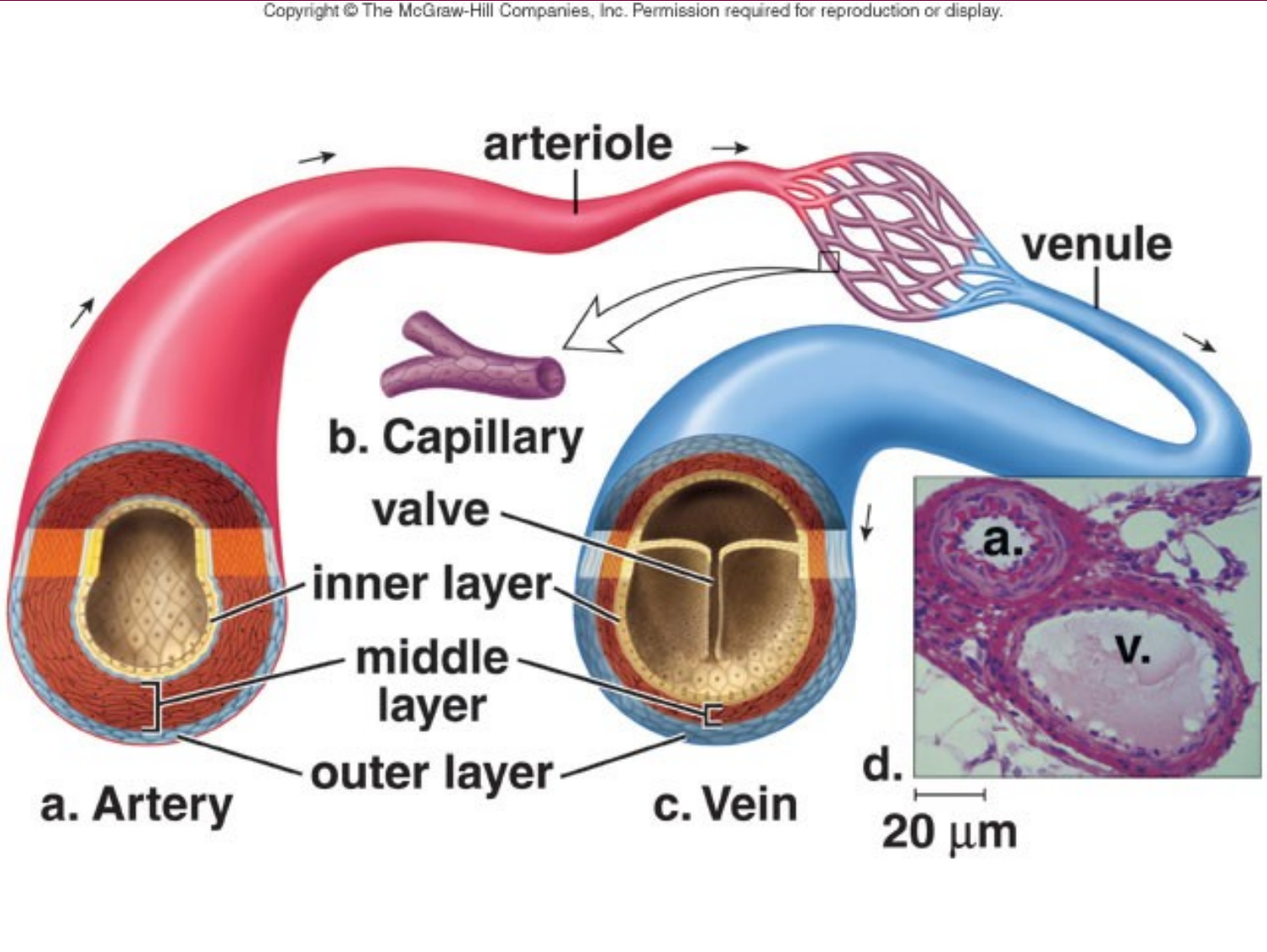
Cardiovascular System

The Blood Vessels

- The *cardiovascular system* has three types of blood vessels:
- *Arteries* (and *arterioles*) – carry blood away from the heart
- *Capillaries* – where nutrient and gas exchange occur
- *Veins* (and *venules*) – carry blood toward the heart.

Blood vessels



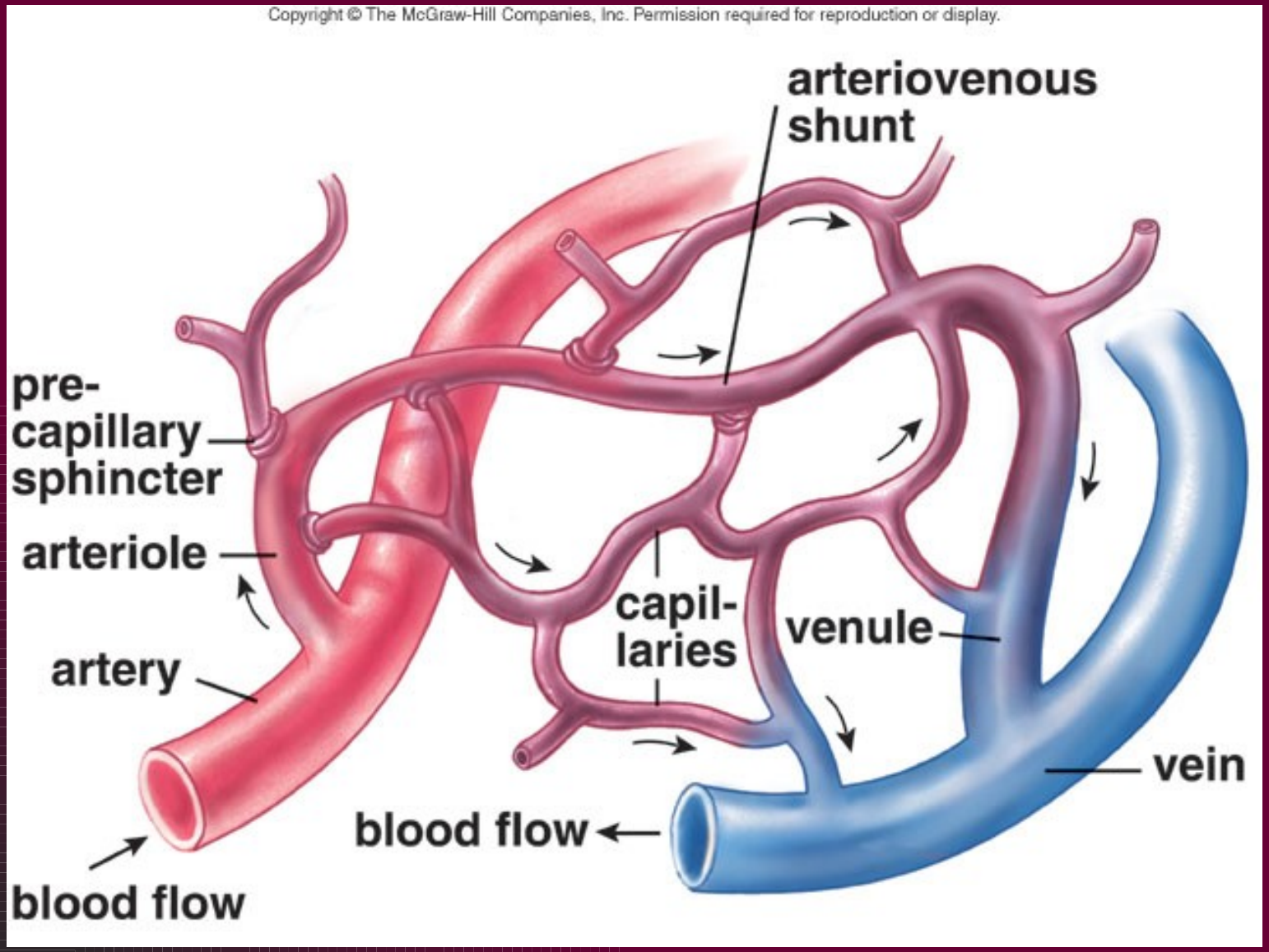
The Arteries

- *Arteries* and arterioles take blood away from the heart.
- The largest artery is the *aorta*.
- The middle layer of an artery wall consists of *smooth muscle* that can constrict to regulate blood flow and blood pressure.
- *Arterioles* can constrict or dilate, changing blood pressure.

The Capillaries

- *Capillaries* have walls only one cell thick to allow exchange of gases and nutrients with tissue fluid.
- Capillary beds are present in all regions of the body but not all capillary beds are open at the same time.
- Contraction of a *sphincter muscle* closes off a bed and blood can flow through an *arteriovenous shunt* that bypasses the capillary bed.

Anatomy of a capillary bed



The Veins

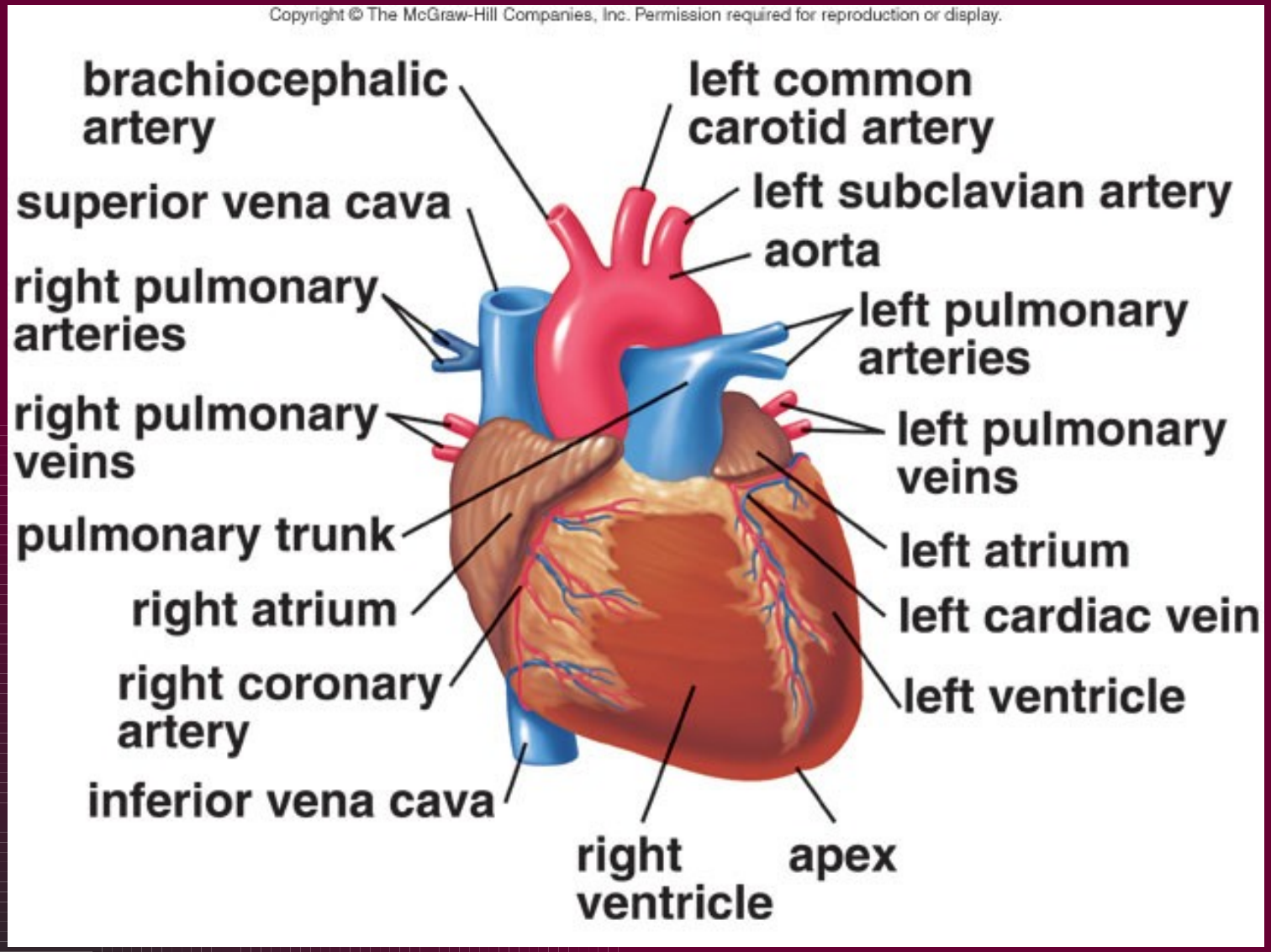
- *Venules* drain blood from capillaries, then join to form *veins* that take blood to the heart.
- Veins have much less smooth muscle and connective tissue than arteries.
- Veins often have *valves* that prevent the backward flow of blood when closed.
- Veins carry about 70% of the body's blood and act as a *reservoir* during hemorrhage.

The Heart

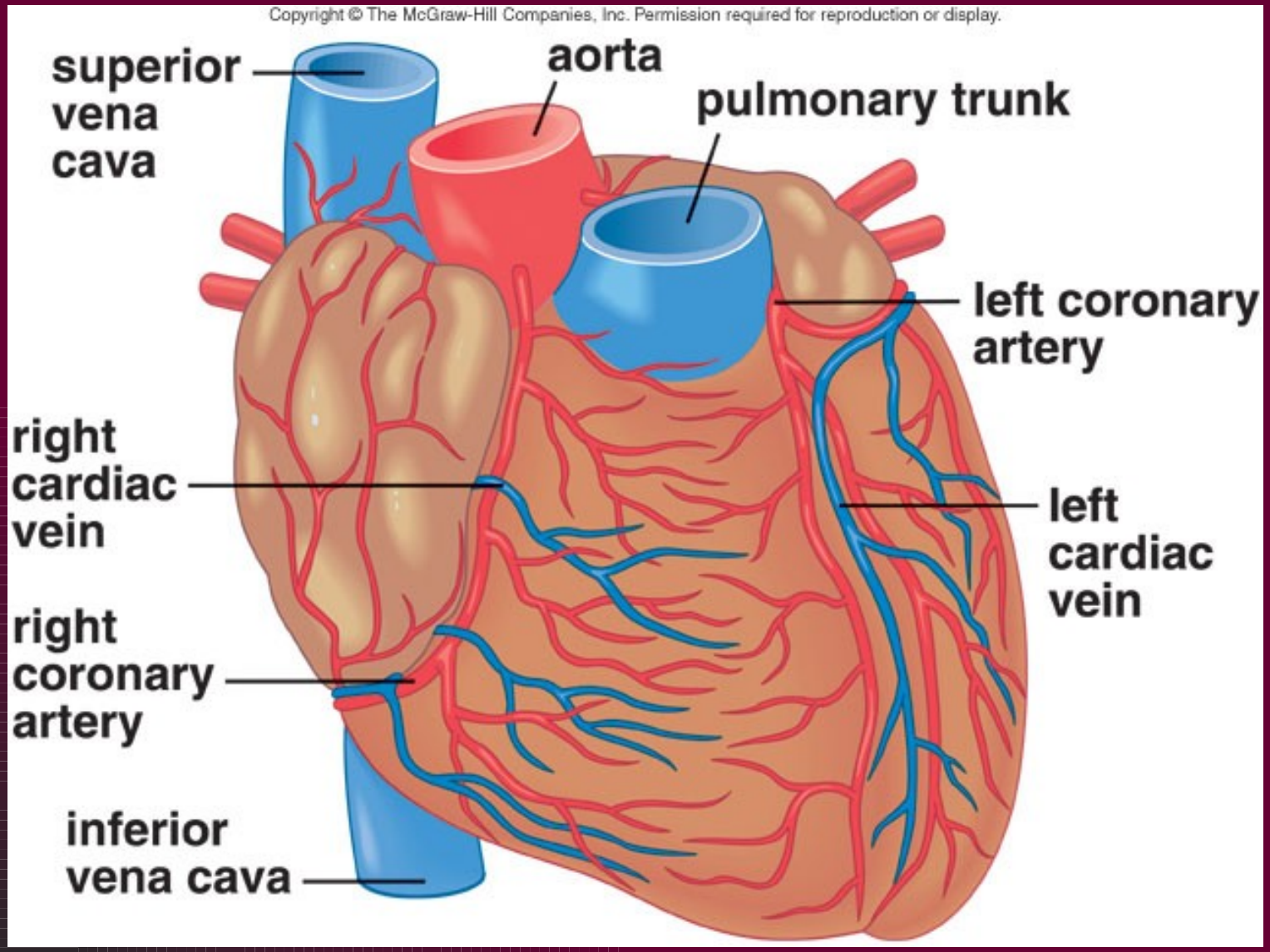
- The *heart* is a cone-shaped, muscular organ located between the lungs behind the sternum.
- The heart muscle forms the *myocardium*, with tightly interconnect cells of *cardiac muscle* tissue.
- The *pericardium* is the outer membranous sac with lubricating fluid.

- The heart has four chambers: two upper, thin-walled *atria*, and two lower, thick-walled *ventricles*.
- The *septum* is a wall dividing the right and left sides.
- *Atrioventricular valves* occur between the atria and ventricles – the *tricuspid valve* on the right and the *bicuspid valve* on the left; both valves are reenforced by *chordae tendinae* attached to muscular projections within the ventricles.

External heart anatomy



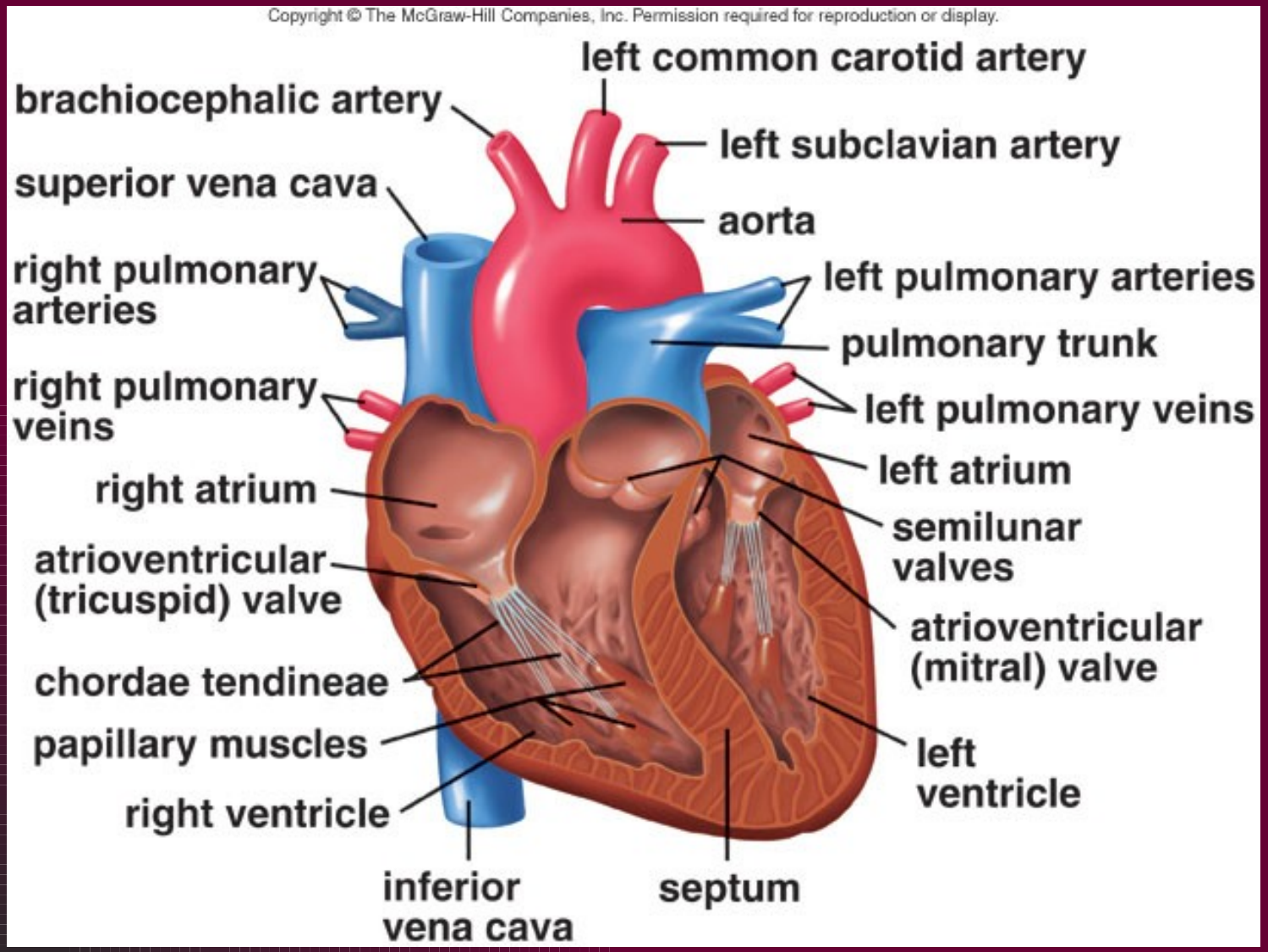
Coronary artery circulation



Passage of Blood Through the Heart

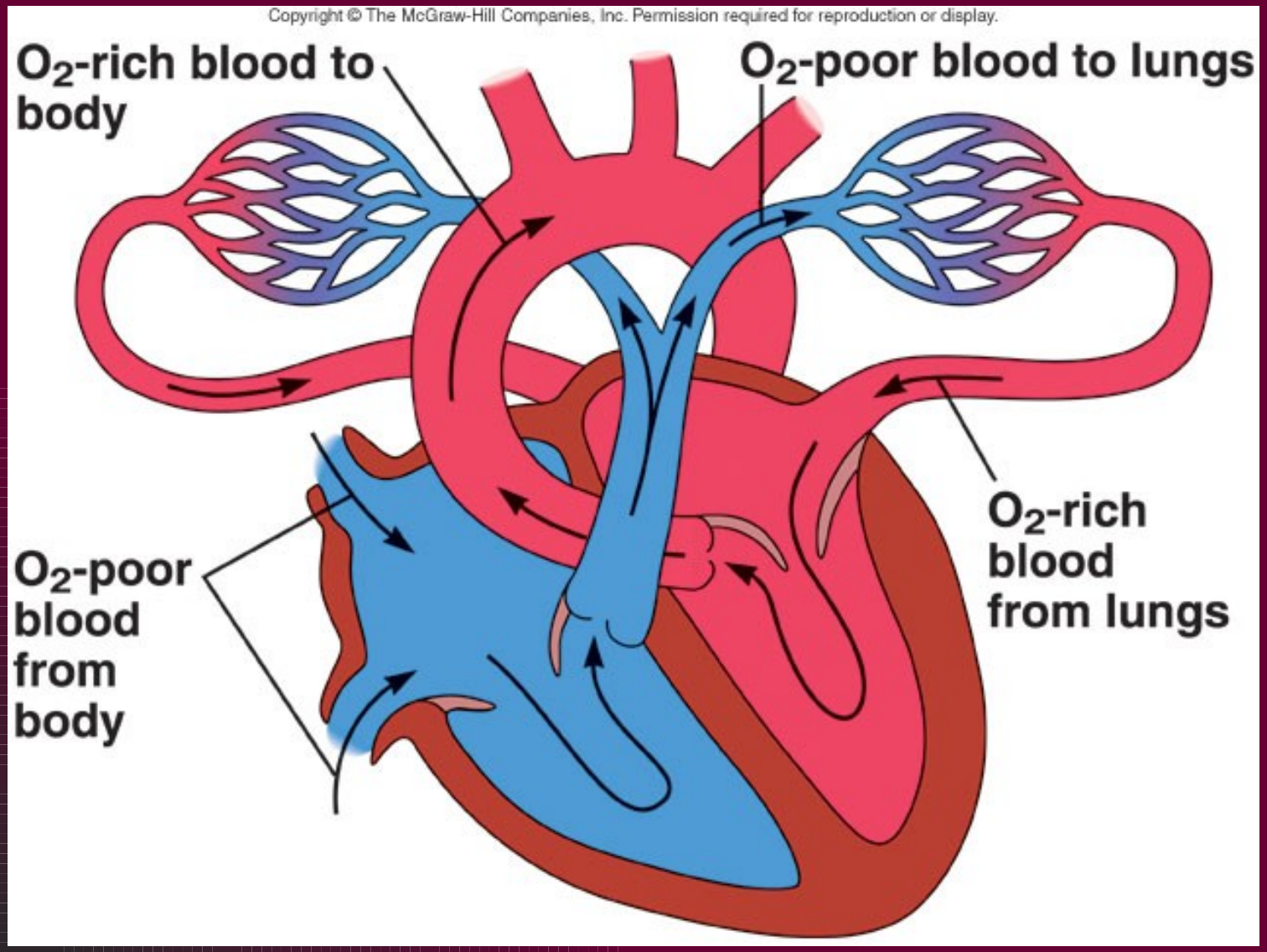
- Blood follows this sequence through the heart: superior and inferior vena cava → right atrium → tricuspid valve → right ventricle → pulmonary semilunar valve → pulmonary trunk and arteries to the lungs → pulmonary veins leaving the lungs → left atrium → bicuspid valve → left ventricle → aortic semilunar valve → aorta → to the body.

Internal view of the heart



- The pumping of the heart sends out blood under pressure to the arteries.
- *Blood pressure* is greatest in the aorta; the wall of the left ventricle is thicker than that of the right ventricle and pumps blood to the entire body.
- Blood pressure then decreases as the cross-sectional area of arteries and then arterioles increases.

Path of blood through the heart



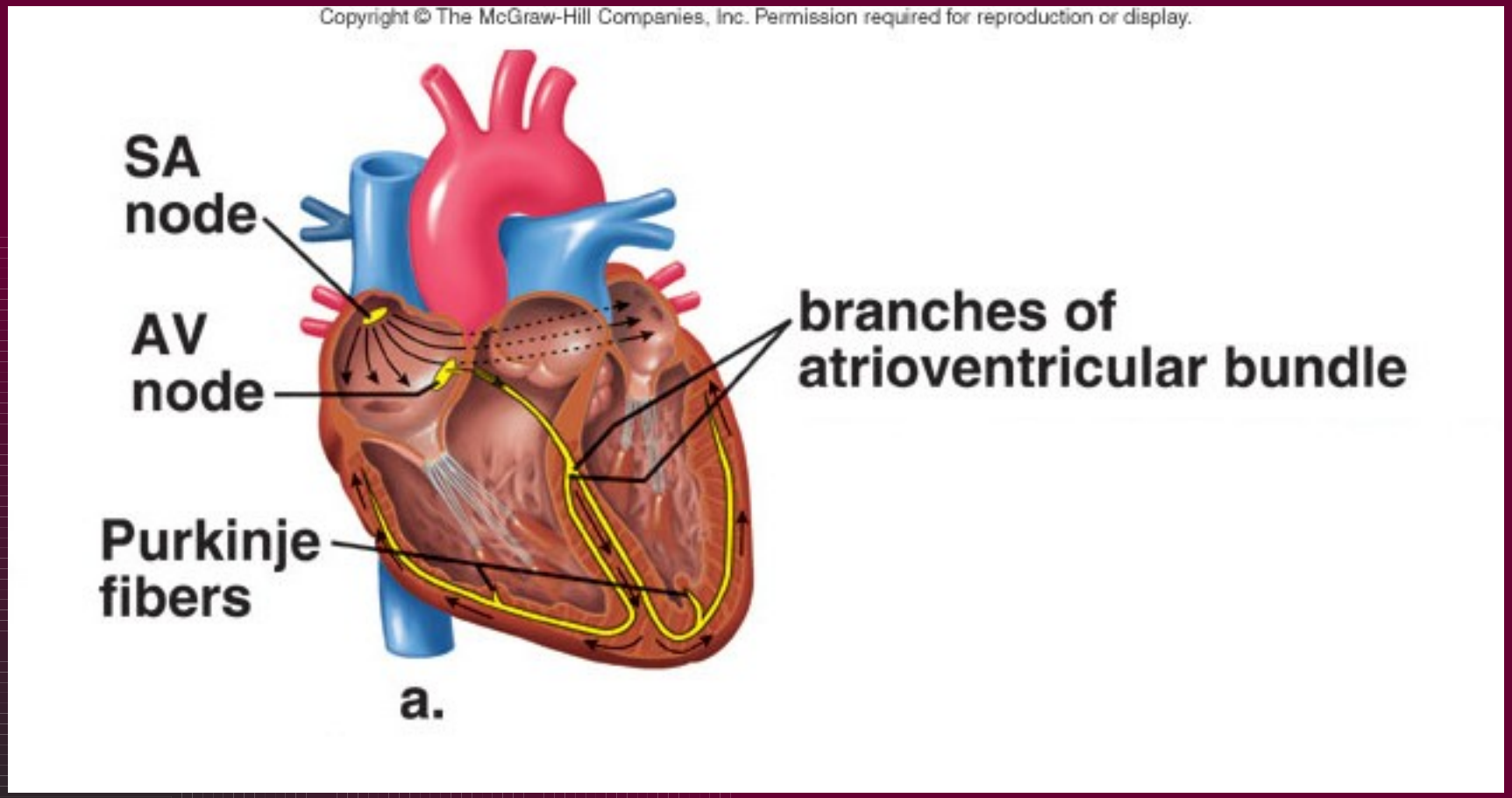
The Heartbeat

- Each heartbeat is called a *cardiac cycle*.
- When the heart beats, the two atria contract together, then the two ventricles contract; then the whole heart relaxes.
- *Systole* is the contraction of heart chambers; *diastole* is their relaxation.
- The *heart sounds*, lub-dup, are due to the closing of the atrioventricular valves, followed by the closing of the semilunar valves.

Intrinsic Control of Heartbeat

- The *SA* (*sinoatrial*) *node*, or *pacemaker*, initiates the heartbeat and causes the atria to contract on average every 0.85 seconds.
- The *AV* (*atrioventricular*) *node* conveys the stimulus and initiates contraction of the ventricles.
- The signal for the ventricles to contract travels from the AV node through the *atrioventricular bundle* to the smaller *Purkinje fibers*.

Conduction system of the heart



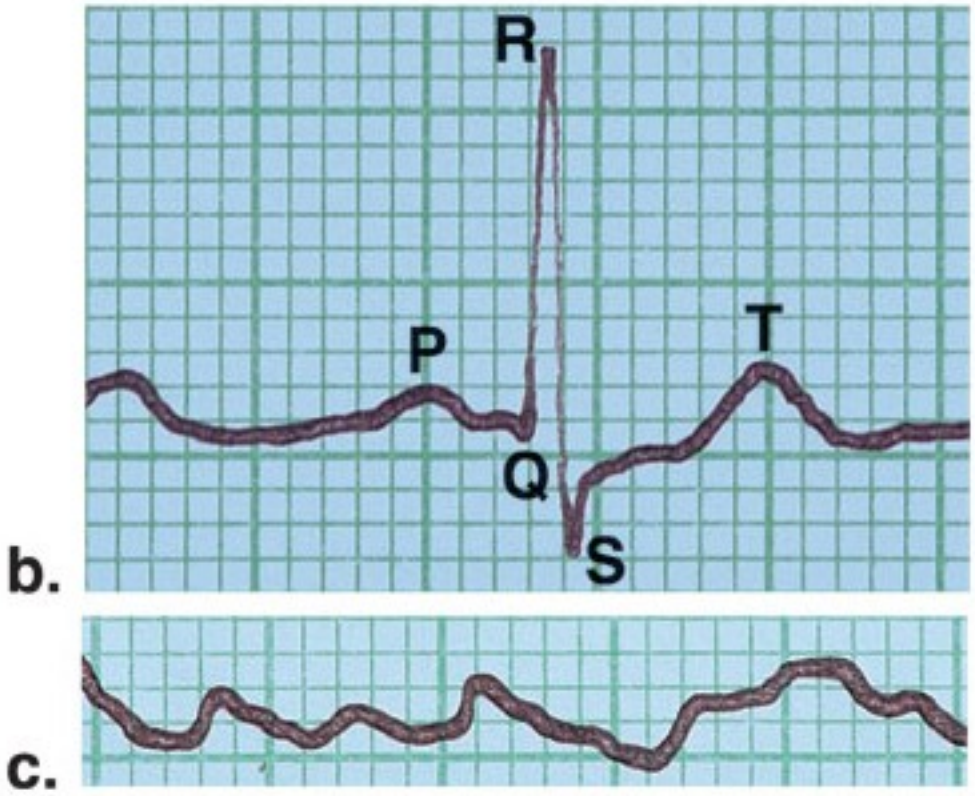
Extrinsic Control of Heartbeat

- A *cardiac control center* in the medulla oblongata speeds up or slows down the heart rate by way of the autonomic nervous system branches: *parasympathetic system* (slows heart rate) and the *sympathetic system* (increases heart rate).
- Hormones *epinephrine* and norepinephrine from the adrenal medulla also stimulate faster heart rate.

The Electrocardiogram

- An *electrocardiogram* (ECG) is a recording of the electrical changes that occur in the myocardium during a cardiac cycle.
- *Atrial depolarization* creates the *P wave*, *ventricle depolarization* creates the *QRS wave*, and *repolarization* of the ventricles produces the *T wave*.

Electrocardiogram

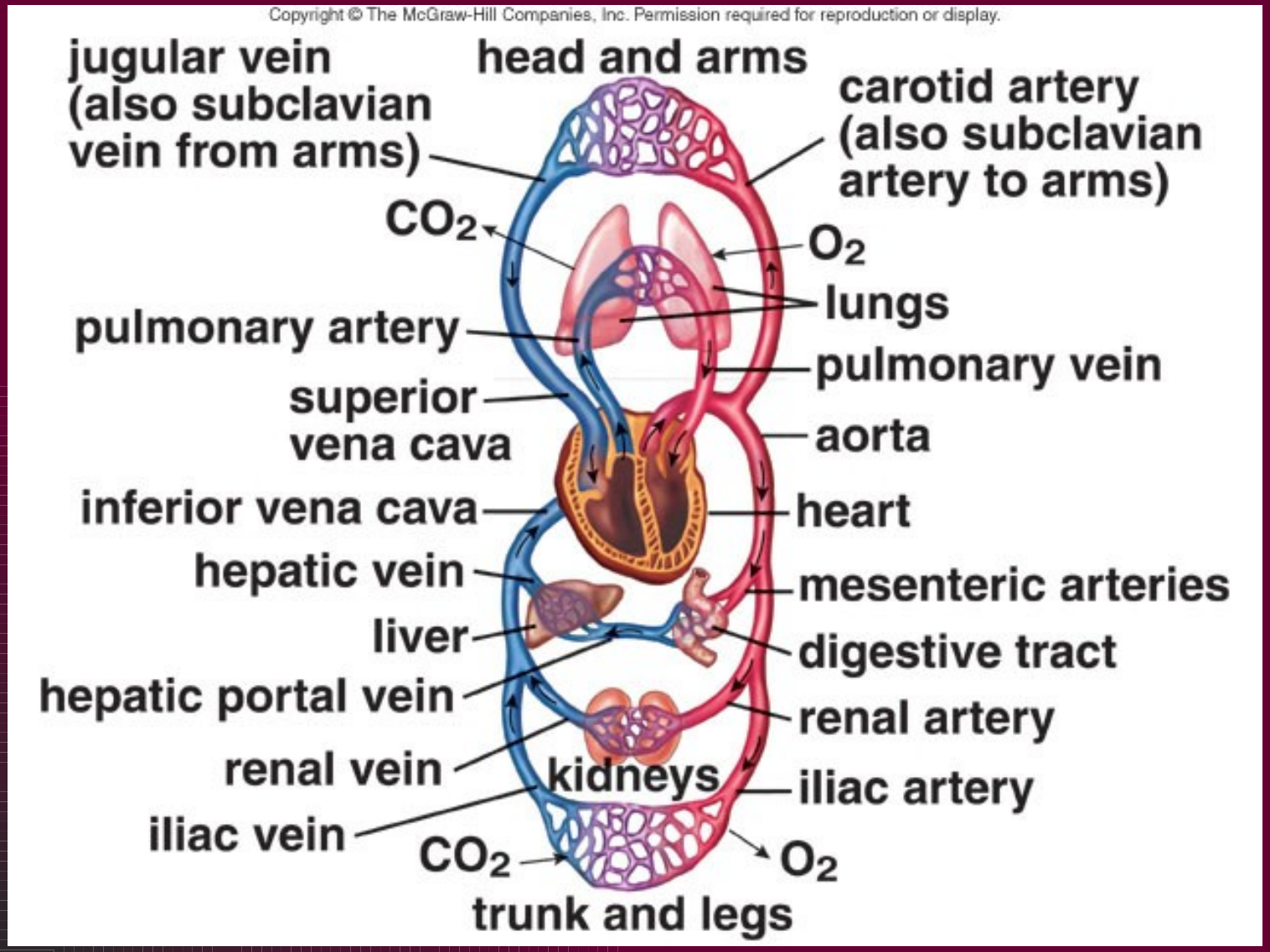


The Vascular Pathways

- The cardiovascular system includes two circuits:

2) *Pulmonary circuit* which circulates blood through the lungs, and
3) *Systemic circuit* which circulates blood to the rest of the body.
4) Both circuits are vital to homeostasis.

Cardiovascular system diagram



The Pulmonary Circuit

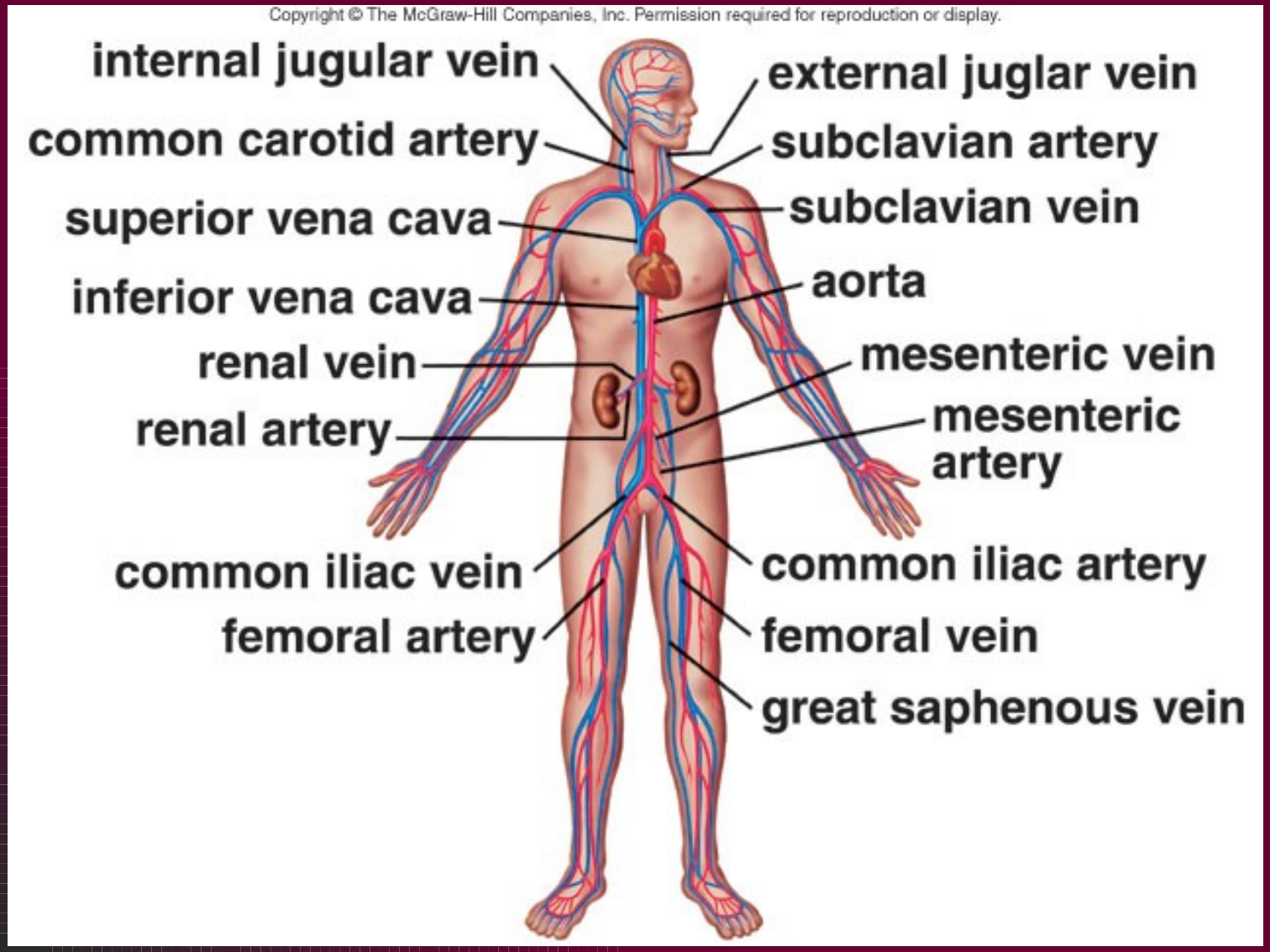
- The *pulmonary circuit* begins with the *pulmonary trunk* from the right ventricle which branches into two *pulmonary arteries* that take oxygen-poor blood to the lungs.
- In the lungs, oxygen diffuses into the blood, and carbon dioxide diffuses out of the blood to be expelled by the lungs.
- Four *pulmonary veins* return oxygen-rich blood to the left atrium.

The Systemic Circuit

- The *systemic circuit* starts with the aorta carrying O_2-rich blood from the left ventricle.
- The aorta branches with an artery going to each specific organ.
- Generally, an artery divides into arterioles and capillaries which then lead to venules.

- The vein that takes blood to the vena cava often has the same name as the artery that delivered blood to the organ.
- In the adult systemic circuit, arteries carry blood that is relatively high in oxygen and relatively low in carbon dioxide, and veins carry blood that is relatively low in oxygen and relatively high in carbon dioxide.
- This is the reverse of the pulmonary circuit.

Major arteries and veins of the systemic circuit



- The *coronary arteries* serve the heart muscle itself; they are the first branch off the aorta.
- Since the coronary arteries are so small, they are easily clogged, leading to heart disease.
- The *hepatic portal system* carries blood rich in nutrients from digestion in the small intestine to the liver, the organ that monitors the composition of the blood.

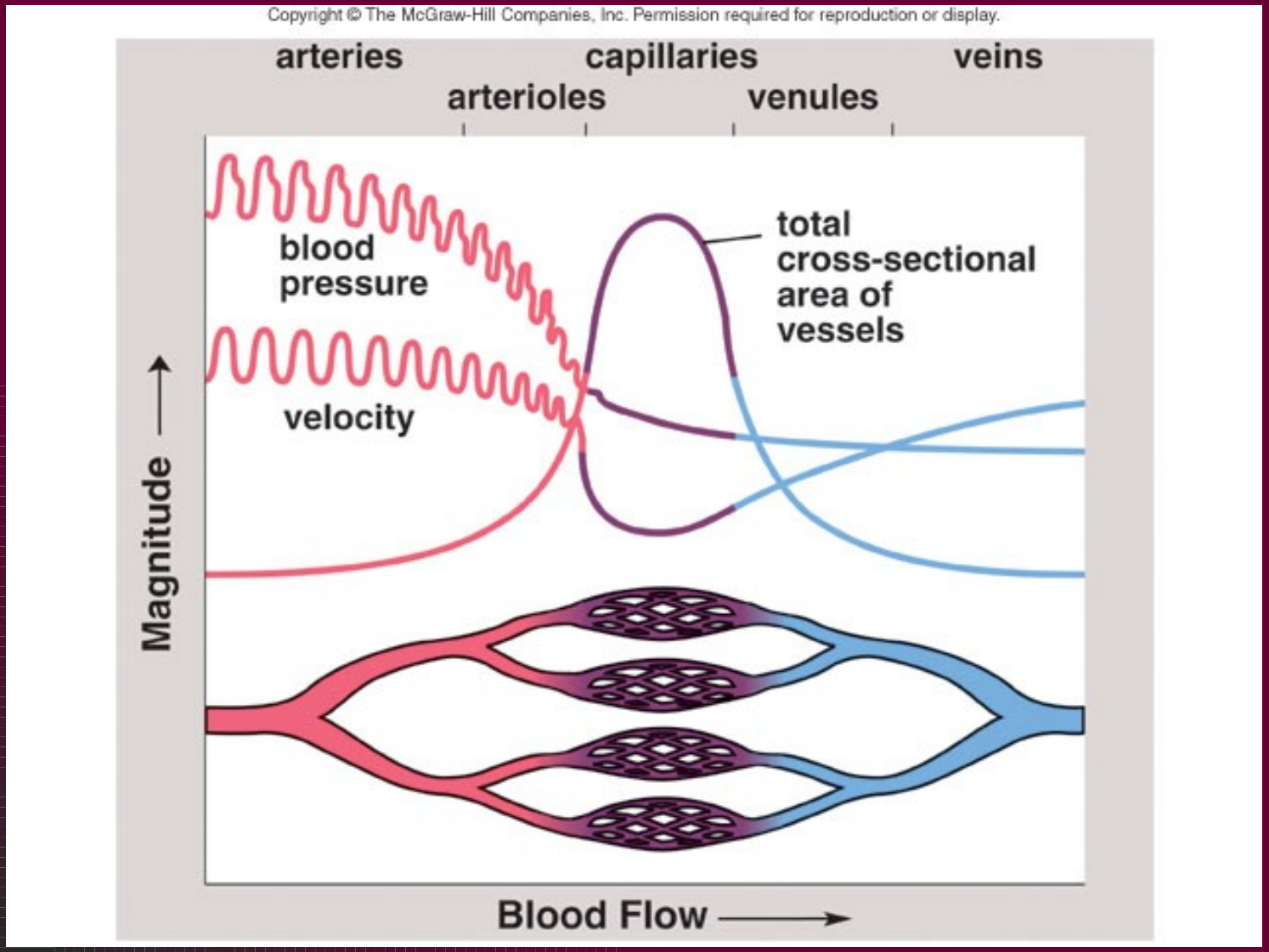
Blood Flow

- The beating of the heart is necessary to homeostasis because it creates pressure that propels blood in arteries and the arterioles.
- Arterioles lead to the capillaries where nutrient and gas exchange with tissue fluid takes place.

Blood Flow in Arteries

- *Blood pressure* due to the pumping of the heart accounts for the flow of blood in the arteries.
- *Systolic pressure* is high when the heart expels the blood.
- *Diastolic pressure* occurs when the heart ventricles are relaxing.
- Both pressures decrease with distance from the left ventricle because blood enters more and more arterioles and arteries.

Cross-sectional area as it relates to blood pressure and velocity



Blood Flow in Capillaries

- Blood moves slowly in capillaries because there are more capillaries than arterioles.
- This allows time for substances to be exchanged between the blood and tissues.

Blood Flow in Veins

- Venous blood flow is dependent upon:

2) skeletal muscle contraction,
3) presence of valves in veins, and
4) respiratory movements.

- Compression of veins causes blood to move forward past a valve that then prevents it from returning backward.

- Changes in thoracic and abdominal pressure that occur with breathing also assist in the return of blood.
- *Varicose veins* develop when the valves of veins become weak.
- *Hemorrhoids* (piles) are due to varicose veins in the rectum.
- *Phlebitis* is inflammation of a vein and can lead to a blood clot and possible death if the clot is dislodged and is carried to a pulmonary vessel.

Blood

- Blood separates into two main parts: *plasma* and *formed elements*.
- Plasma accounts for 55% and formed elements 45% of blood volume.
- Plasma contains mostly water (90–92%) and plasma proteins (7–8%), but it also contains nutrients and wastes.
- *Albumin* is a large plasma protein that transports bilirubin; *globulins* are plasma proteins that transport lipoproteins.

Composition of blood

FORMED ELEMENTS

Red Blood Cells (erythrocytes)

4 million–6 million per mm^3 blood

White Blood Cells (leukocytes)
4,000–11,000 per mm^3 blood

Granular leukocytes

- Basophils

20–50 per mm^3 blood

- Eosinophils

100–400 per mm^3 blood

- Neutrophils

3,000–7,000 per mm^3 blood

FORMED ELEMENTS

Agranular leukocytes

- Lymphocytes

1,500–3,000 per mm^3 blood

- Monocytes

100–700 per mm^3 blood

- Platelets (thrombocytes)

150,000–300,000 per mm^3 blood

PLASMA

Water (90–92% of plasma)

Plasma proteins (7–8% of plasma)

- Albumin
- Globulins
- Fibrinogen

Salts (less than 1% of plasma)

Gases
- Oxygen
- Carbon dioxide

Nutrients
- Lipids
- Glucose
- Amino acids

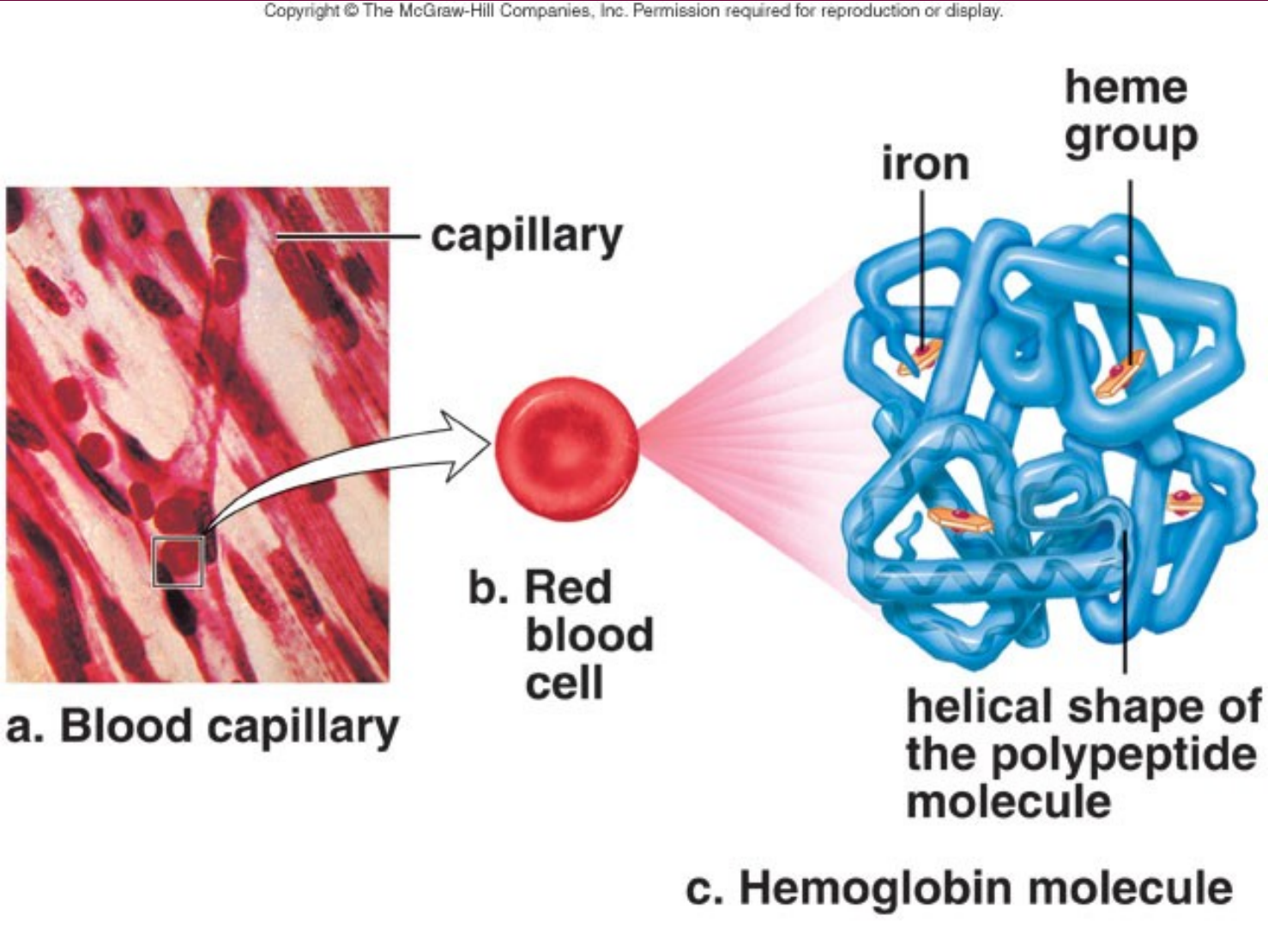
Nitrogenous wastes
- Urea
- Uric acid

Other
- Hormones, vitamins, etc.

The Red Blood Cells

- *Red blood cells* (*erythrocytes* or *RBCs*) are made in the *red bone marrow* of the skull, ribs, vertebrae, and the ends of long bones.
- Normally there are 4 to 6 million RBCs per mm^3 of whole blood.
- Red blood cells contain the pigment *hemoglobin* for oxygen transport; hemogobin contains *heme*, a complex iron-containing group that transports oxygen in the blood.

Physiology of red blood cells



- The air pollutant *carbon monoxide* combines more readily with hemoglobin than does oxygen, resulting in oxygen deprivation and possible death.
- Red blood cells lack a nucleus and have a 120 day life span.
- When worn out, the red blood cells are dismantled in the liver and spleen.

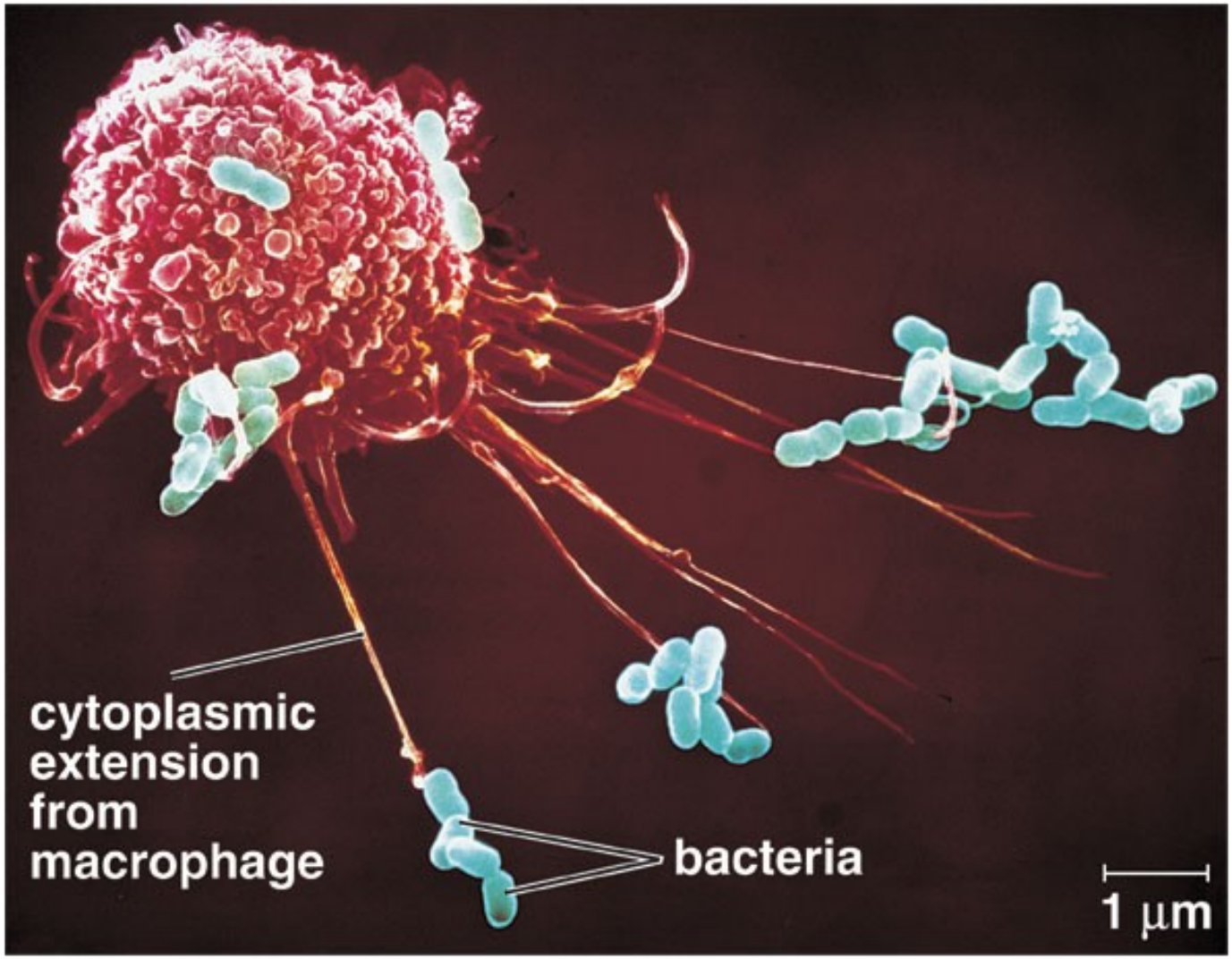
- Iron is reused by the red bone marrow where stem cells continually produce more red blood cells; the remainder of the heme portion undergoes chemical degradation and is excreted as bile pigments into the bile.
- Lack of enough hemoglobin results in *anemia*.
- The kidneys produce the hormone *erythropoietin* to increase blood cell production when oxygen levels are low.

The White Blood Cells

- *White blood cells* (*leukocytes*) have nuclei, are fewer in number than RBCs, with 5,000 – 10,000 cells per mm^3, and defend against disease.
- Leukocytes are divided into *granular* and *agranular* based on appearance.
- Granular leukocytes (*neutrophils*, *eosinophils*, and *basophils*) contain enzymes and proteins that defend the body against microbes.

- The aganular leukocytes (*monocytes* and *lymphocytes*) have a spherical or kidney-shaped nucleus.
- Monocytes can differentiate into *macrophages* that *phagocytize* microbes and stimulate other cells to defend the body.
- Lymphocytes are involved in immunity.
- An excessive number of white blood cells may indicate an infection or *leukemia*; HIV infection drastically reduces the number of lymphocytes.

Macrophage engulfing bacteria



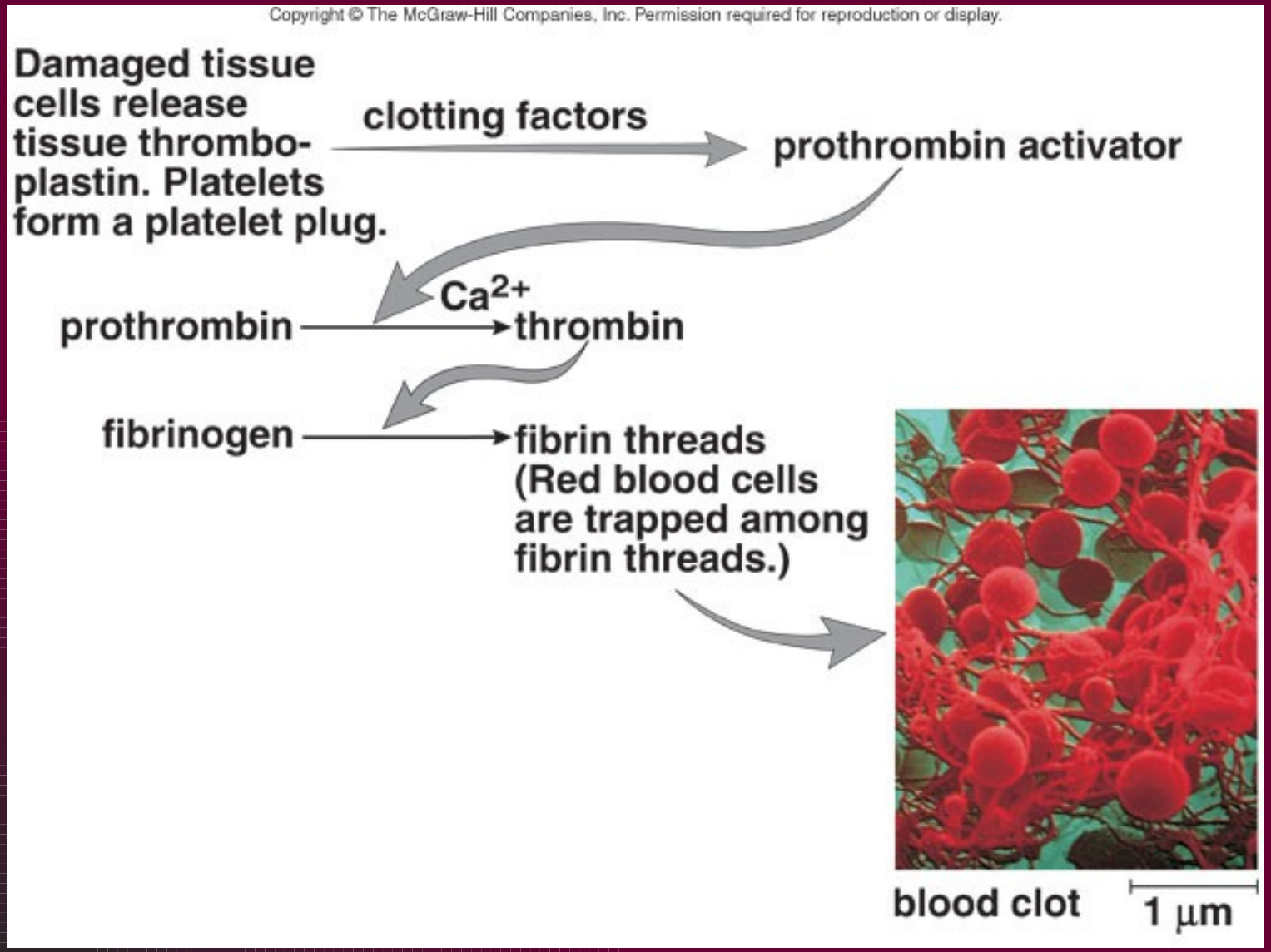
The Platelets and Blood Clotting

- Red bone marrow produces large cells called *megakaryocytes* that fragment into *platelets* at a rate of 200 billion per day; blood contains 150,000–300,000 platelets per mm^3.
- Twelve *clotting factors* in the blood help platelets form blood clots.

Blood Clotting

- Injured tissues release a clotting factor called *prothrombin activator*, which converts prothrombin into thrombin.
- Thrombin, in turn, acts as an enzyme and converts fibrinogen into insoluble threads of *fibrin*.
- These conversions require the presence of calcium ions (Ca^{2+}).
- Trapped red blood cells make a clot appear red.

Blood clotting



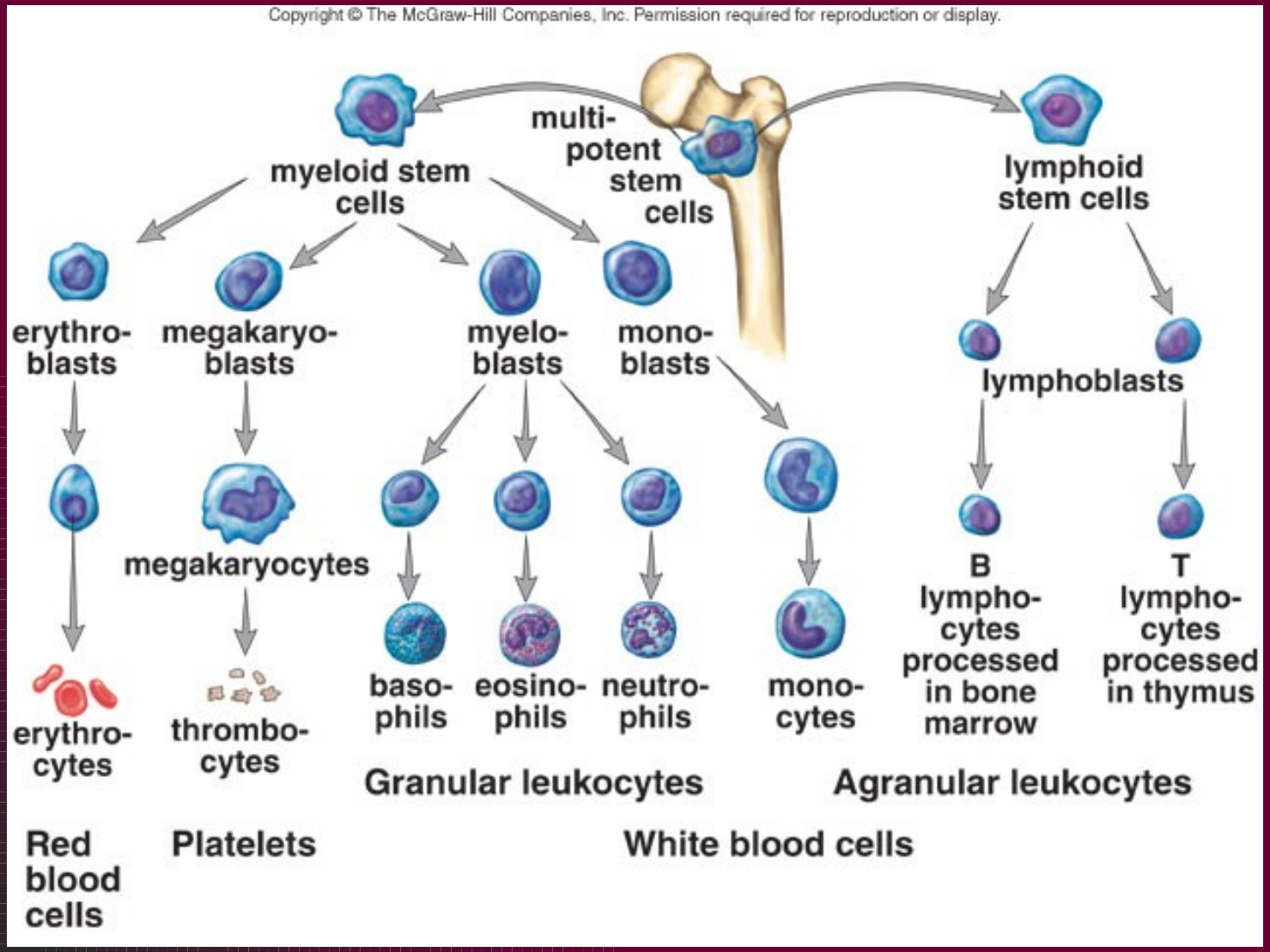
Hemophilia

- *Hemophilia* is an inherited clotting disorder due to a deficiency in a clotting factor.
- Bumps and falls cause bleeding in the joints; cartilage degeneration and resorption of bone can follow.
- The most frequent cause of death is bleeding into the brain with accompanying neurological damage.

Bone Marrow Stem Cells

- A *stem cell* is capable of dividing into new cells that differentiate into particular cell types.
- Bone marrow is *multipotent*, able to continually give rise to particular types of blood cells.
- The skin and brain also have stem cells, and *mesenchymal stem cells* give rise to connective tissues including heart muscle.

Blood cell formation in red bone marrow

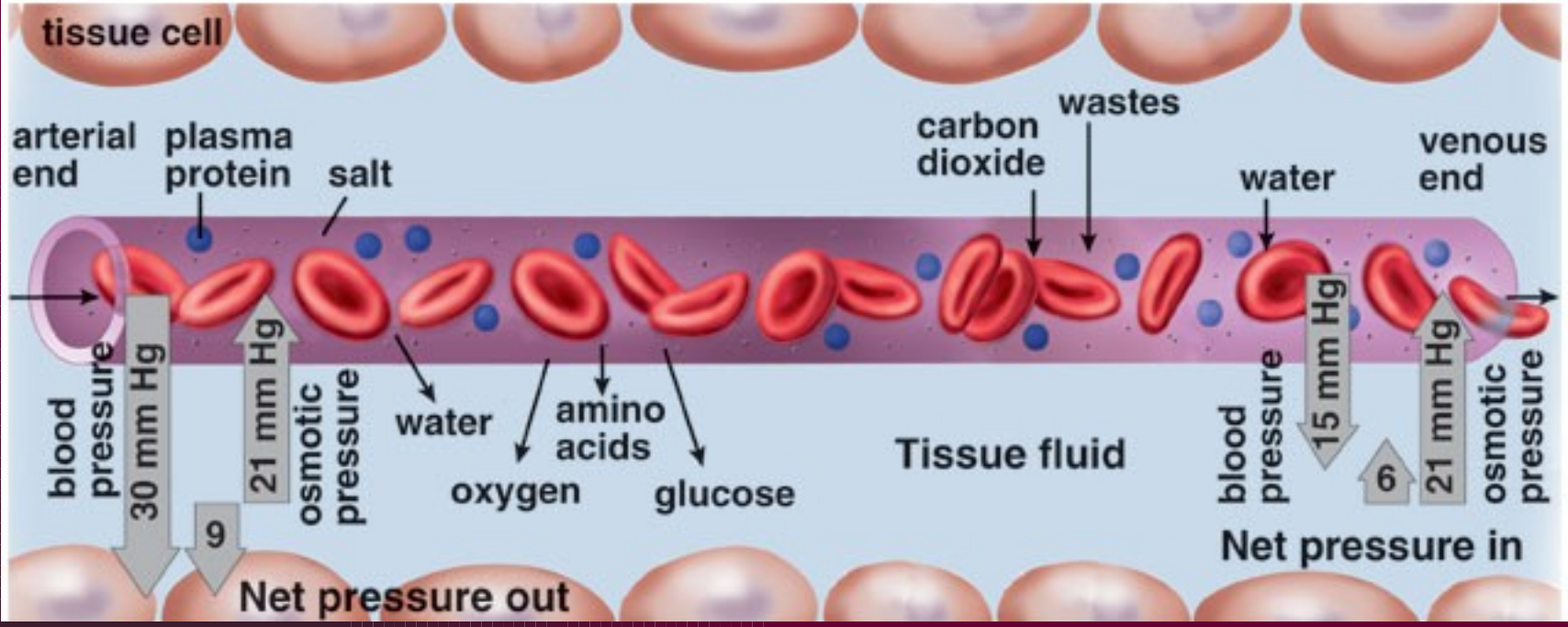


Capillary Exchange

- At the arteriole end of a capillary, water moves out of the blood due to the force of *blood pressure*.
- At the venule end, water moves into the blood due to *osmotic pressure* of the blood.
- Substances that leave the blood contribute to *tissue fluid*, the fluid between the body's cells.

- In the midsection of the capillary, nutrients diffuse out and wastes diffuse into the blood.
- Since plasma proteins are too large to readily pass out of the capillary, tissue fluid tends to contain all components of plasma except it has lesser amounts of protein.
- Excess tissue fluid is returned to the blood stream as *lymph* in *lymphatic vessels*.

Capillary exchange



Cardiovascular Disorders

- *Cardiovascular disease* (*CVD*) is the leading cause of death in Western countries.
- Modern research efforts have improved diagnosis, treatment, and prevention.
- Major cardiovascular disorders include atherosclerosis, stroke, heart attack, aneurysm, and hypertension.

Atherosclerosis

- *Atherosclerosis* is due to a build-up of fatty material (*plaque*), mainly cholesterol, under the inner lining of arteries.
- The plaque can cause a *thrombus* (blood clot) to form.
- The thrombus can dislodge as an *embolus* and lead to *thromboembolism*.

Stroke, Heart Attack, and Aneurysm

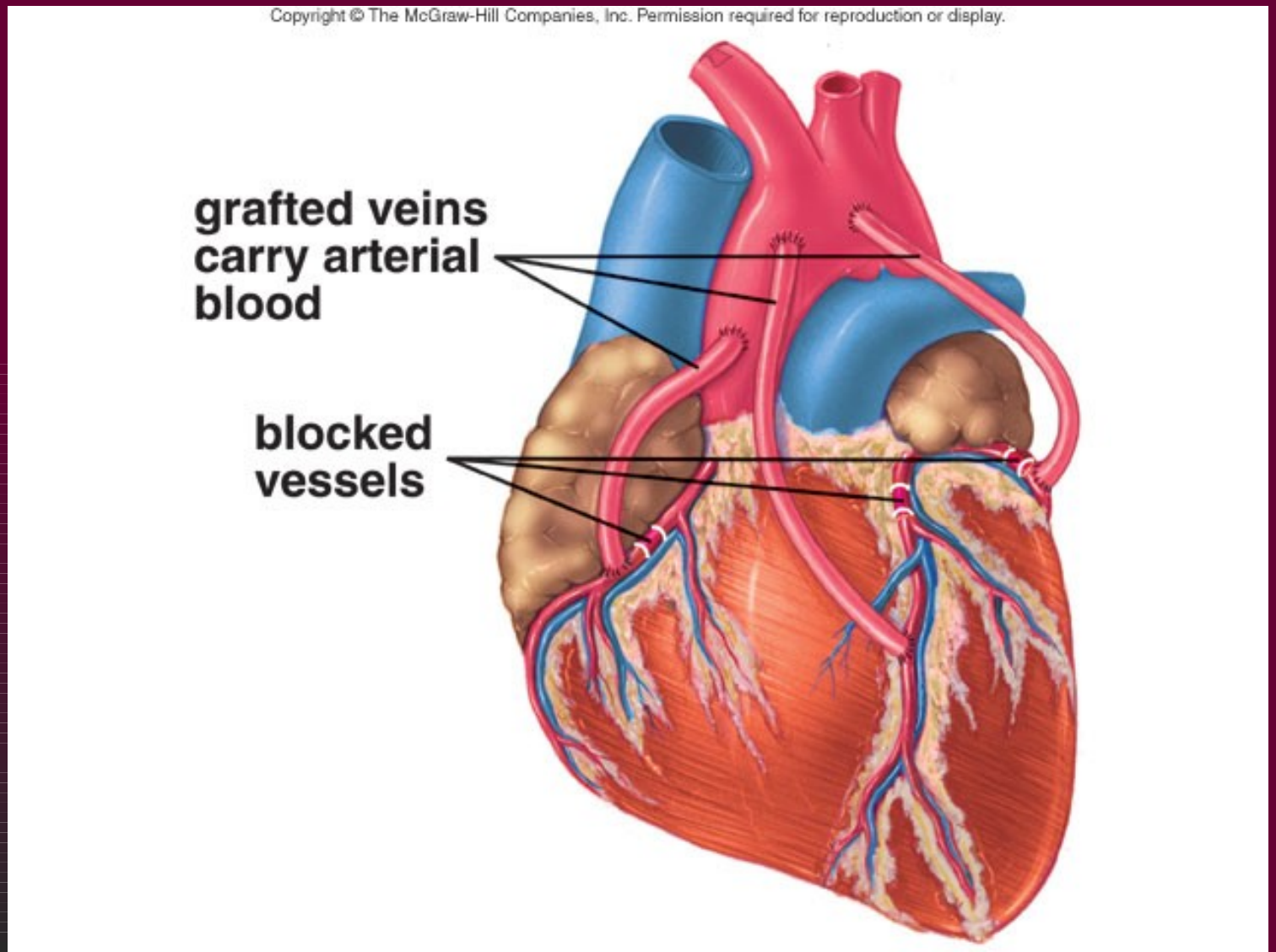
- A *cerebrovascular accident*, or *stroke*, results when an embolus lodges in a cerebral blood vessel or a cerebral blood vessel bursts; a portion of the brain dies due to lack of oxygen.
- A *myocardial infarction*, or *heart attack*, occurs when a portion of heart muscle dies due to lack of oxygen.

- Partial blockage of a coronary artery causes *angina pectoris*, or chest pain.
- An *aneurysm* is a ballooning of a blood vessel, usually in the abdominal aorta or arteries leading to the brain.
- Death results if the aneurysm is in a large vessel and the vessel bursts.
- Atherosclerosis and hypertension weaken blood vessels over time, increasing the risk of aneurysm.

Coronary Bypass Operations

- A *coronary bypass operation* involves removing a segment of another blood vessel and replacing a clogged coronary artery.
- It may be possible to replace this surgery with *gene therapy* that stimulates new blood vessels to grow where the heart needs more blood flow.

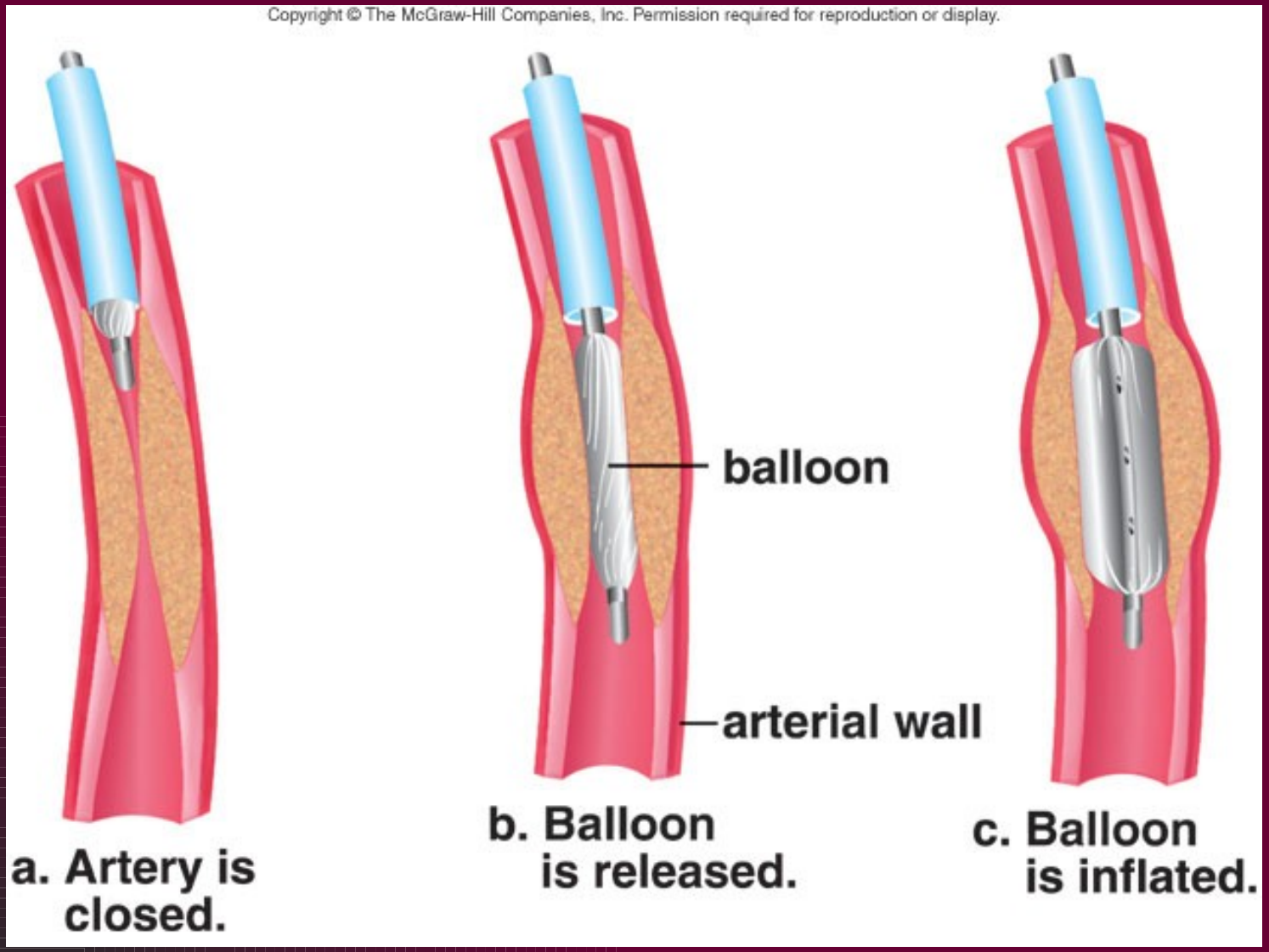
Coronary bypass operation



Clearing Clogged Arteries

- *Angioplasty* uses a long tube threaded through an arm or leg vessel to the point where the coronary artery is blocked; inflating the tube forces the vessel open.
- Small metal *stents* are expanded inside the artery to keep it open.
- Stents are coated with *heparin* to prevent blood clotting and with chemicals to prevent arterial closing.

Angioplasty



Dissolving Blood Clots

- Medical treatments for dissolving blood clots include use of *t-PA* (*tissue plasminogen activator*) that converts plasminogen into plasmin, an enzyme that dissolves blood clots, but can cause brain bleeding.
- *Aspirin* reduces the stickiness of platelets and reduces clot formation and lowers the risk of heart attack.

Heart Transplants and Artificial Hearts

- *Heart transplants* are routinely performed but immunosuppressive drugs must be taken thereafter.
- There is a shortage of human organ donors.
- Work is currently underway to improve self-contained *artificial hearts*, and muscle cell transplants may someday be useful.

Hypertension

- About 20% of Americans suffer from *hypertension* (*high blood pressure*).
- Hypertension is present when systolic pressure is 140 or greater or diastolic pressure is 100 or greater; diastolic pressure is emphasized when medical treatment is considered.
- A genetic predisposition for hypertension occurs in those who have a gene that codes for *angiotensinogen*, a powerful vasoconstrictor.