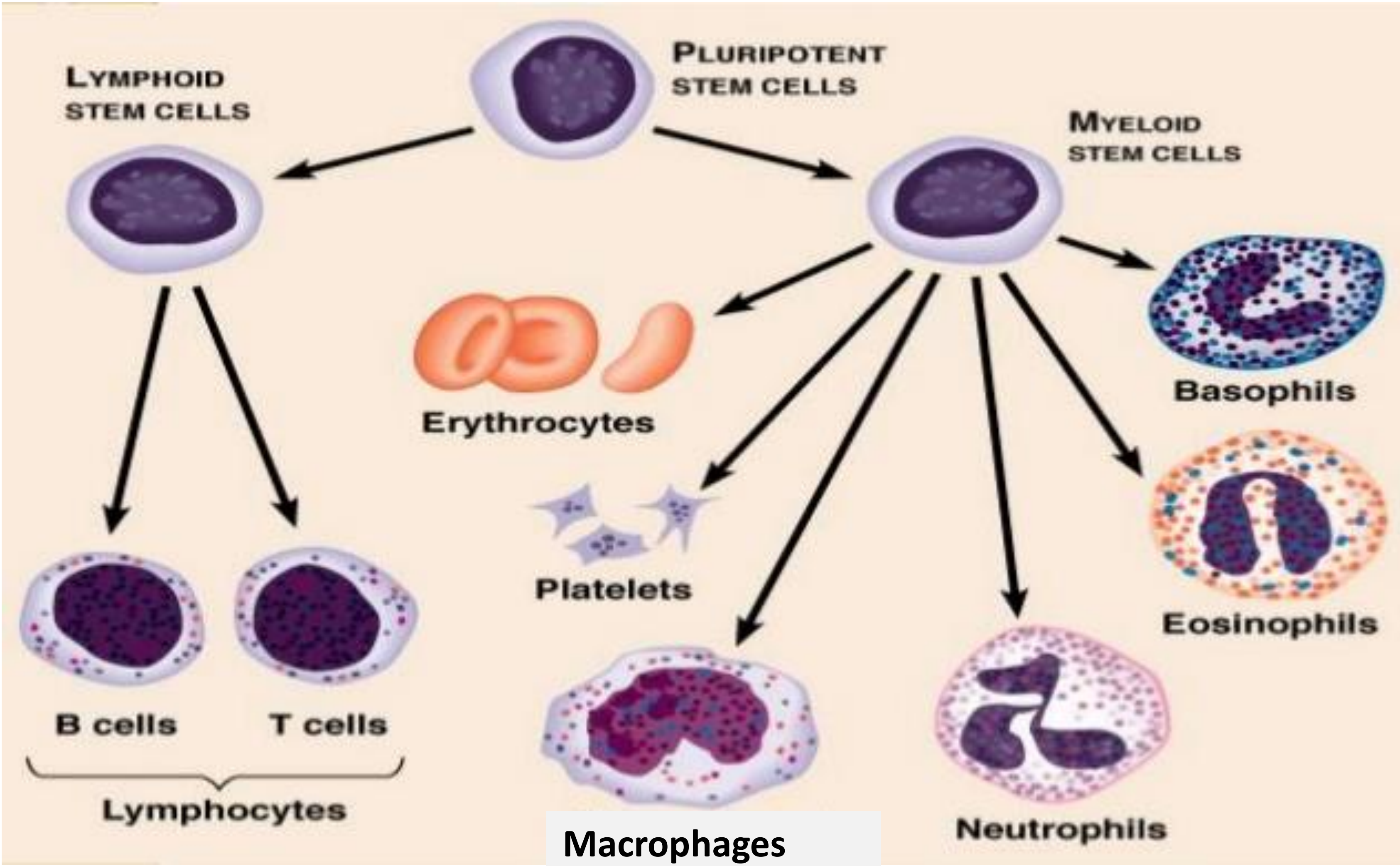


Figure 33–1

Genesis of white blood cells. The different cells of the myelocyte series are 1, myeloblast; 2, promyelocyte; 3, megakaryocyte; 4, neutrophil myelocyte; 5, young neutrophil metamyelocyte; 6, “band” neutrophil metamyelocyte; 7, polymorphonuclear neutrophil; 8, eosinophil myelocyte; 9, eosinophil metamyelocyte; 10, polymorphonuclear eosinophil; 11, basophil myelocyte; 12, polymorphonuclear basophil; 13–16, stages of monocyte formation.



PLURIPOTENT
STEM CELLS
LYMPHOID
STEM CELLS
MYELOID
STEM CELLS
Erythrocytes
Basophils
Platelets
Eosinophils
B cells
T cells
Lymphocytes
Macrophages
Neutrophils

➢ Neutrophils and Macrophages Defend Against Infections

- White Blood Cells Enter the Tissue Spaces by Diapedesis.
- White Blood Cells Are Attracted to Inflamed Tissue Areas by Chemotaxis.

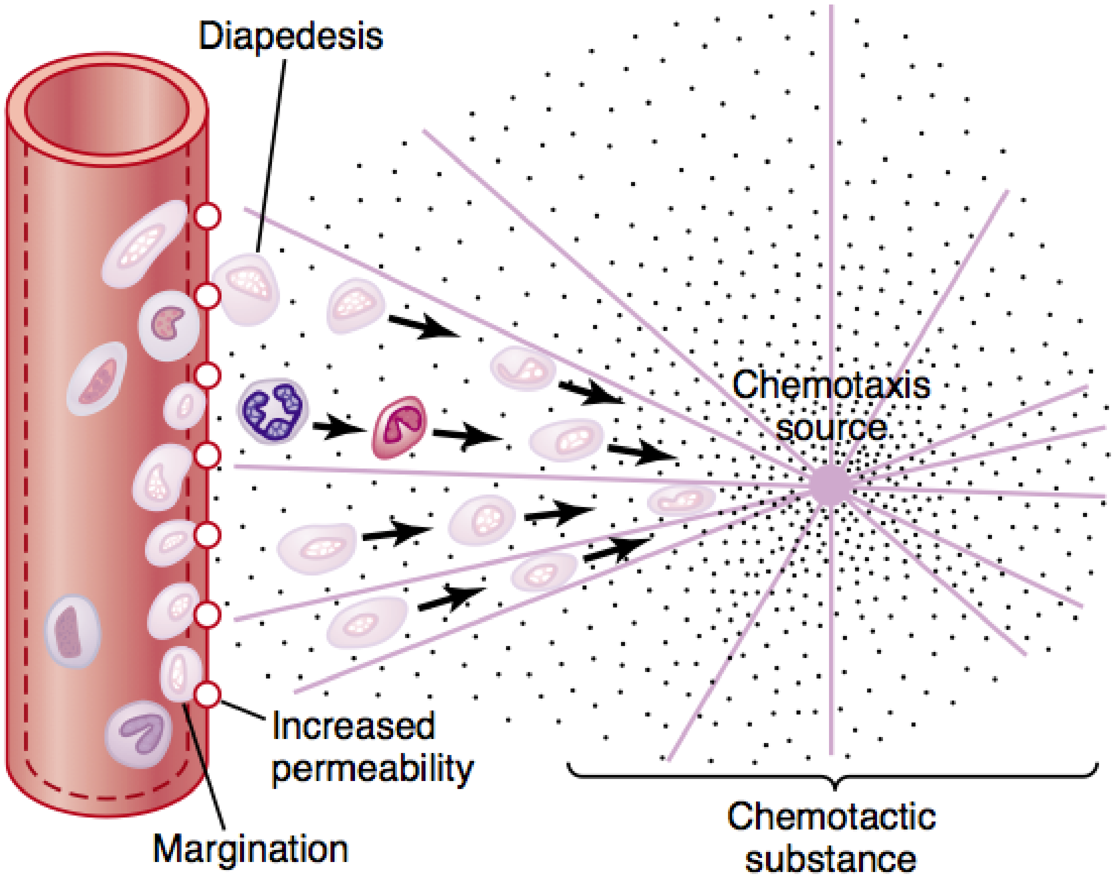


Figure 33–2

Movement of neutrophils by *diapedesis* through capillary pores and by *chemotaxis* toward an area of tissue damage.

▪ NEUTROPHILS AND MACROPHAGES

- It is mainly the ***neutrophils and tissue macrophages*** that attack and destroy invading bacteria, viruses, and other injurious agents

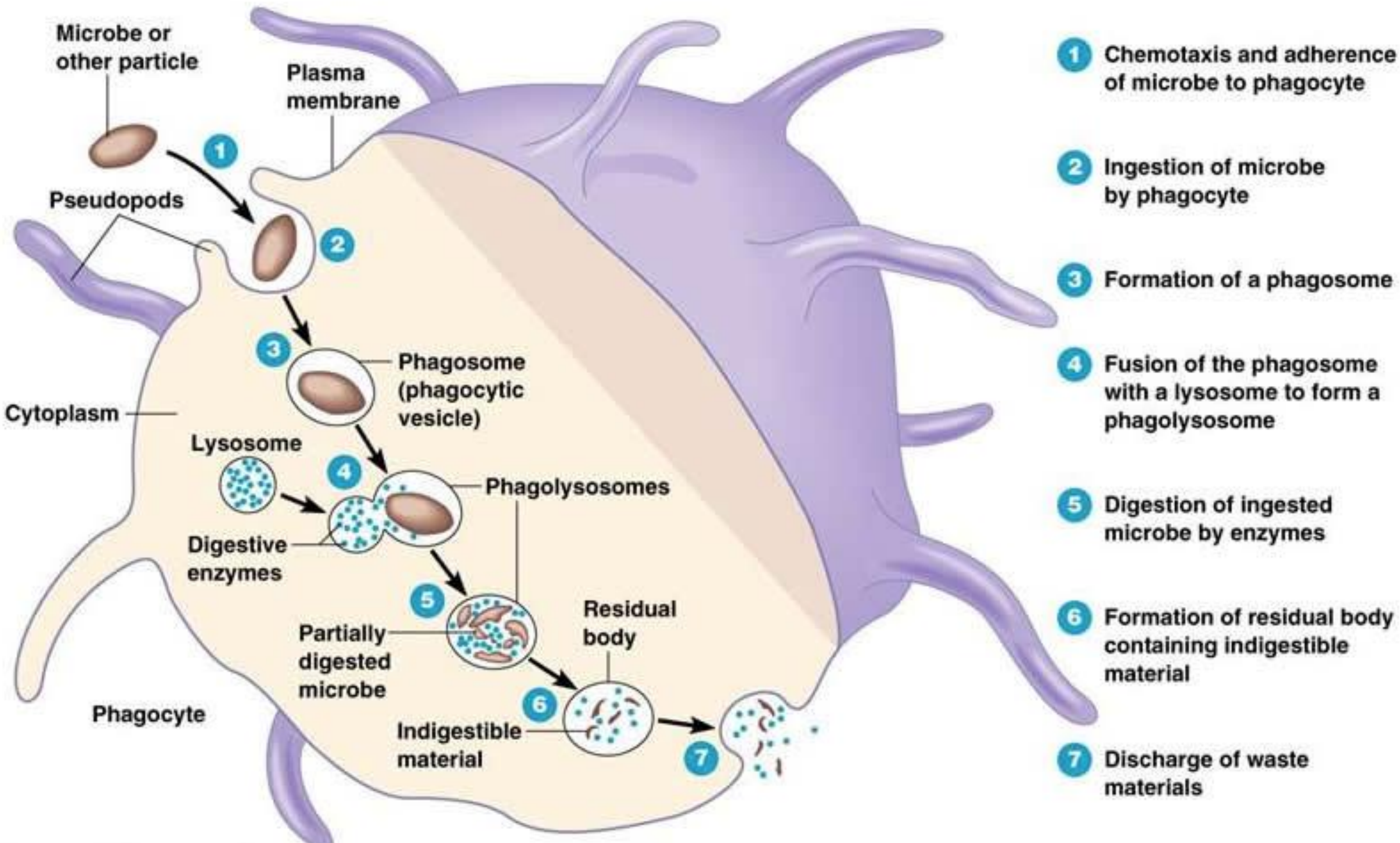
- The **neutrophils are mature cells** that can attack and destroy bacteria even in the circulating blood.

- the tissue macrophages **begin life as blood monocytes**, which are ***immature cells*** while still in the blood and have little ability to fight infectious agents

- once they enter the tissues, they **begin to swell** – sometimes increasing their diameters as much as fivefold – ***macrophages*** -extremely capable of combating intratissue disease agents.

▪ Phagocytosis

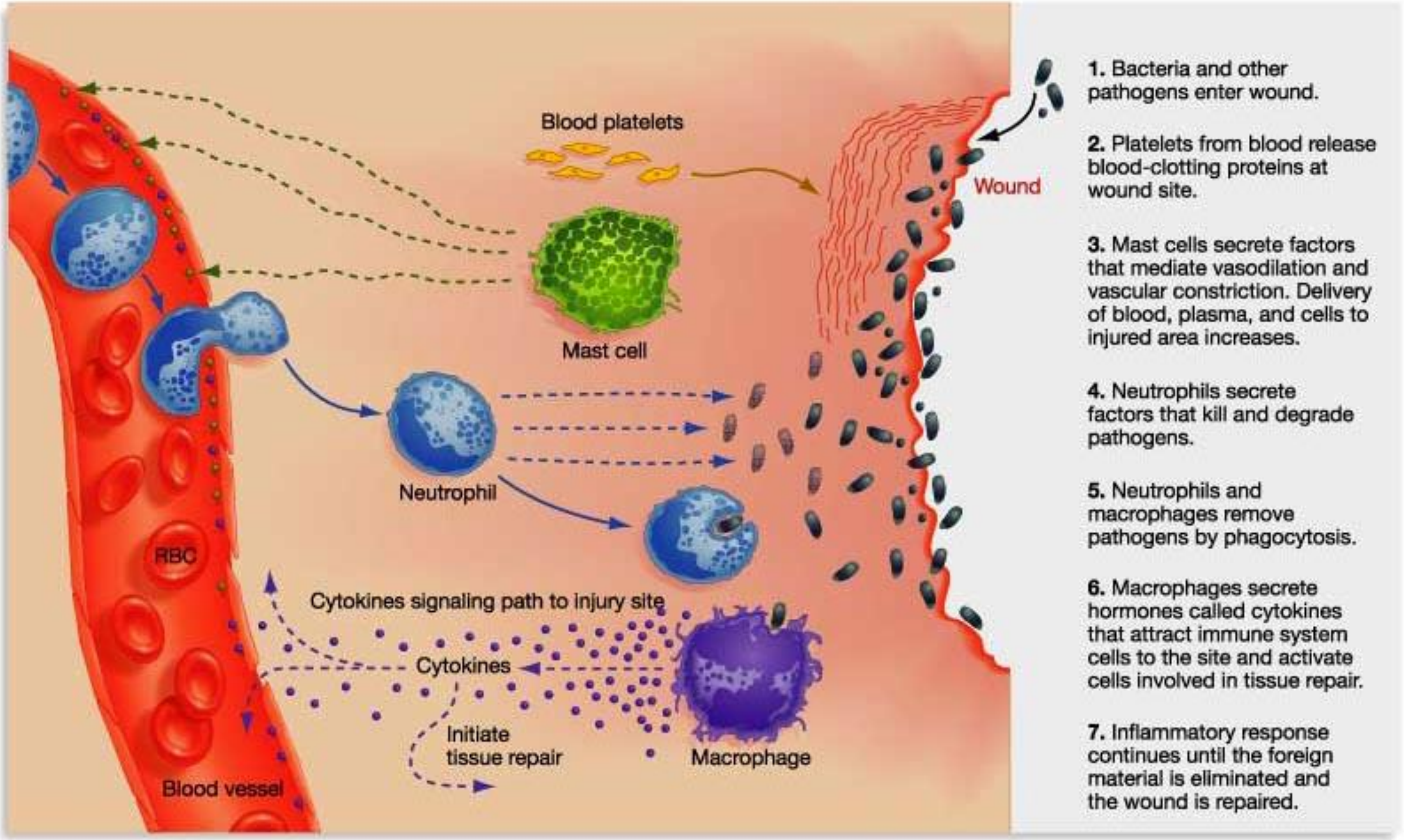
- The most important function of the neutrophils and macrophages is phagocytosis, which means cellular ingestion of the offending agent. Phagocytes must be selective of the material that is phagocytized; other- wise, normal cells and structures of the body might be ingested.



Phases of phagocytosis

▪ Inflammation

- When tissue injury occurs, whether caused by bacteria, trauma, chemicals, heat, or any other phenomenon, multiple substances are released by the injured tissues and cause dramatic secondary changes in the surrounding uninjured tissues. This entire complex of tissue changes is called inflammation.



The Leukemias

- Uncontrolled production of white blood cells can be caused by cancerous mutation of a myelogenous or lymphogenous cell. This causes leukemia, which is usually characterized by greatly increased numbers of abnormal white blood cells in the circulating blood.

- Leukemias are divided into two general types: **lymphocytic leukemias** and **myelogenous leukemias**.

- The lymphocytic leukemias are caused by cancerous production of lymphoid cells, usually beginning in a lymph node or other lymphocytic tissue and spreading to other areas of the body.

- Myelogenous leukemia, begins by cancerous production of young myelogenous cells in the bone marrow and then spreads throughout the body so that white blood cells are produced in many extramedullary tissues—especially in the lymph nodes, spleen, and liver.