CARDIOVASCULAR SYSTEM

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Systematic physiology

Second Semester

lecture 6

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Outline

- Cardiovascular system components
- Double circulation
- Heart structure
- Cardiac conduction system
- Blood vessel structure

Objectives

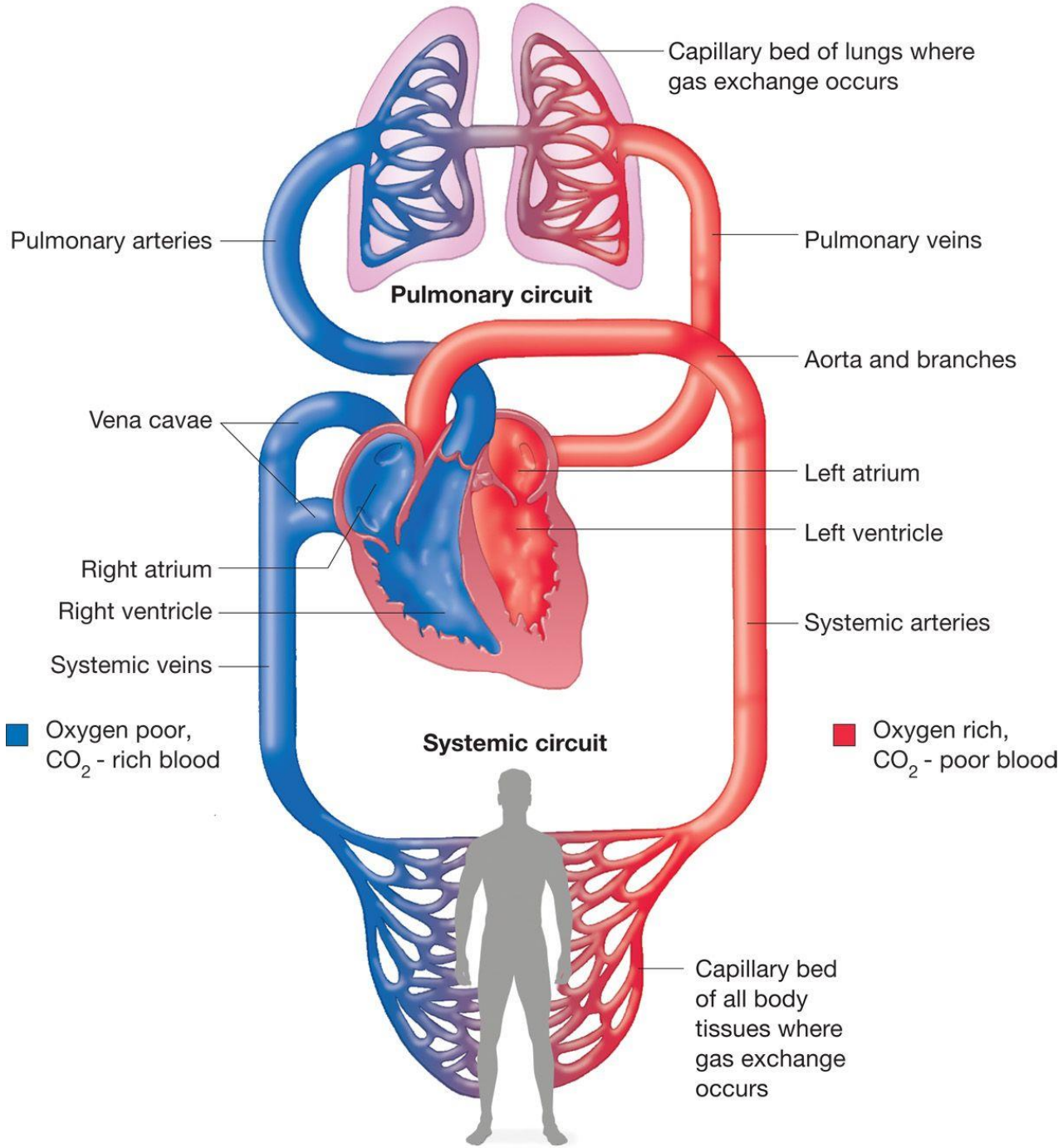
- Understanding the structure of heart and blood vessels
- Understanding the circuits of double circulatory system
- Understanding cardiac conduction system
- Understanding the differences between arteries and veins

Cardiovascular system or circulatory system

- The closed circulatory system following structures:

1. **Heart propels blood through the system**
2. **Blood**
3. **Blood vessels Arteries, veins, and capillaries**

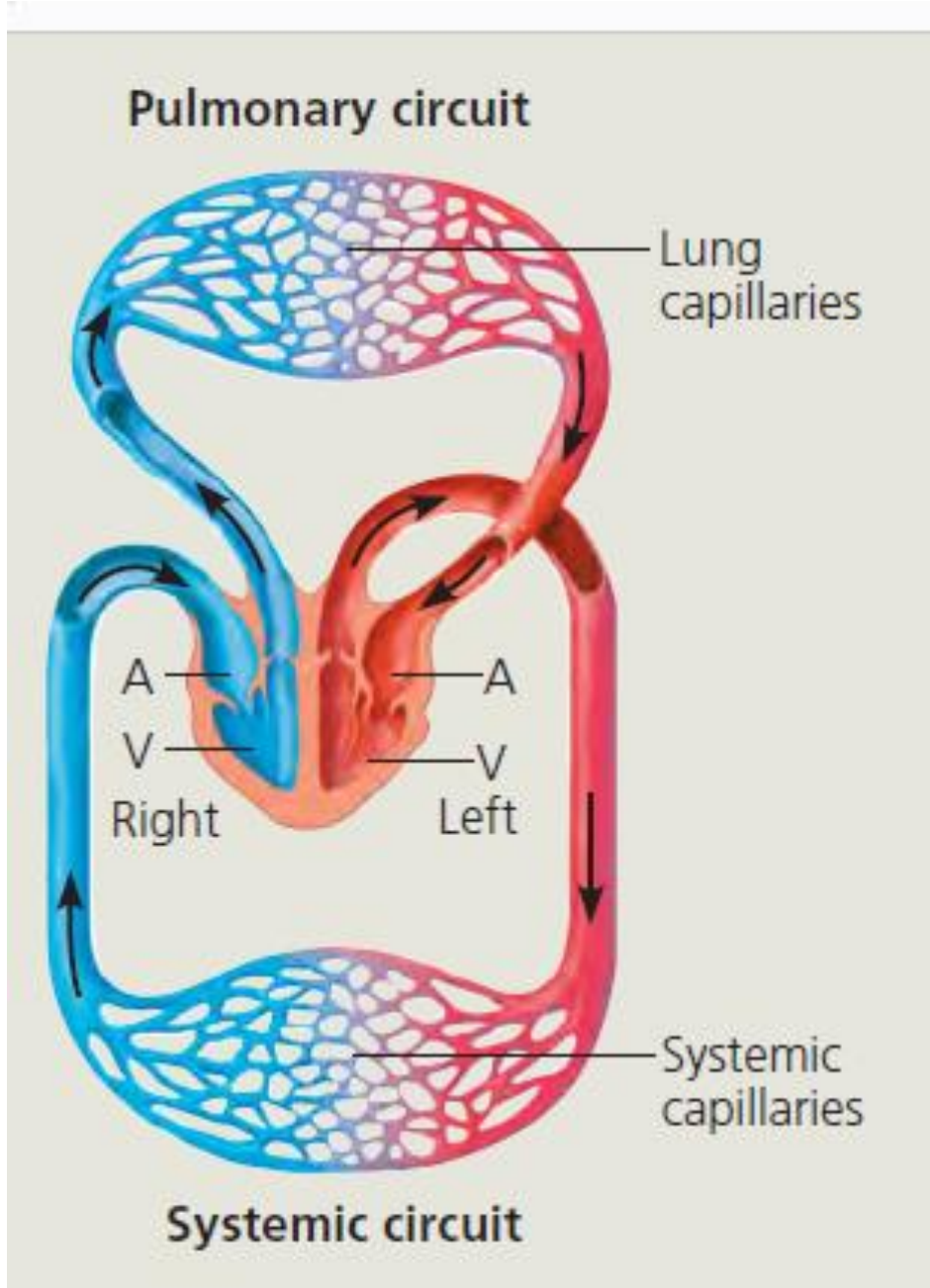
- **Arteries**, a series of vessels efferent from the heart that become smaller as they branch into the various organs, carry blood to the tissues. Within organs, arteries branch into arterioles, small vessels that convey blood to the capillaries
- **Capillaries**, microscopic vessels with very thin, porous walls, are the sites of O2, CO2, nutrient, and waste product exchange between blood and tissues.
- Networks of these vessels, called **capillary beds**, infiltrate **every tissue**, passing within a few cell diameters of every cell in the body..


Capillary bed of lungs where gas exchange occurs
Pulmonary arteries
Pulmonary veins
Pulmonary circuit
Aorta and branches
Vena cavae
Left atrium
Left ventricle
Right atrium
Right ventricle
Systemic arteries
Systemic veins
Oxygen poor, CO_2 - rich blood
Systemic circuit
Oxygen rich, CO_2 - poor blood
Capillary bed of all body tissues where gas exchange occurs

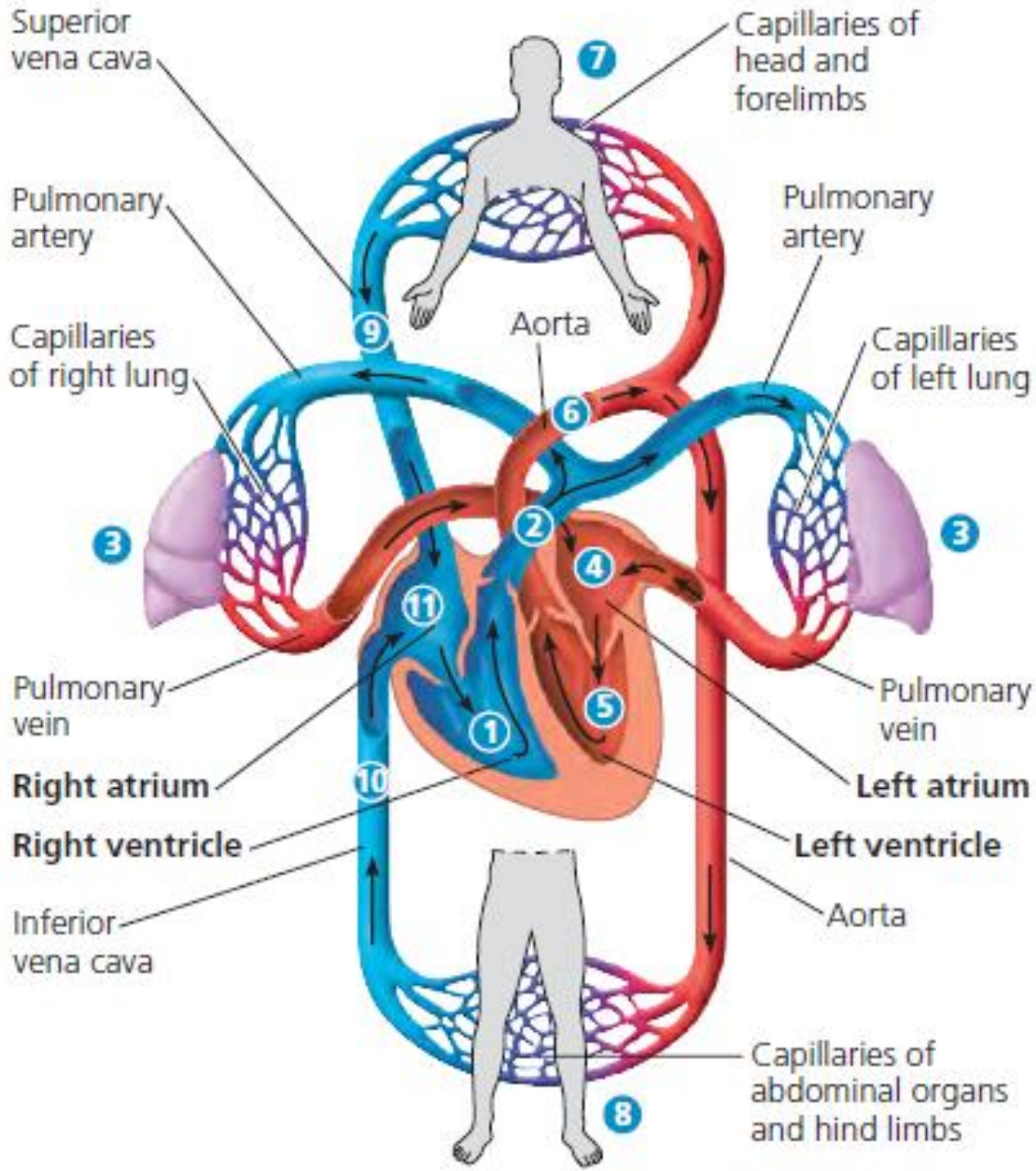
- At their “downstream” end, capillaries converge into **venules**, and venules converge into **veins**, the vessels that carry blood back to the heart.
- Arteries and veins are distinguished by the *direction* in which they carry blood, not by the O2 content or other characteristics of the blood they contain.
- **Arteries carry blood from the heart *toward* capillaries, and veins return blood to the heart *from* capillaries.**

Double circulation

- The circulatory systems of mammals have two circuits, an arrangement called **double circulation**
- The pumps for the two circuits are combined into a single organ, the heart
- **Pulmonary circuit:** the right side of the heart, delivers oxygen-poor blood to the capillary beds of the gas exchange tissues(lung), where there is a net movement of O2 into the blood and of CO2 out of the blood.
- **Systemic circuit:** After the oxygen-enriched blood leaves the gas exchange tissues(lung), it enters the other pump, the left side of the heart. Contraction of the heart propels this blood to capillary beds in organs and tissues throughout the body. Following the exchange of O2 and CO2, as well as nutrients and waste products, the now oxygen-poor blood returns to the heart, completing the **systemic circuit**


Pulmonary circuit
Lung capillaries
A
V
Right
A
V
Left
Systemic capillaries
Systemic circuit

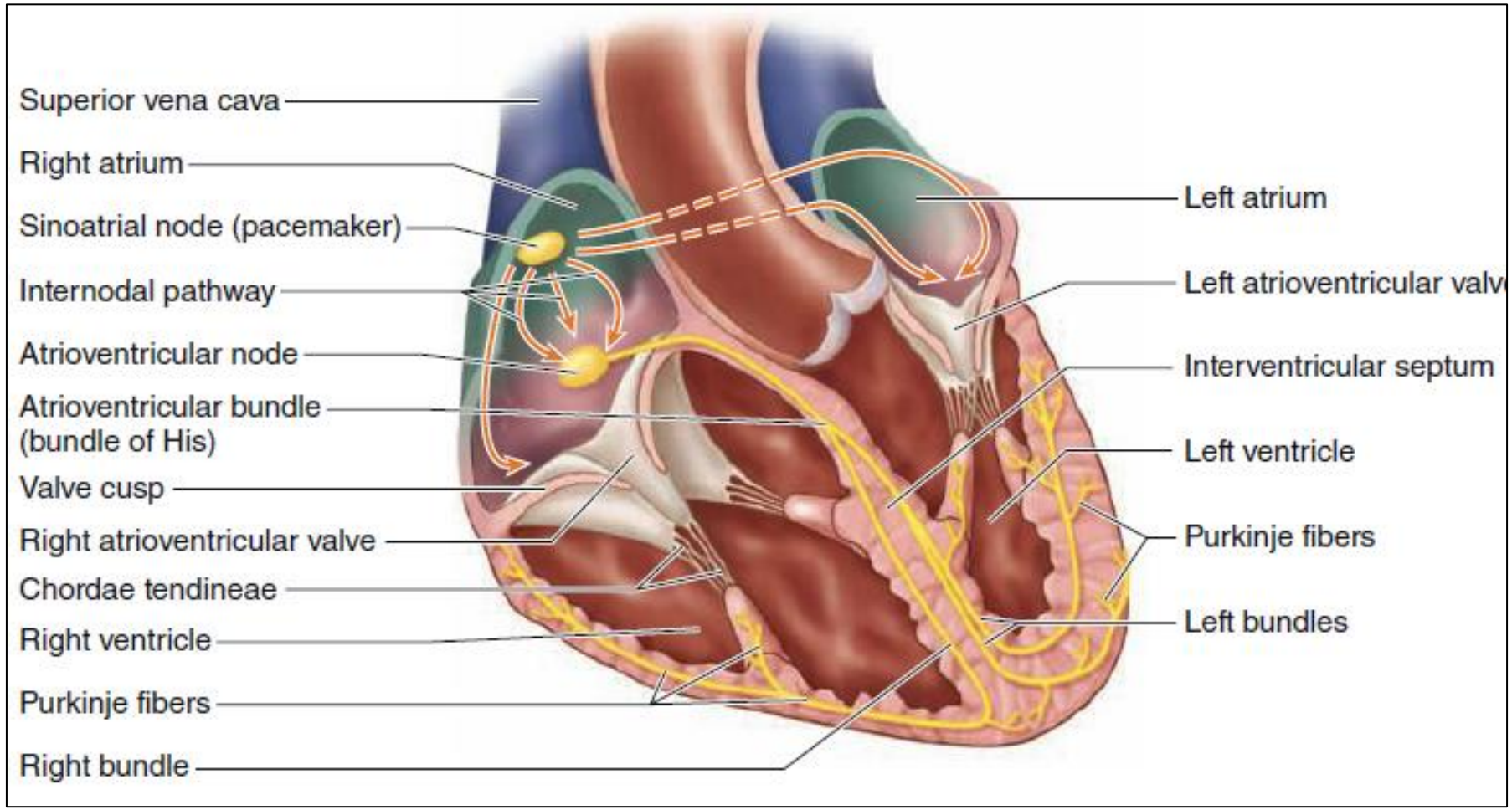
Mammalian Circulation



Heart:

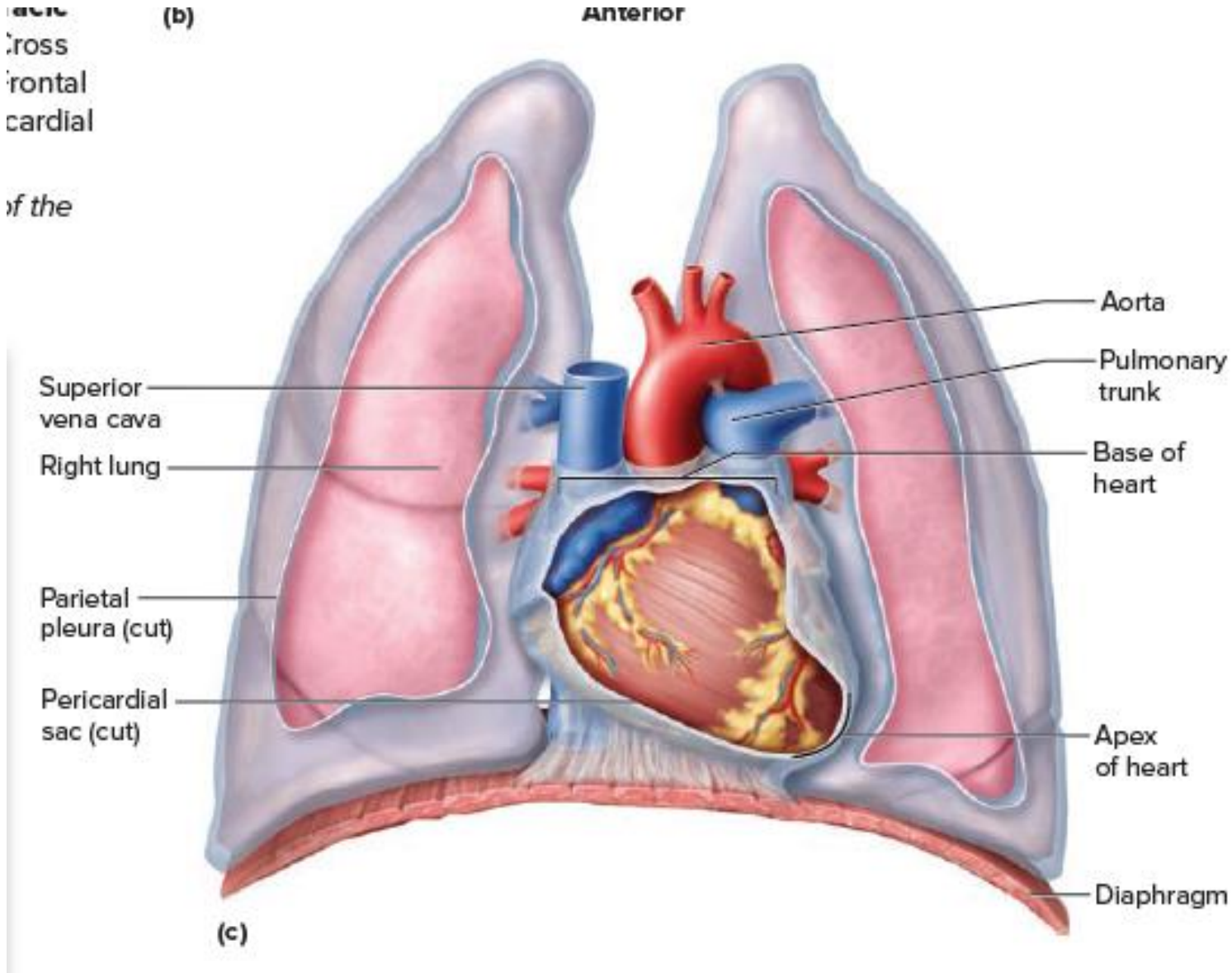
- Consist of 4 chambers (**2 atria and 2 ventricles**)
- Located behind the sternum (breastbone), the human heart is about the size of a clenched fist and consists mostly of **cardiac muscle**
- The two atria have relatively thin walls and serve as collection chambers for blood returning to the heart from the lungs or other body tissues.
- **Much of the blood that enters the atria flows into the ventricles while all heart chambers are relaxed**
- **The remainder is transferred by contraction of the atria before the ventricles begin to contract.**

The ventricles have thicker walls and contract much more forcefully than the atria—especially the left ventricle, which pumps blood to all body organs through the systemic circuit.



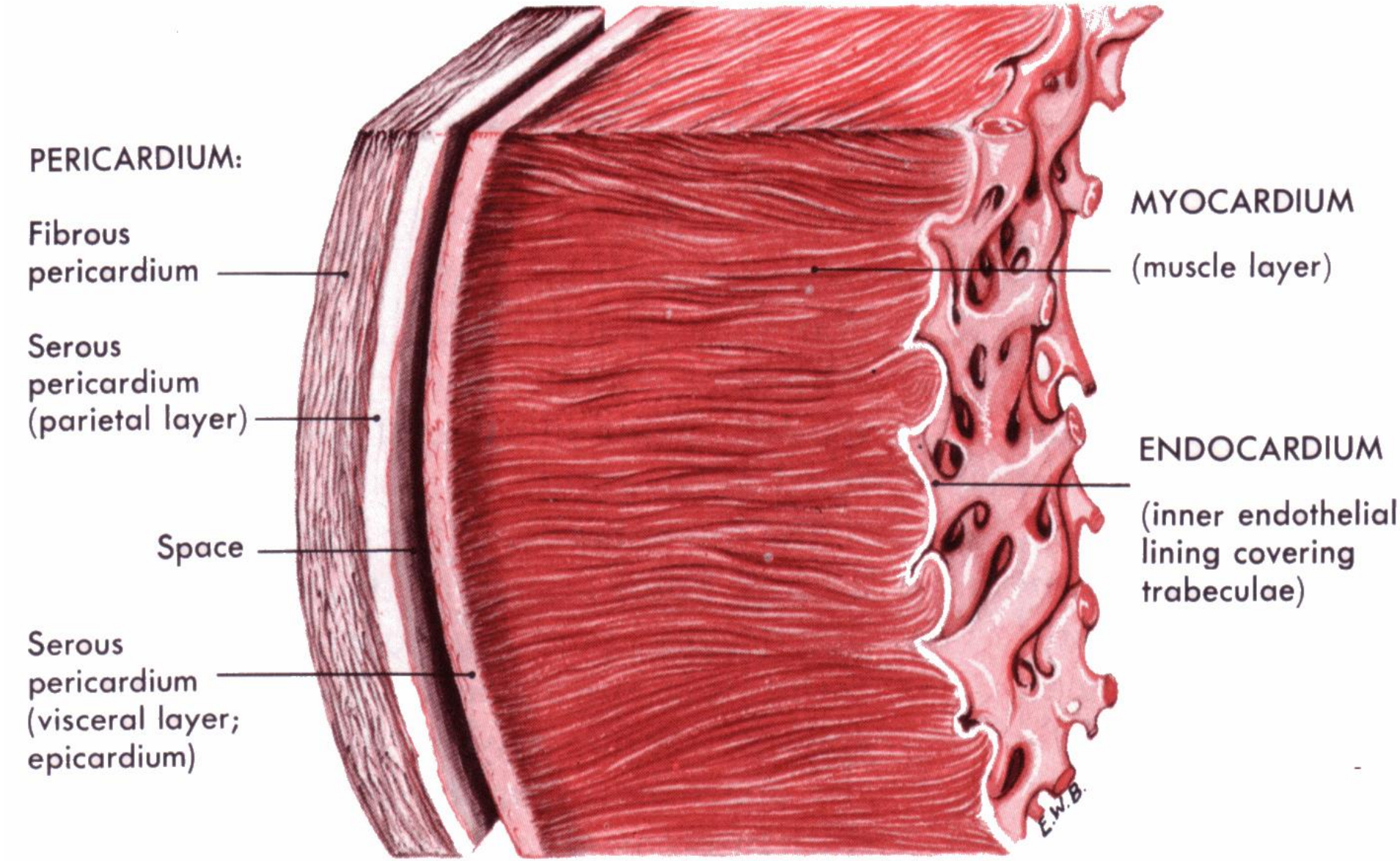
Position, Size, and Shape of the Heart

- The heart lies within a thick partition called the **mediastinum** between the two lungs.
- It extends from a broad **base** at its uppermost end, where the great vessels are attached, to a bluntly pointed **apex** at the lower end, just above the diaphragm. **It tilts toward the left from base to apex, so somewhat more than half the heart is to the left of the body's median plane**
- The adult heart is about 9 cm (3.5 in.) wide at the base, 13 cm (5 in.) from base to apex, and 6 cm (2.5 in.) from anterior to posterior at its thickest point.
- Whatever one's body size, from child to adult, the heart is roughly the same size as the fist. It weighs about 300 g (10 ounces) in adults.

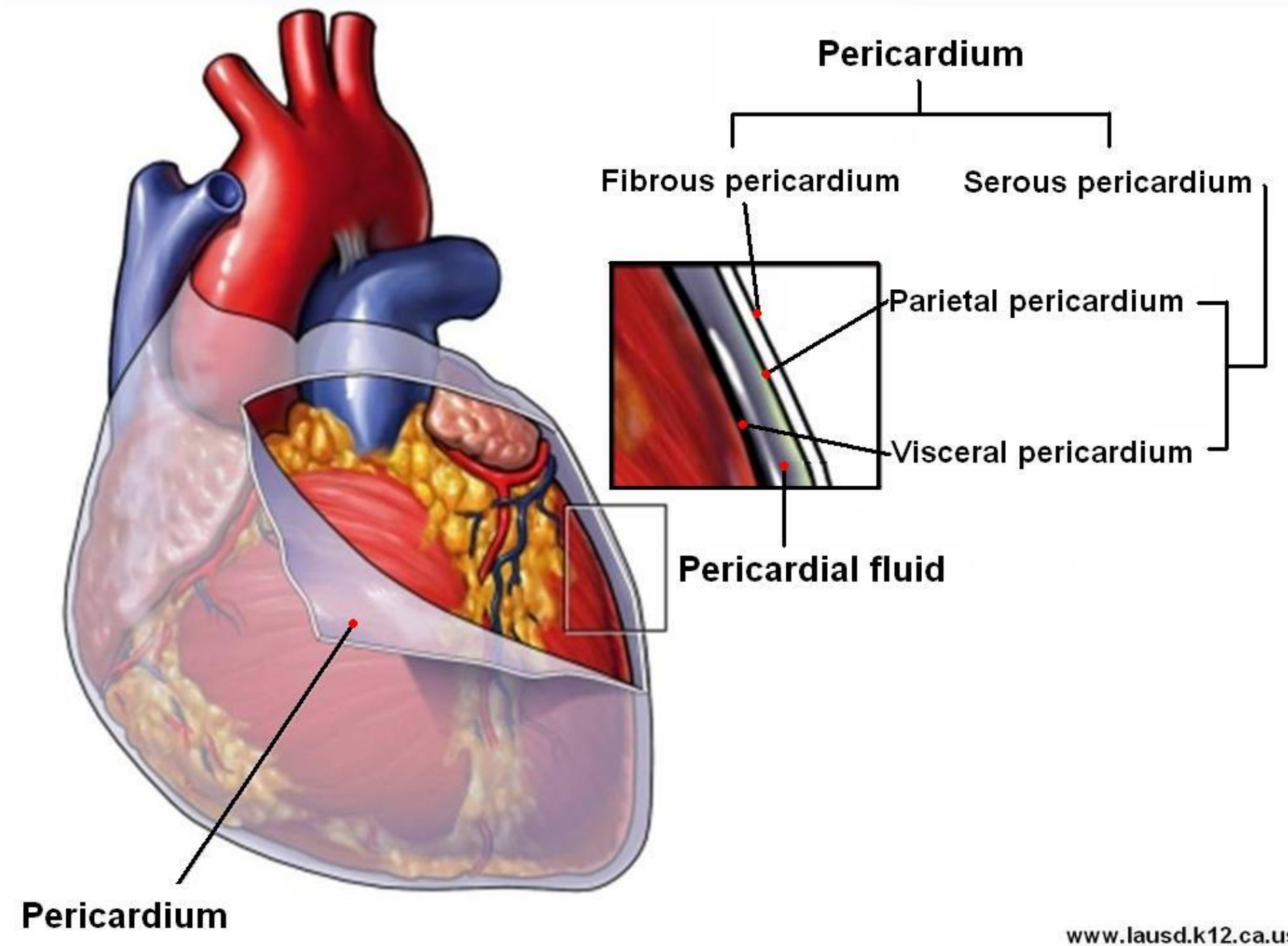

(b)
Anterior
Aorta
Pulmonary trunk
Superior vena cava
Right lung
Base of heart
Parietal pleura (cut)
Pericardial sac (cut)
Apex of heart
Diaphragm
(c)

The Pericardium

- The heart is enclosed in double walled sac called the **pericardium.**
- **The Heart Wall**
- The heart wall consists of three layers: ***epicardium***, ***myocardium***, and ***endocardium***



Section of the heart wall showing the components of the outer pericardium (heart sac), muscle layer (myocardium), and inner lining (endocardium).


Pericardium
Fibrous pericardium
Serous pericardium
Parietal pericardium
Visceral pericardium
Pericardial fluid
Pericardium
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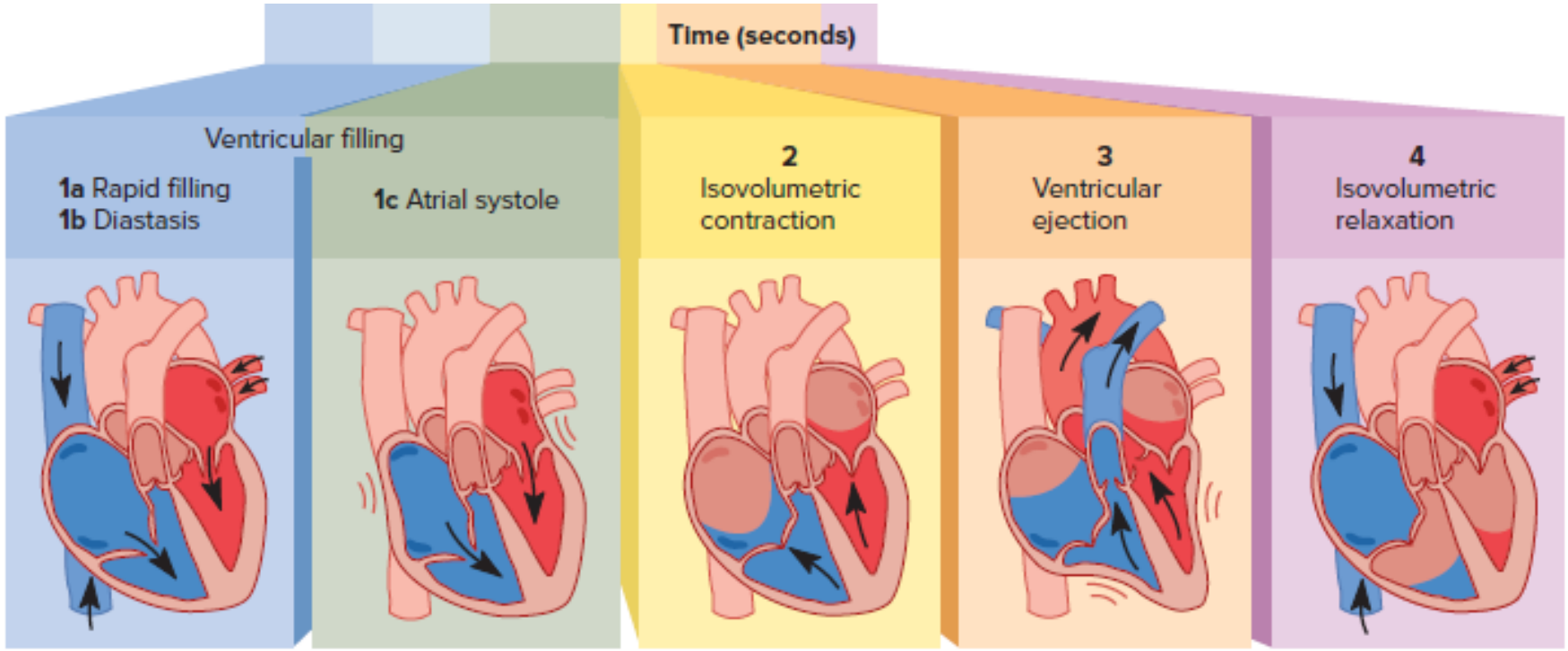
- Between the pericardium and epicardium there a space called the **pericardial cavity**
- The pericardial cavity contains 5 to 30 mL of **pericardial fluid,** exuded by the serous layer of the pericardial sac.
- The fluid lubricates the membranes and allows the heart to beat with minimal friction. In *pericarditis*—inflammation of the pericardium— the membranes may become roughened and produce a painful *friction rub* with each heartbeat.

Cardiac cycle

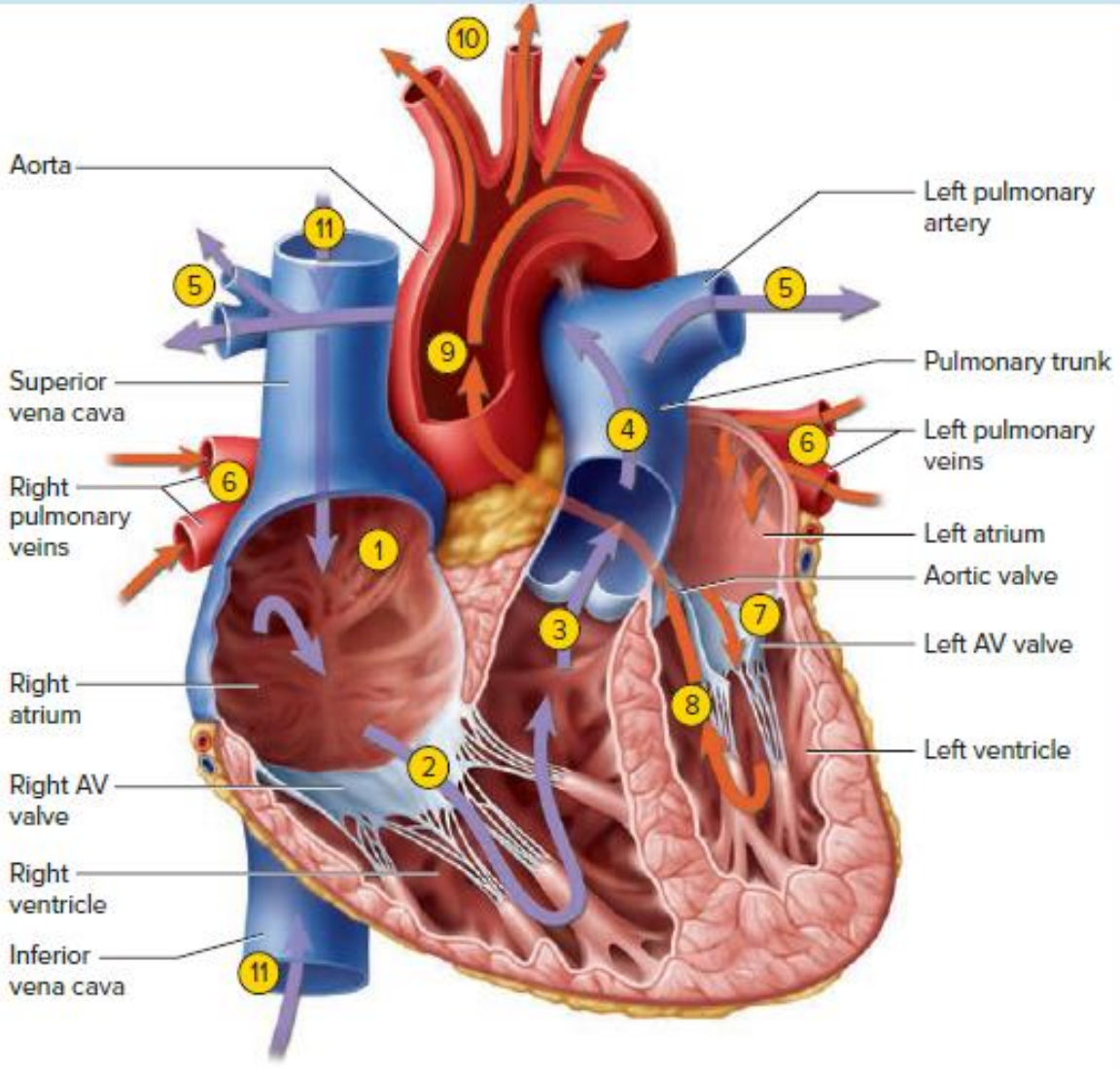
- The heart contracts and relaxes in a rhythmic cycle. When it contracts, it pumps blood; when it relaxes, its chambers fill with blood.
- **The contraction phase of the cycle is called systole**, **and the relaxation phase is called diastole**

- A **cardiac cycle** consists of one complete contraction and relaxation of all four heart chambers.
- The cardiac cycle refers to the sequence of events that occur during one complete heartbeat.
- The cardiac cycle refers to all of the events that occur from the beginning of one heartbeat to the beginning of the next



- The volume of blood each ventricle pumps per minute is the cardiac output.
- Two factors determine cardiac output: the rate of contraction, or **heart rate** (number of beats per minute), and the **stroke volume**, the amount of blood pumped by a ventricle in a single contraction.
- The average stroke volume in humans is about 70 mL. Multiplying this stroke volume by a resting heart rate of 72 beats per minute yields a cardiac output of 5 L/min—about equal to the total volume of blood in the human body.
- During heavy exercise, cardiac output increases as much as five fold.

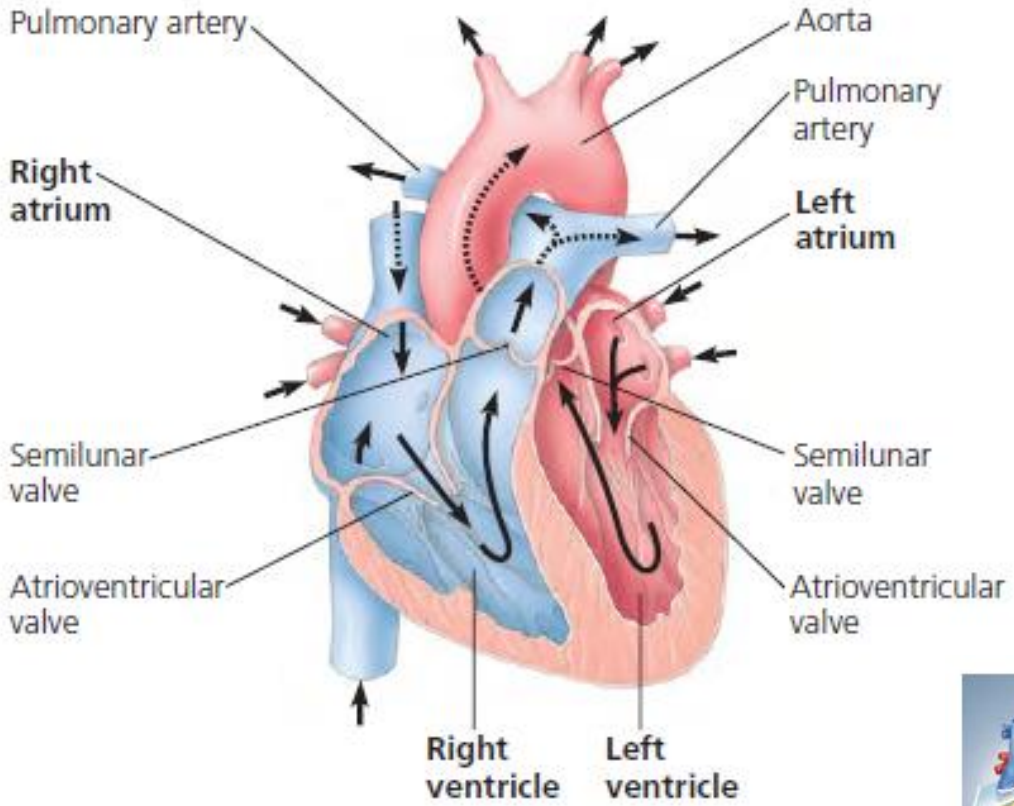
Blood flow through the heart

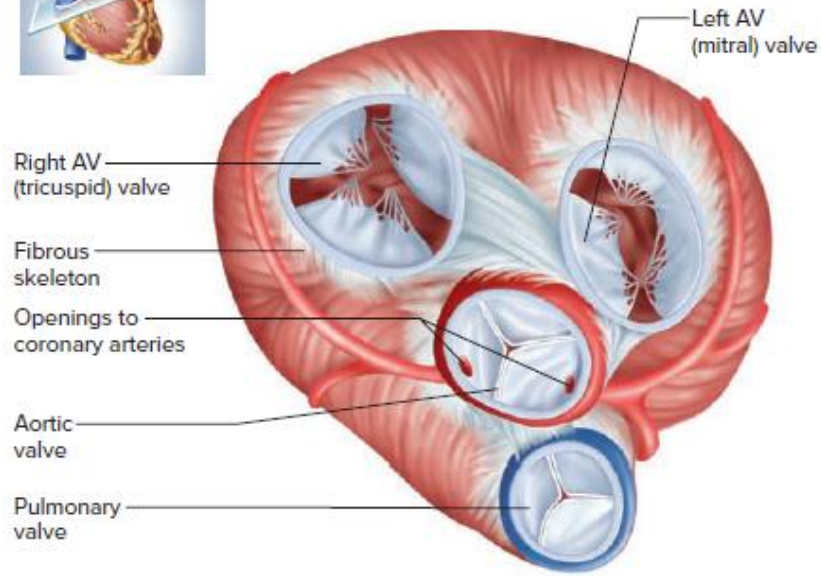


1. Blood enters right atrium from superior and inferior venae cavae.
2. Blood in right atrium flows through right AV valve into right ventricle.
3. Contraction of right ventricle forces pulmonary valve open.
4. Blood flows through pulmonary valve into pulmonary trunk.
5. Blood is distributed by right and left pulmonary arteries to the lungs, where it unloads CO_2 and loads O_2.
6. Blood returns from lungs via pulmonary veins to left atrium.
7. Blood in left atrium flows through left AV valve into left ventricle.
8. Contraction of left ventricle (simultaneous with step 3) forces aortic valve open.
9. Blood flows through aortic valve into ascending aorta.
10. Blood in aorta is distributed to every organ in the body, where it unloads O_2 and loads CO_2.
11. Blood returns to right atrium via venae cavae.

Heart valves

- **Four valves in the heart prevent backflow and keep blood moving in the correct direction**
- Made of flaps of connective tissue, the valves open when pushed from one side and close when pushed from the other
- An **atrioventricular (AV) valve** lies between each atrium and ventricle. The AV valves are anchored by strong fibers that prevent them from turning inside out
- **Semilunar valves** are located at the two exits of the heart: where the aorta leaves the left ventricle and where the pulmonary artery leaves the right ventricle.


Pulmonary artery
Aorta
Pulmonary artery
Right atrium
Left atrium
Semilunar valve
Semilunar valve
Atrioventricular valve
Atrioventricular valve
Right ventricle
Left ventricle

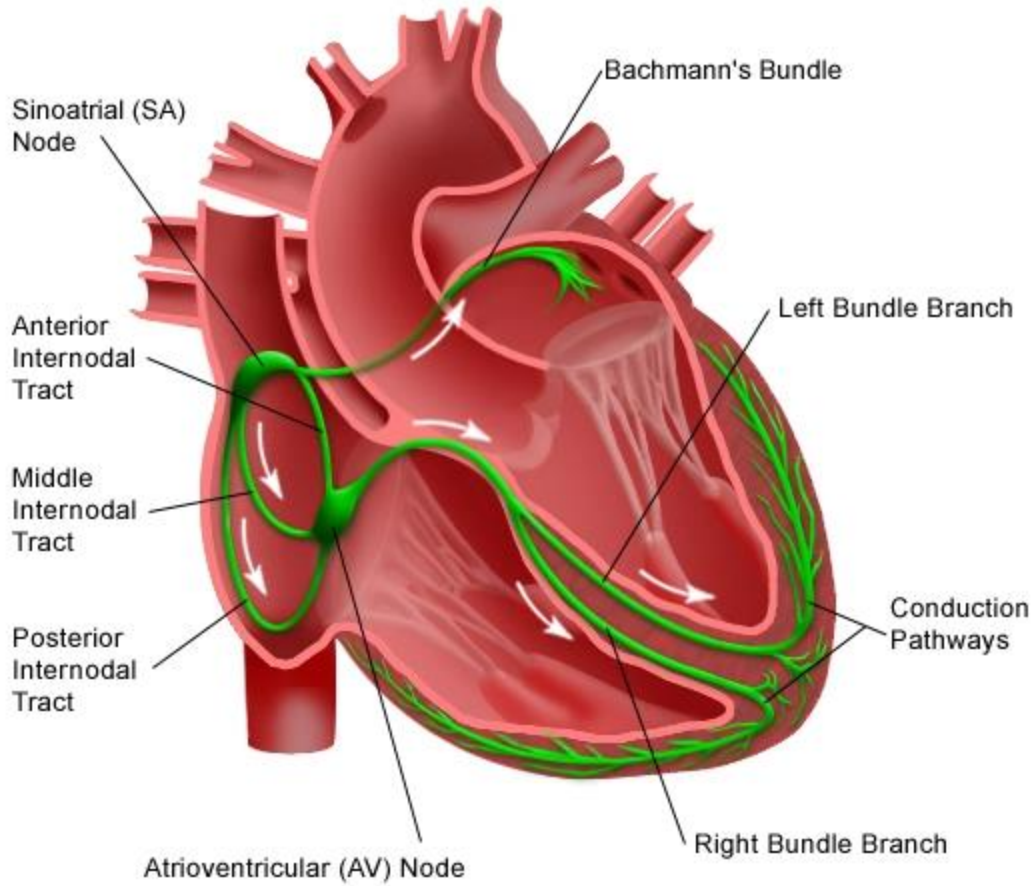

Left AV (mitral) valve
Right AV (tricuspid) valve
Fibrous skeleton
Openings to coronary arteries
Aortic valve
Pulmonary valve

- If blood squirts backward through a defective valve, it may produce an abnormal sound called a **heart murmur**.
- **Some people are born with heart murmurs; in others, the valves may be damaged by infection (from rheumatic fever, for instance).**
- When a valve defect is severe enough to endanger health, surgeons may implant a mechanical replacement valve.

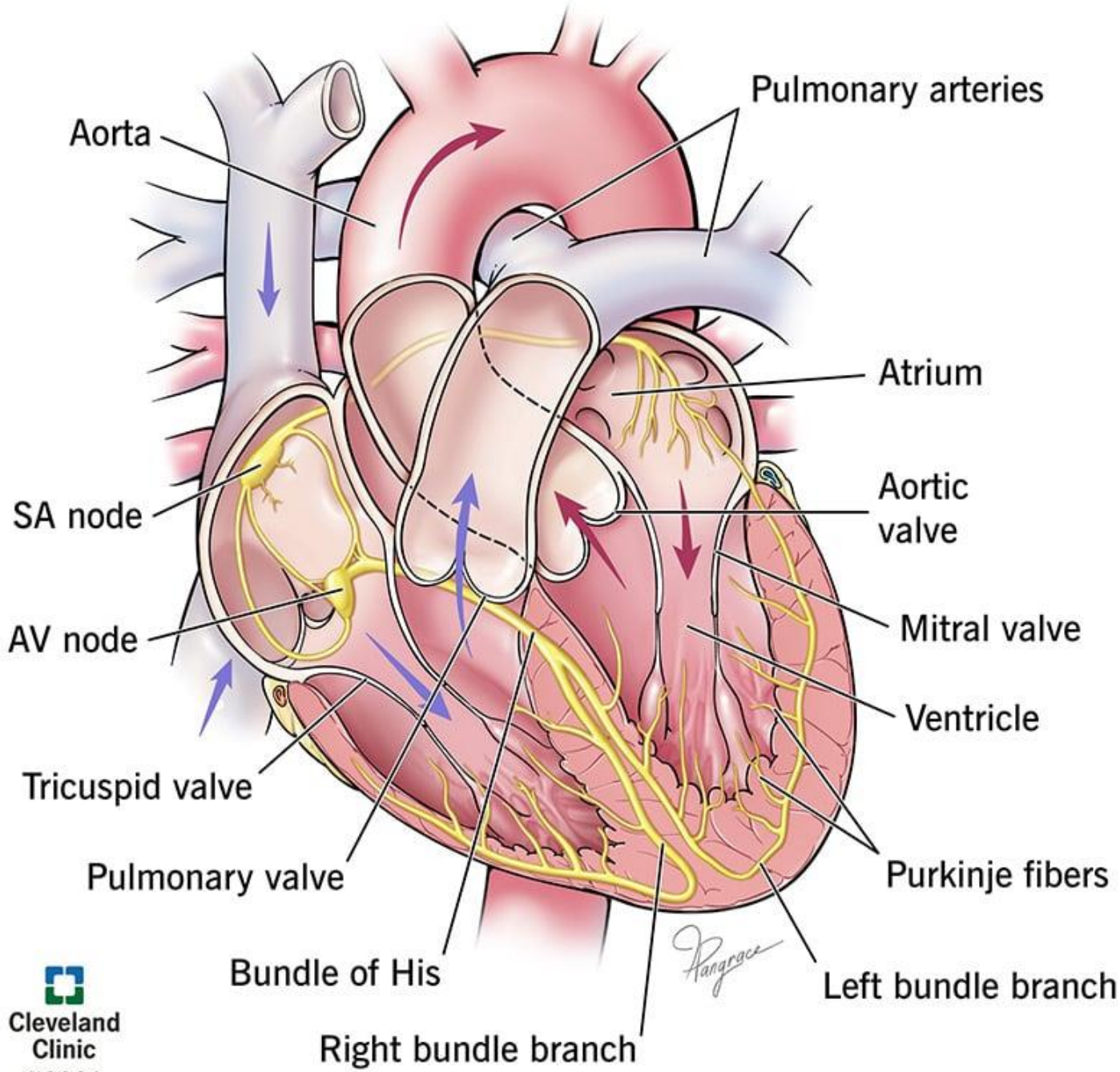
Cardiac Conduction System

- **In vertebrates, the heartbeat originates in the heart itself**
- Some cardiac muscle cells are **autorhythmic**, meaning they contract and relax repeatedly without any signal from the nervous system.
- **Sinoatrial (SA) node or *pacemaker*:** Group of autorhythmic cells located in the wall of the right atrium, near where the superior vena cava enters the heart.
- **The SA node generates electrical impulses much like those produced by nerve cells.**
- It sets the rate and timing at which all cardiac muscle cells contract
- **Because cardiac muscle cells are electrically coupled through gap junctions impulses from the SA node spread rapidly within heart tissue**

Electrical System of the Heart



- Impulses from the SA node first spread rapidly through the walls of the atria, causing both atria to **contract** in unison.
- During atrial contraction, the impulses originating at the SA node reach **other autorhythmic cells located** in the wall between the left and right atria.
- These cells form a relay point called the **atrioventricular (AV) node**.
- Here the impulses are delayed for about 0.1 second before spreading to the heart apex.
- This delay allows the atria to empty completely before the ventricles contract. Then the signals from the AV node are conducted to the heart apex and throughout the ventricular walls by specialized muscle fibers called bundle branches and Purkinje fibers.
- **The AV (atrioventricular) node conveys the stimulus and initiates contraction of the ventricles**


Aorta
Pulmonary arteries
Atrium
SA node
Aortic valve
AV node
Mitral valve
Ventricle
Tricuspid valve
Pulmonary valve
Purkinje fibers
Bundle of His
Left bundle branch
Right bundle branch
Cleveland Clinic
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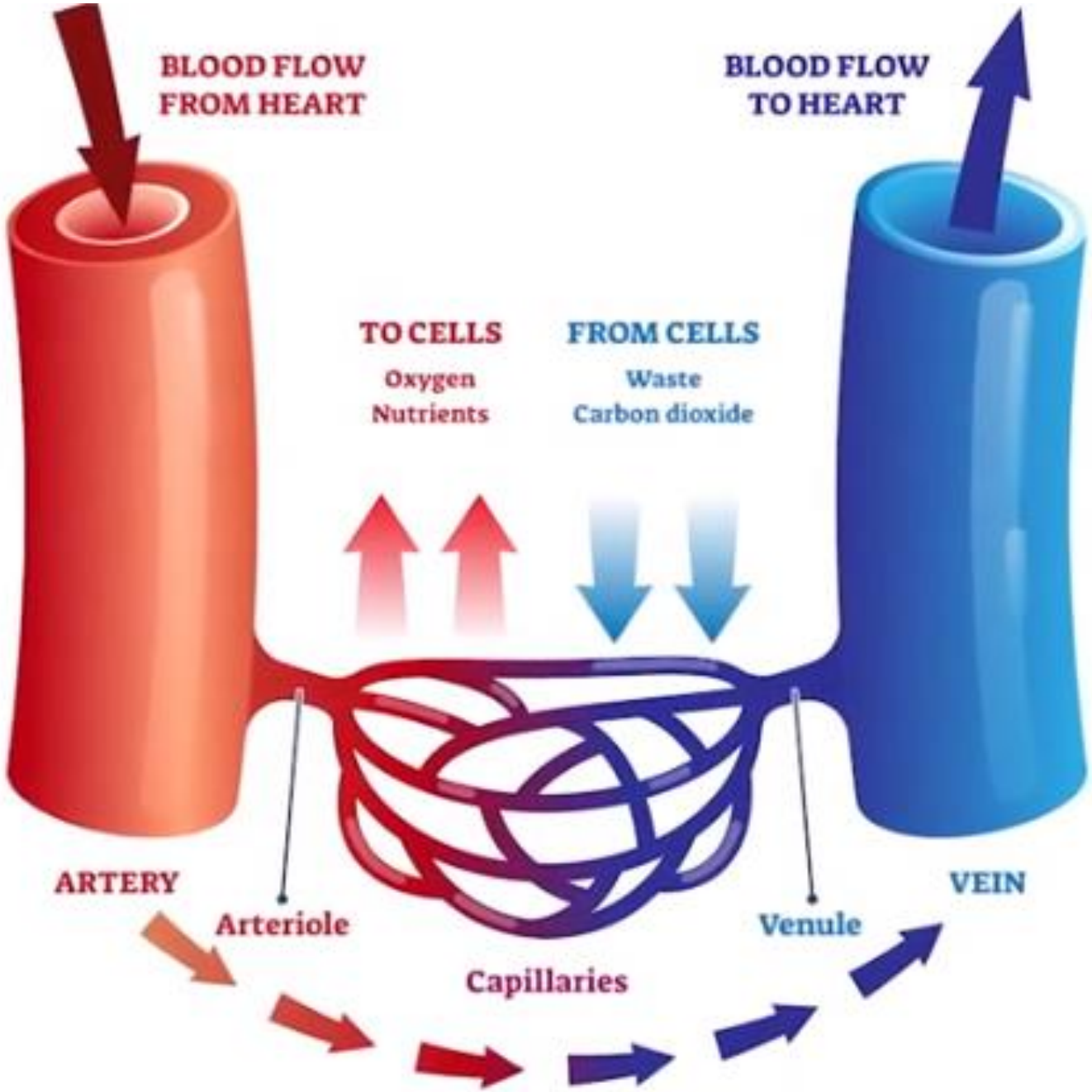
Physiological signals alter heart tempo by regulating the SA node.

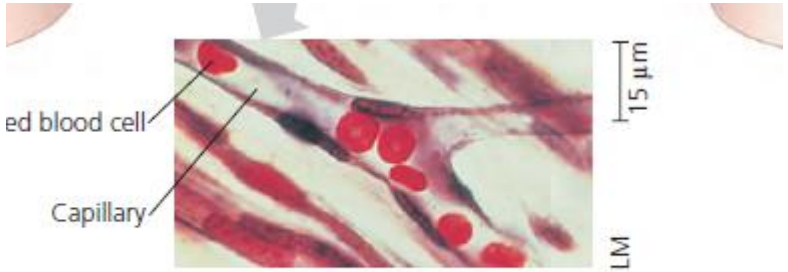
1. Two portions of the nervous system, the sympathetic and parasympathetic divisions, are largely responsible for this regulation
2. **The sympathetic division speeds up the pacemaker**, and the parasympathetic division slows it down
3. Hormones secreted into the blood also influence the pacemaker. For instance, epinephrine, the “fight-or-flight” hormone secreted by the adrenal glands, causes the heart rate to increase.
4. **A third type of input that affects the pacemaker is body temperature. An increase of only 1°C raises the heart rate by about 10 beats per minute. This is the reason your heart beats faster when you have a fever**

Blood Vessel Structure and Function

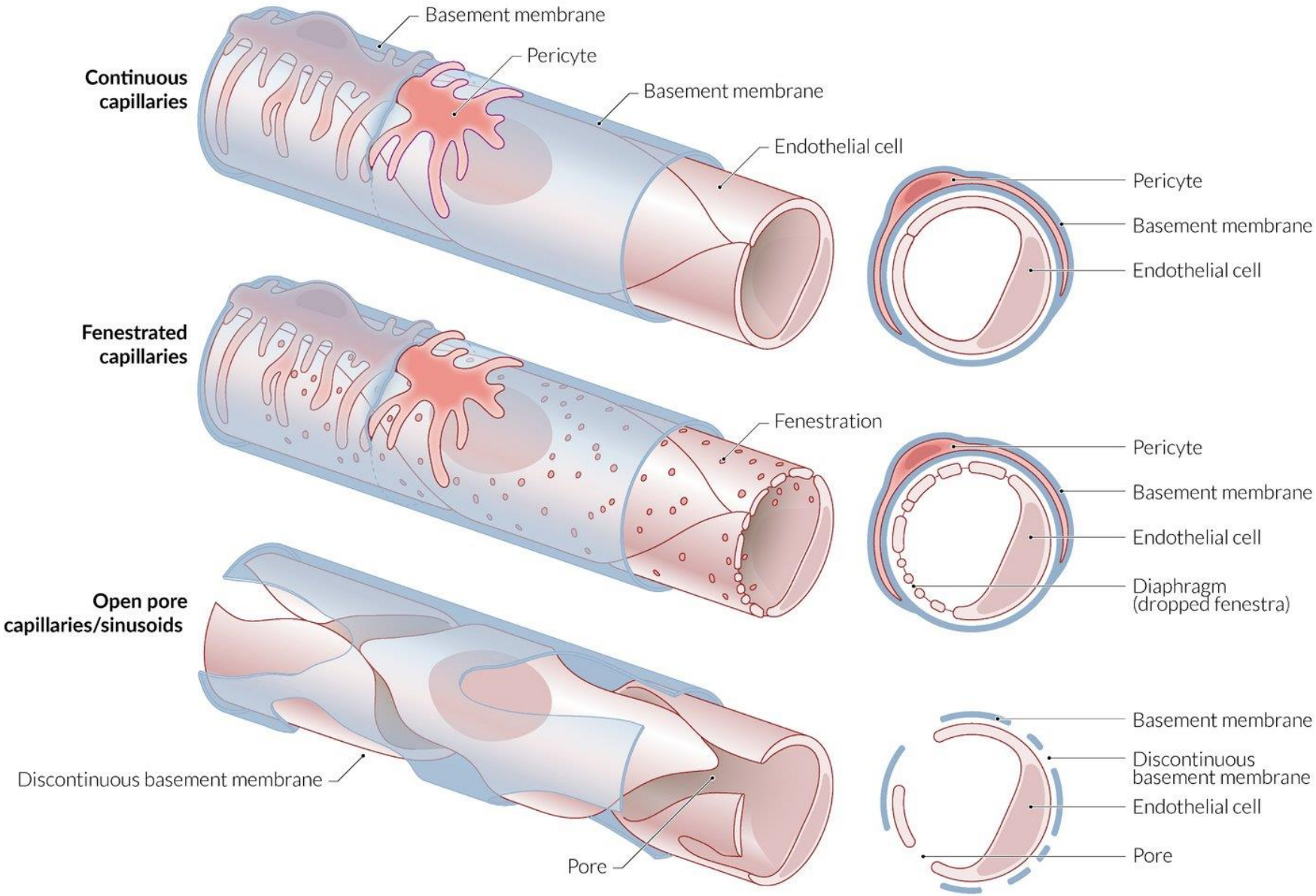
- Blood vessels contain a central lumen (cavity) lined with an **endothelium**, a single layer of flattened epithelial cells.
- The smooth surface of the endothelium minimizes resistance to the flow of blood. Surrounding the endothelium are layers of tissue that differ in capillaries, arteries, and veins, reflecting the specialized functions of these vessels


BLOOD FLOW
FROM HEART
BLOOD FLOW
TO HEART
TO CELLS
Oxygen
Nutrients
FROM CELLS
Waste
Carbon dioxide
ARTERY
Arteriole
Capillaries
Venule
VEIN

- Capillaries are the smallest blood vessels, having a diameter only slightly greater than that of a red blood cell
- Capillaries also have very thin walls, which consist of just an **endothelium** and a surrounding extracellular layer called the ***basal lamina*.**
- The exchange of substances between the blood and interstitial fluid occurs only in capillaries because only there are blood vessel walls thin enough to permit this exchange.

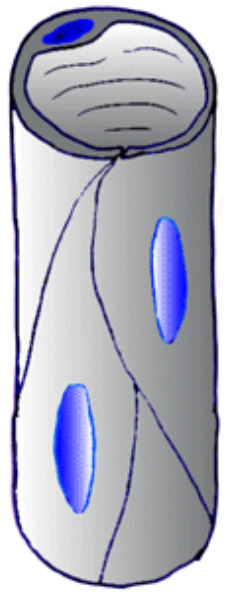


le ▲ **Figure 42.10 The structure of blood vessels.**


Continuous capillaries
Basement membrane
Pericyte
Basement membrane
Endothelial cell
Pericyte
Basement membrane
Endothelial cell
Fenestrated capillaries
Fenestration
Pericyte
Basement membrane
Endothelial cell
Diaphragm (dropped fenestra)
Open pore capillaries/sinusoids
Discontinuous basement membrane
Pore
Basement membrane
Discontinuous basement membrane
Endothelial cell
Pore

CAPILLARY TYPES

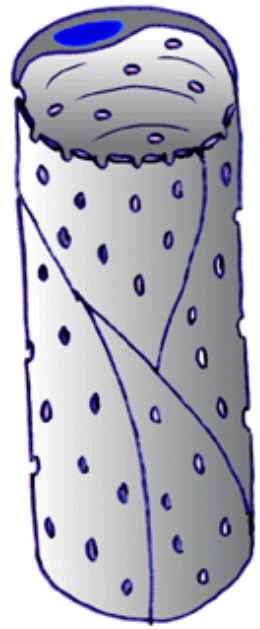
Continuous Capillary



Typical Locations

fat
muscle
nervous system

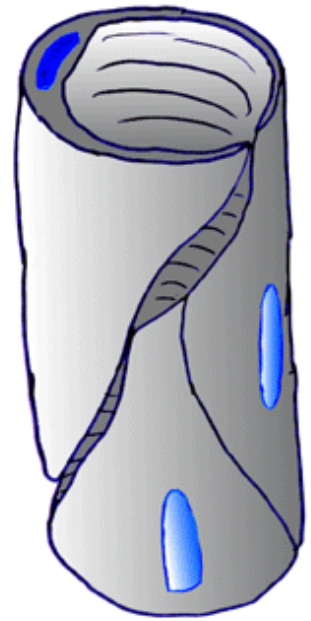
Fenestrated Capillary



Typical Locations

intestinal villi
endocrine glands
kidney glomeruli

Discontinuous Capillary

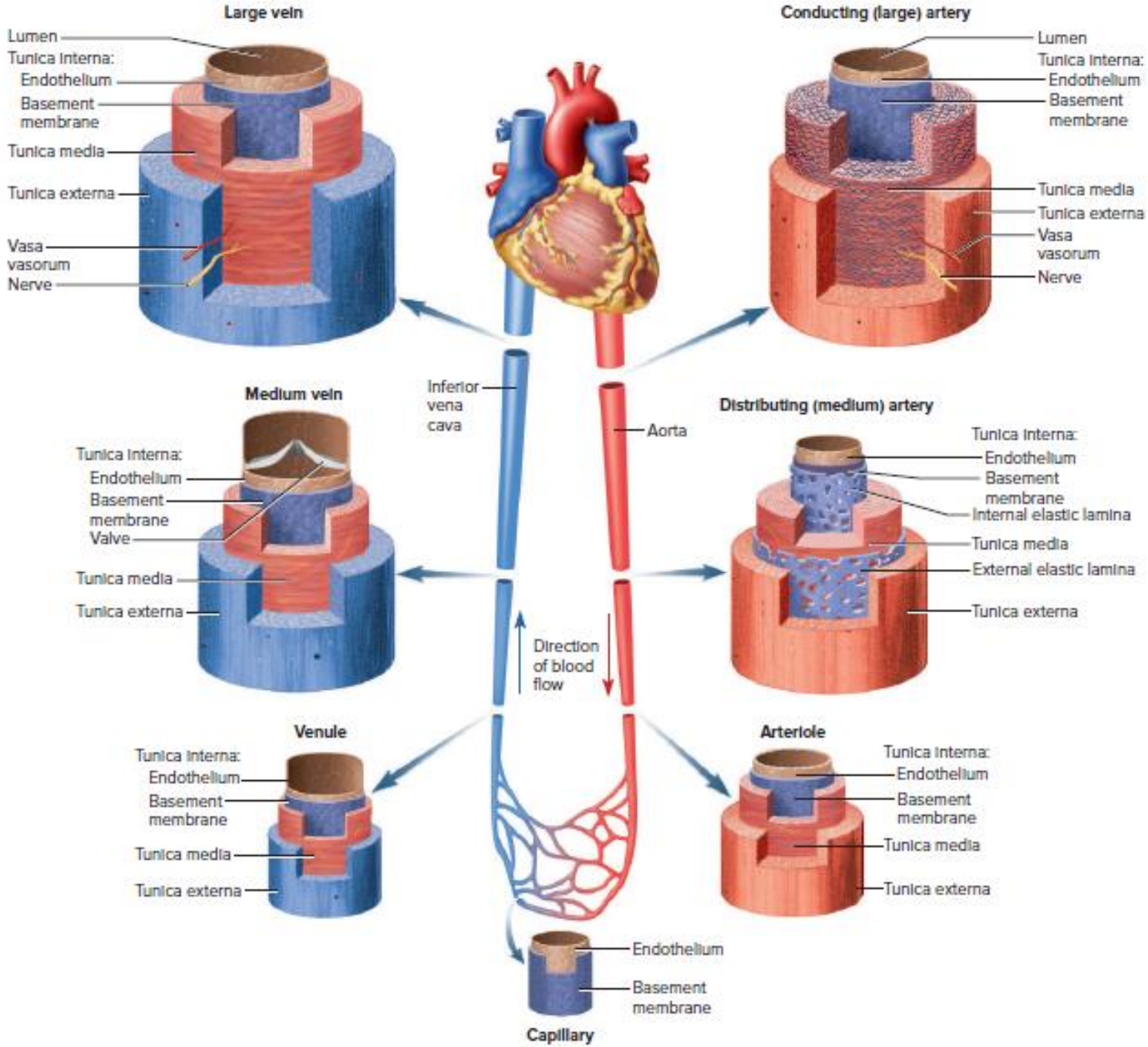


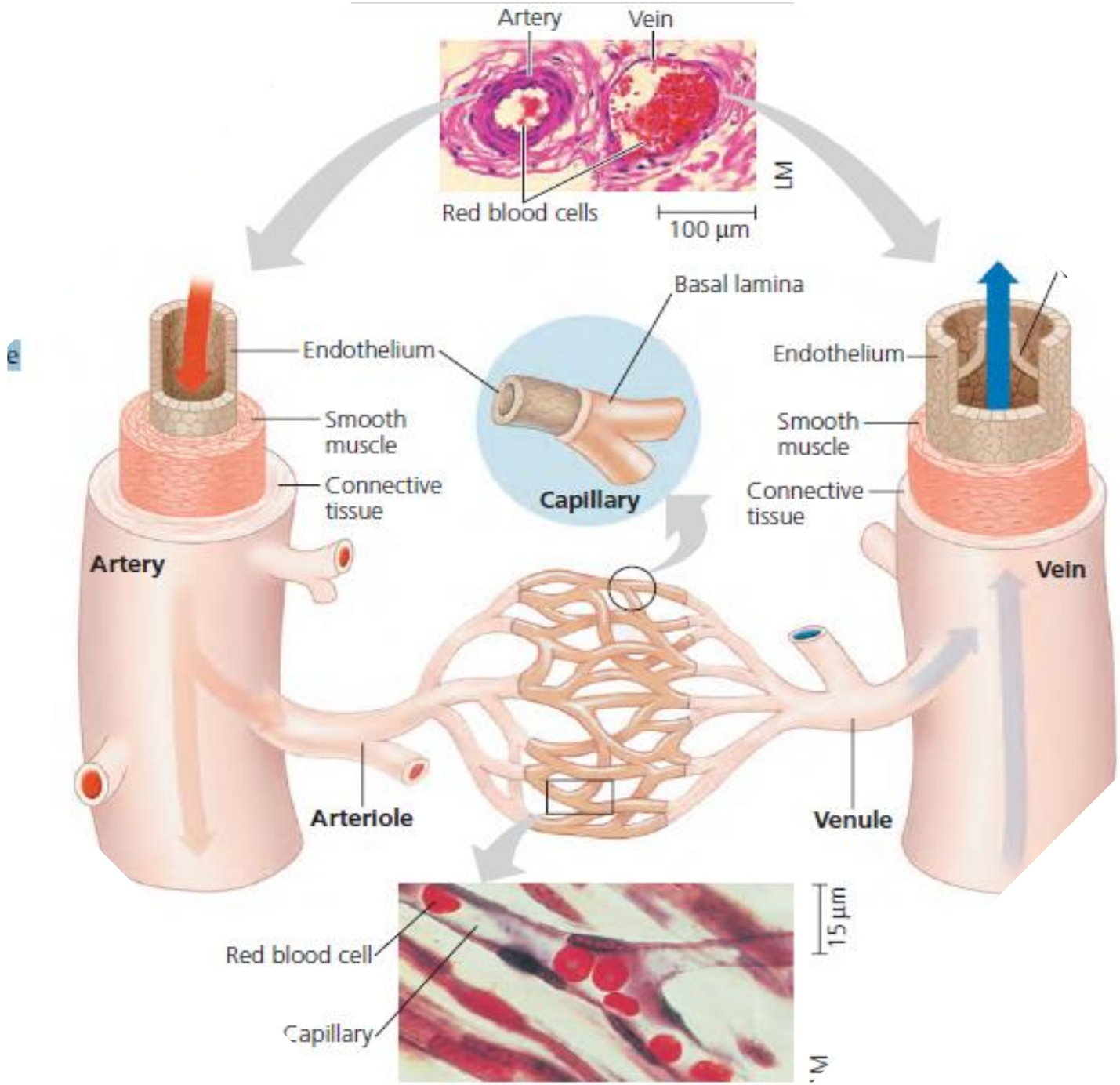
Typical Locations

liver
bone marrow
spleen

The walls of arteries and veins

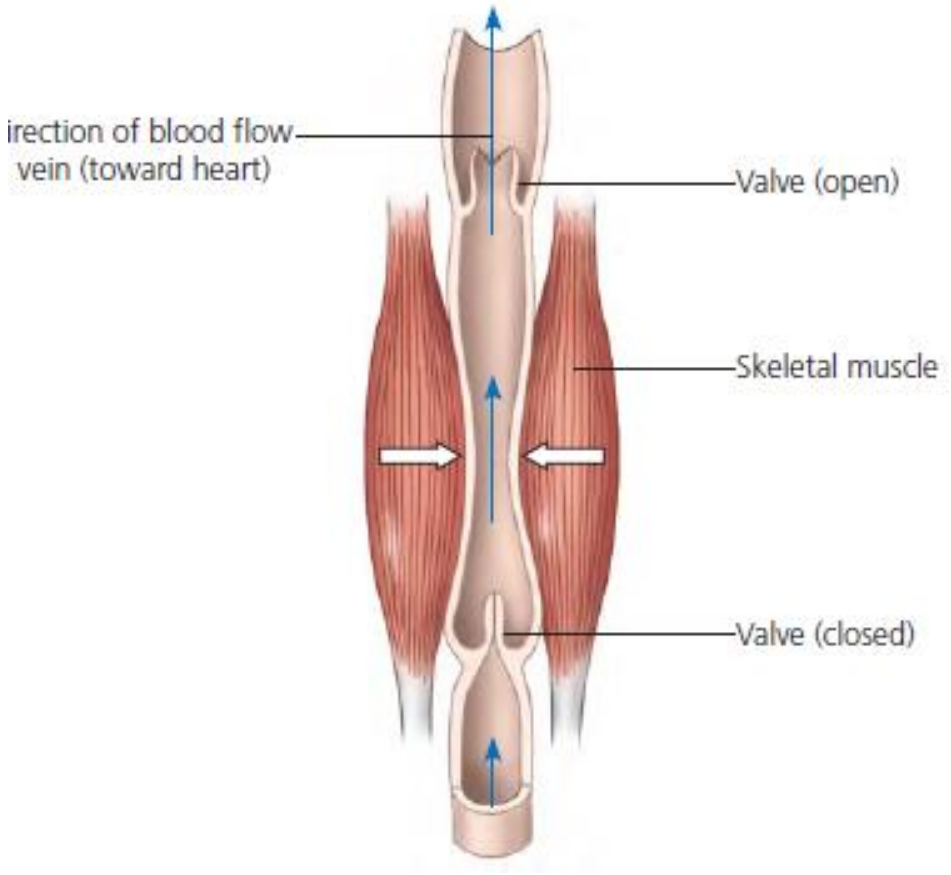
- The walls of arteries and veins have a more complex organization than those of capillaries.
- Both arteries and veins have two layers of tissue surrounding the endothelium: an outer layer of connective tissue containing elastic fibers, which allow the vessel to stretch and recoil, **and a middle layer containing smooth muscle and more elastic fibers.**
- However, the walls of arteries and veins also differ, reflecting distinct adaptations of these vessels to their particular functions in circulation.


Large vein
Lumen
Tunica interna:
Endothelium
Basement membrane
Tunica media
Tunica externa
Vasa vasorum
Nerve
Conducting (large) artery
Lumen
Tunica interna:
Endothelium
Basement membrane
Tunica media
Tunica externa
Vasa vasorum
Nerve
Inferior vena cava
Aorta
Medium vein
Tunica interna:
Endothelium
Basement membrane
Valve
Tunica media
Tunica externa
Distributing (medium) artery
Tunica interna:
Endothelium
Basement membrane
Internal elastic lamina
Tunica media
External elastic lamina
Tunica externa
Direction of blood flow
Venule
Tunica interna:
Endothelium
Basement membrane
Tunica media
Tunica externa
Arteriole
Tunica interna:
Endothelium
Basement membrane
Tunica media
Tunica externa
Endothelium
Basement membrane
Capillary

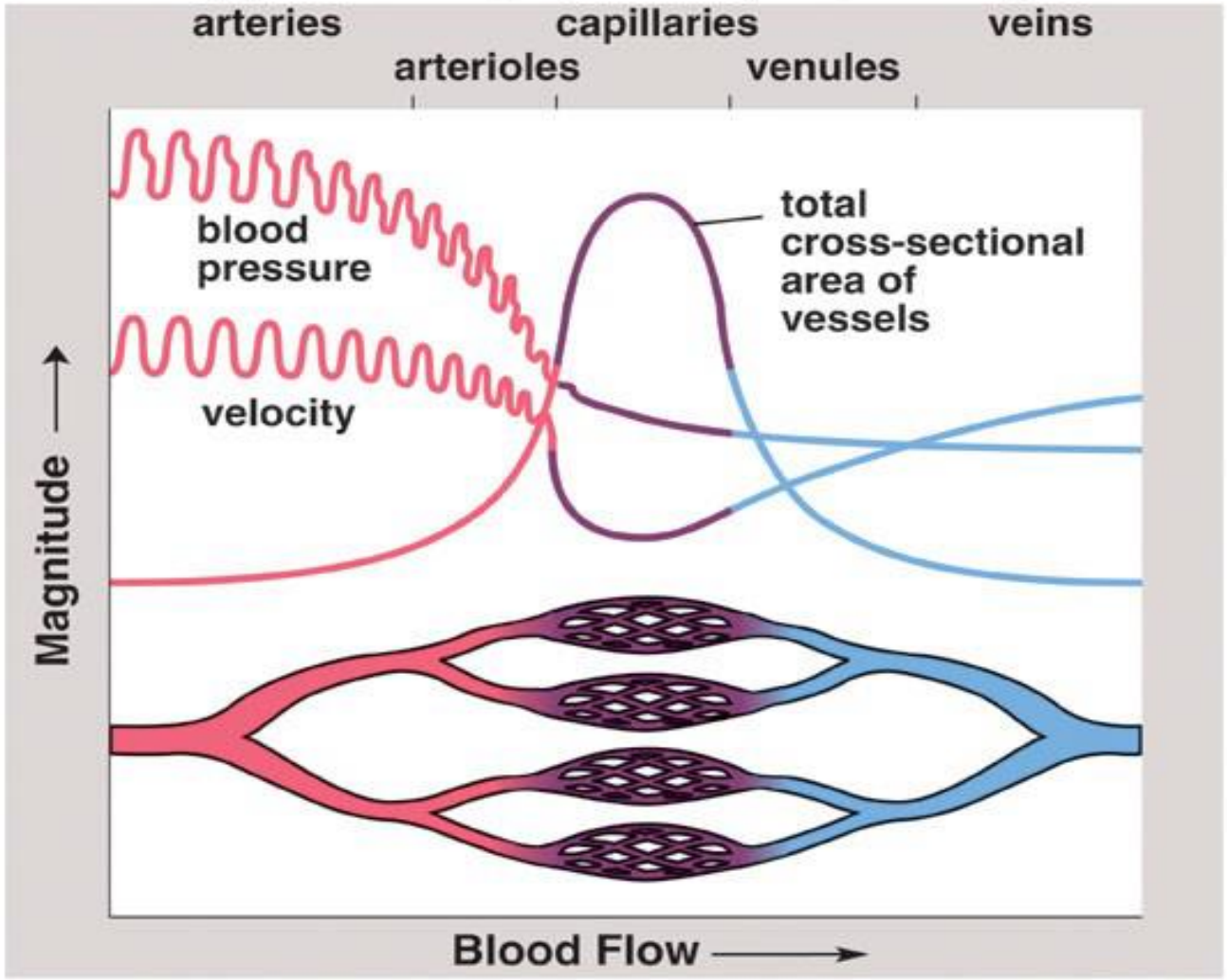

Artery
Vein
Red blood cells
100 µm
LM
Basal lamina
Endothelium
Smooth muscle
Connective tissue
Capillary
Artery
Arteriole
Venule
Vein
Red blood cell
Capillary
15 µm

- The walls of arteries are thick and strong, accommodating blood pumped at high pressure by the heart. They are also elastic. When the heart relaxes between contractions, the arterial walls recoil, helping maintain blood pressure and flow to capillaries.
- Signals from the nervous system and hormones circulating in the blood act on the smooth muscle in arteries and arterioles, dilating or constricting these vessels and thus controlling blood flow to different parts of the body

- Because veins convey blood back to the heart at a lower pressure, they do not require thick walls.
- For a given blood vessel diameter, a vein has a wall only about a third as thick as that of an artery.
- **Unlike arteries, veins contain valves, which maintain a unidirectional flow of blood despite the low blood pressure in these vessels.**
- Blood travels 500 times more slowly in the capillaries (about 0.1 cm/sec) than in the aorta (about 48 cm/sec).
- After passing through the capillaries, the blood speeds up as it enters the venules and veins, which have smaller *total* cross sectional areas than the capillaries.



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



Blood Flow in Veins

- Venous blood flow is dependent upon:

1. skeletal muscle contraction,
2. presence of valves in veins,
3. respiratory movements.

- Changes in thoracic and abdominal pressure that occur with breathing also assist in the return of blood.
- Compression of veins causes blood to move forward past a valve that then prevents it from returning backward

References

- Hall, J. E., & Hall, M. E. (2020). Guyton and Hall Textbook of Medical Physiology. Elsevier.
- Saladin, K. (2020). Anatomy & Physiology: The Unity of Form and Function. McGraw-Hill Education.