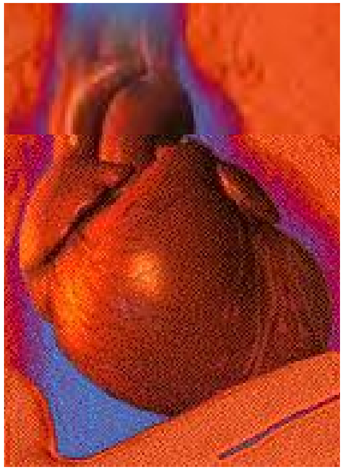
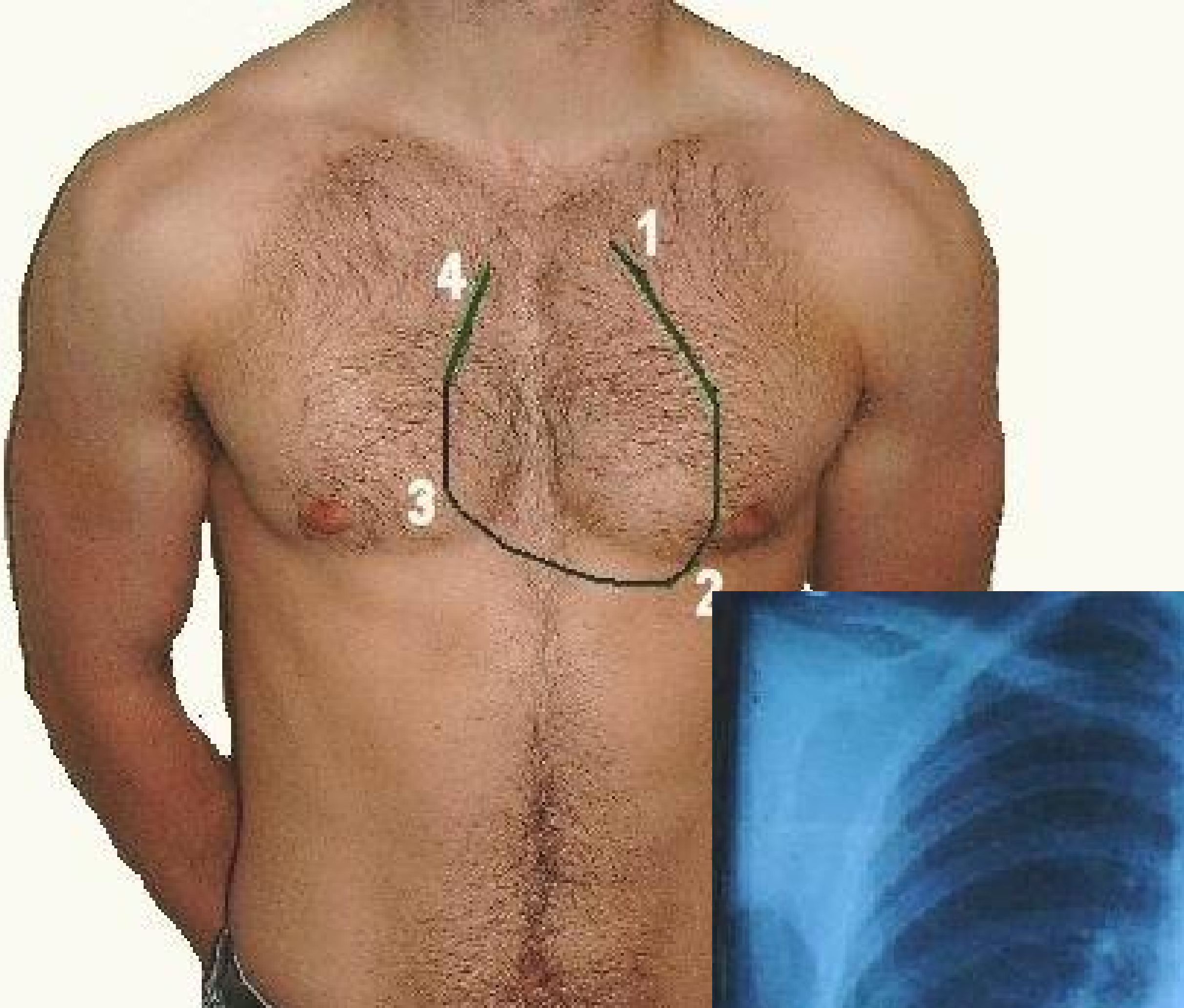
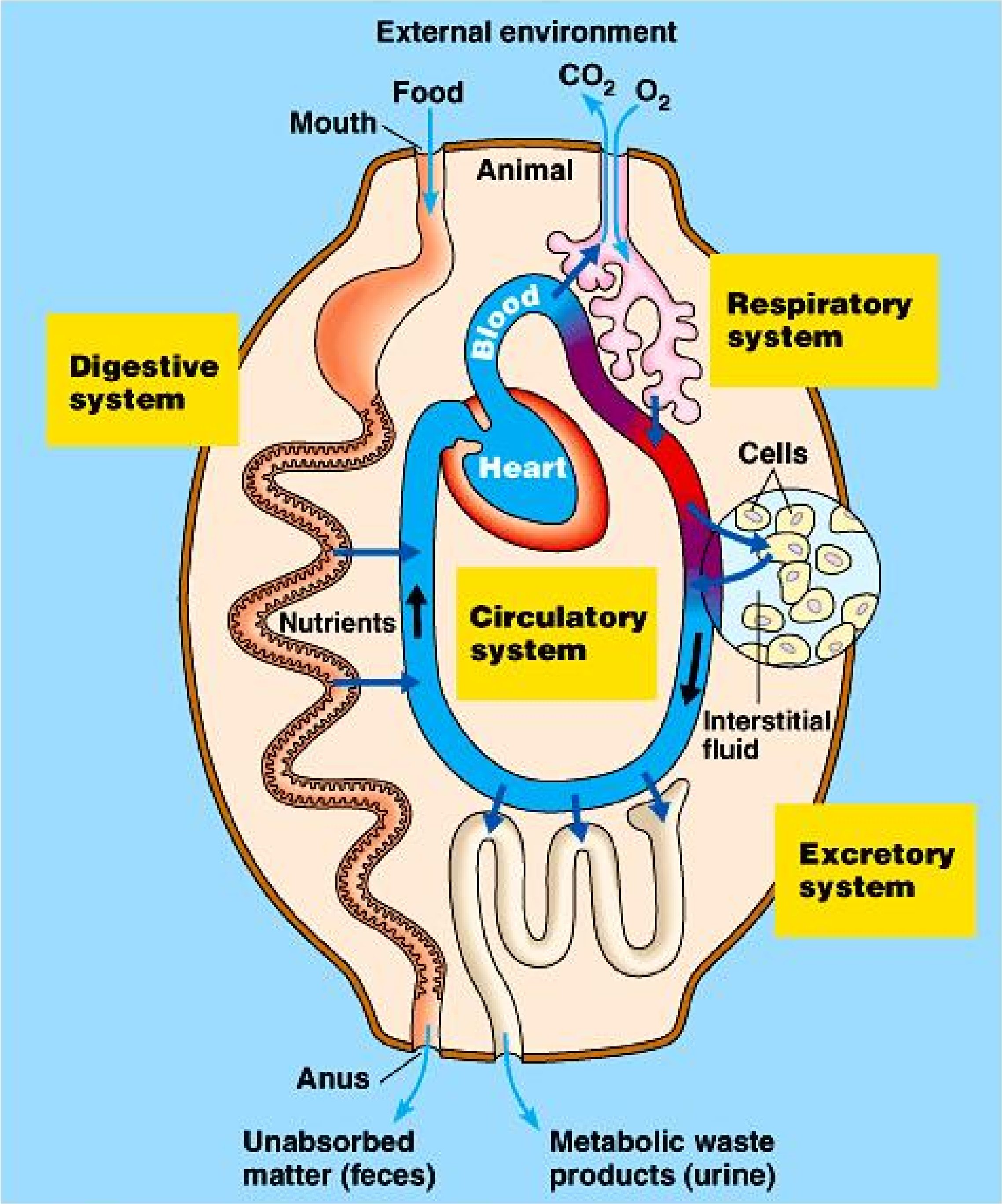
Cardiovascular System




1
4
3
2

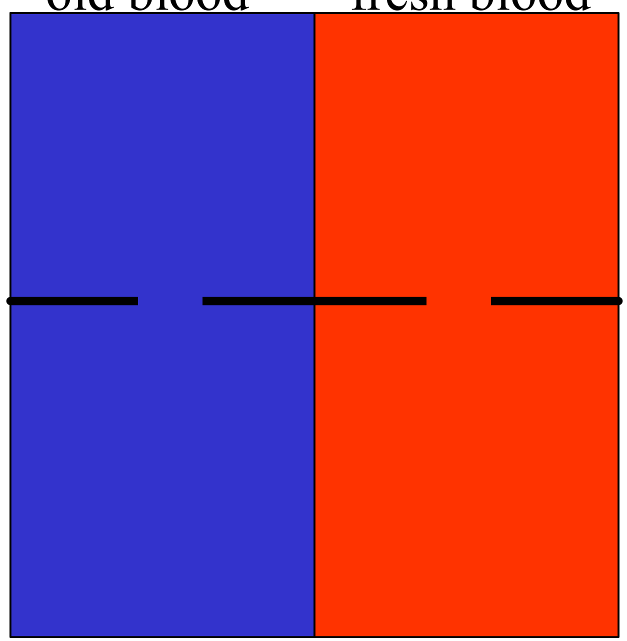


External environment
Food
Mouth
CO_2
O_2
Animal
Blood
Respiratory system
Digestive system
Heart
Cells
Nutrients
Circulatory system
Interstitial fluid
Excretory system
Anus
Unabsorbed matter (feces)
Metabolic waste products (urine)

The Heart: A Two Sided Pump

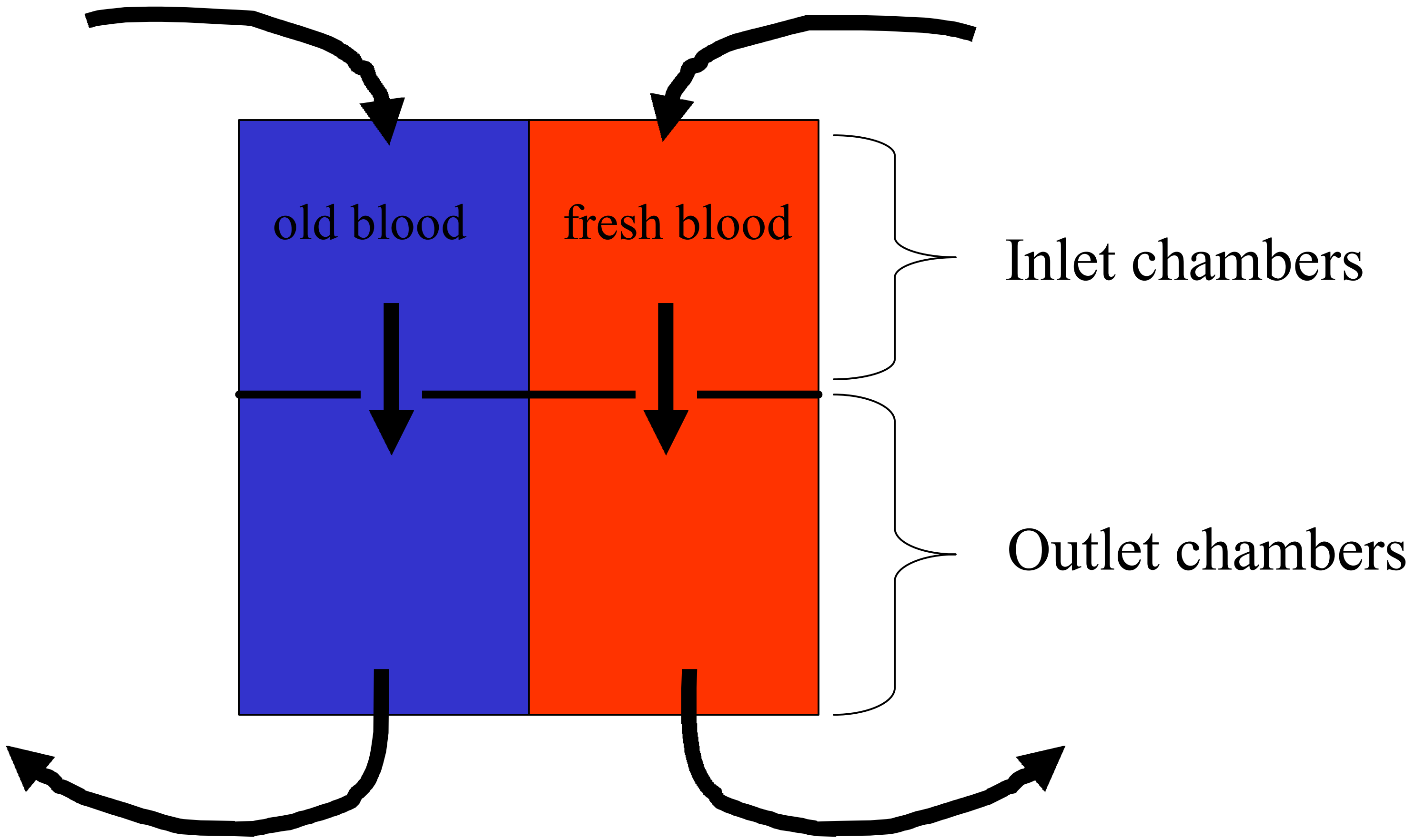
Handles two types of blood
- Deoxygenated- blue
- Oxygenated- red

Right side Left side

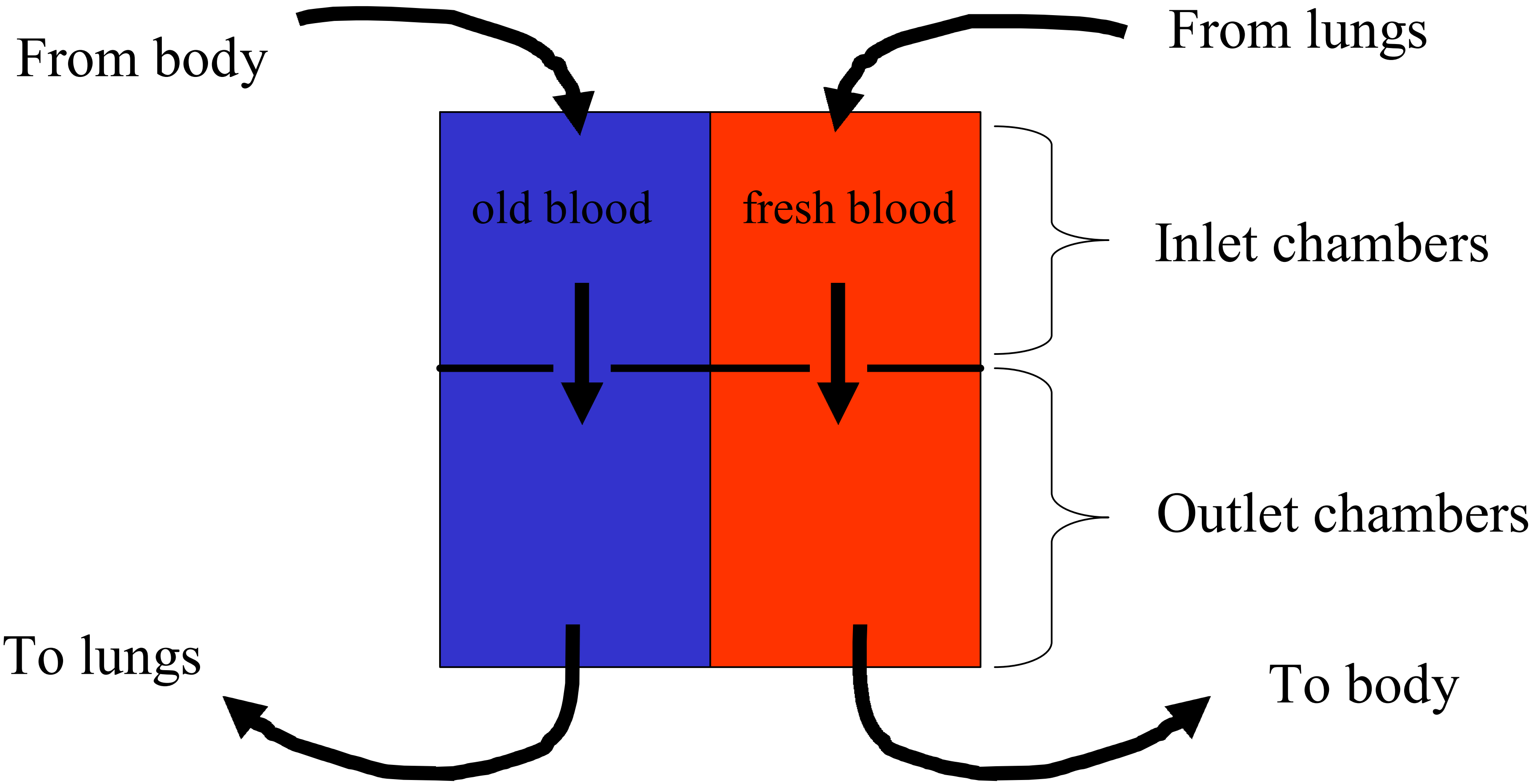
old blood fresh blood



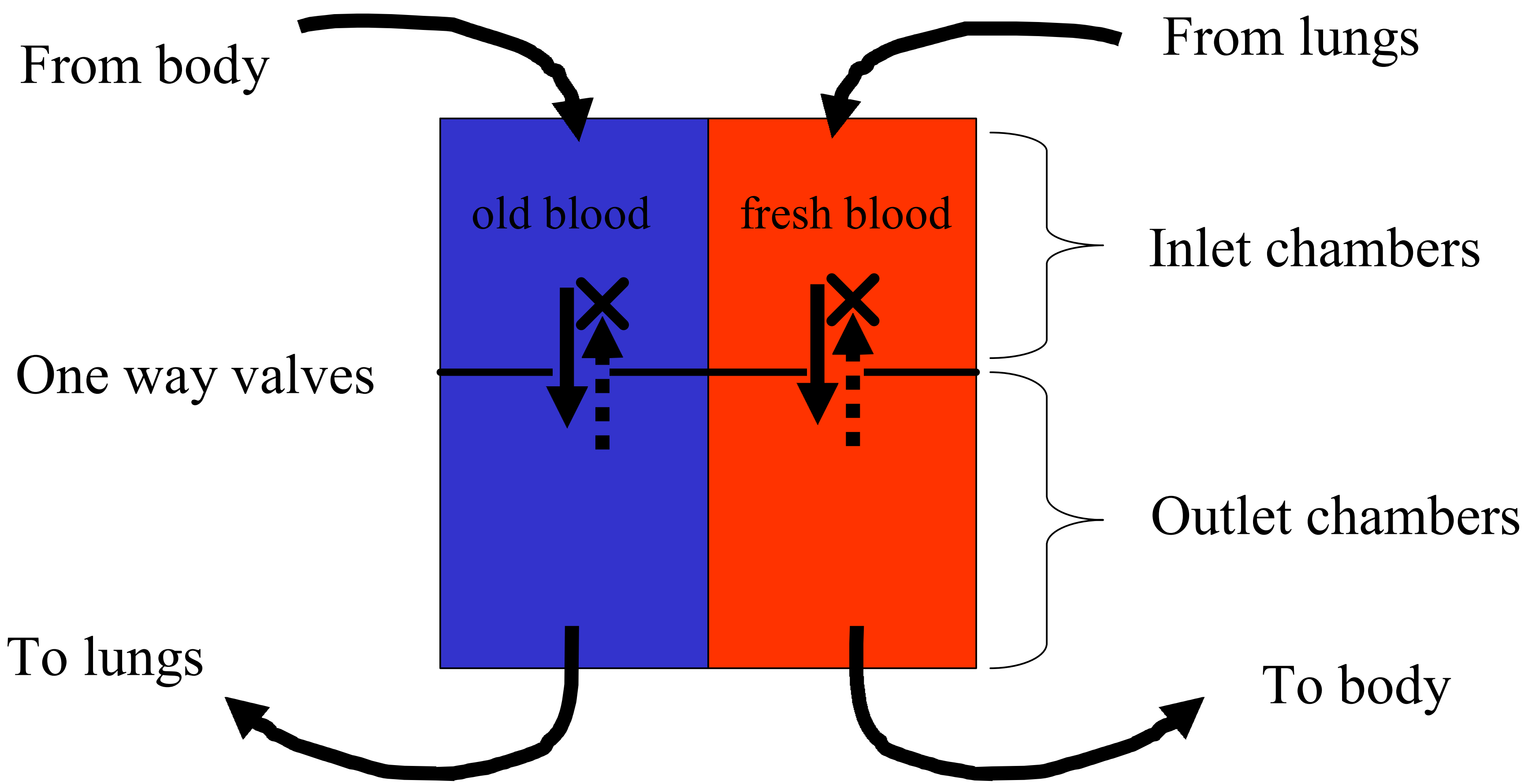
The Heart: A Two Sided Pump



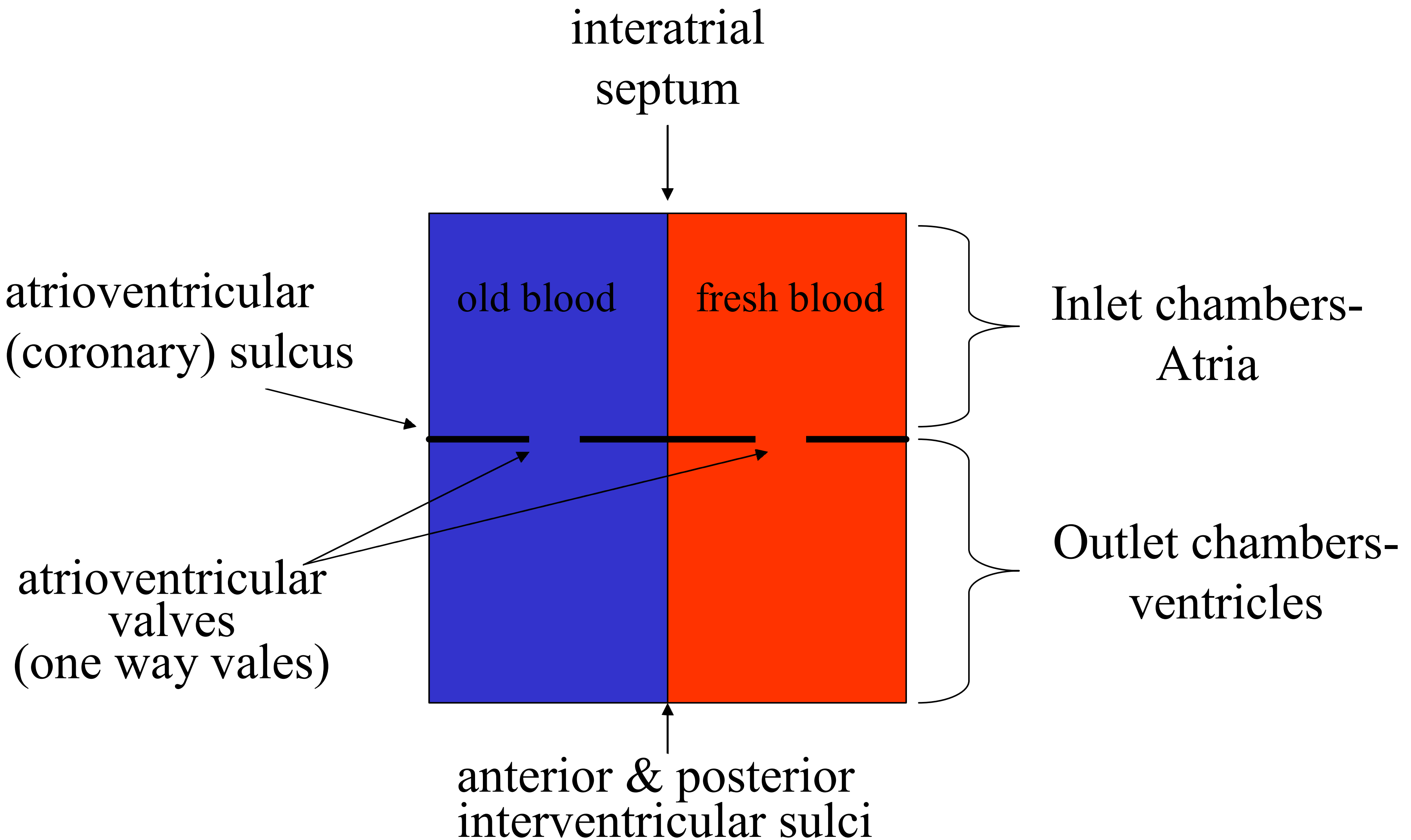
The Heart: A Two Sided Pump

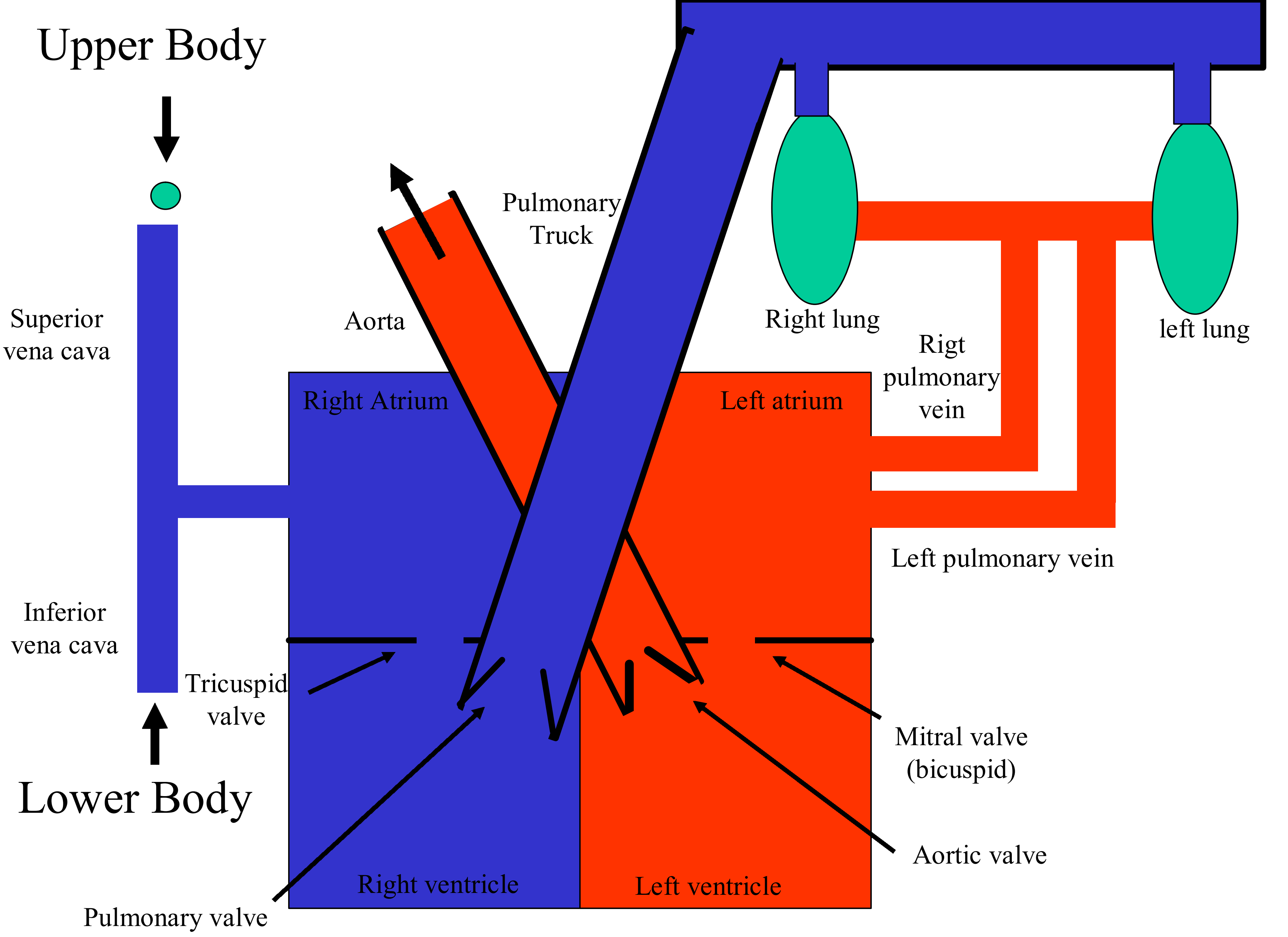


The Heart: A Two Sided Pump

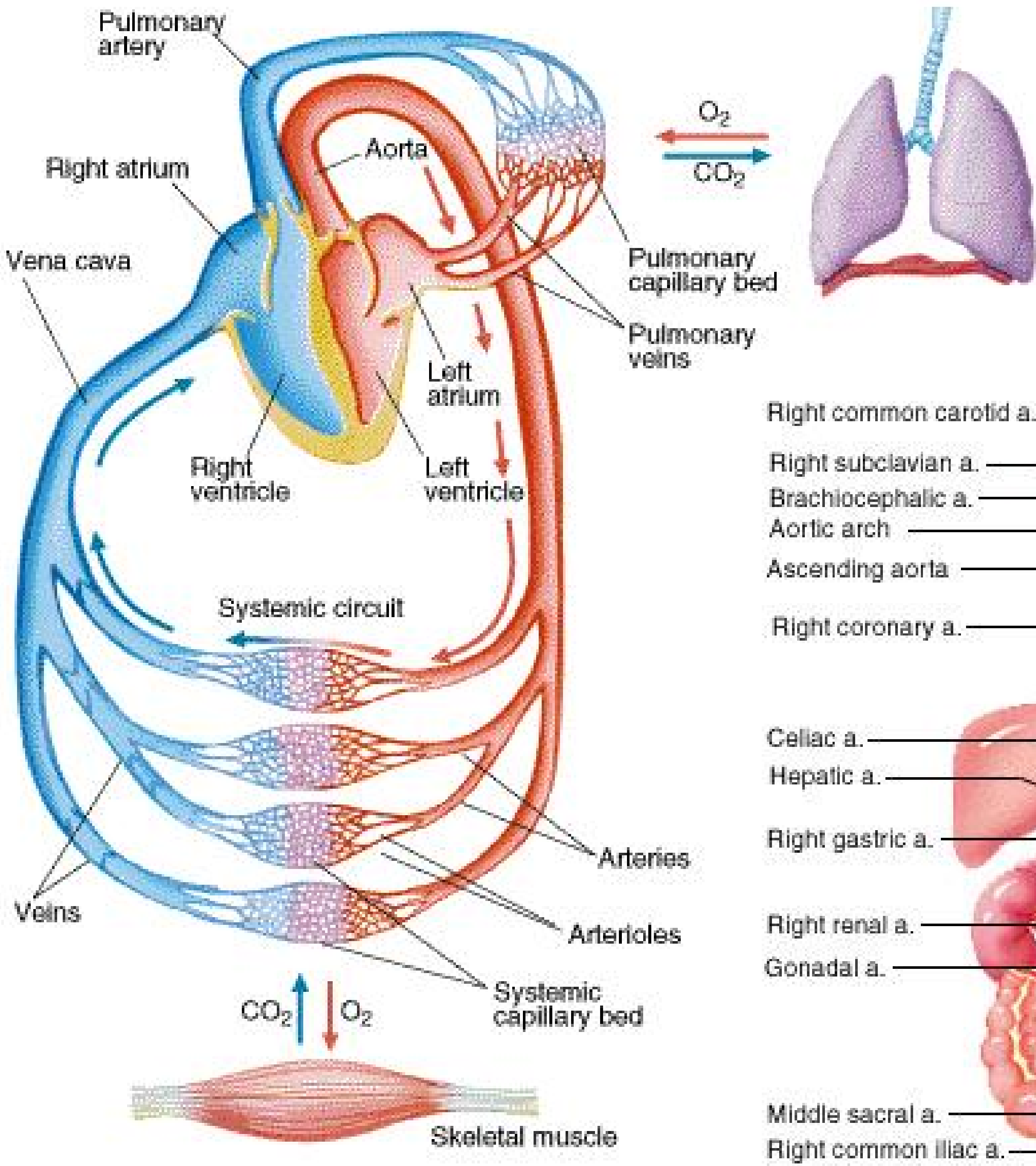


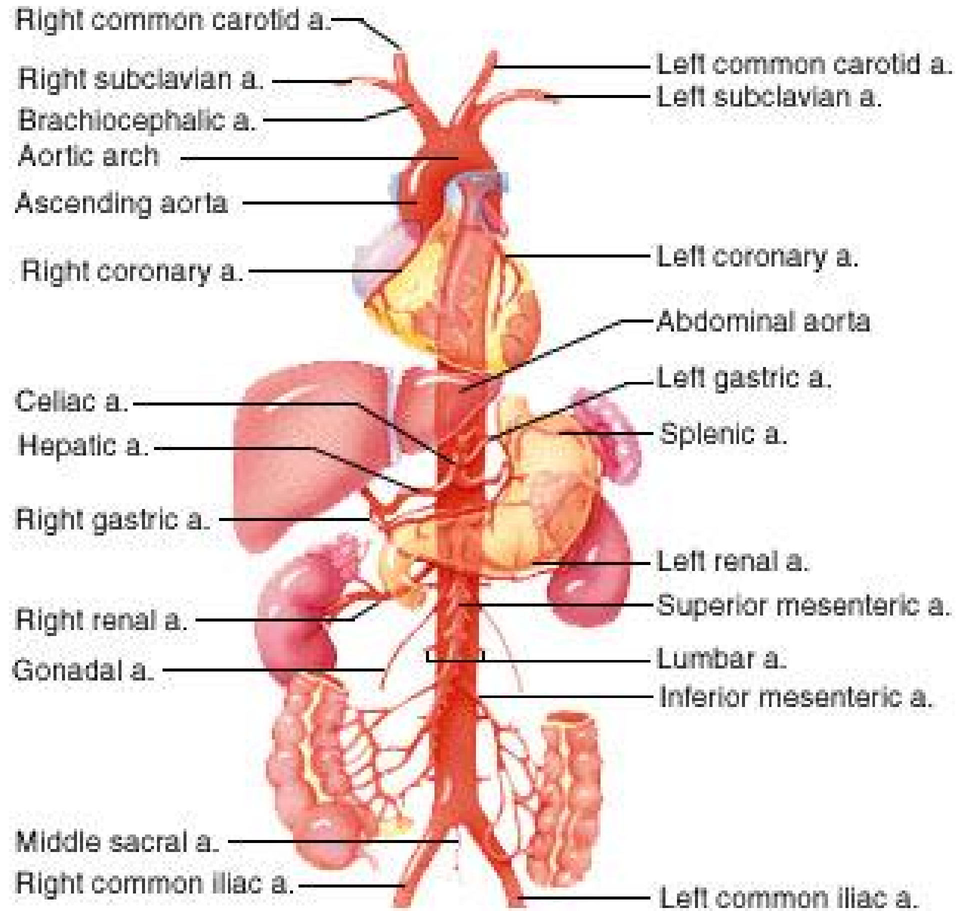
The Heart: A Two Sided Pump

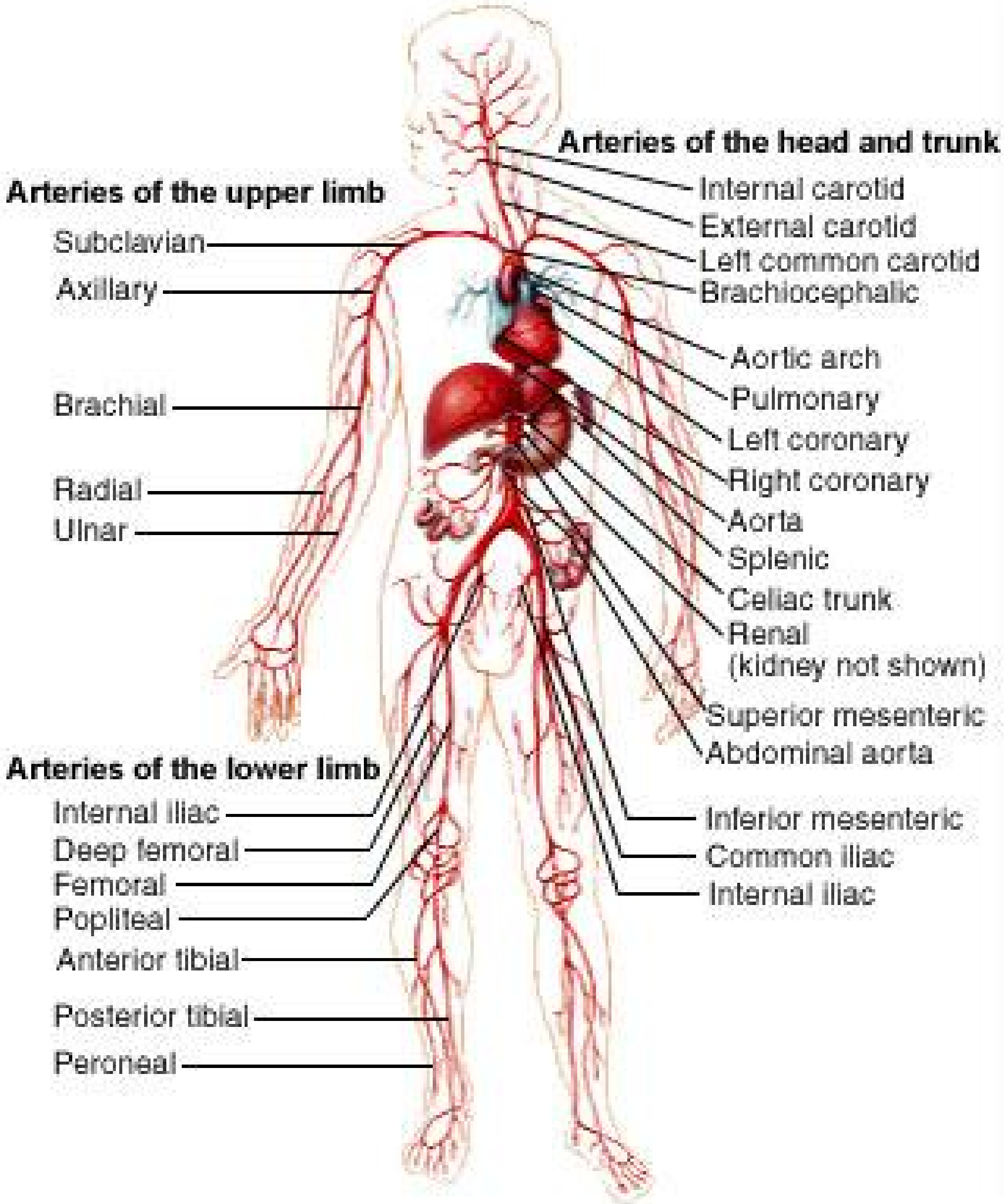


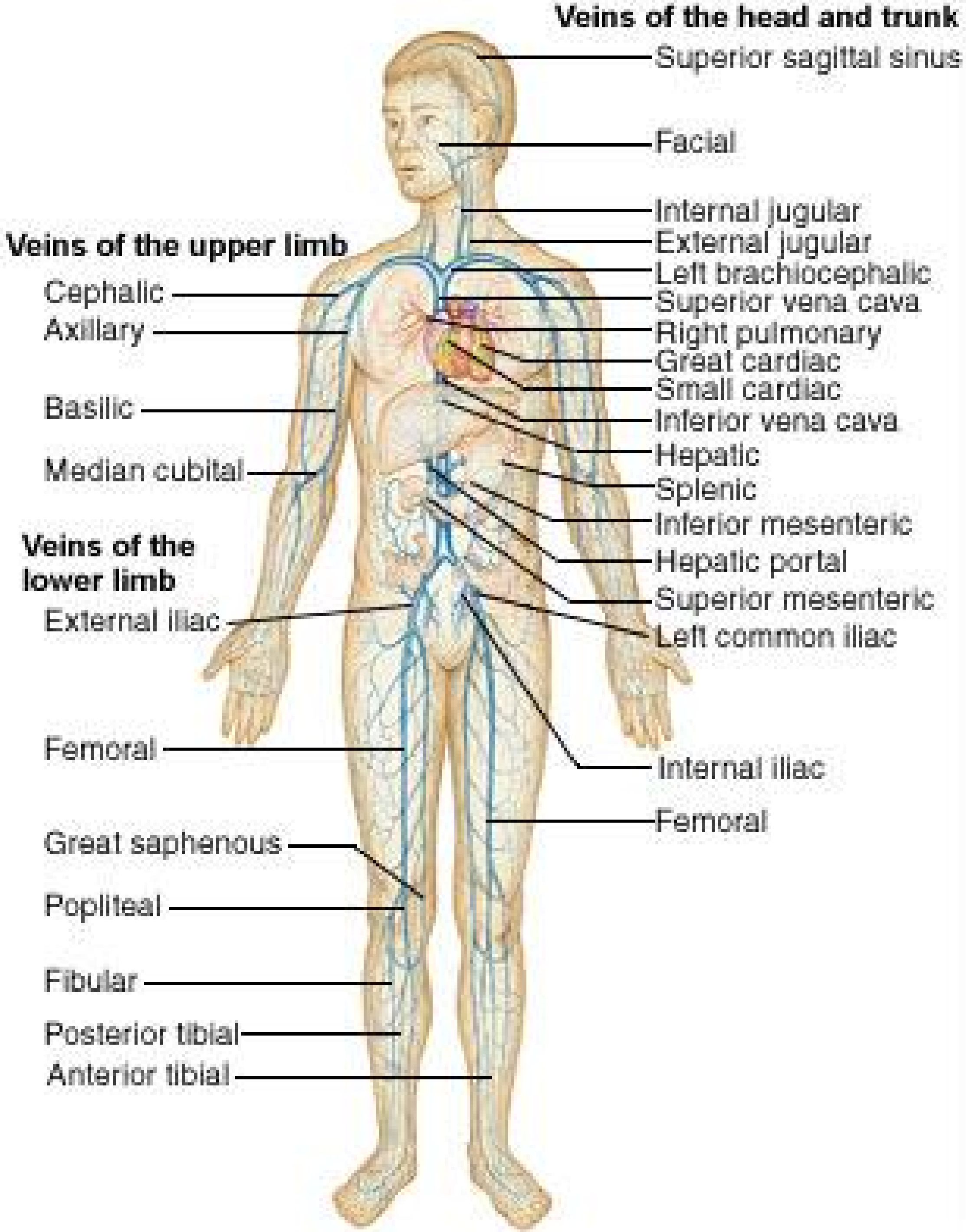


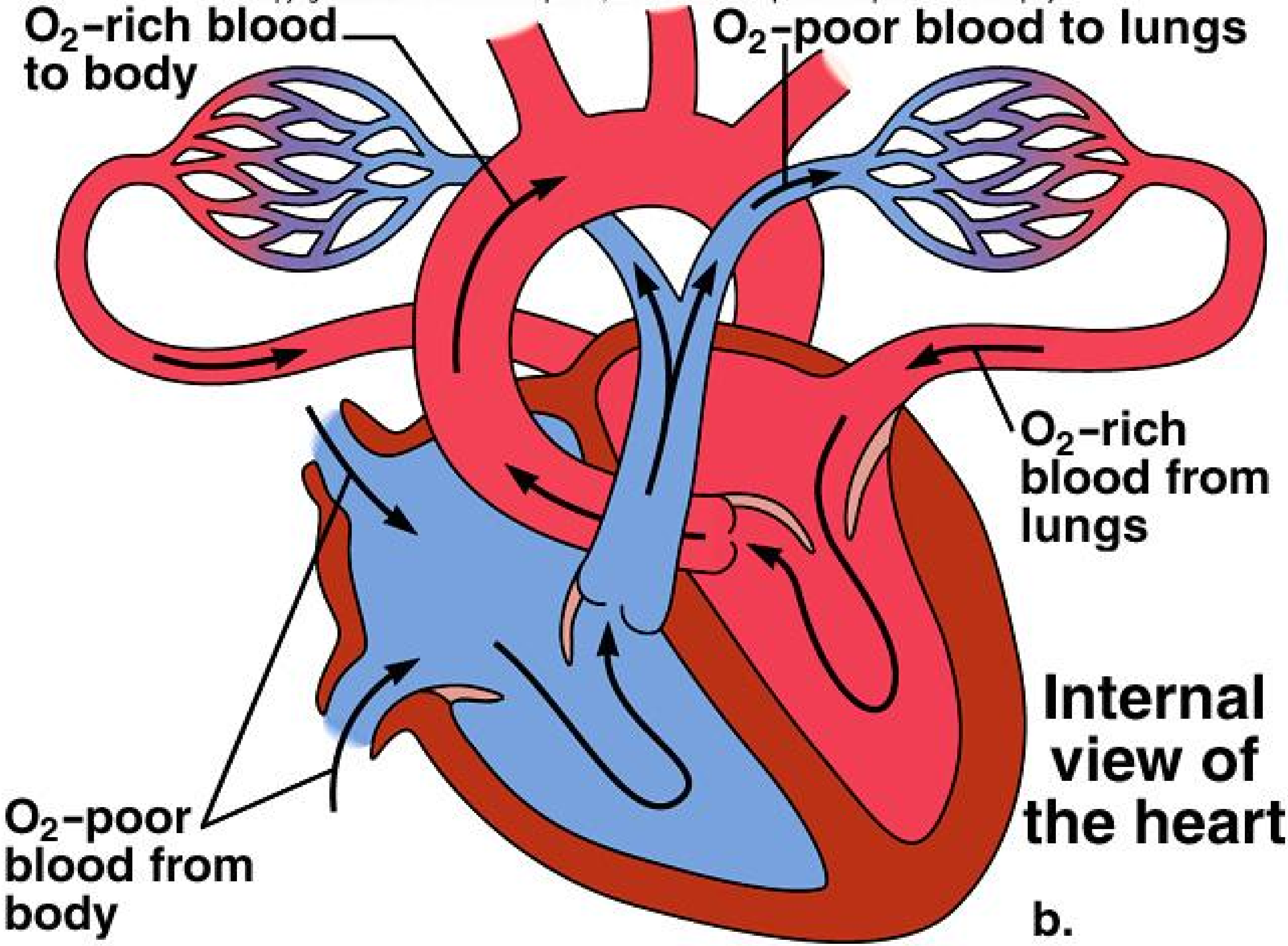
Upper Body
Pulmonary
Truck
Aorta
Superior
vena cava
Right lung
left lung
Rigt
pulmonary
vein
Right Atrium
Left atrium
Left pulmonary vein
Inferior
vena cava
Tricuspid
valve
Mitral valve
(bicuspid)
Lower Body
Aortic valve
Right ventricle
Left ventricle
Pulmonary valve


Pulmonary artery
Aorta
Right atrium
Vena cava
O_2
CO_2
Pulmonary capillary bed
Pulmonary veins
Left atrium
Right ventricle
Left ventricle
Systemic circuit
Arteries
Veins
Arterioles
Systemic capillary bed
CO_2
O_2
Skeletal muscle


Right common carotid a.
Right subclavian a.
Brachiocephalic a.
Aortic arch
Ascending aorta
Right coronary a.
Celiac a.
Hepatic a.
Right gastric a.
Right renal a.
Gonadal a.
Middle sacral a.
Right common iliac a.
Left common carotid a.
Left subclavian a.
Left coronary a.
Abdominal aorta
Left gastric a.
Splenic a.
Left renal a.
Superior mesenteric a.
Lumbar a.
Inferior mesenteric a.
Left common iliac a.


Arteries of the head and trunk
Internal carotid
External carotid
Left common carotid
Brachiocephalic
Aortic arch
Pulmonary
Left coronary
Right coronary
Aorta
Splenic
Celiac trunk
Renal
(kidney not shown)
Superior mesenteric
Abdominal aorta
Inferior mesenteric
Common iliac
Internal iliac
Arteries of the upper limb
Subclavian
Axillary
Brachial
Radial
Ulnar
Arteries of the lower limb
Internal iliac
Deep femoral
Femoral
Popliteal
Anterior tibial
Posterior tibial
Peroneal

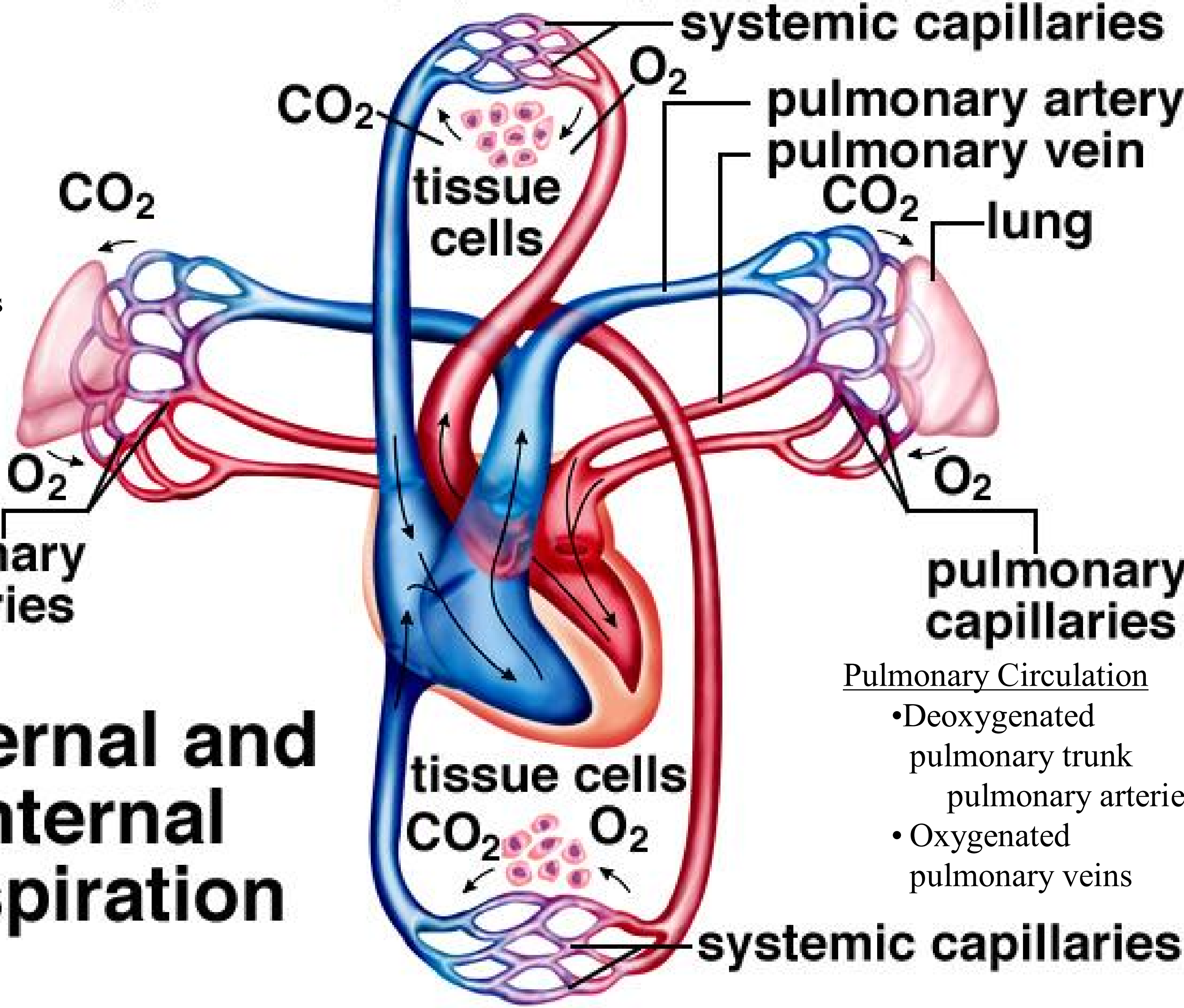

Veins of the head and trunk
Superior sagittal sinus
Facial
Internal jugular
External jugular
Left brachiocephalic
Superior vena cava
Right pulmonary
Great cardiac
Small cardiac
Inferior vena cava
Hepatic
Splenic
Inferior mesenteric
Hepatic portal
Superior mesenteric
Left common iliac
Internal iliac
Femoral
Veins of the upper limb
Cephalic
Axillary
Basilic
Median cubital
Veins of the lower limb
External iliac
Femoral
Great saphenous
Popliteal
Fibular
Posterior tibial
Anterior tibial



O_2-rich blood to body
O_2-poor blood to lungs
O_2-rich blood from lungs
O_2-poor blood from body
Internal view of the heart
b.

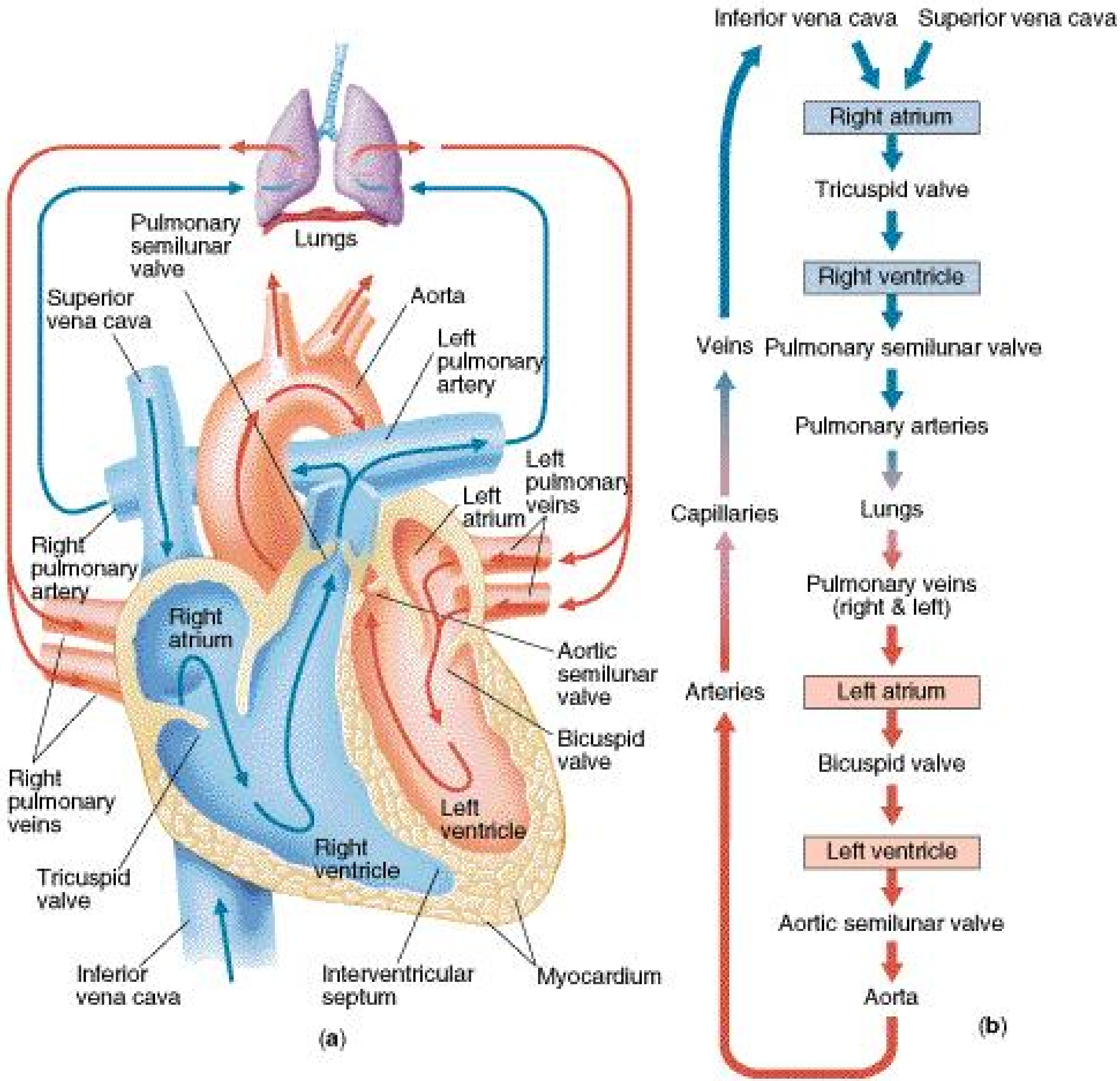
Systemic Circulation
- Deoxygenated
  - vena cavas
- Oxygenated
  - aorta
    - ascending
    - aortic arch
    - descending
    - thoracic
    - abdominal

Cardiac Circulation
- coronary arteries
- coronary sinus

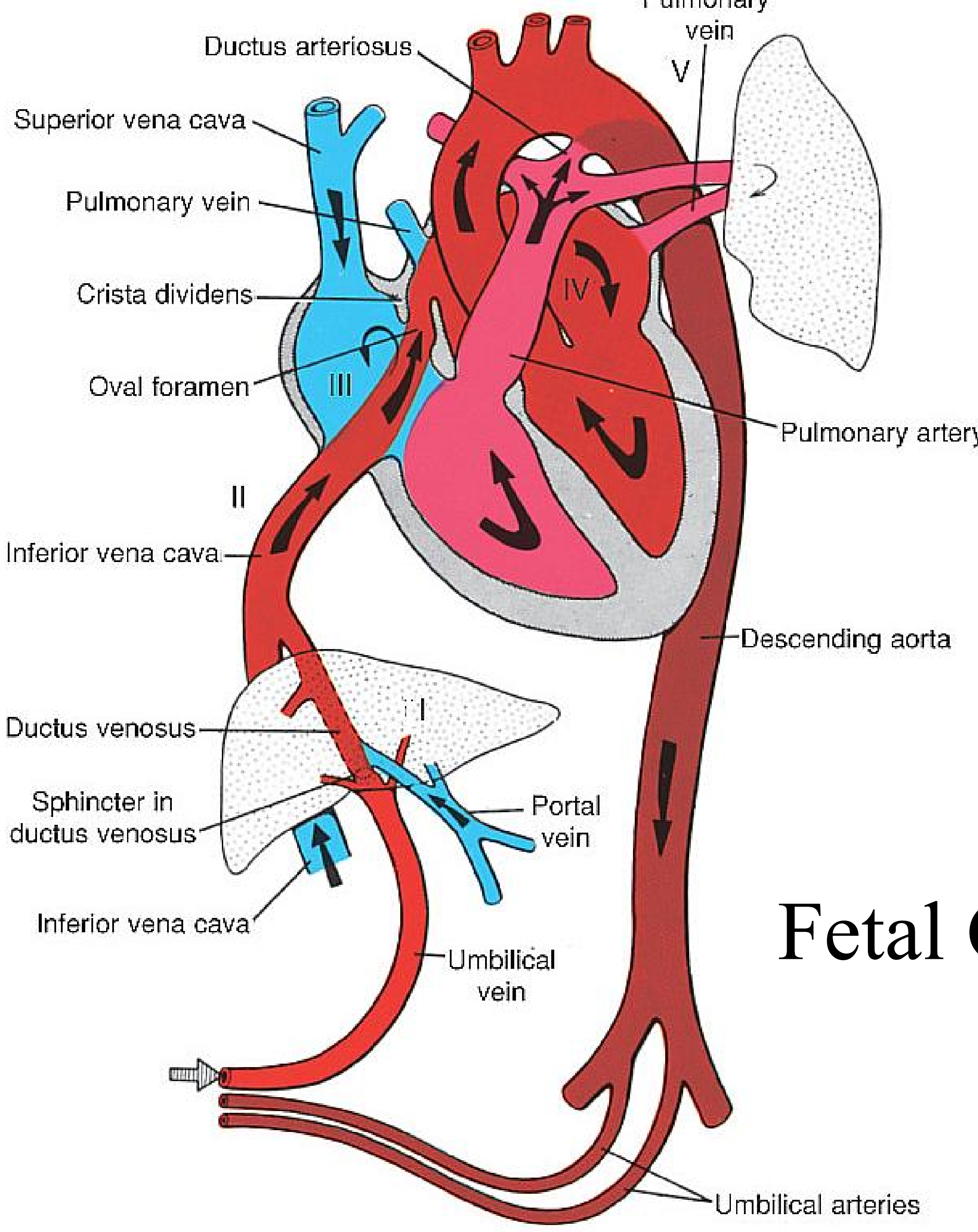


External and internal respiration

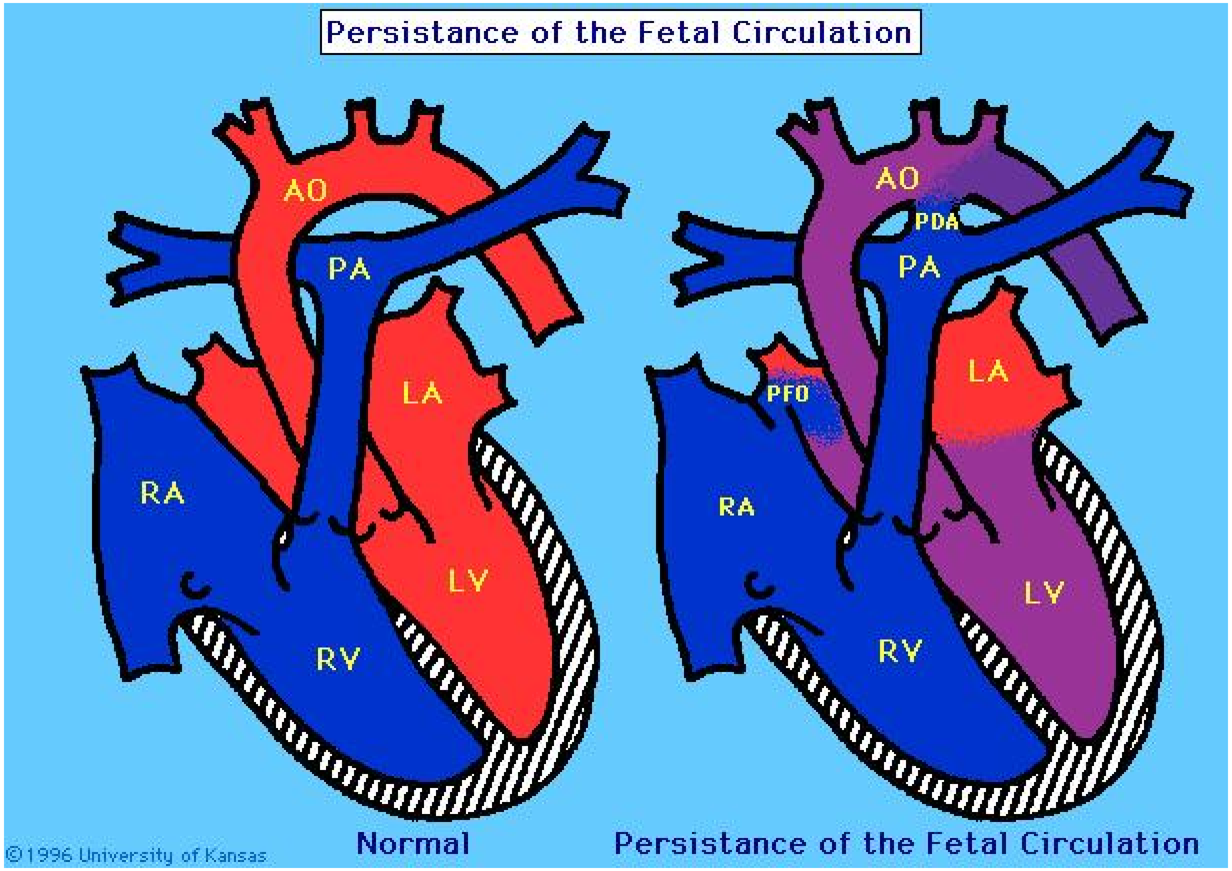
Pulmonary Circulation
- Deoxygenated
  - pulmonary trunk
    - pulmonary arteries
- Oxygenated
  - pulmonary veins



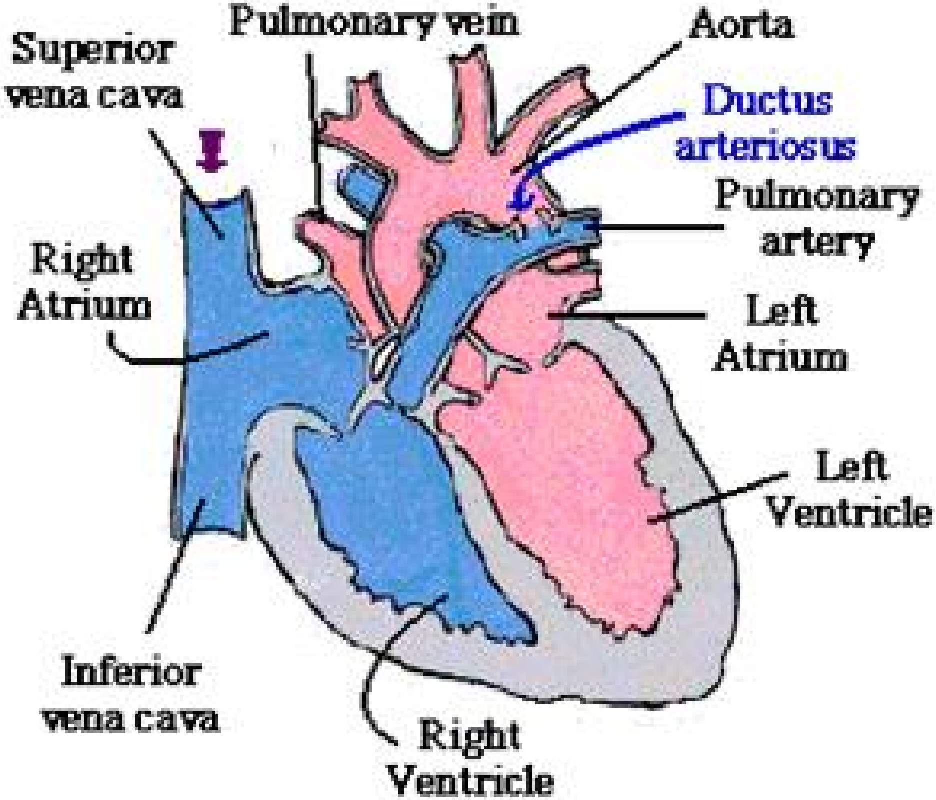
Lungs
Pulmonary semilunar valve
Superior vena cava
Aorta
Left pulmonary artery
Left pulmonary veins
Left atrium
Right pulmonary artery
Right atrium
Aortic semilunar valve
Bicuspid valve
Right pulmonary veins
Left ventricle
Tricuspid valve
Right ventricle
Inferior vena cava
Interventricular septum
Myocardium
(a)
Inferior vena cava
Superior vena cava
Right atrium
Tricuspid valve
Right ventricle
Veins
Pulmonary semilunar valve
Pulmonary arteries
Capillaries
Lungs
Pulmonary veins (right & left)
Arteries
Left atrium
Bicuspid valve
Left ventricle
Aortic semilunar valve
Aorta
(b)



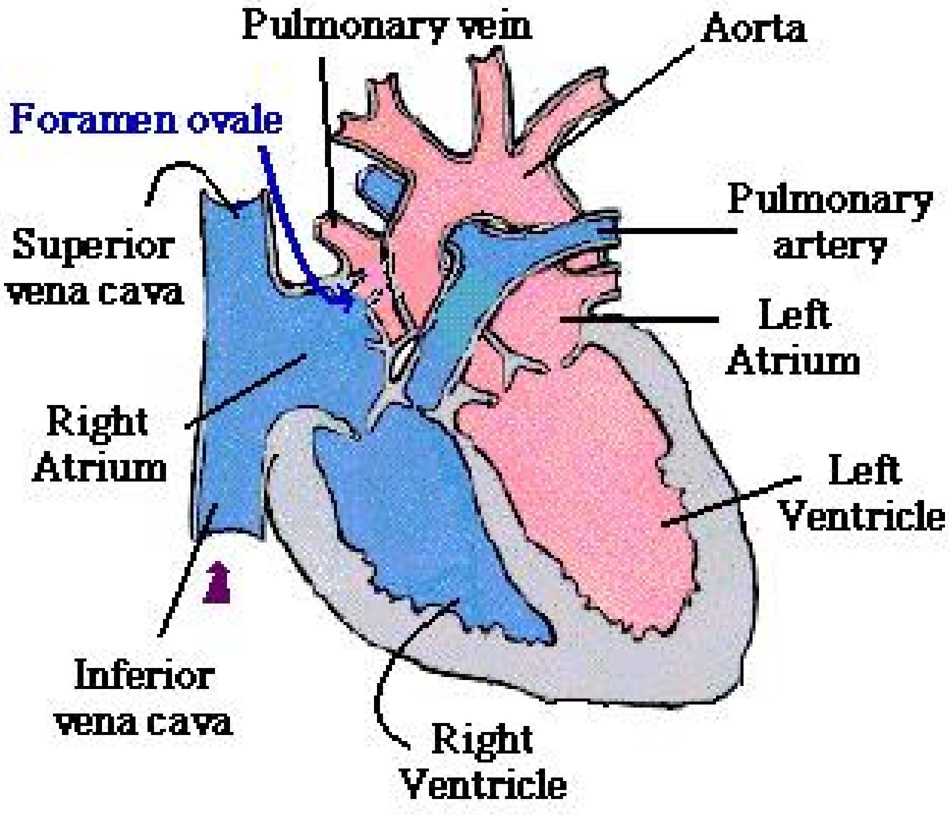
Fetal Circulation



Persistance of the Fetal Circulation
AO
PA
LA
RA
LV
RV
AO
PDA
PA
PFO
LA
RA
LV
RV
©1996 University of Kansas
Normal
Persistance of the Fetal Circulation

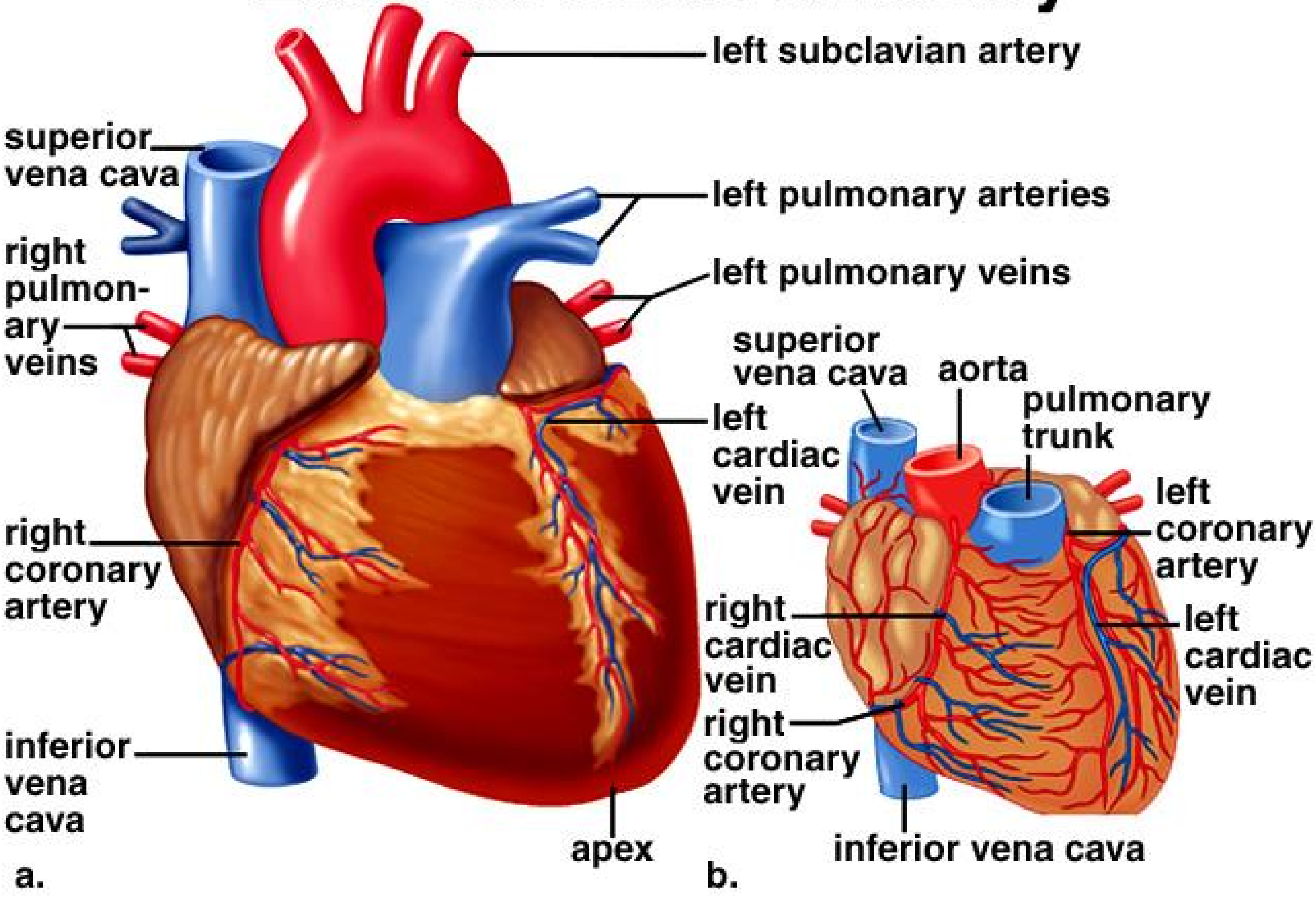


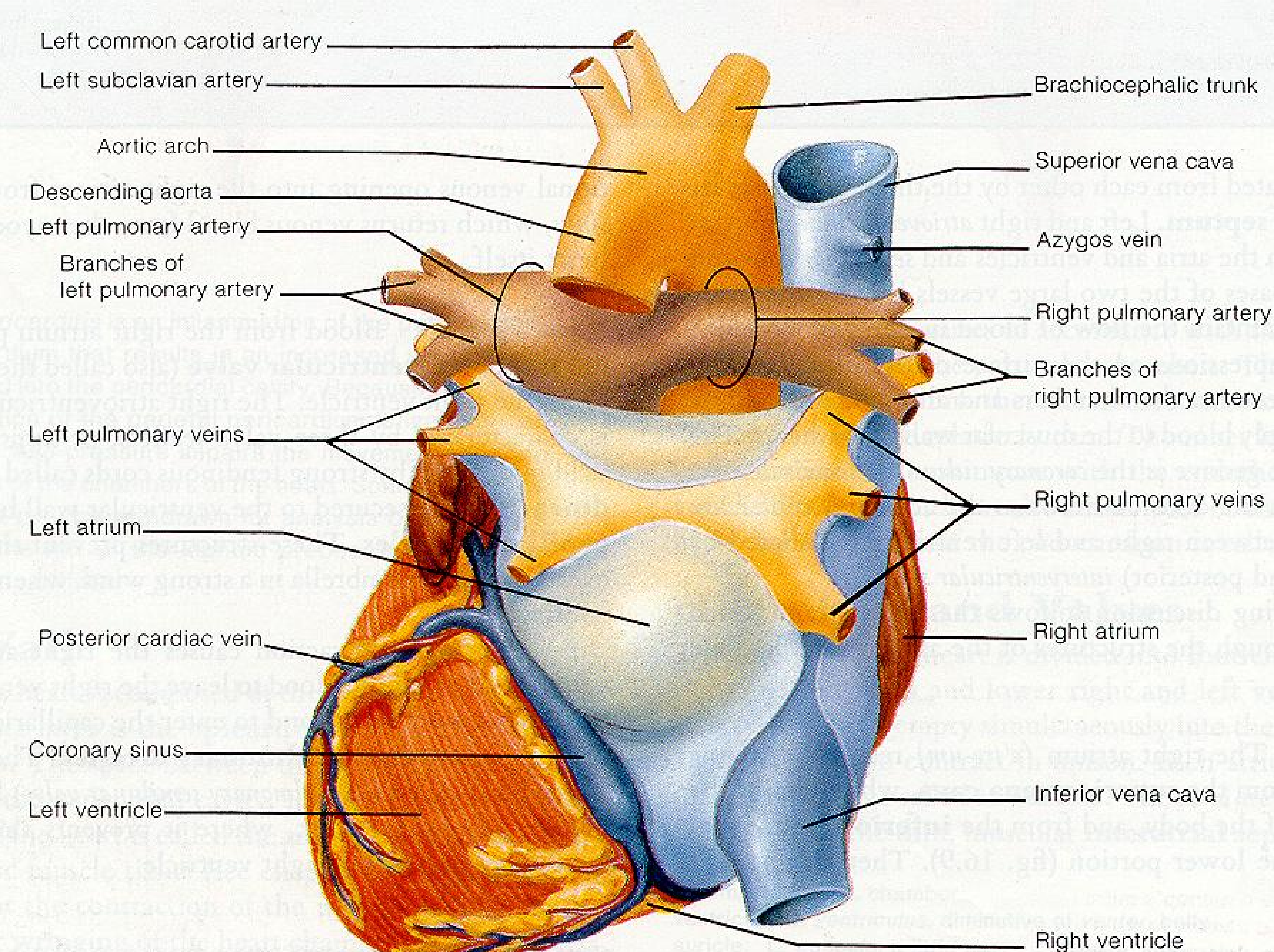
Pulmonary vein
Aorta
Superior vena cava
Ductus arteriosus
Pulmonary artery
Right Atrium
Left Atrium
Left Ventricle
Inferior vena cava
Right Ventricle



Pulmonary vein
Aorta
Foramen ovale
Superior vena cava
Pulmonary artery
Left Atrium
Right Atrium
Left Ventricle
Inferior vena cava
Right Ventricle

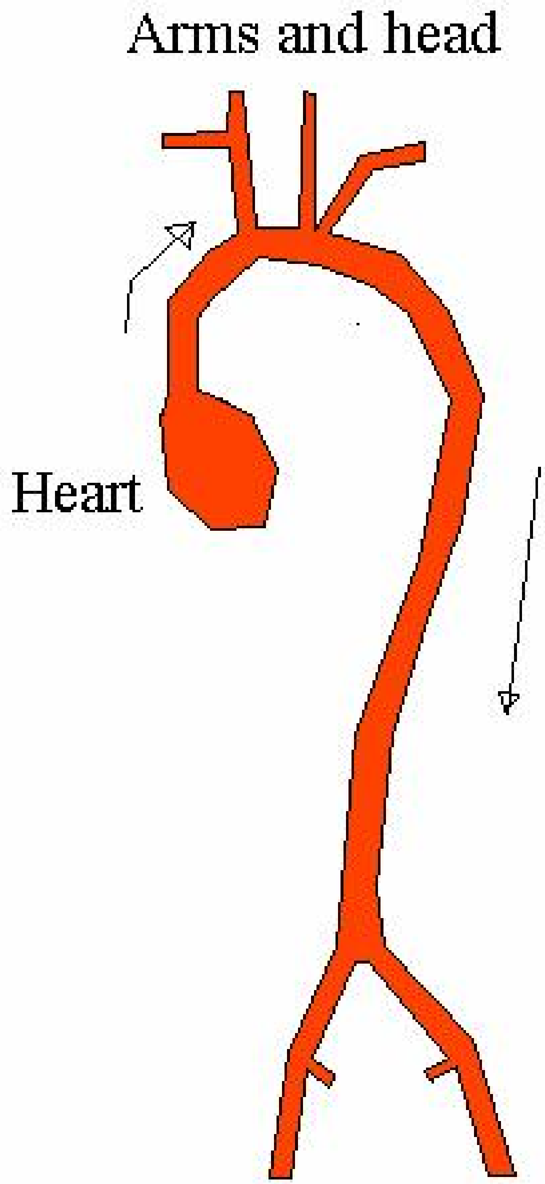
External heart anatomy



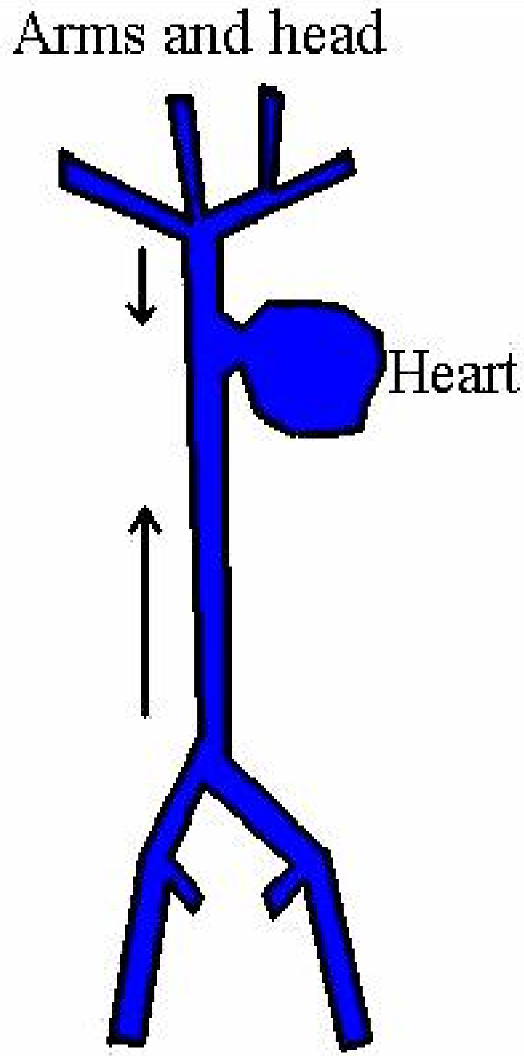


Left common carotid artery
Left subclavian artery
Aortic arch
Descending aorta
Left pulmonary artery
Branches of left pulmonary artery
Left pulmonary veins
Left atrium
Posterior cardiac vein
Coronary sinus
Left ventricle
Brachiocephalic trunk
Superior vena cava
Azygos vein
Right pulmonary artery
Branches of right pulmonary artery
Right pulmonary veins
Right atrium
Inferior vena cava
Right ventricle

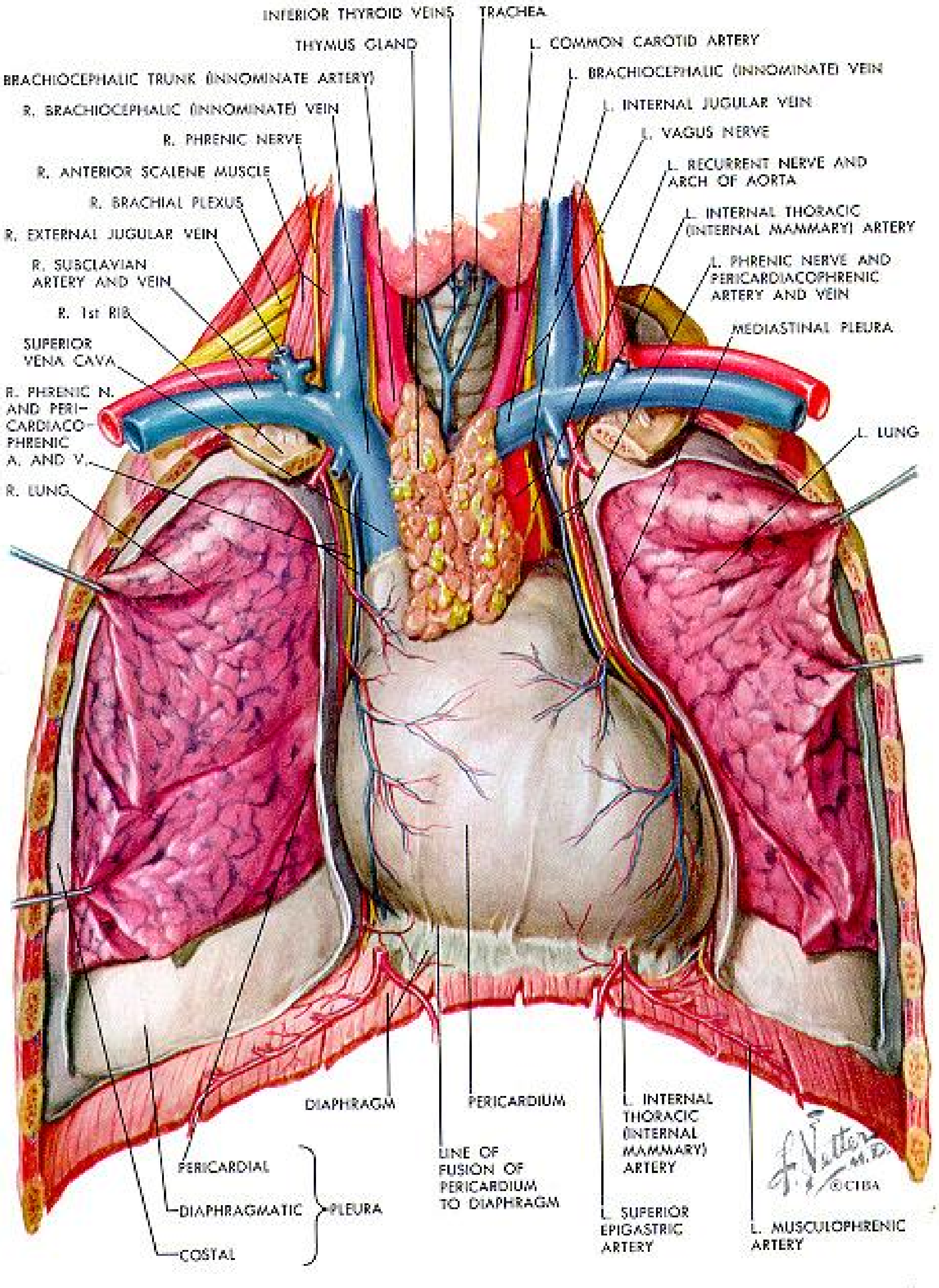
(b)



Arteries



Veins

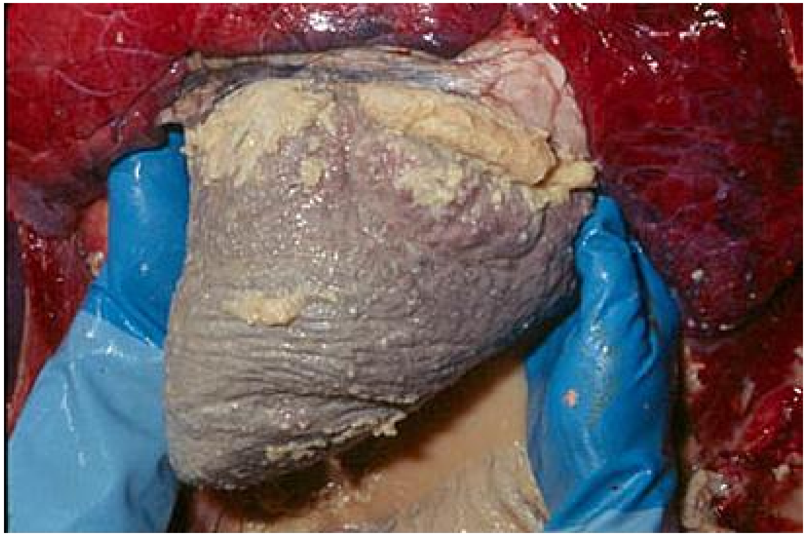


Pericardium

- •Fibrous- dense connective tissue that prevents outstretching of the heart and anchors the heart to the mediastinum
- •Serous- thin double layered serous membrane around the heart
  - •parietal- directly beneath the fibrous pericardium.
  - •visceral (epicardium)- attached directly to the heart
- •Pericardial fluid- a thin film of serous fluid that is contained within the pericardial sac (pericardial cavity) and serves to prevent friction between the membranes of the heart.

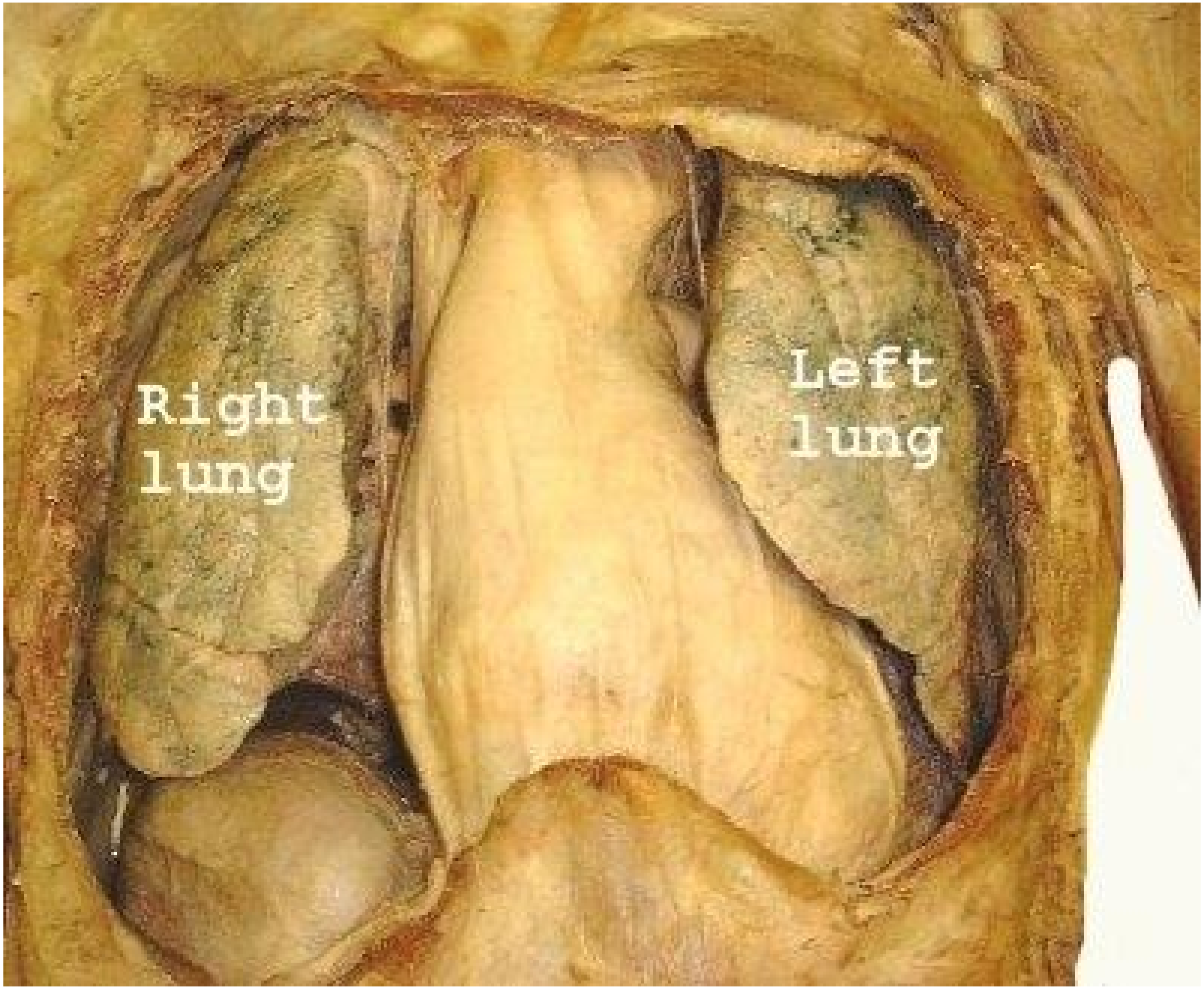
- •Cardiac tamponade

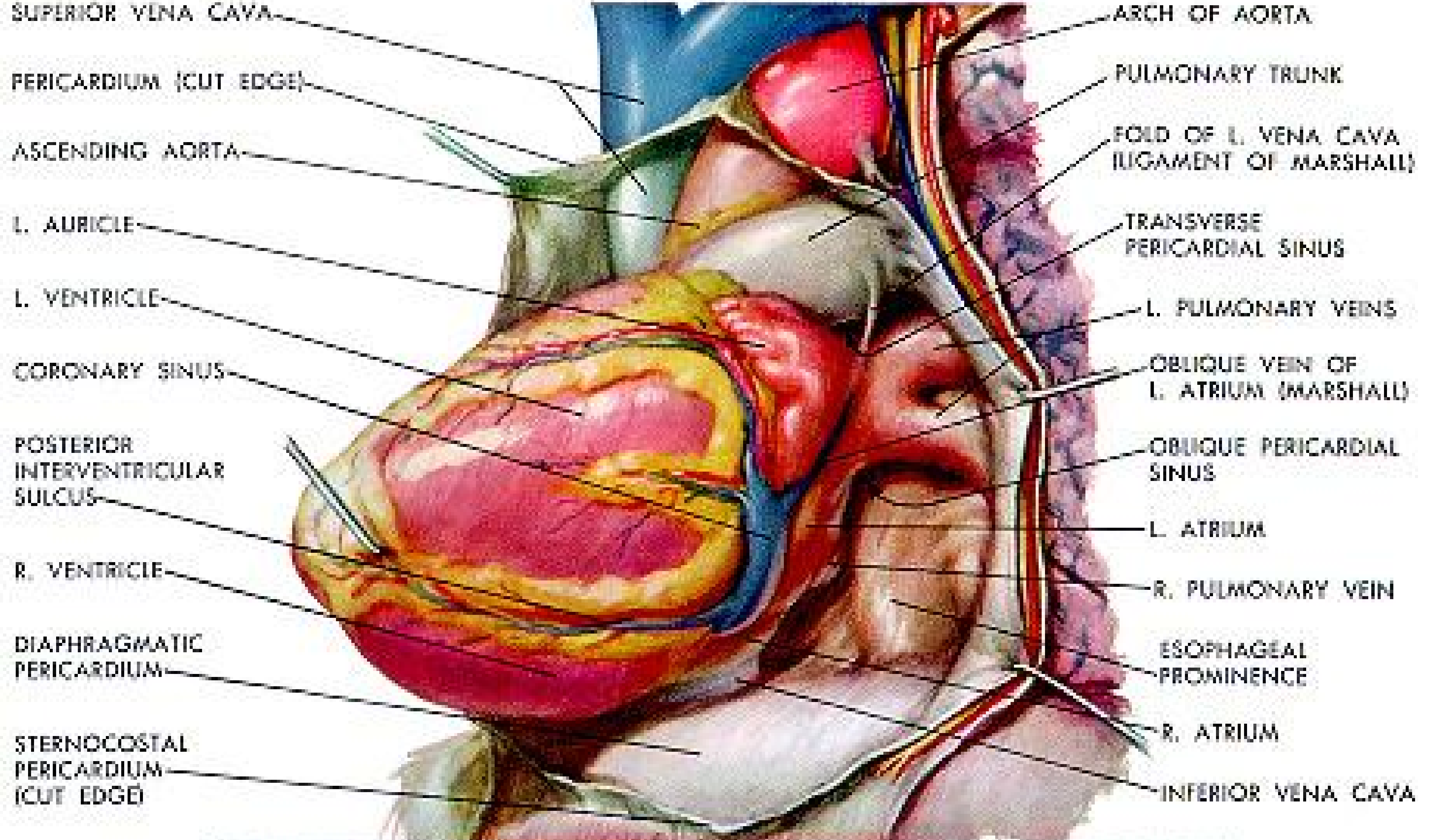
Pericarditis (Cow's Heart)



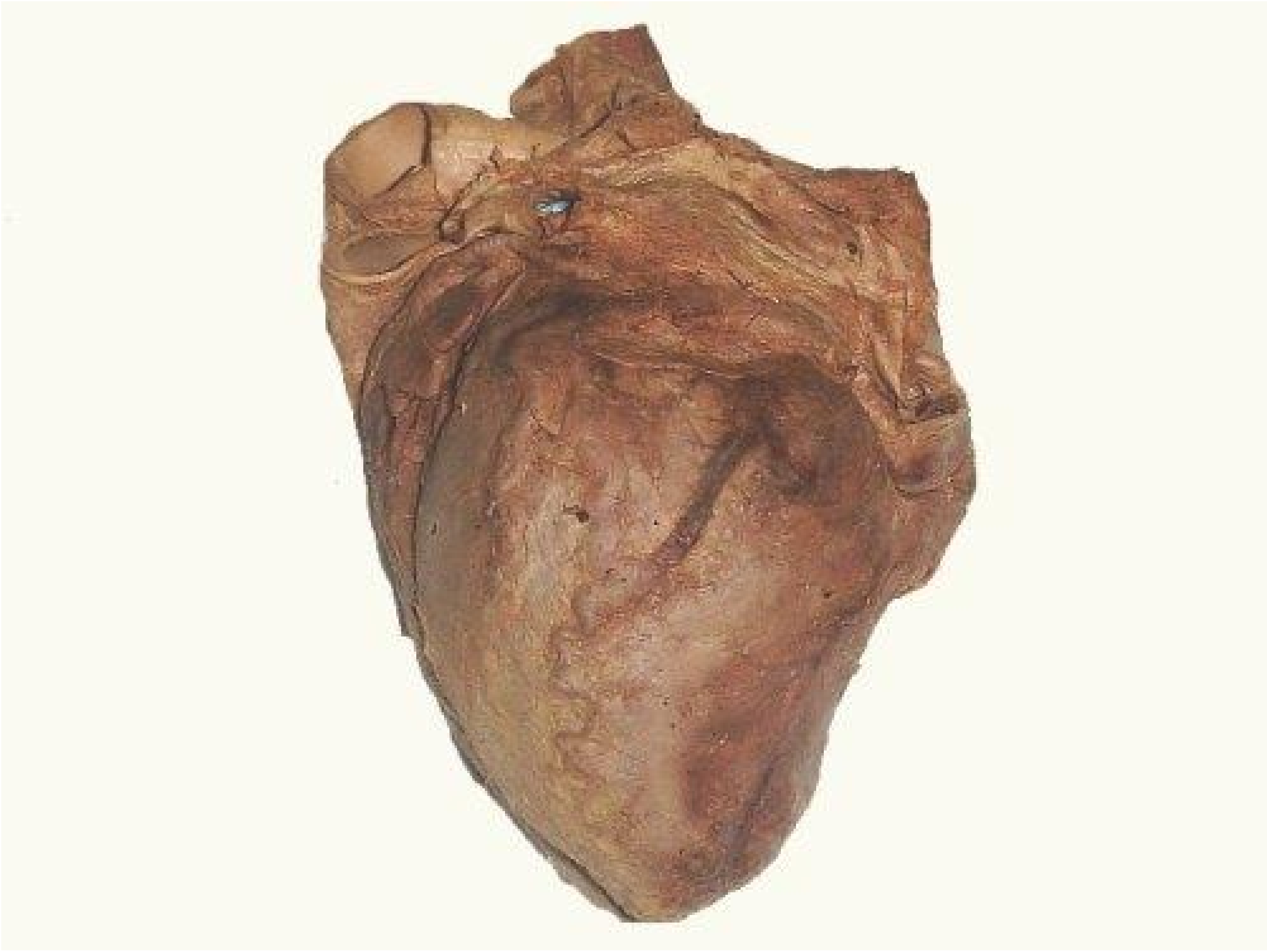
the heart sac has been opened and you can see that the heart is surrounded by fibrous material. This material is due to infection within the heart sac. This can be referred to as a "shaggy heart".

This is a heart after the fibrous material has been removed.

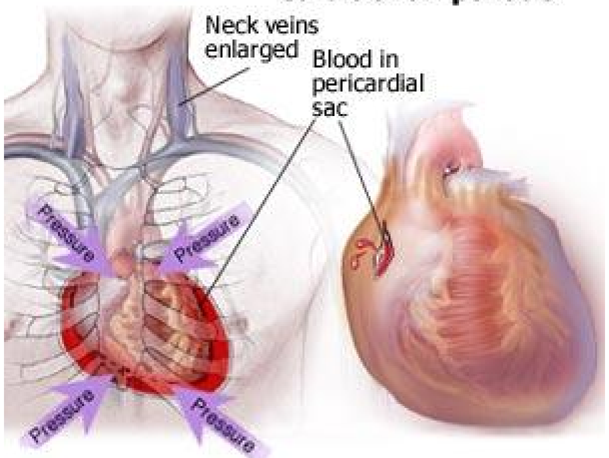

Right lung
Left lung



HEART DRAWN OUT OF PERICARDIAL SAC (OPENED AND VIEWED 3/4 FROM LEFT)

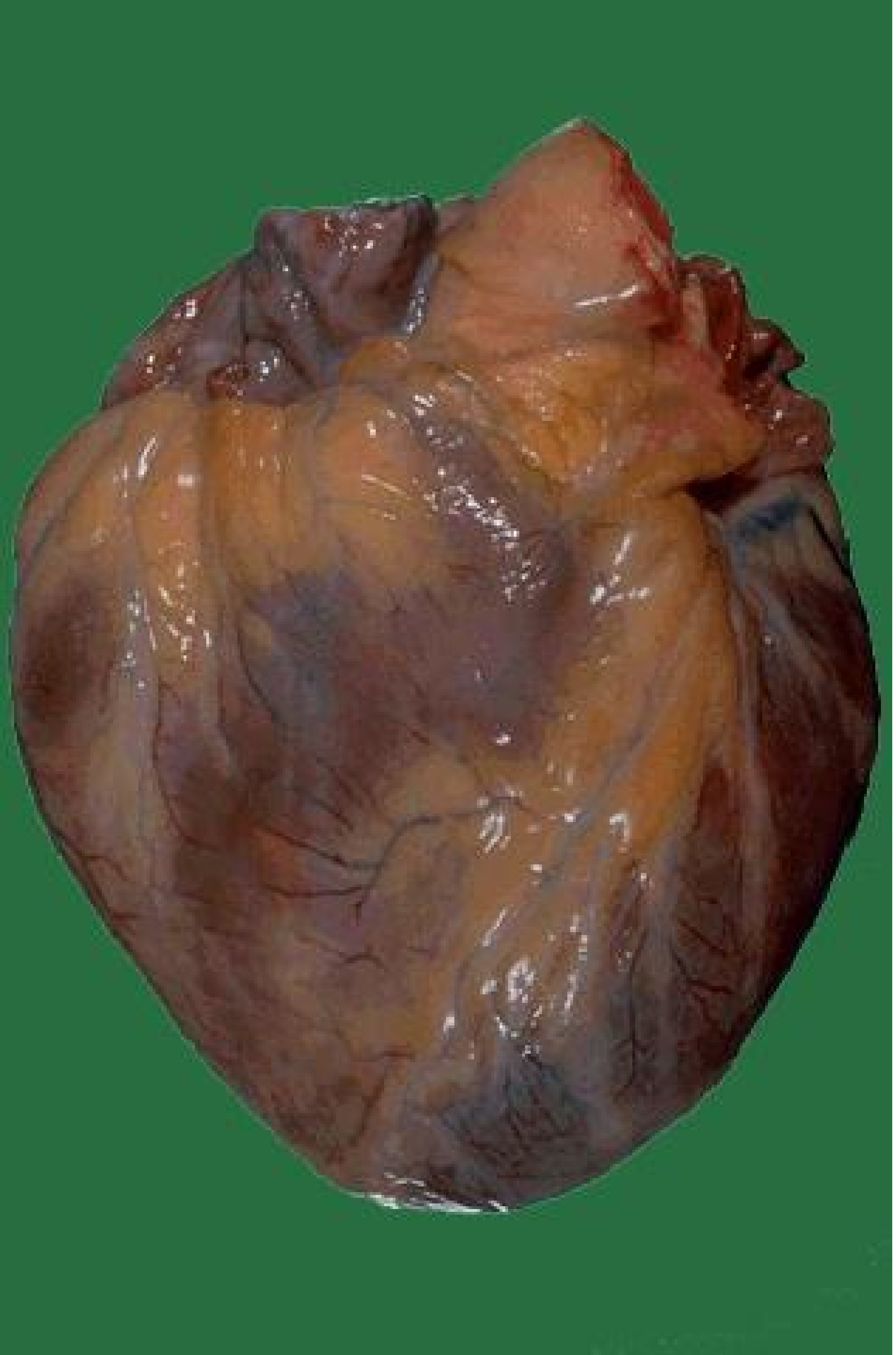


Cardiac Tamponade

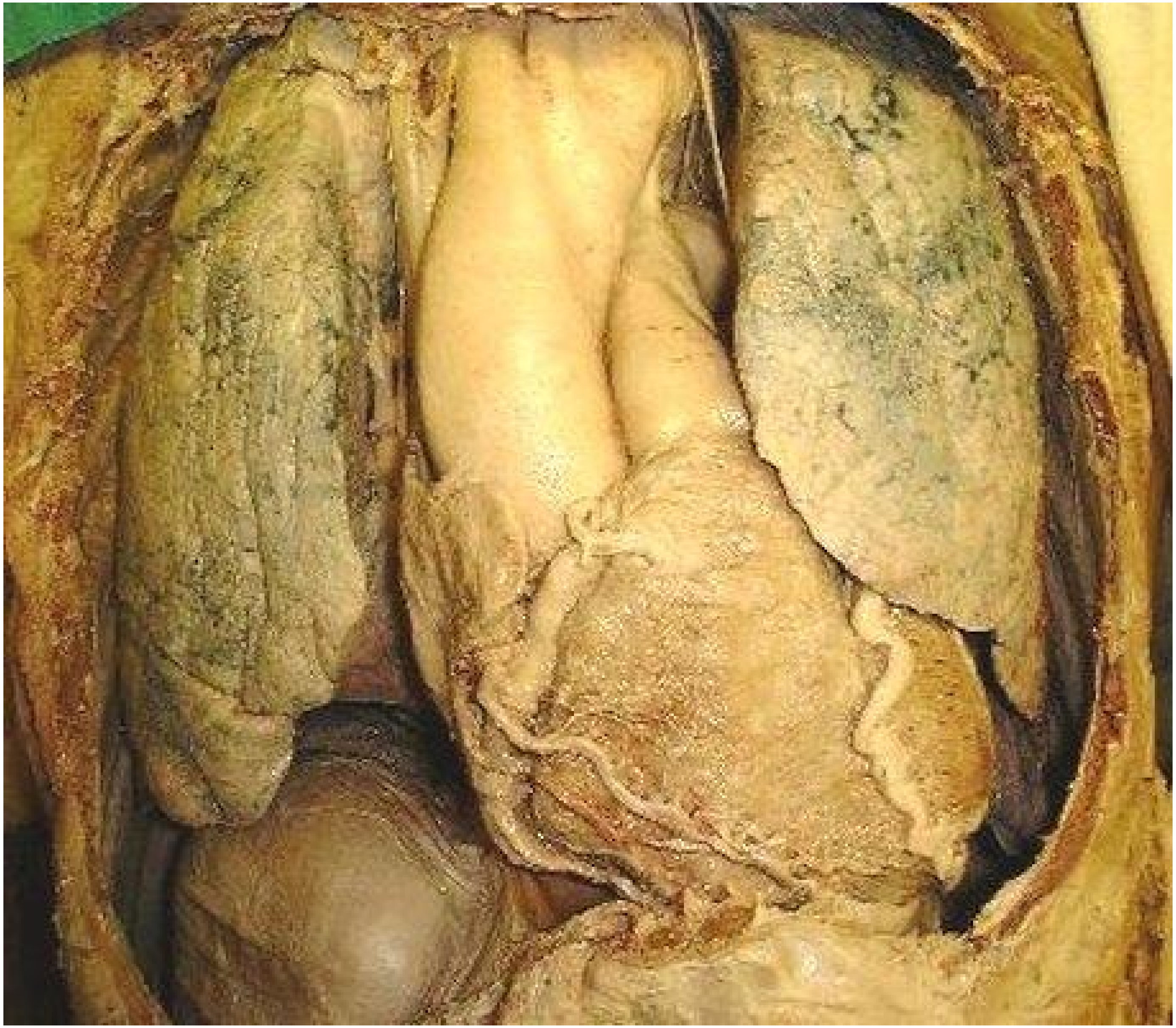


Under pressure, blood or other fluid in the pericardial sac compresses the heart, which interferes with heart function.

Perecardiocentesis, Movies.htm



This is the external appearance of a **normal heart**.The epicardial surface is smooth and glistening.The amount of epicardial fat is usual.The left anterior descending coronary artery extends down from the aortic root to the apex.

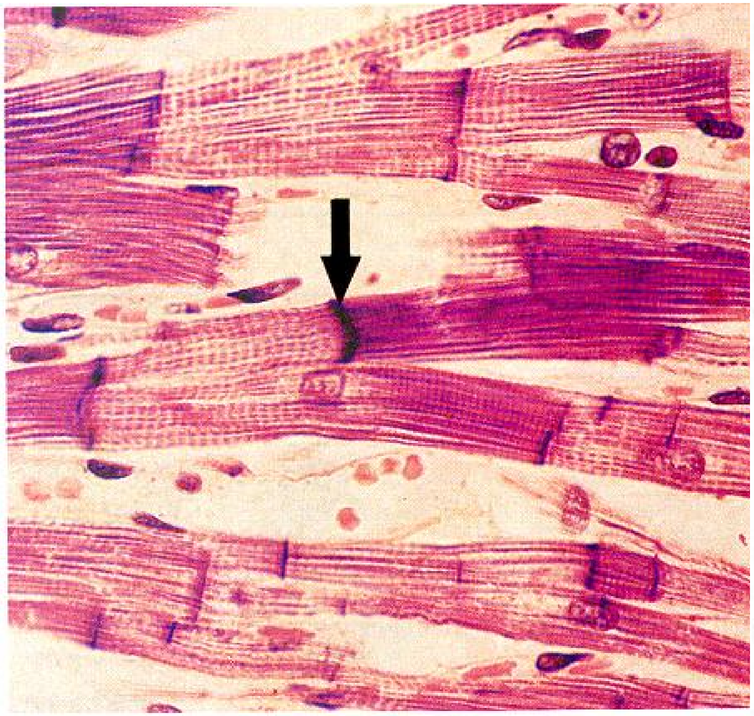


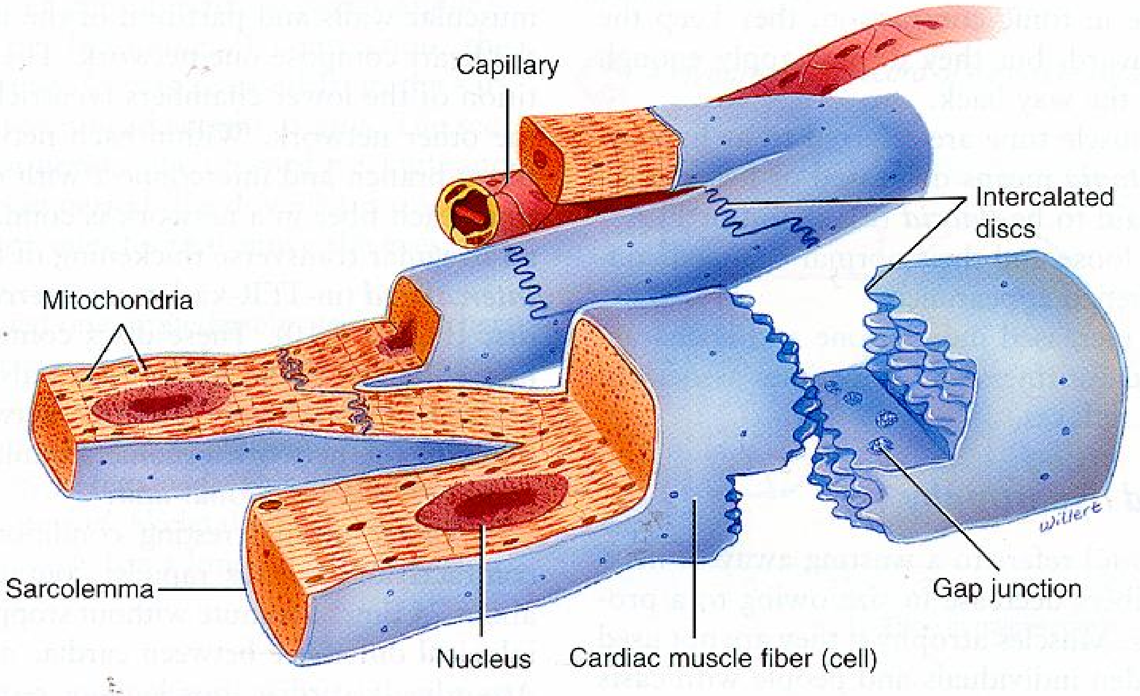
Cardiac Muscle

- involuntary
- striated
- have only a single centrally located nuclei
- exhibit branching

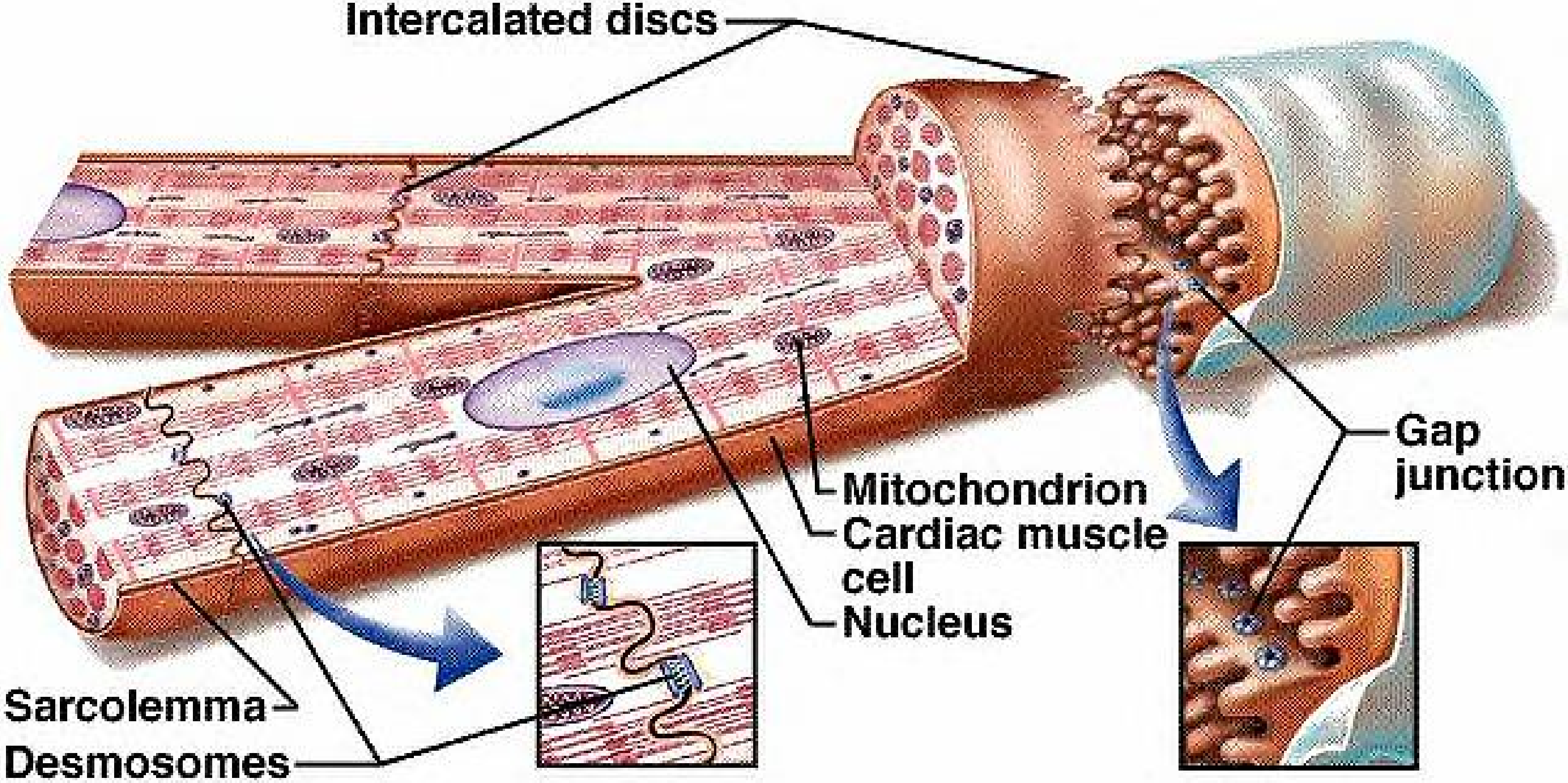
Consist of two separate networks:atria and ventricles

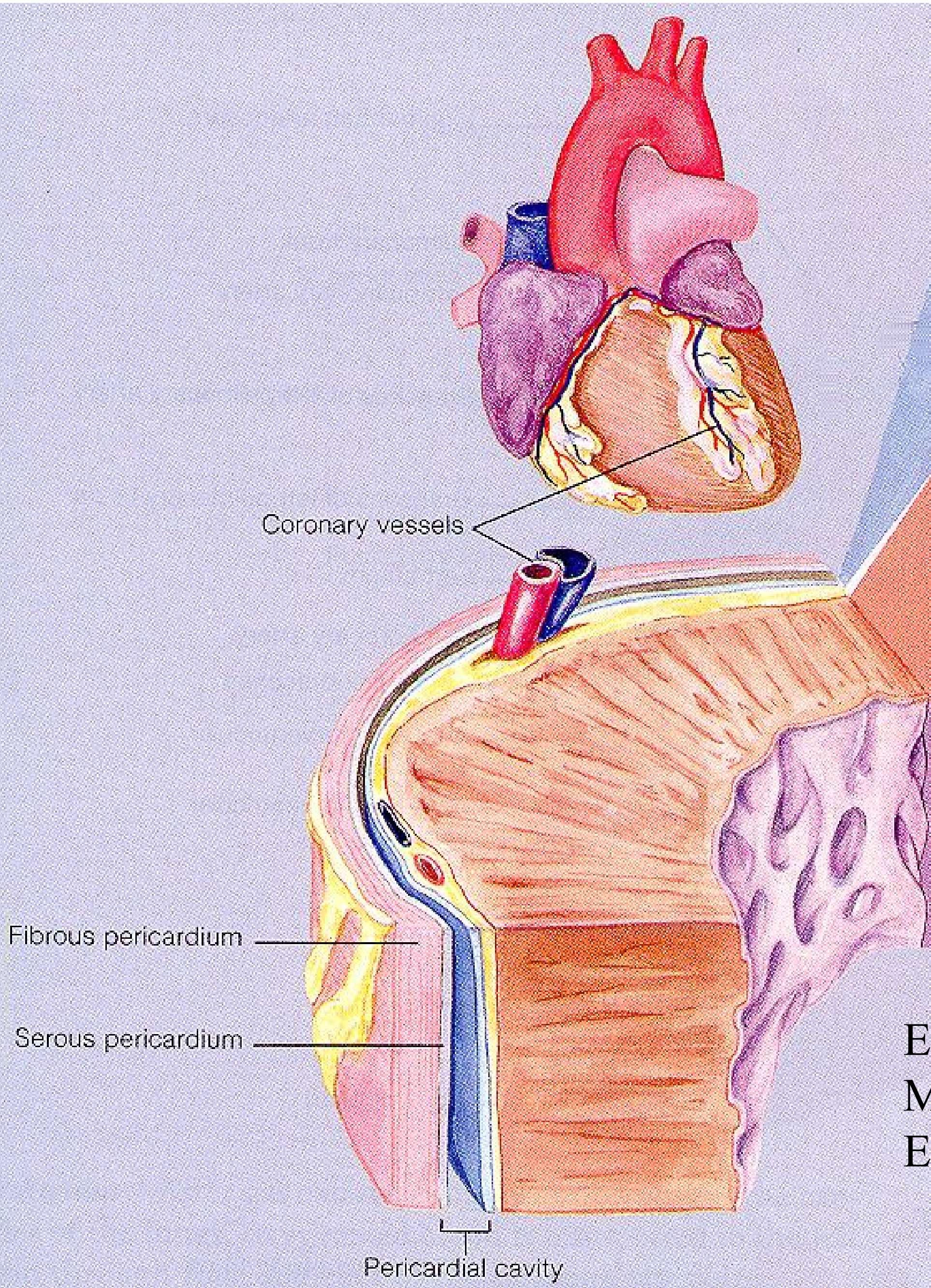
- fibers in each network are connected to each other via **intercalated disks** (irregular transverse thickening of the sarcolemma).
- the discs contain **gap junctions**, which conduct muscle action potentials from one fiber to the other. This enables each network to conduct as a unit.





Cardiac Muscle Structure and Intercalated Discs

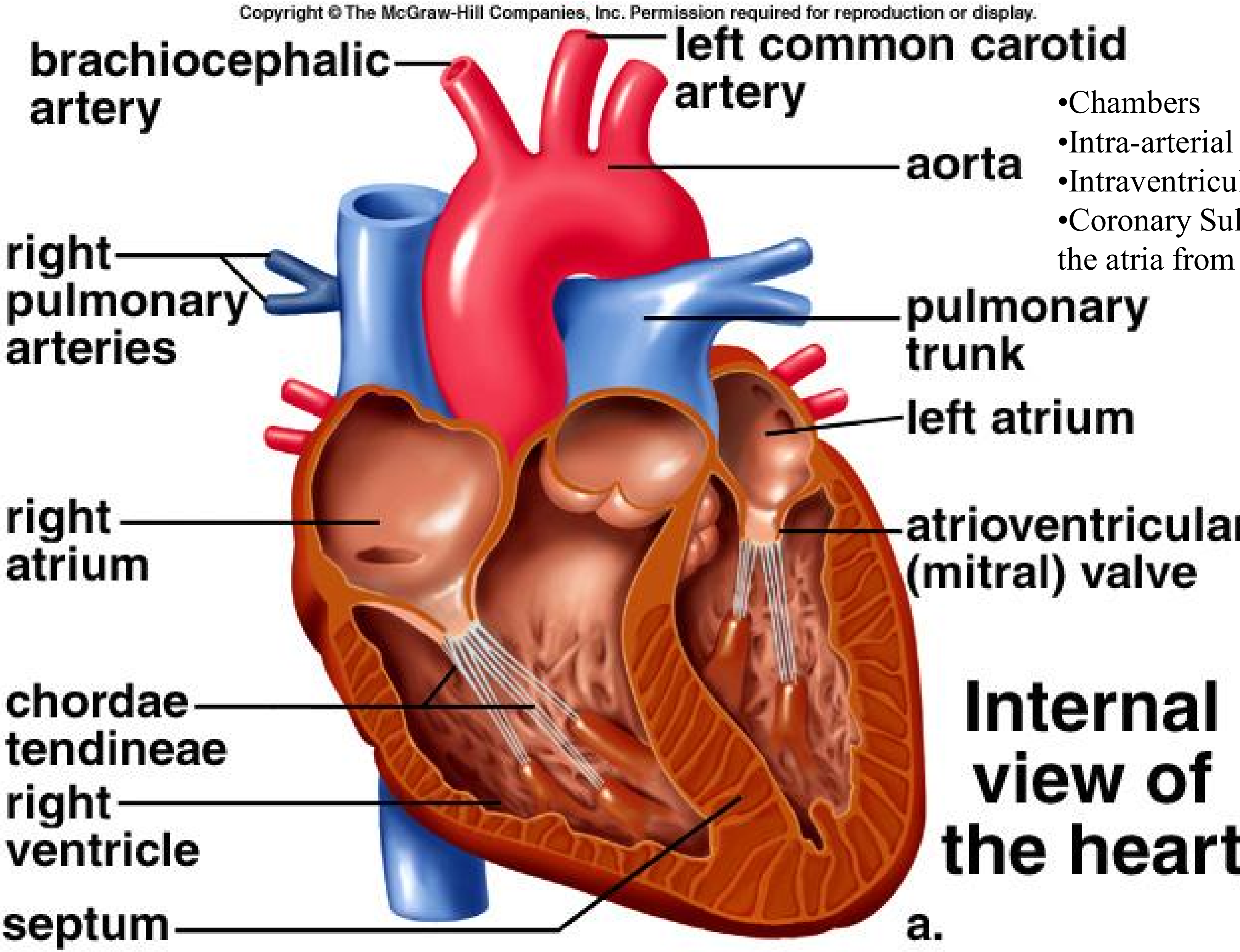




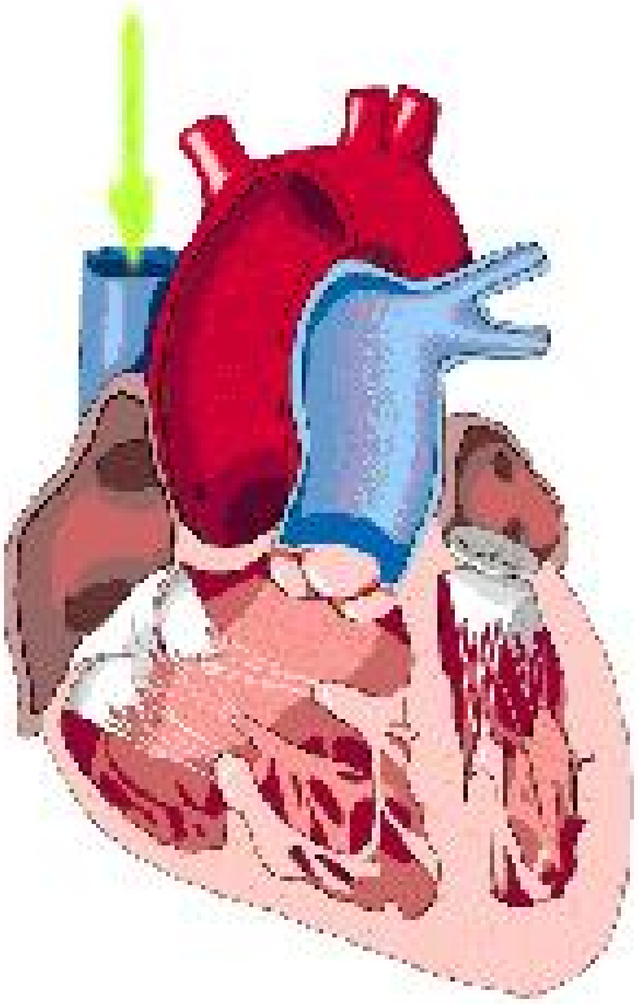
Layer	Characteristics	Function
Epicardium (visceral pericardium)	Serous membrane including blood capillaries, lymph capillaries, and nerve fibers	Serves as lubricative outer covering
Myocardium	Cardiac muscle tissue separated by connective tissues and including blood capillaries, lymph capillaries, and nerve fibers	Provides muscular contractions that eject blood from the heart chambers
Endocardium	Endothelial tissue and a thick subendothelial layer of elastic and collagenous fibers	Serves as protective inner lining of the chambers and valves

Paras

Epicarditis
Myocarditis
Endocarditis



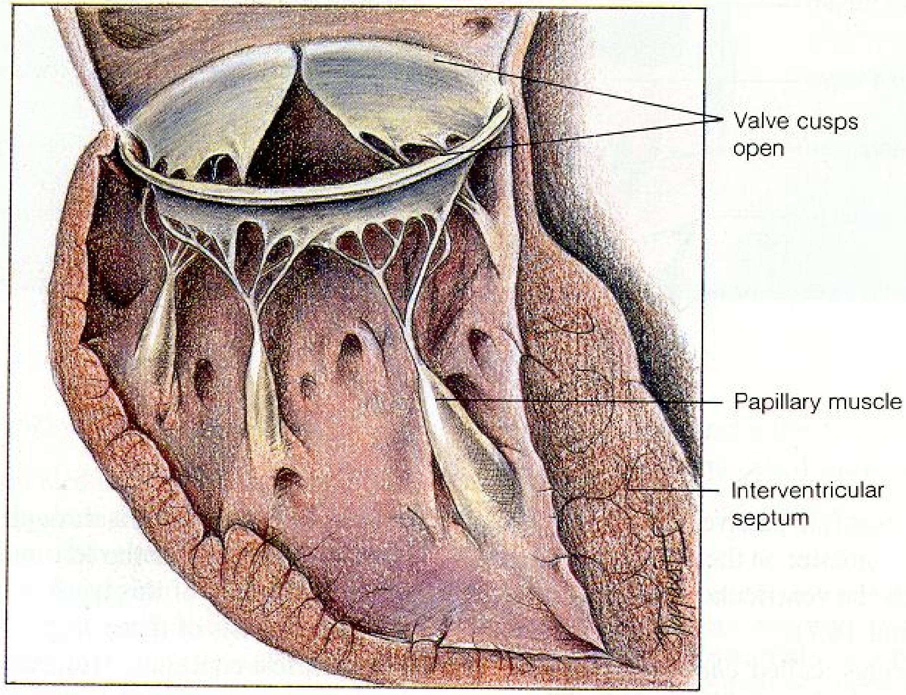
- Chambers
- Intra-arterial Septum
- Intraventricular Septum
- Coronary Sulcus- separates the atria from the ventricles

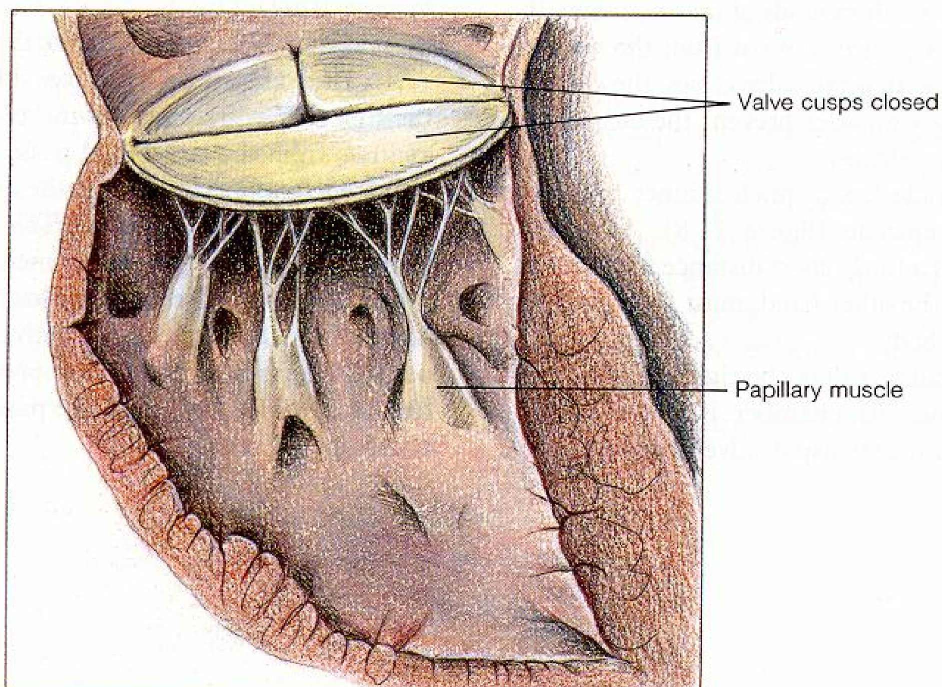


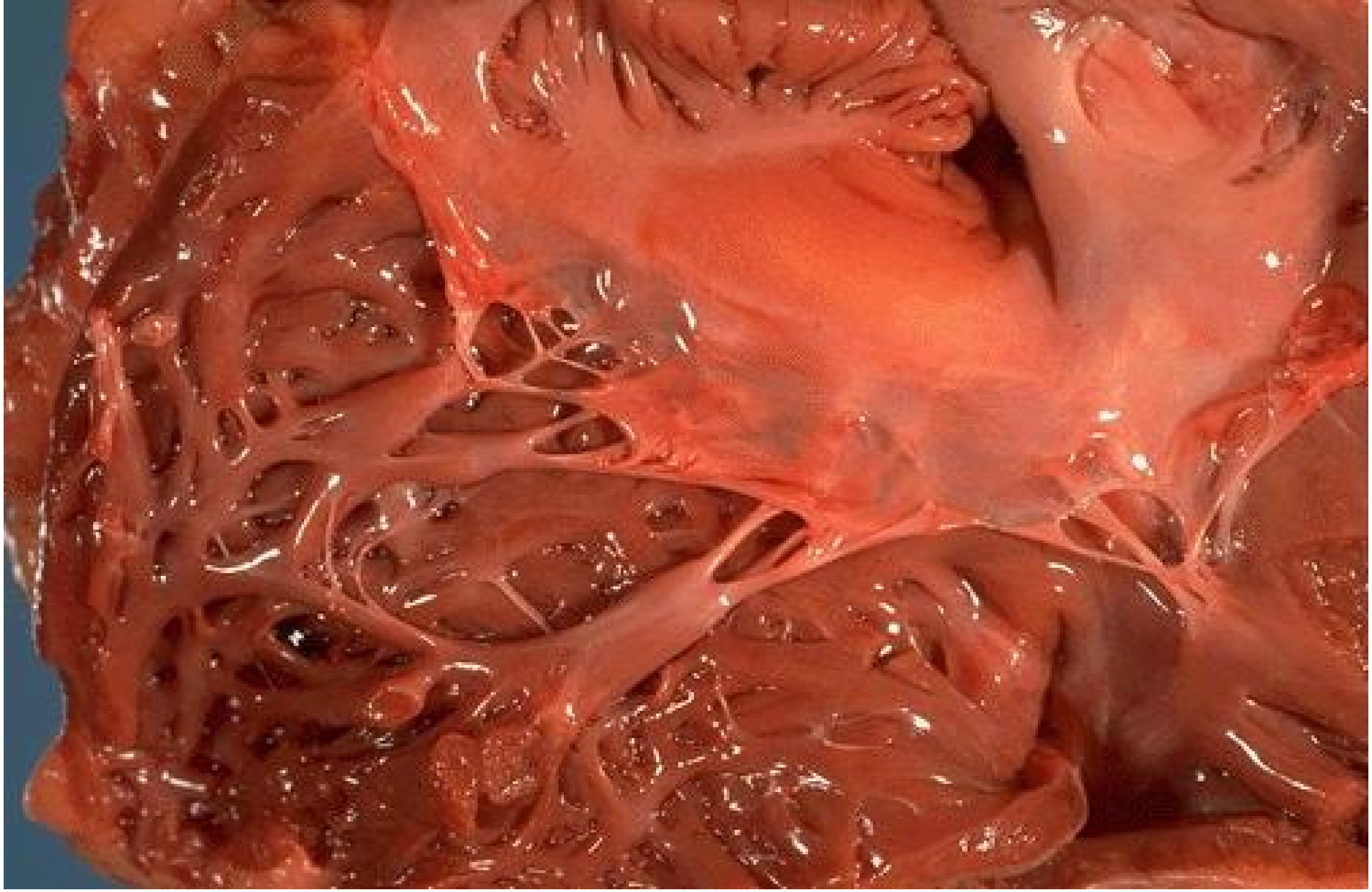
- Right Atrium
- Tricuspid Valve
- Right Ventricle
- Pulmonic Valve
- Pulmonary Arteries
- Pulmonic Veins
- Left Atrium
- Mitral Valve
- Left Ventricle
- Aortic Valve
- Aorta

Atrioventricular Valves- prevent backflow into the atria

- tricuspid
- bicuspid (mitral)
- papillary muscles
- chordae tendineae





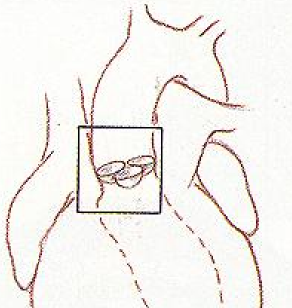


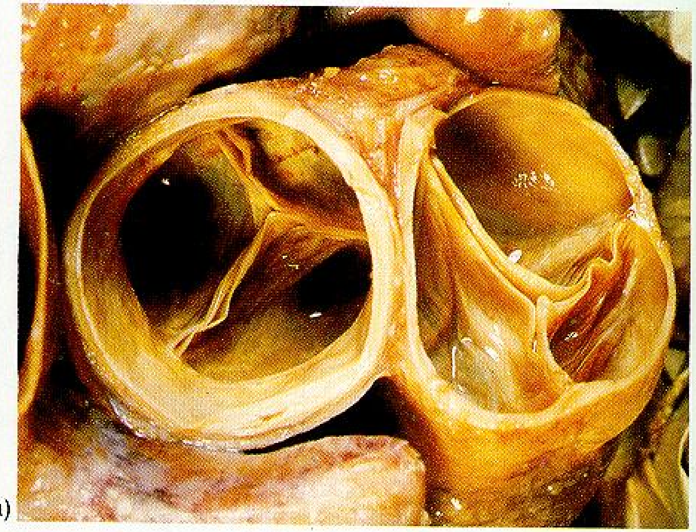
- This is the tricuspid valve. The leaflets and thin and delicate. Just like the mitral valve, the leaflets have thin chordae tendineae that attach the leaflet margins to the papillary muscles of the ventricular wall below.

Semilunar Valves- prevent backflow into the ventricles

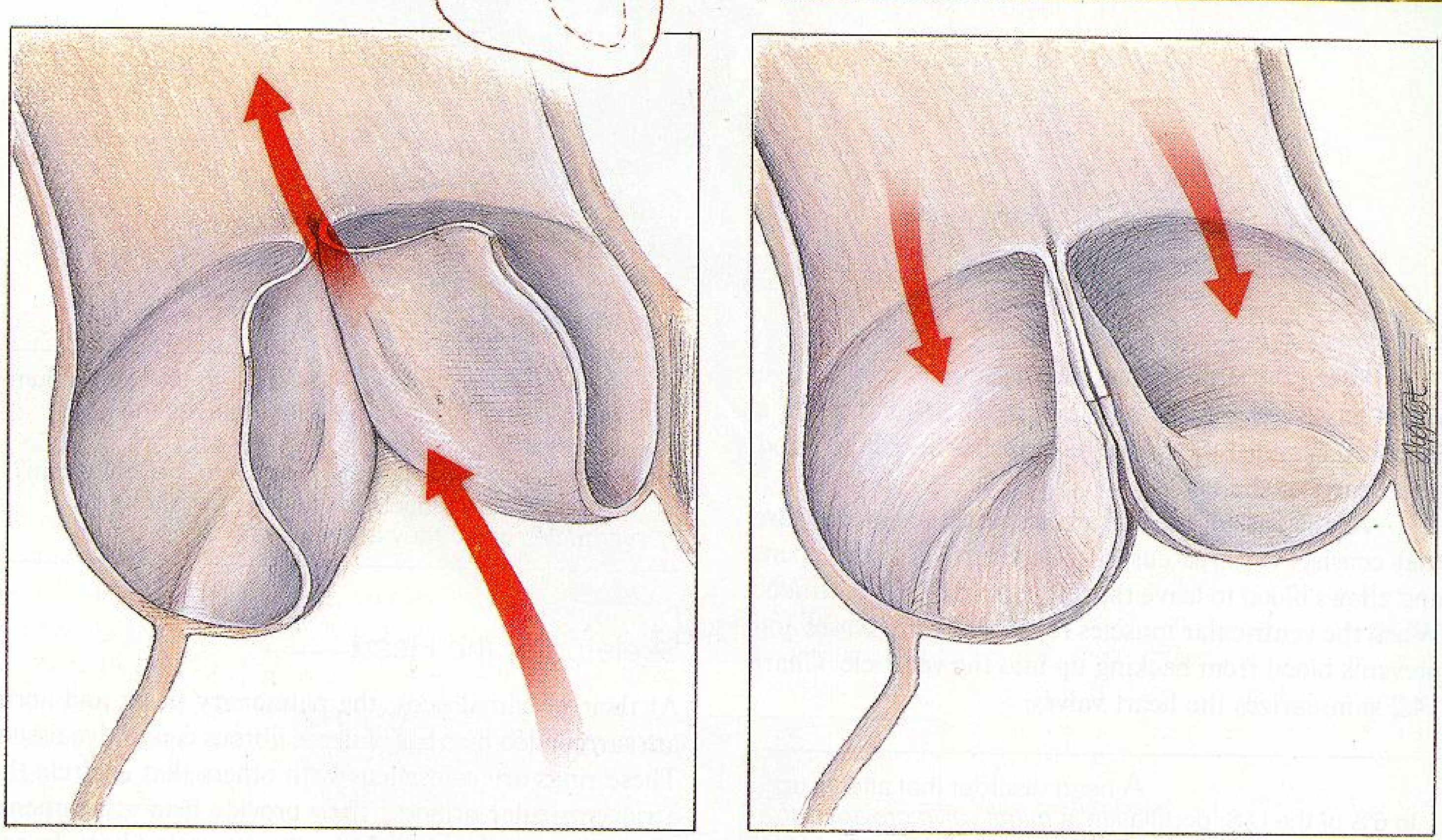
Aorta

Pulmonary

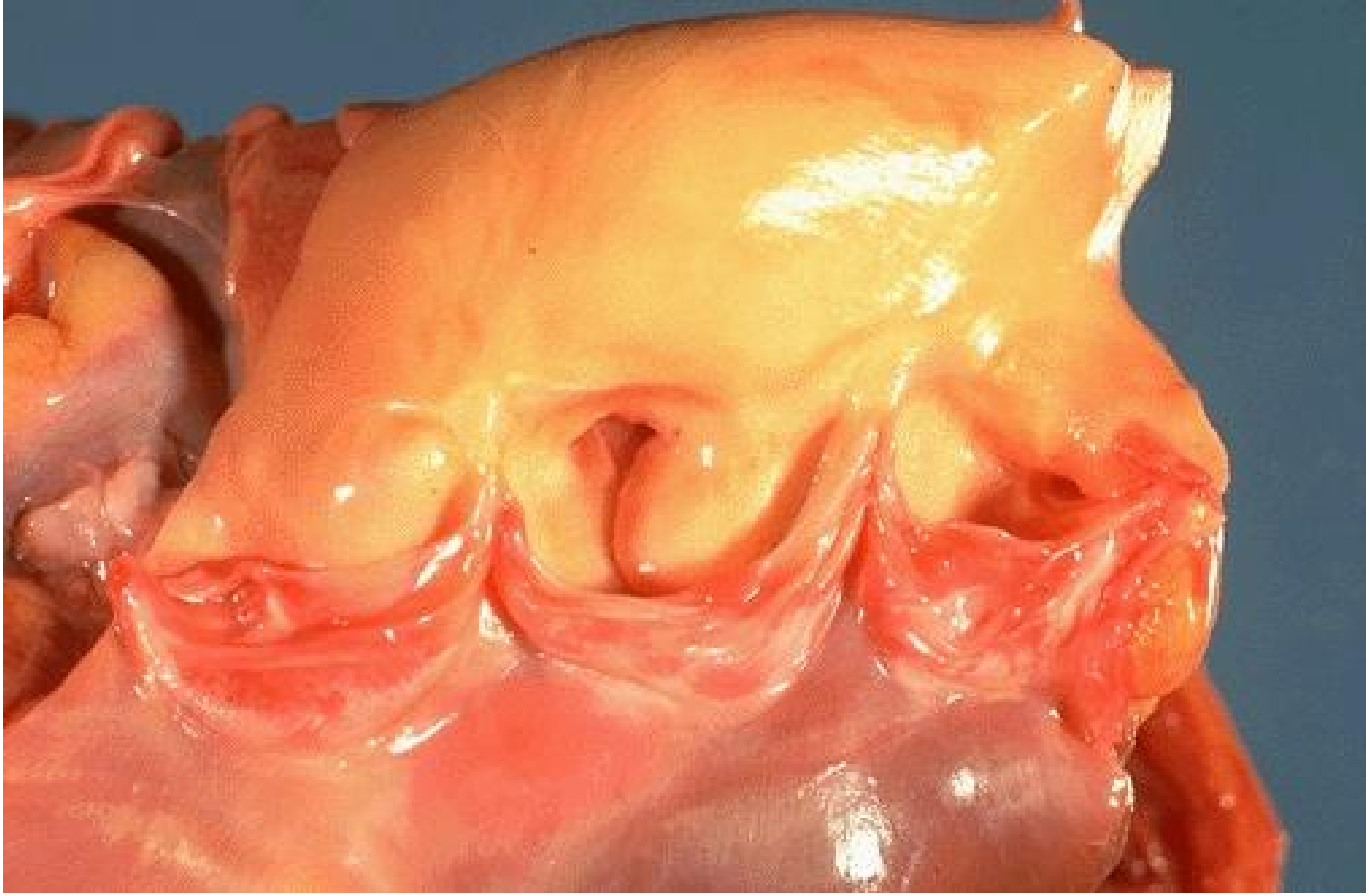




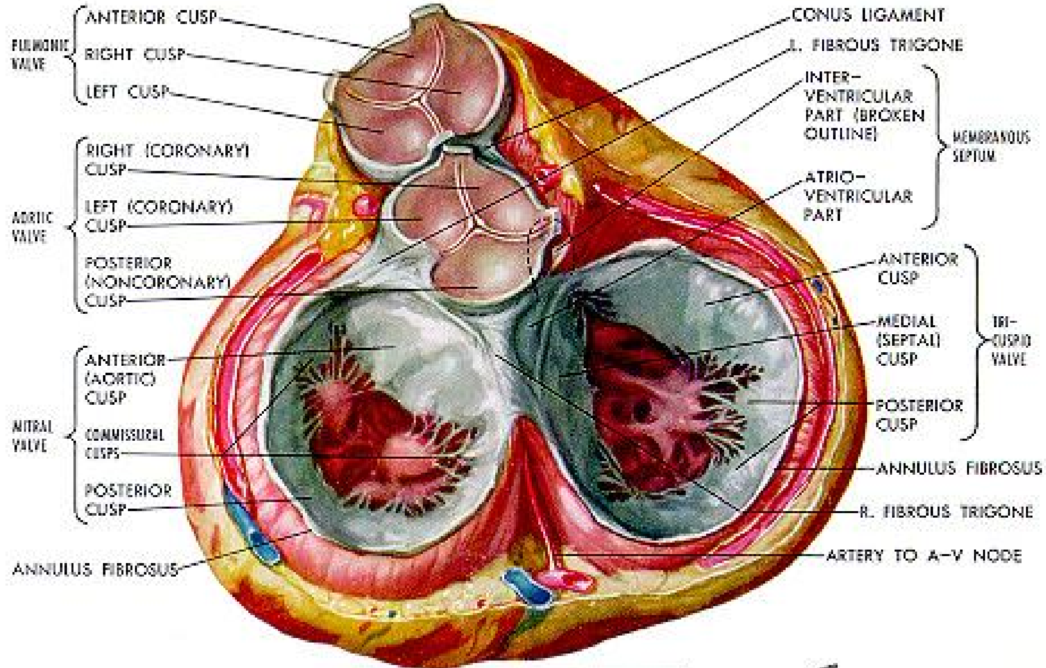
(a)



(b)

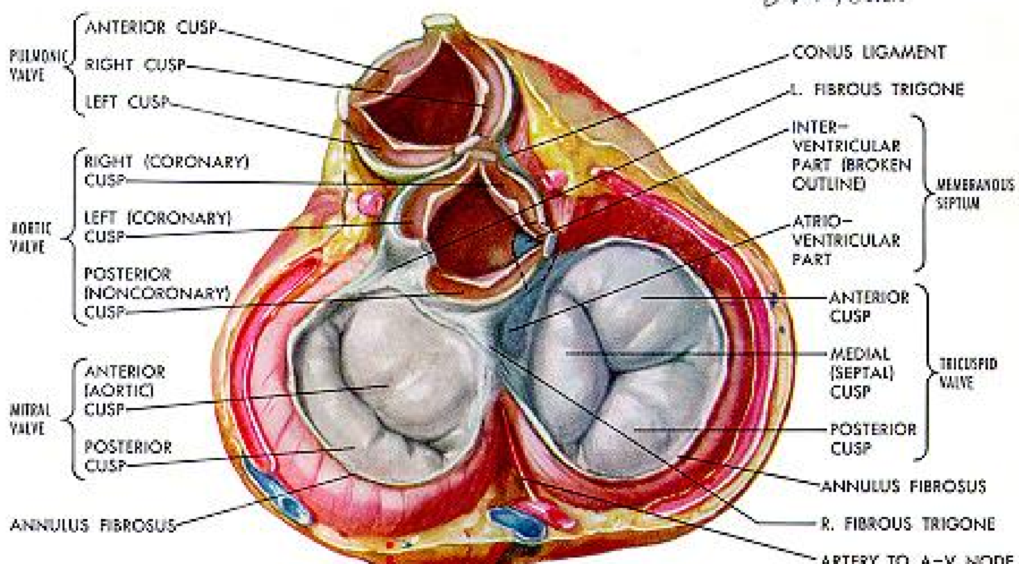


- The aortic valve shows three thin and delicate cusps. The coronary artery orifices can be seen just above. The endocardium is smooth, beneath which can be seen a red-brown myocardium. The aorta above the valve displays a smooth intima with no atherosclerosis.



THE HEART IN DIASTOLE: VIEWED FROM BASE WITH ATRIA REMOVED

F. Netter M.D. ©CIBA



THE HEART IN SYSTOLE: VIEWED FROM BASE WITH ATRIA REMOVED

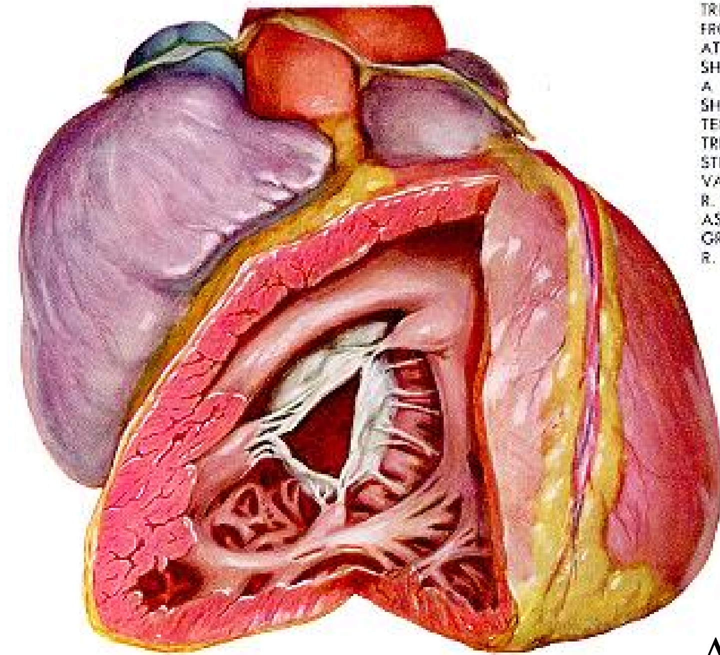
Heart Valve Movie

Opening Pericardium

Pumping of heat in chest cavity

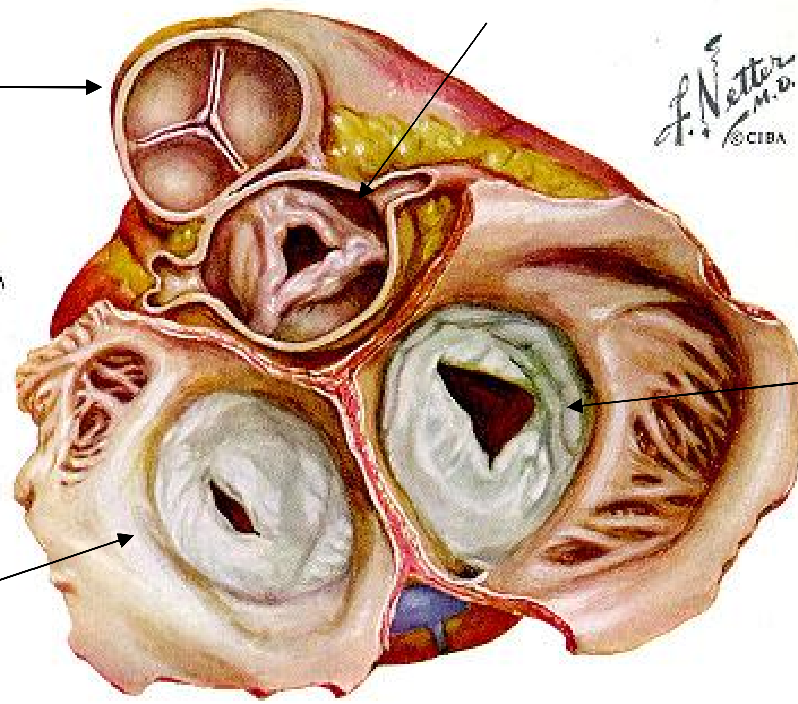
Viewing and lifting the heart

Heart removal from the chest

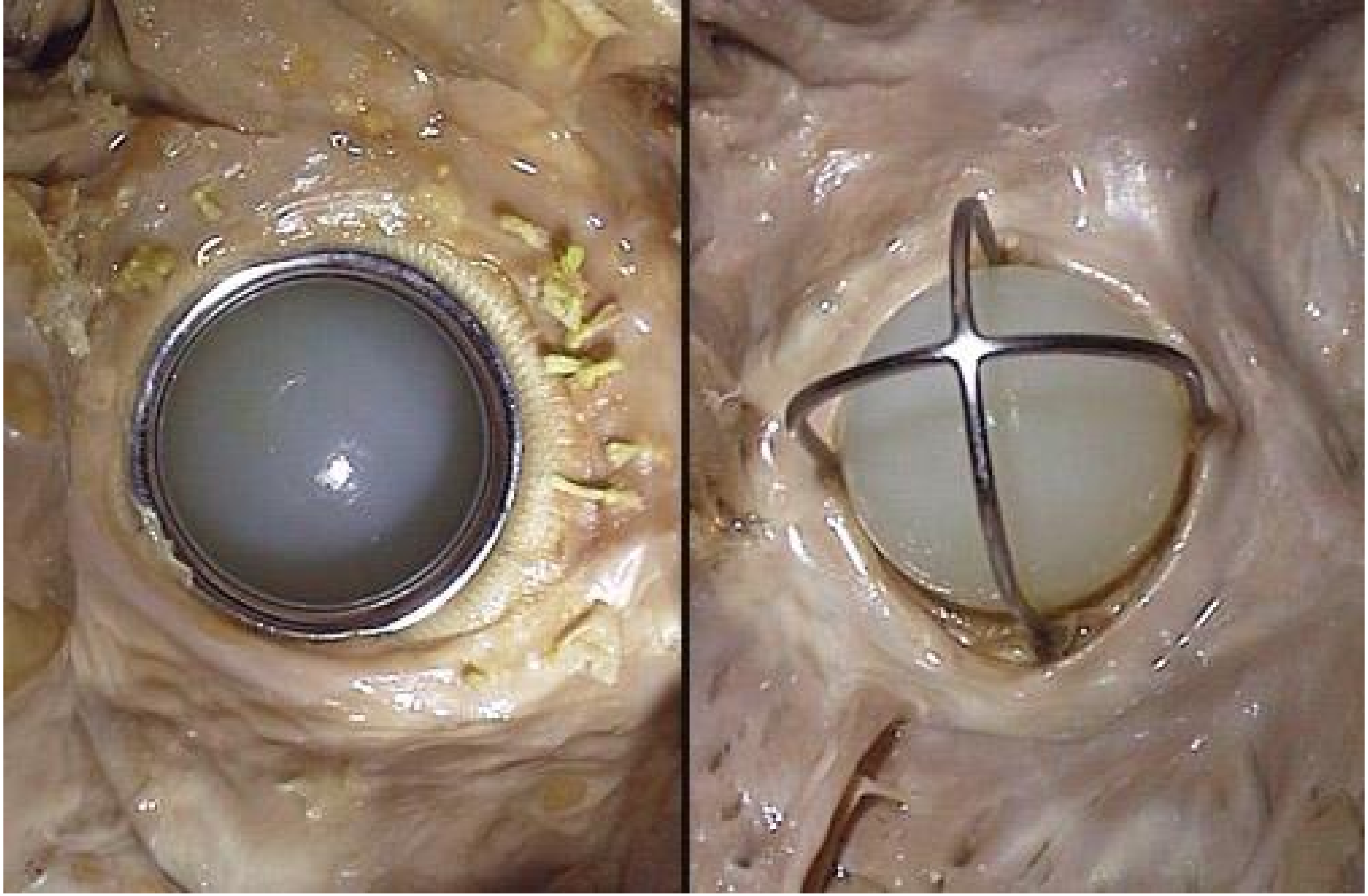


TRICUSPID VALVE VIEWED FROM BELOW: SOME FUSION AT EACH COMMISSURE, SHORTENING OF CUSPS, AND A LITTLE THICKENING AND SHORTENING OF CHORDAE TENDINEAE, LEAVING A TRIANGULAR ORIFICE OF A STENOTIC, INSUFFICIENT VALVE; HYPERTROPHY OF R. VENTRICLE DUE TO ASSOCIATED MITRAL DISEASE; GREAT ENLARGEMENT OF R. ATRIUM

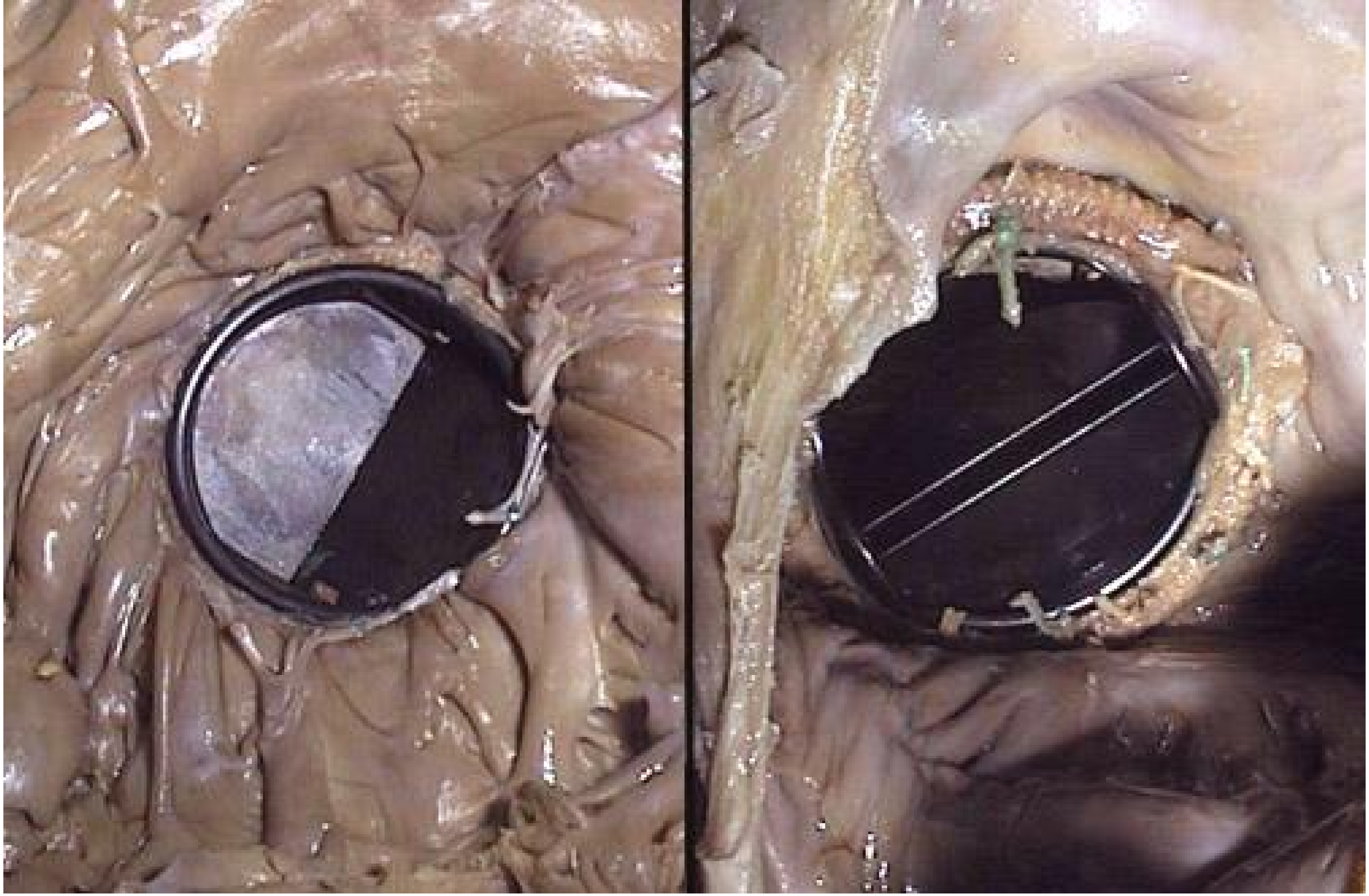
Valvular Heart Disease
- Valvular incompetence
- Stenosis
- Regurgitation



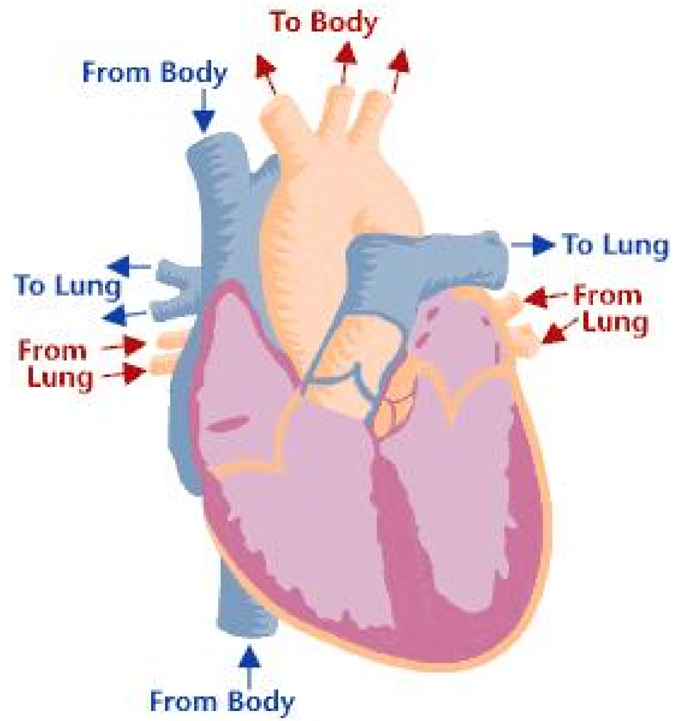
MULTIVALVULAR DISEASE VIEWED FROM ABOVE: AORTIC VALVE STENOTIC AND INCOMPETENT FROM FUSION OF ALL THREE COMMISSURES; MITRAL VALVE HAS ONLY A "SLITLIKE" STENOTIC ORIFICE, TRICUSPID VALVE A TRIANGULAR, FIXED, STENOTIC, AND INCOMPETENT ORIFICE; PULMONARY VALVE NORMAL



- This is a mechanical valve prosthesis of the older ball and cage variety. Such mechanical prostheses will last indefinitely from a structural standpoint, but the patient requires continuing anticoagulation because of the exposed non-biologic surfaces. The superior aspect (here the left atrium) is seen at the left, while the outflow is at the right into the left ventricle in this mitral valve prosthesis.

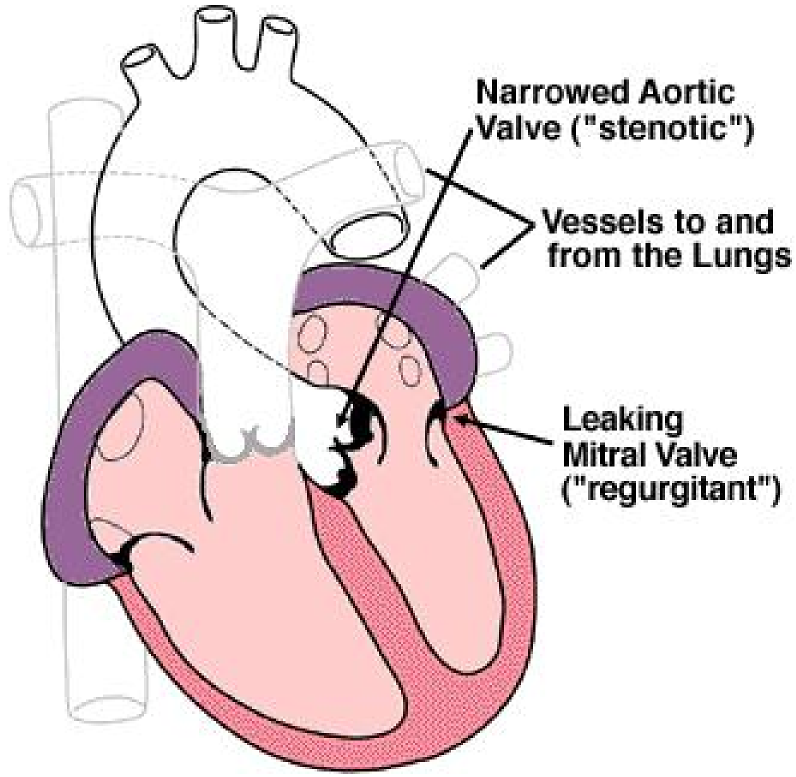


- This is a mechanical valve prosthesis of the more modern tilting disk variety. Such mechanical prostheses will last indefinitely from a structural standpoint, but the patient requires continuing anticoagulation because of the exposed non-biologic surfaces. The superior aspect (here the left atrium) is seen at the left, while the outflow, with the two leaflets tilted outward toward the left ventricle, is at the right in this mitral valve prosthesis.

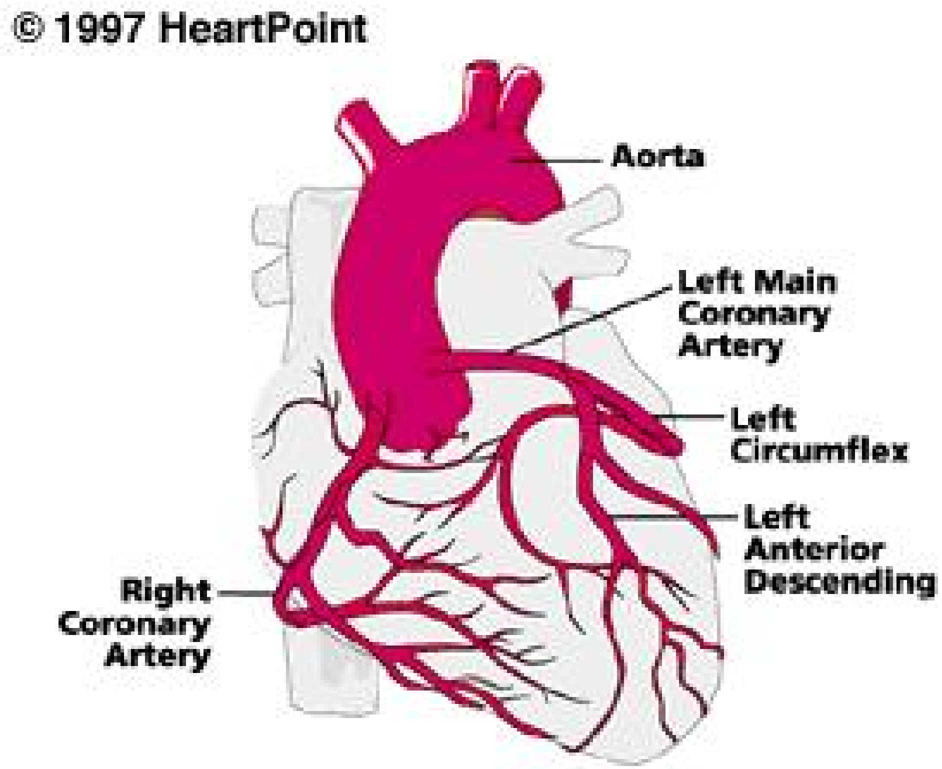


To Body
From Body
To Lung
From Lung
To Lung
From Lung
From Body

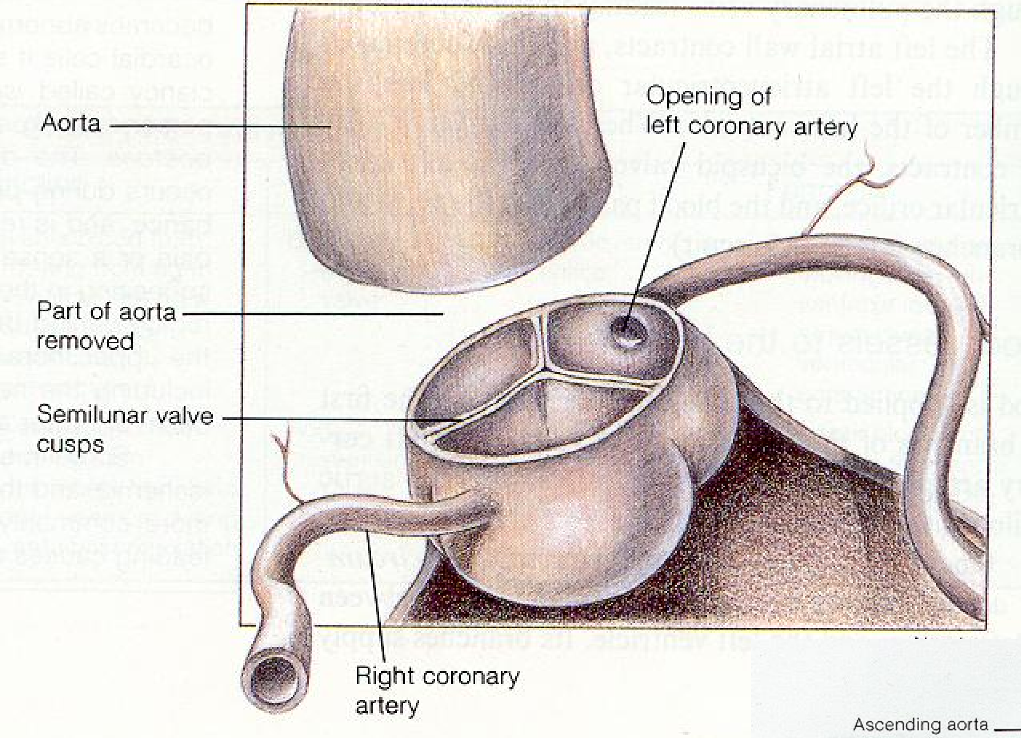
Valvular Regurgitation and Stenosis



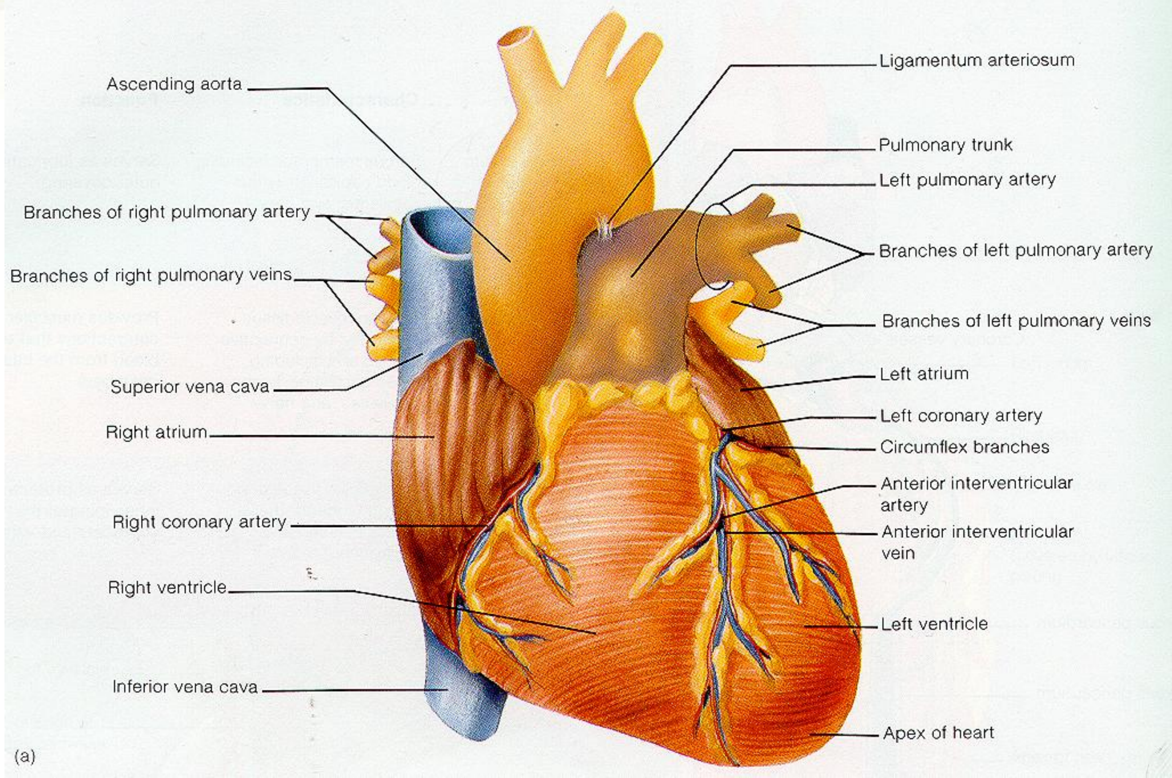
Coronary Circulation



Coronary Circulation

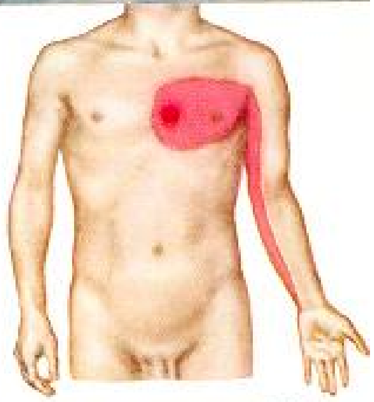


Ischemia
Angina pectoris
Myocardial infarction
Ventricular fibrillation



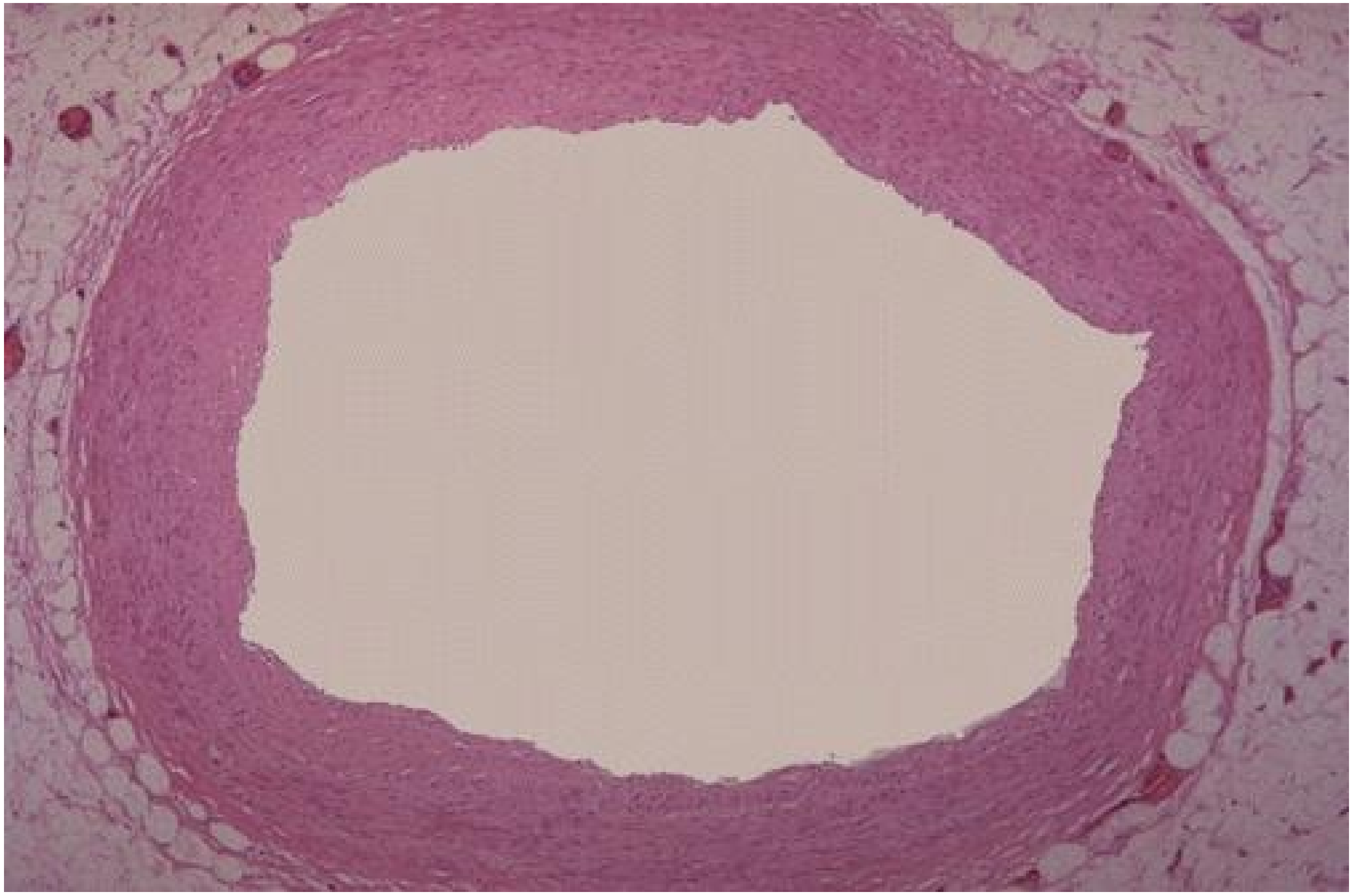
(a)

COMMON PRECIPITATING FACTORS IN ANGINA PECTORIS: HEAVY MEAL, EXERTION, COLD, SMOKING

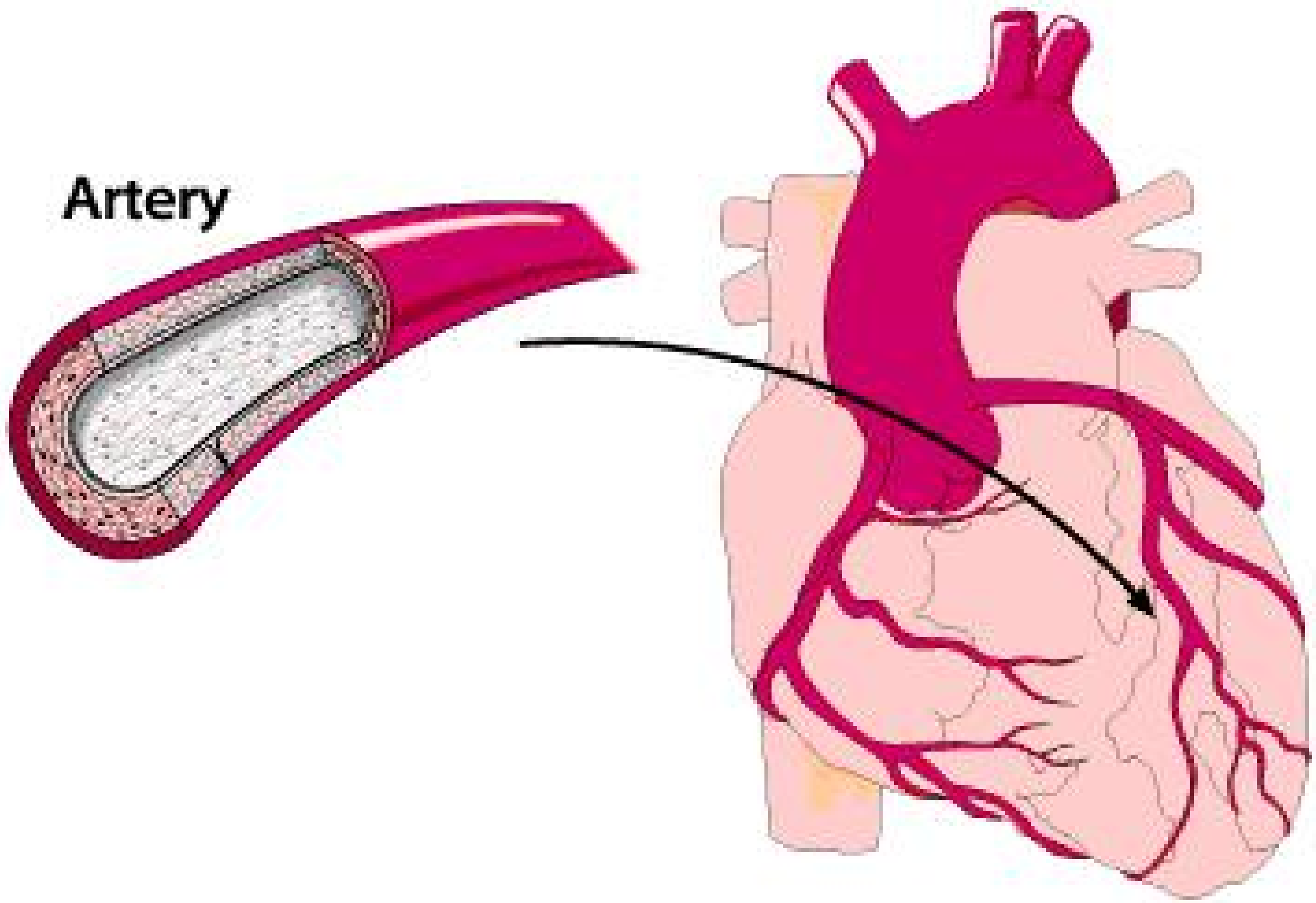


CHARACTERISTIC DISTRIBUTION OF PAIN IN ANGINA PECTORIS

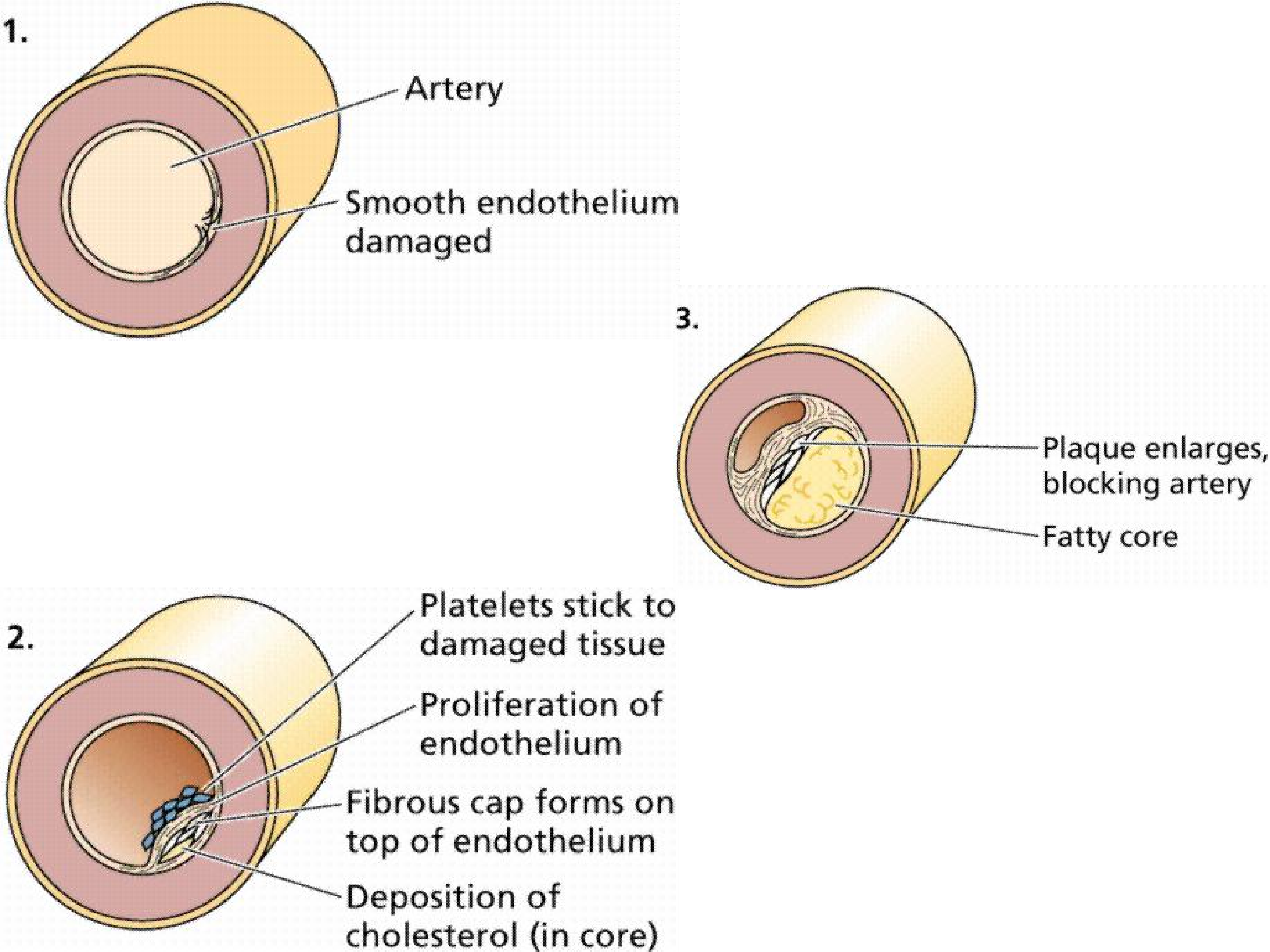
Normal Coronary Artery



- This is a normal coronary artery with a nice, big, unobstructed lumen for supplying plenty of blood to the myocardium.

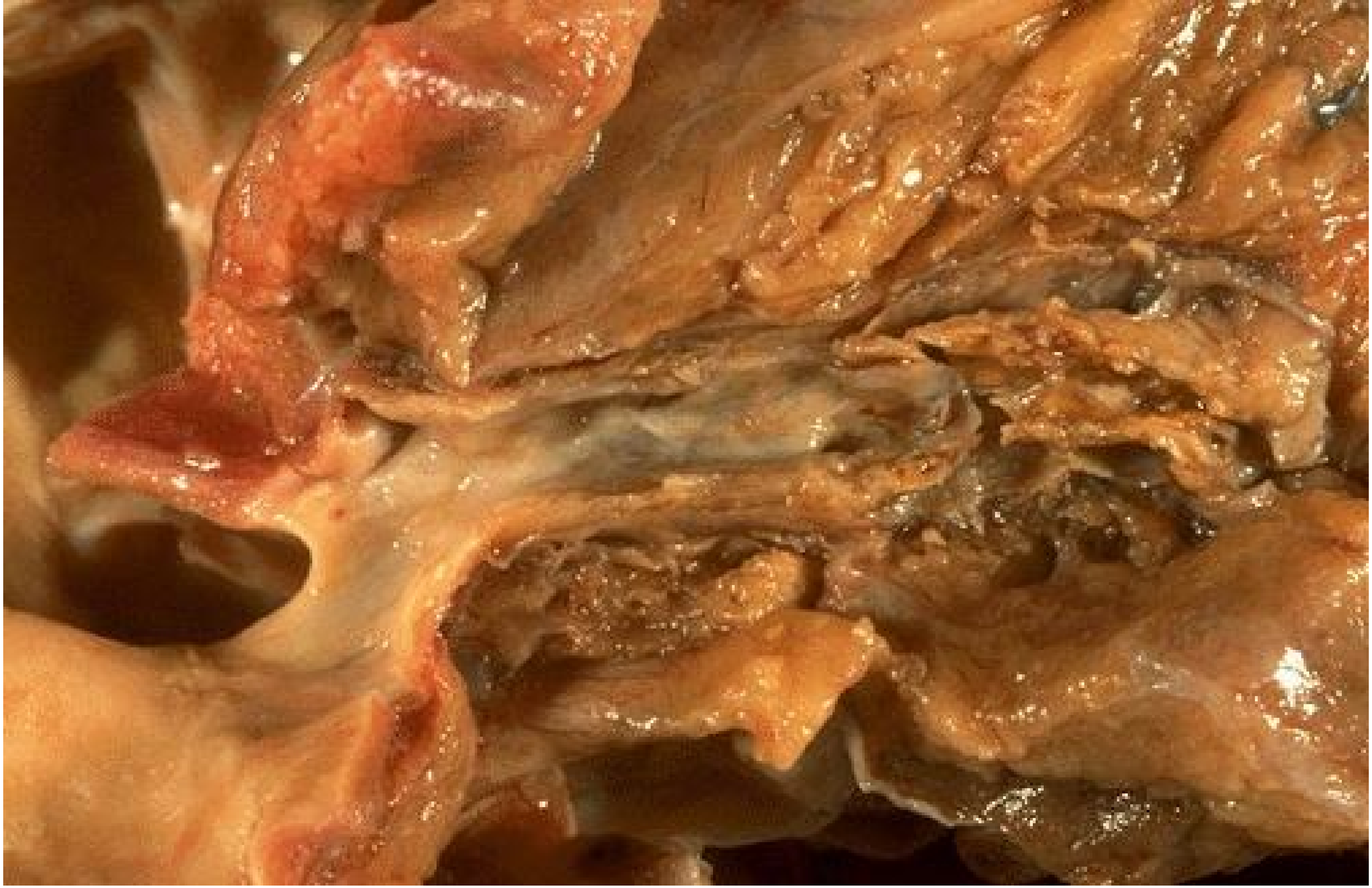


"Myocardial Infarction" (abbreviated as "MI") means there is death of some of the muscle cells of the heart as a result of a lack of supply of oxygen and other nutrients. This lack of supply is caused by closure of the artery ("coronary artery") that supplies that particular part of the heart muscle with blood. This occurs 98% of the time from the process of arteriosclerosis ("hardening of the arteries") in coronary vessels.


1.
Artery
Smooth endothelium
damaged
3.
Plaque enlarges,
blocking artery
Fatty core
2.
Platelets stick to
damaged tissue
Proliferation of
endothelium
Fibrous cap forms on
top of endothelium
Deposition of
cholesterol (in core)

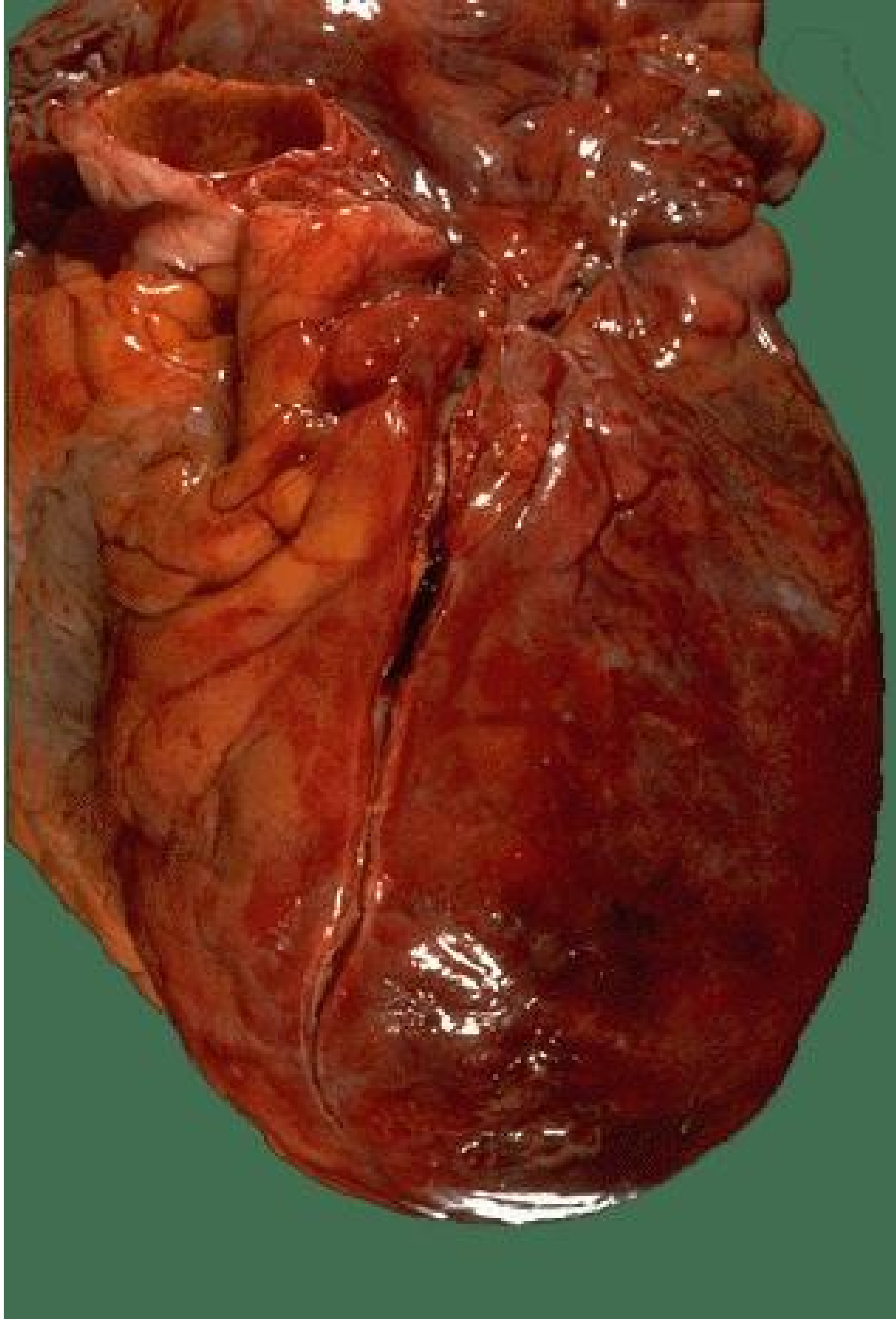
Serial Section of Coronary Artery

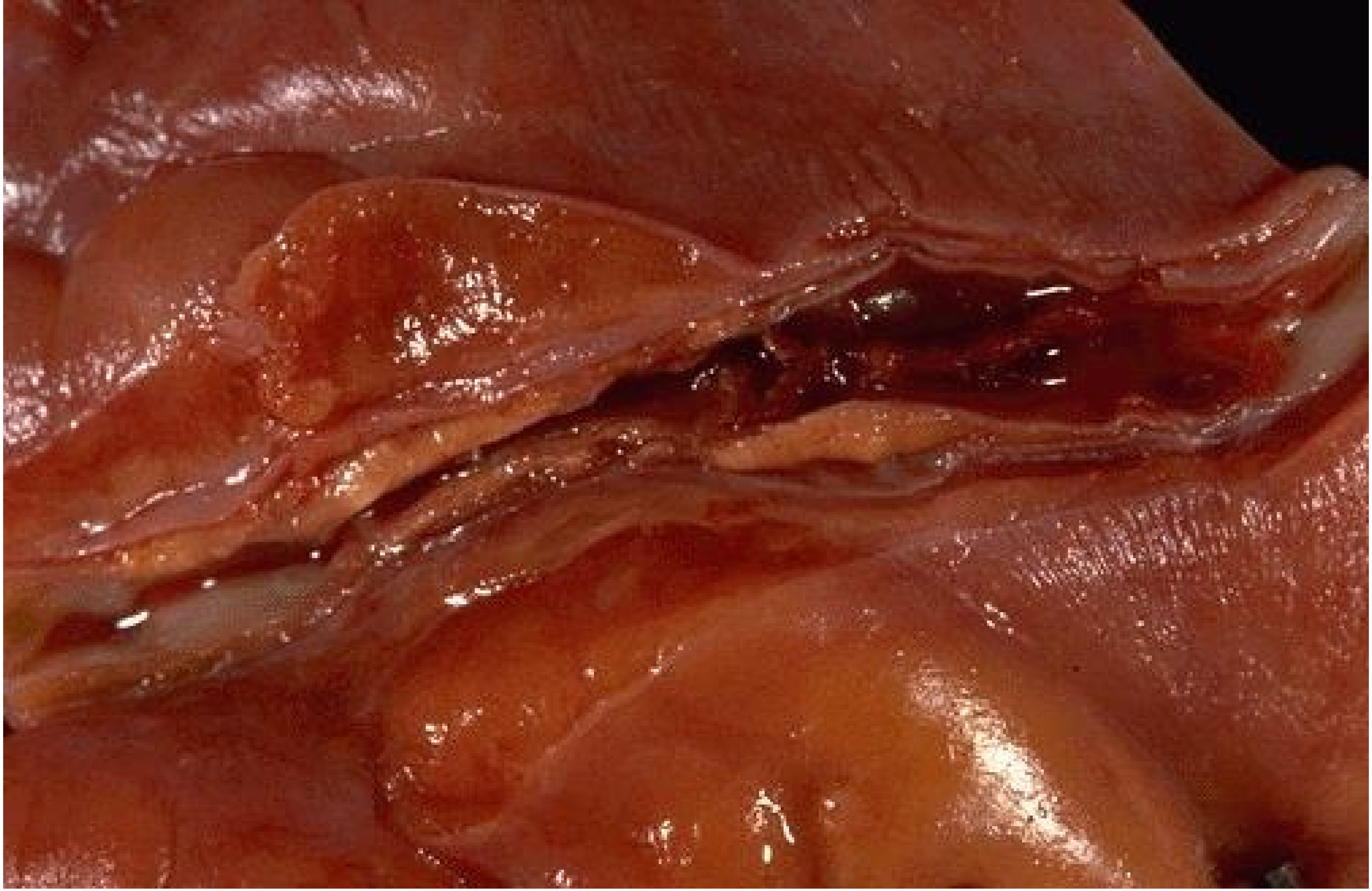
These serial sections of a coronary artery demonstrate grossly the appearance of lumenal narrowing with atherosclerosis.



- This coronary artery opened longitudinally demonstrates severe atherosclerosis

The anterior surface of the heart demonstrates an opened left anterior descending coronary artery. Within the lumen of the coronary can be seen a dark red recent coronary thrombosis. The dull red color to the myocardium as seen below the glistening epicardium to the lower right of the thrombus is consistent with underlying myocardial infarction.



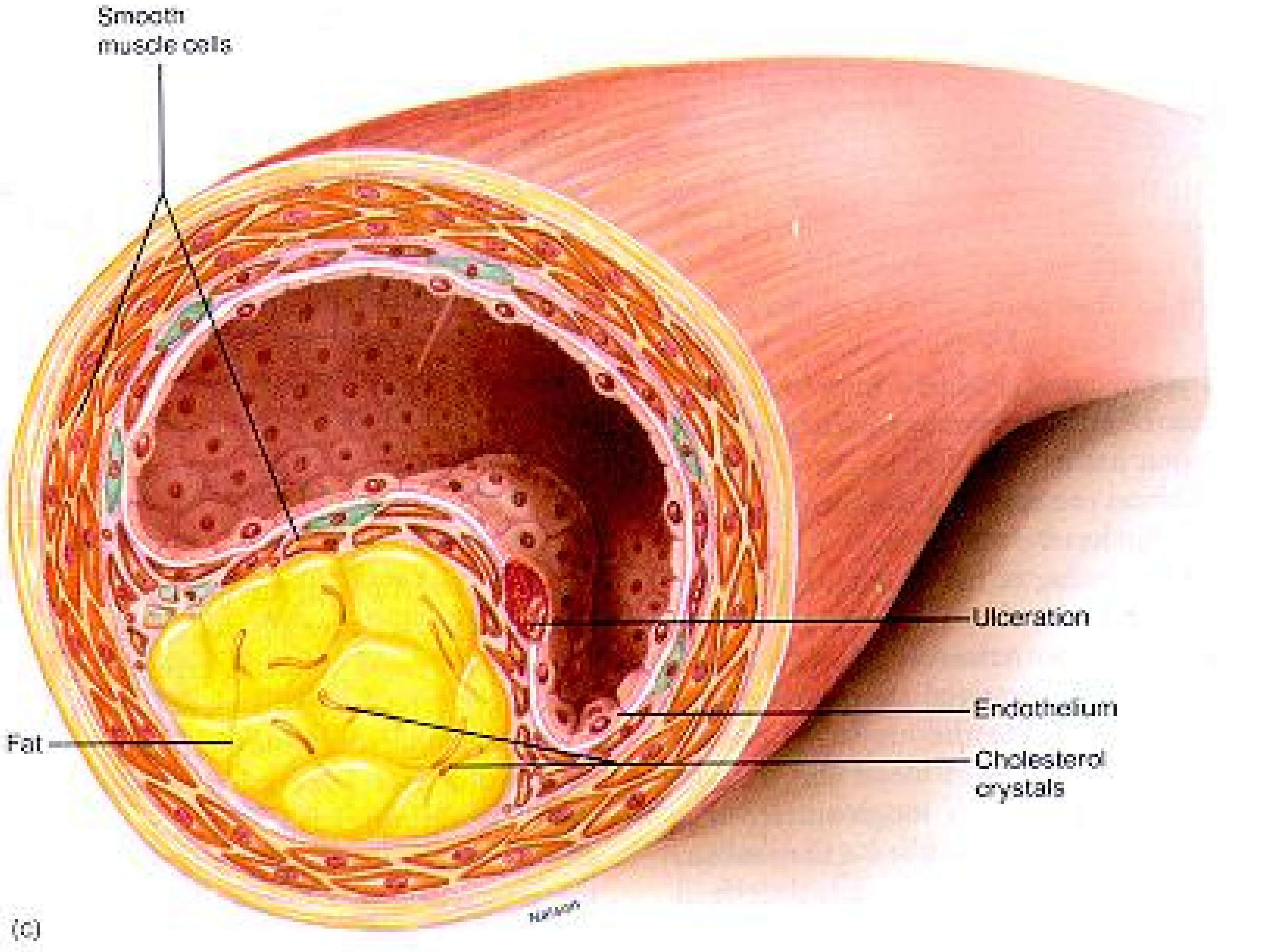


- This is thrombosis in a coronary artery. Such a thrombus severely narrows or occludes the lumen and can produce a sudden ischemic event. "Sudden death" as well as infarction can occur.

Myocardial infarction of the left ventricular wall and septum

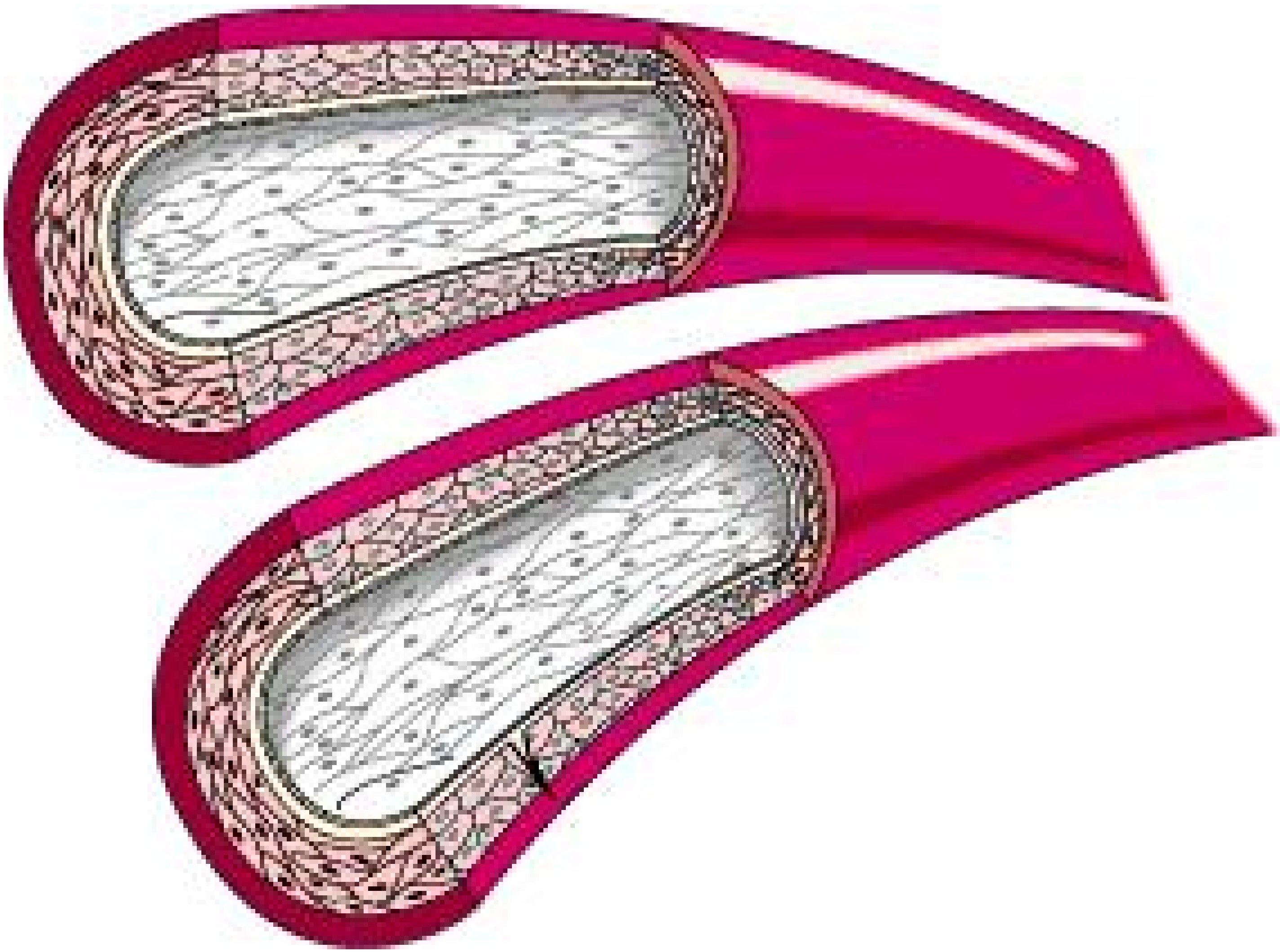
Risk Factors in Heart Disease

- Hypercholesterolemia
- Hypertension
- Cigarette smoking
- Obesity
- Lack of exercise
- Diabetes mellitus
- Genetic predisposition
- Male gender
- Alcohol

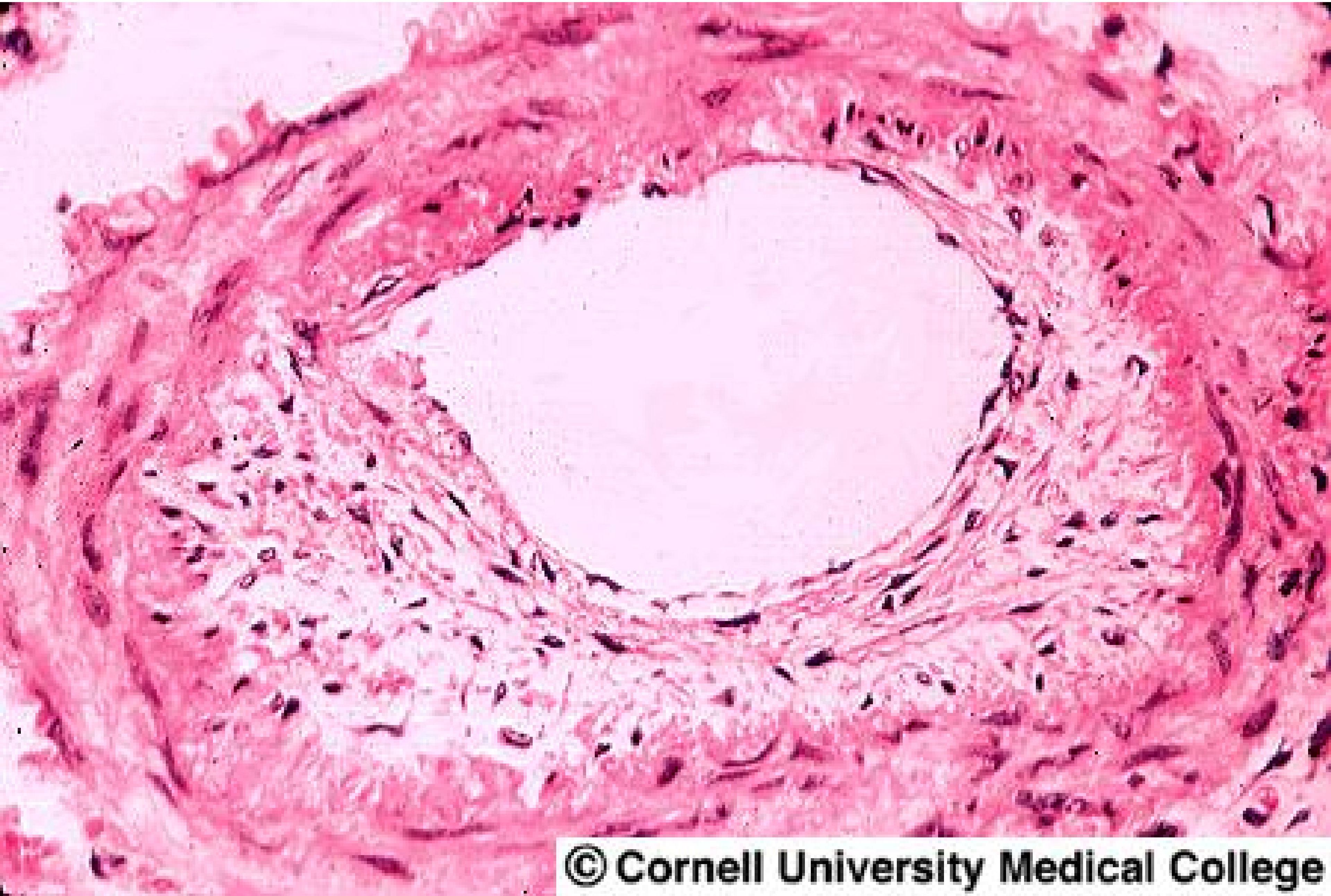

Smooth muscle cells
Ulceration
Endothelium
Fat
Cholesterol crystals

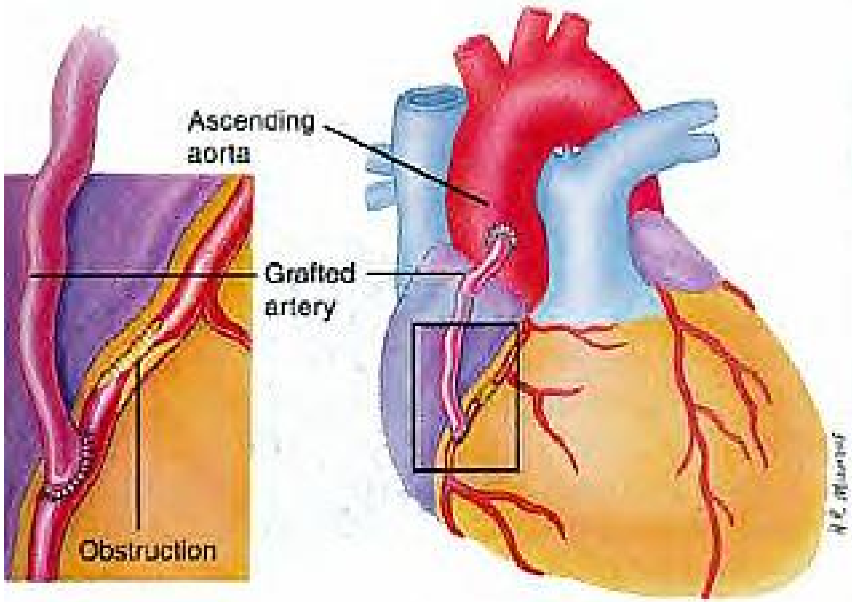
(c)

Atherosclerosis and Blood Clotting

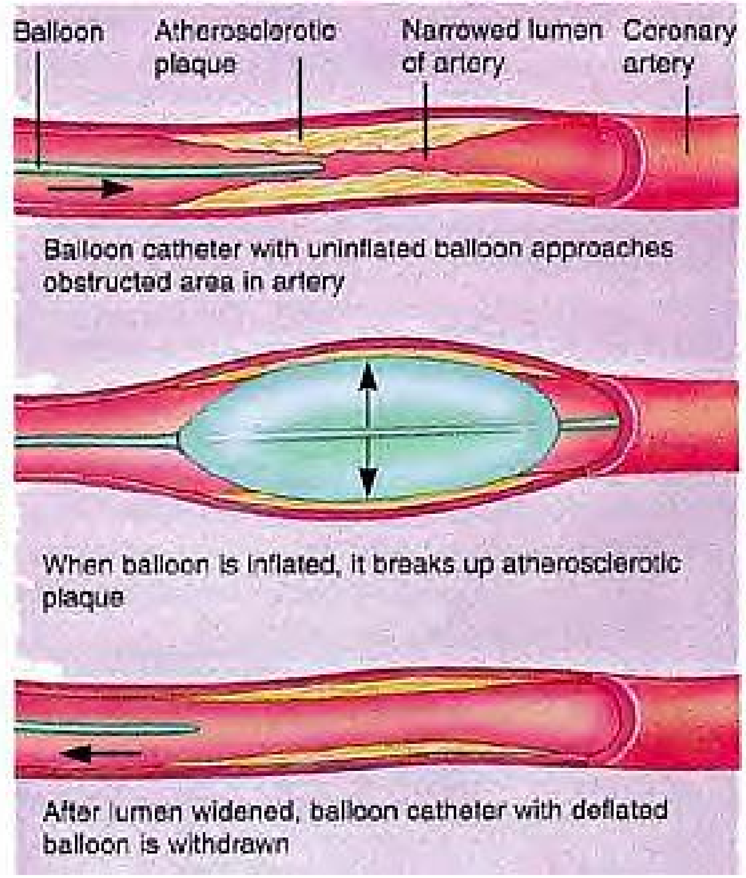


Organized Thrombi



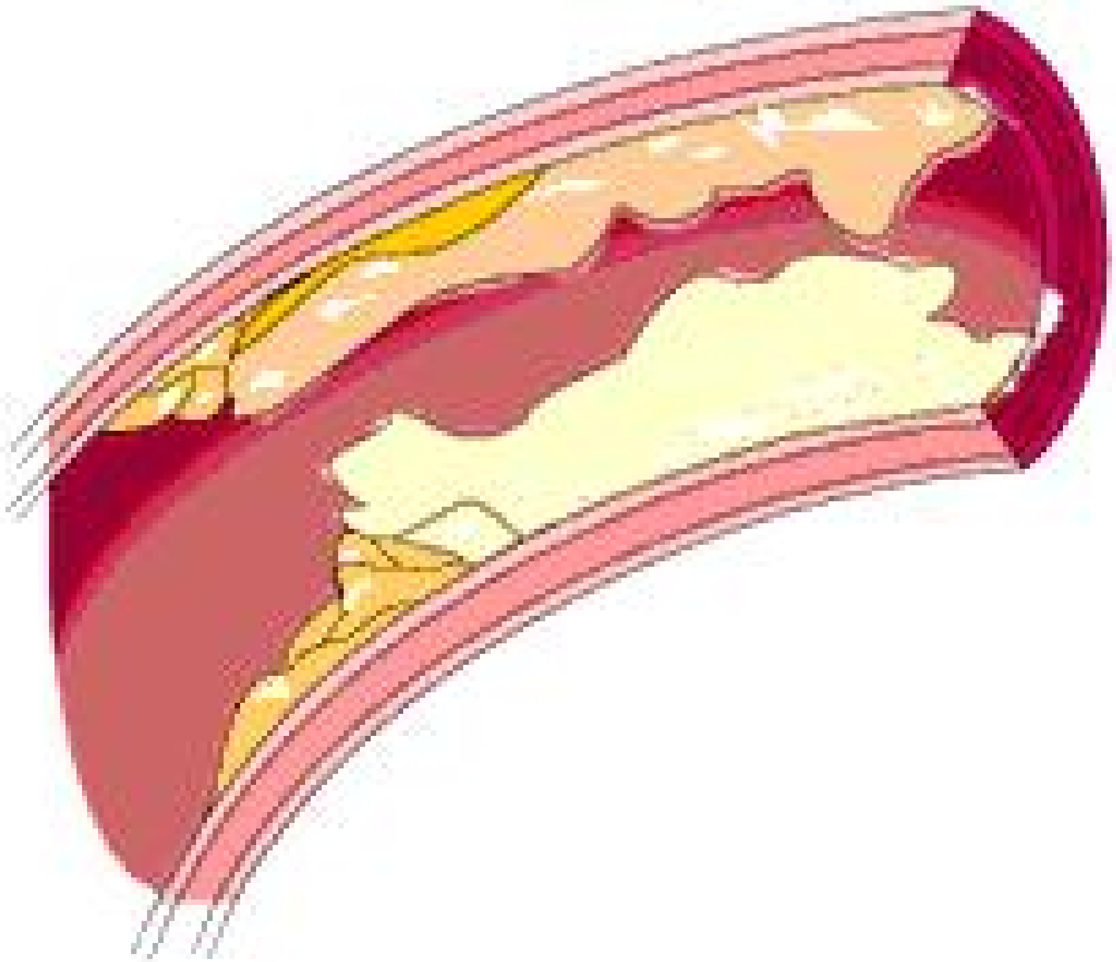


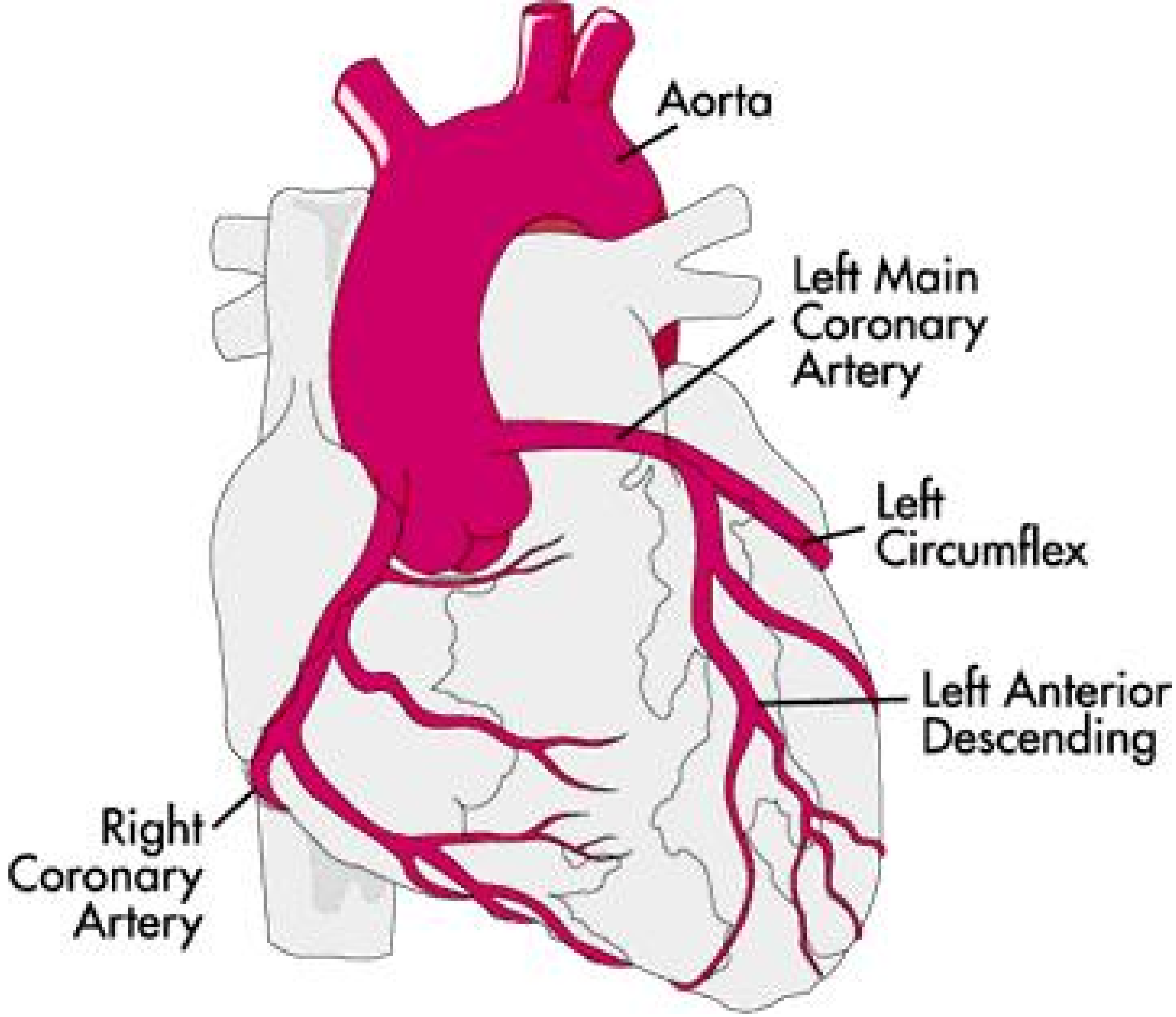
Coronary artery bypass grafting (CABG)



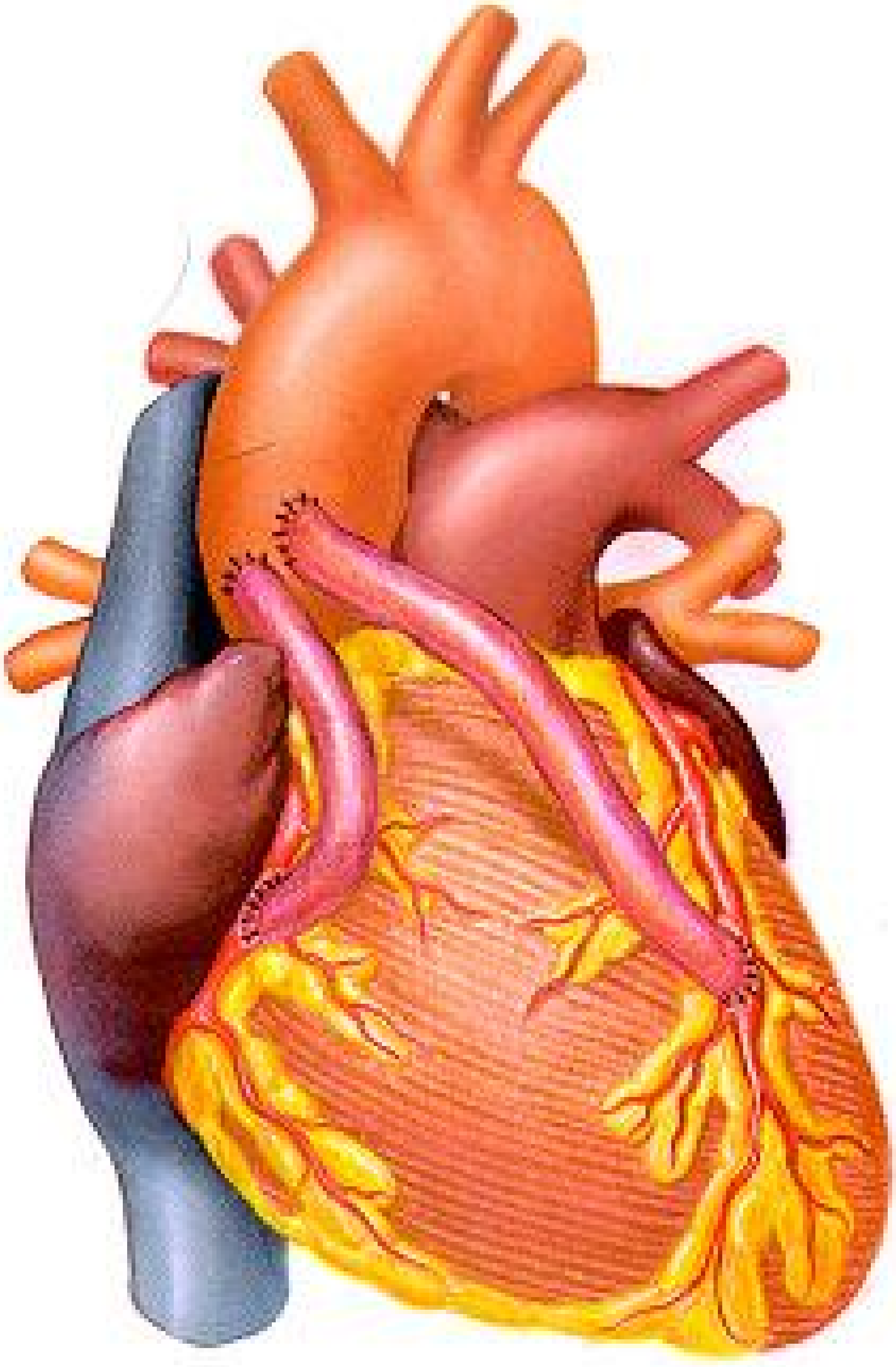
Balloon angioplasty (percutaneous transluminal coronary angioplasty or PTCA) is widely used for treatment of the blockages of coronary artery disease. This procedure is relatively simple, with only a small incision in the groin needed to introduce the equipment. As shown above, the balloon is inflated to compress the plaque and enlarge the artery, and provide an adequate area for blood to flow through. To learn more about PTCA and similar procedures, read on.

Balloon Angioplasty

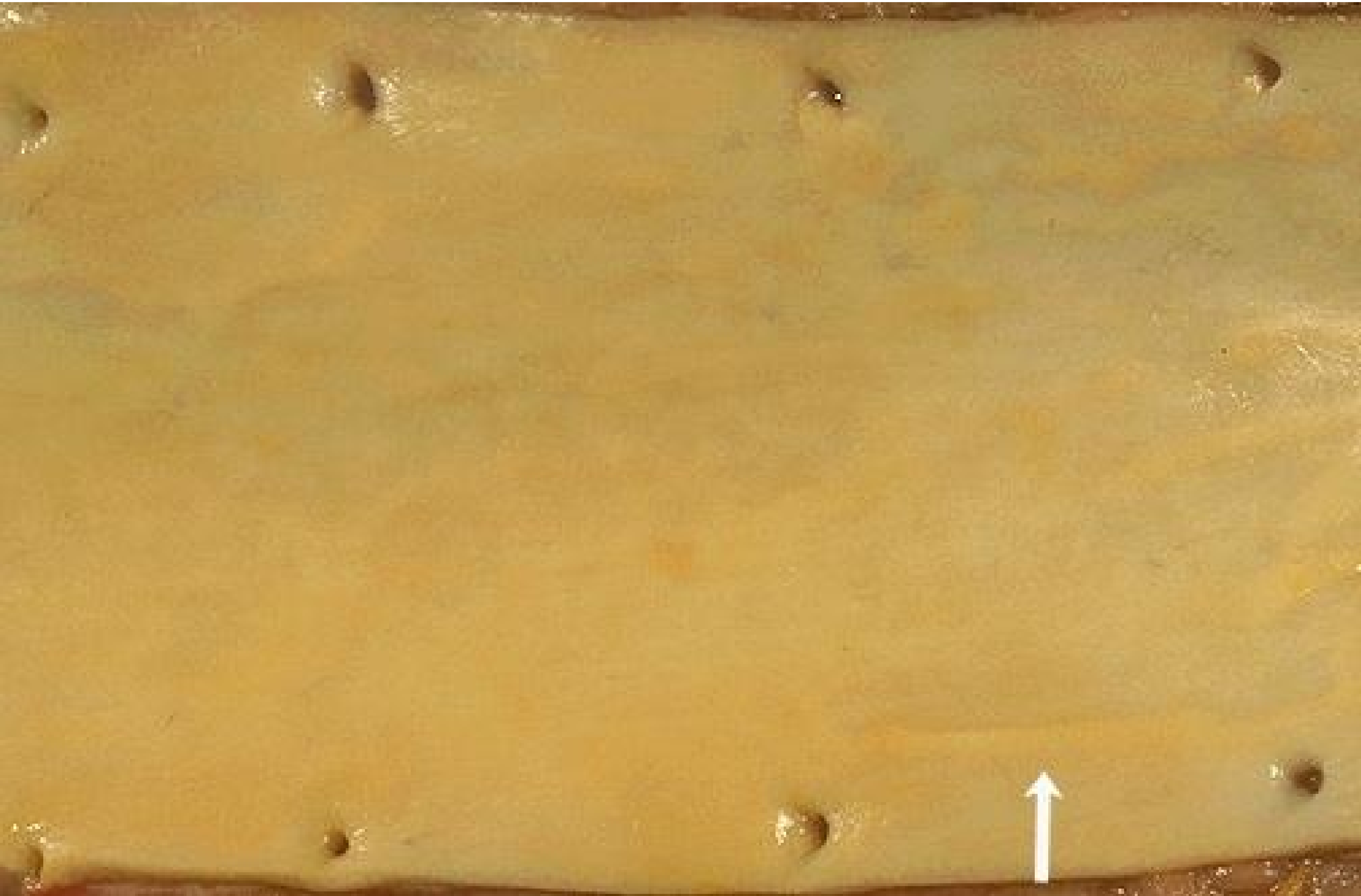




When the heart builds up blockages, it is often in more than one place. In this illustration, the patient has developed a 100% blockage of one artery (the Right Coronary Artery), while another vessel has several blockages including one at a branch point between the LAD and circumflex. Catheter techniques such as PTCA are of limited utility in both of these types of situations. In this illustration, a bypass surgery is being performed. Veins are taken from the leg, and sewn to the aorta, and then to the coronary arteries beyond the blockages.

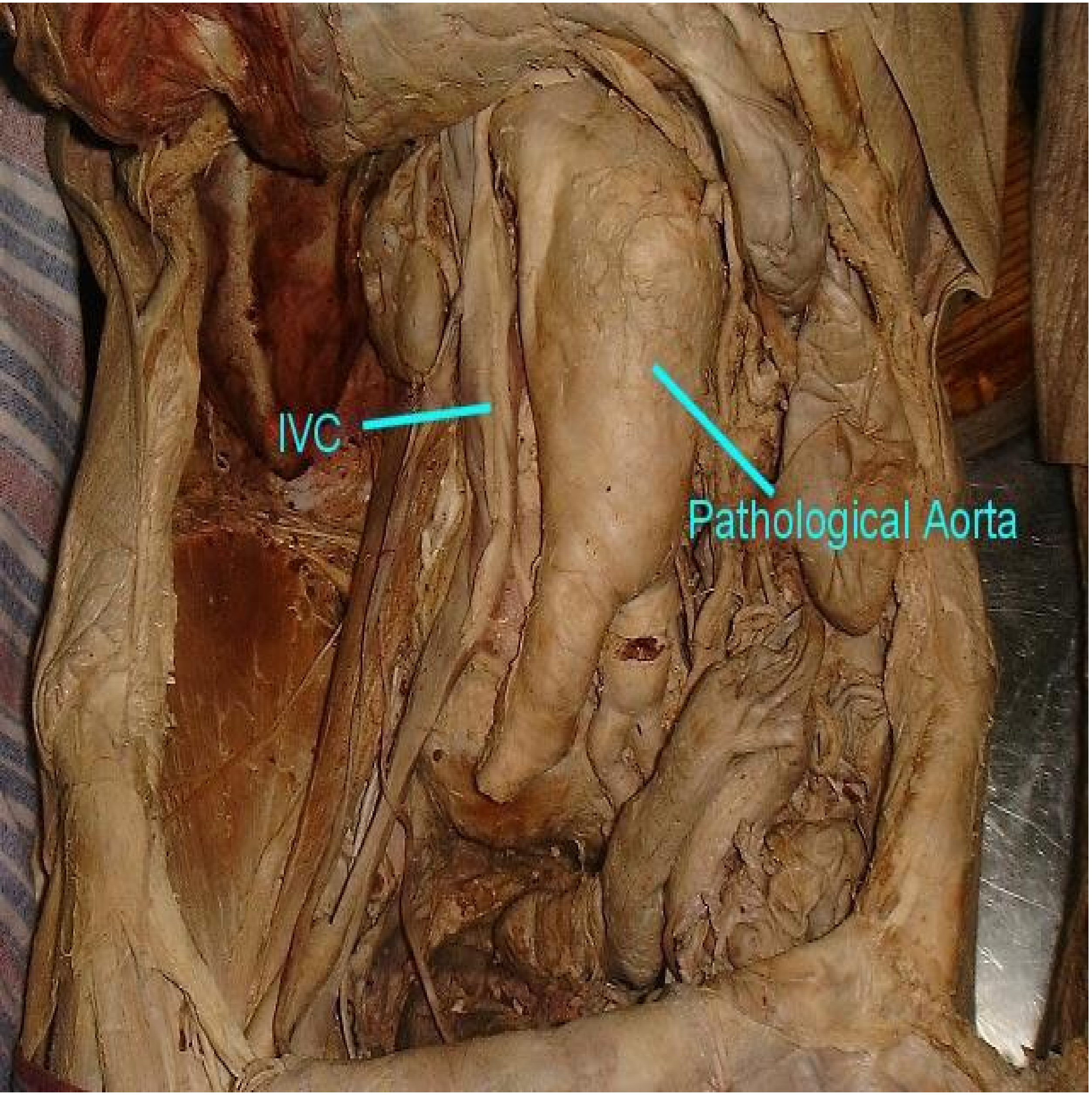


Fatty Streaks in Aorta



Atherosclerosis, Mild, Moderate, and Severe

Atherosclerosis of the aorta w/ mural thrombi



AAA stands for abdominal aortic aneurysm. An aneurysm is a permanent, localised dilatation of an artery and may involve several or all of the layers. There are various types and they are commonly found in the elderly population. They are thought to arise from a systemic collagen synthetic or structural defect such as atheromatous plaques.

Ruptured AAA has a very high mortality rate - in excess of 80%. Yet, prior to rupture many are asymptomatic. If they are diagnosed before presentation with rupture they are treated dependent on size and rate of growth by surgical prosthetic grafting.

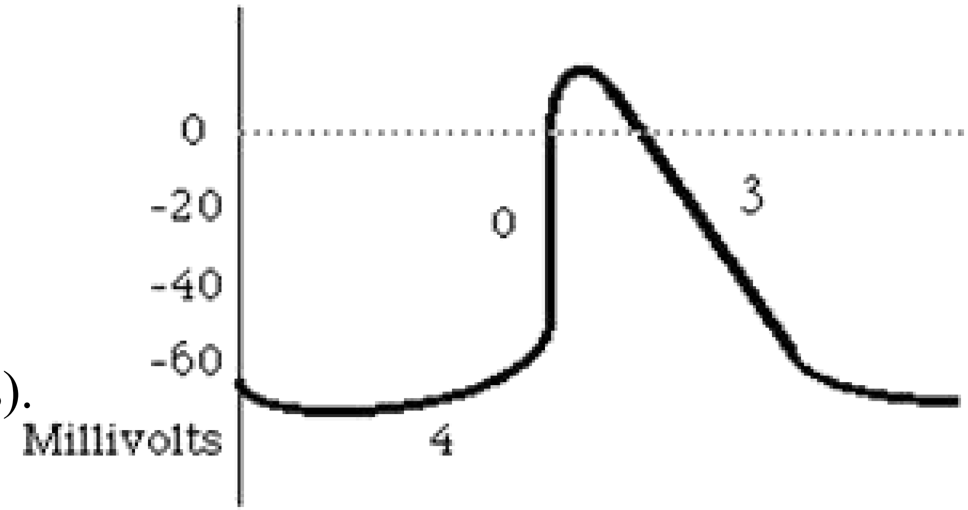
Abdominal Aortic Aneurysm

This aorta has been opened longitudinally to reveal an area of fairly limited dissection that is organizing. The red-brown thrombus can be seen in on both sides of the section as it extends around the aorta. The intimal tear would have been at the left. This creates a "double lumen" to the aorta. This aorta shows severe atherosclerosis which, along with cystic medial necrosis and hypertension, is a risk factor for dissection.

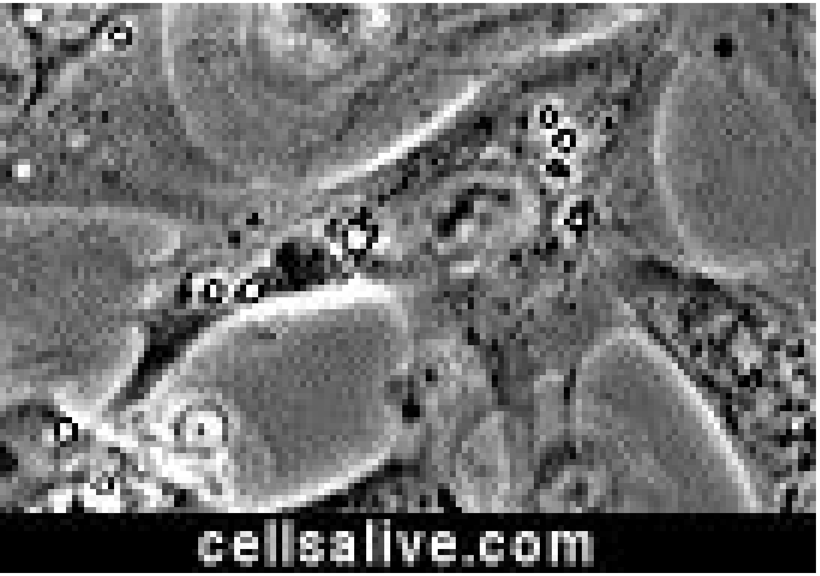
In cardiac muscle, there are two types of cells:

- Contractile cells
- Autorhythmic (or automatic) cells.

- **Autorhythmic cells** exhibit PACEMAKER POTENTIALS.
  - **Depolarization is due to the inward diffusion of calcium** (not sodium as in nerve cell membranes).
  - Depolarization begins when:
    - the slow calcium channels open (4),
    - then conclude
s (quickly) when the fast calcium channels open (0).
    - Repolarization is due to the outward diffusion of potassium (3).



Myocyte

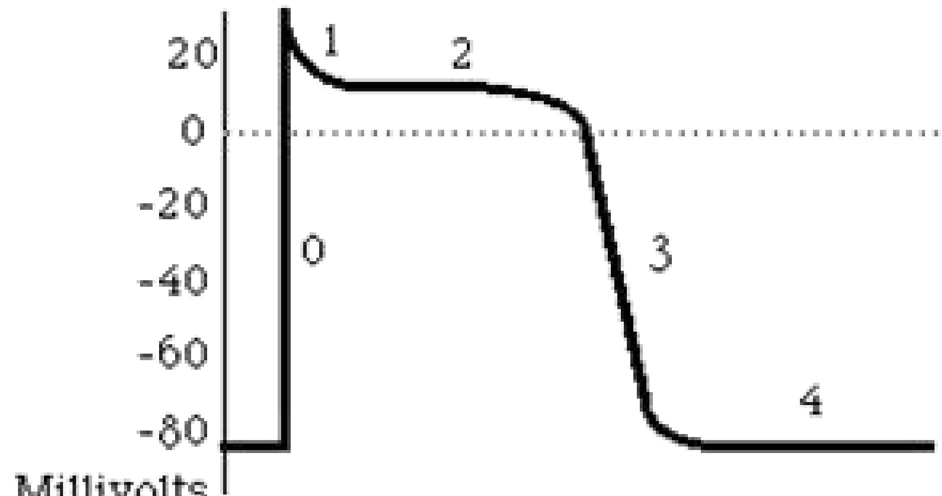


Autorhythmic cells

Sheet of cells

In **Contractile cells:**

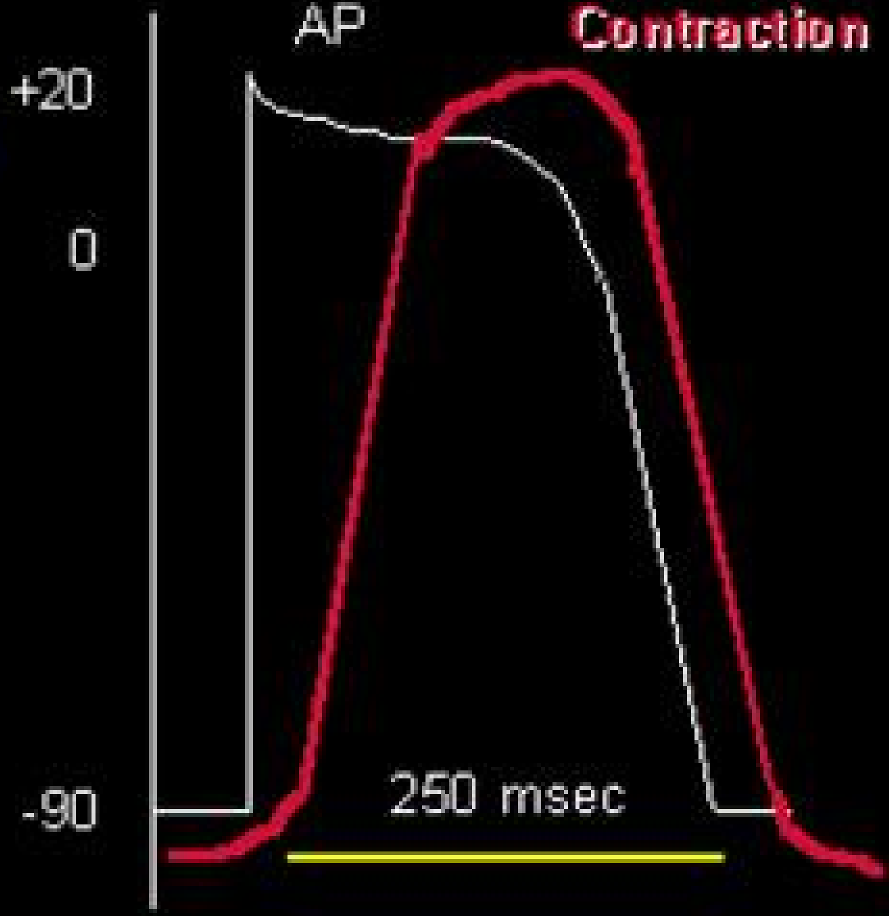
- **depolarization** is very rapid & is due to the **inward diffusion of sodium** (0).
- **repolarization** begins with a slow outward diffusion of potassium, but that is largely offset by the slow inward diffusion of calcium (1 & 2). So, repolarization begins with a plateau phase. Then, potassium diffuses out much more rapidly as the calcium channels close (3), and the membrane potential quickly reaches the 'resting' potential (4).



Refractory Period

- **L-O-N-G** *(250 msec)*
- membrane is refractory to further stimulation until the contraction is over

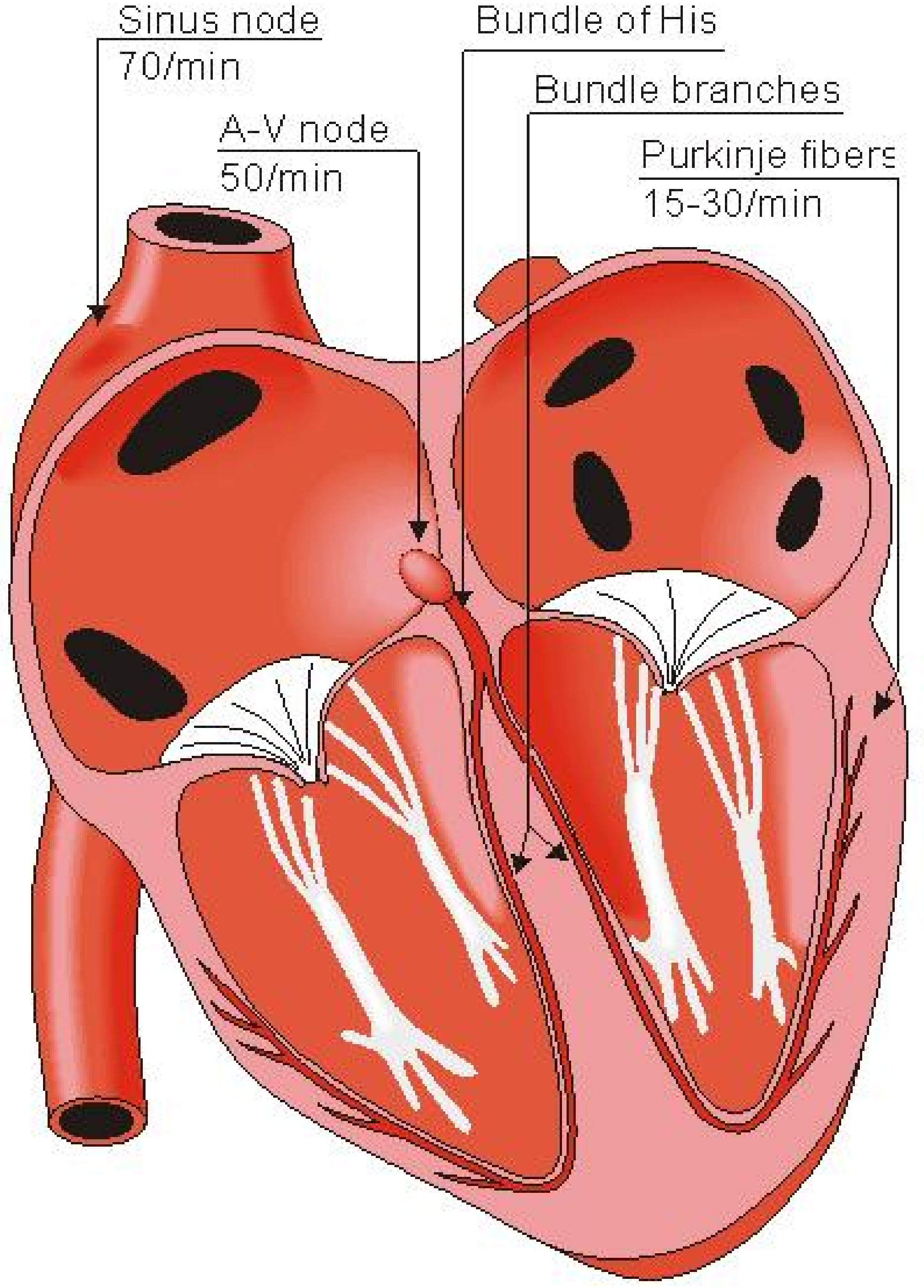
➡ NO SUMMATION OR TETANY POSSIBLE!

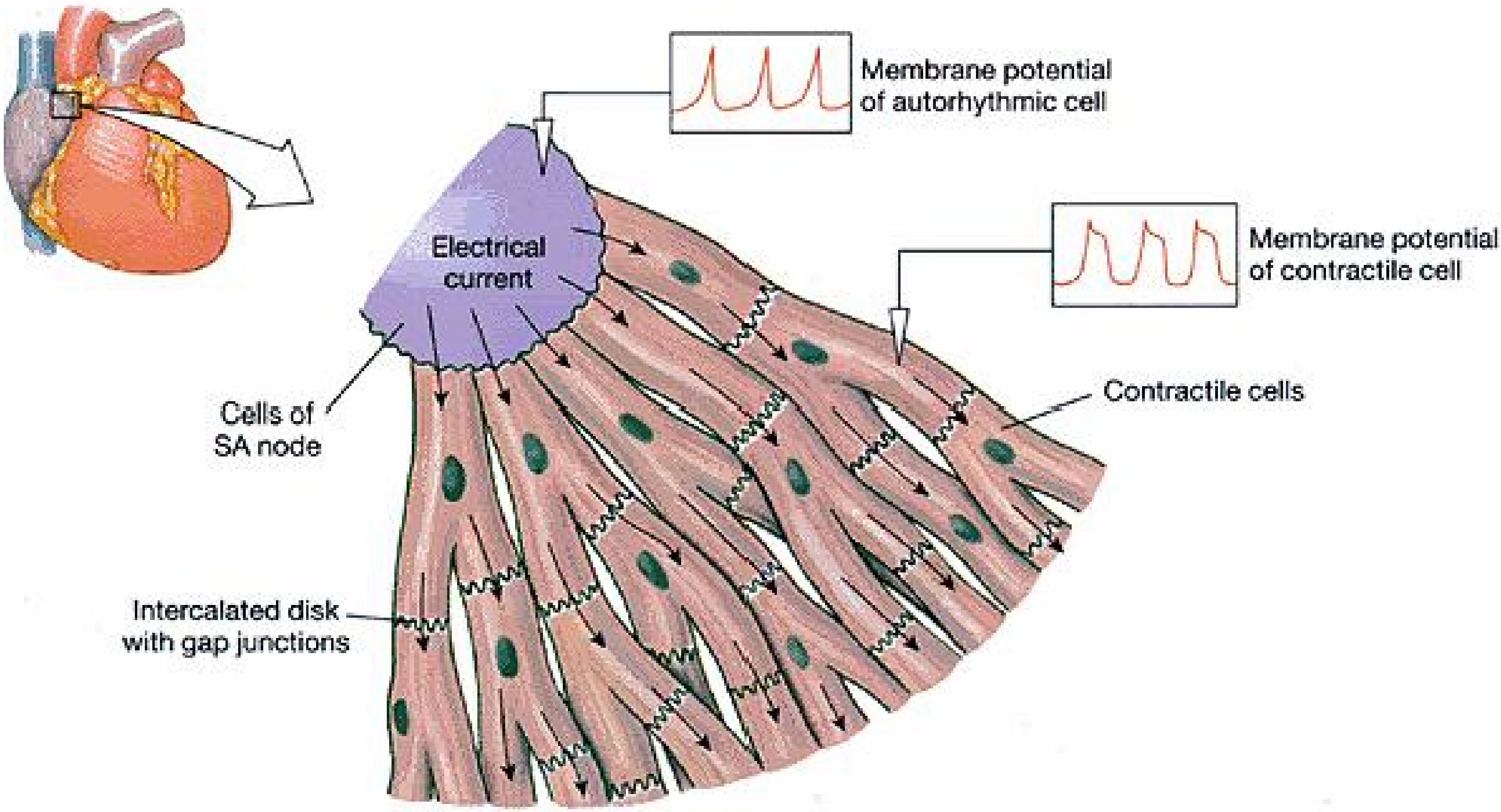


Most of the muscle cells in the heart are contractile cells. The **autorhythmic cells** are located in these areas:

- **Sinoatrial (SA),** or sinus, node **-** 60 - 100 per minute (usually 70 - 80 per minute)
- **Atrioventricular (AV) node -** 40 - 60 per minute
- Atrioventricular (AV) bundle (also sometimes called the bundle of His)
- Right & left bundle branches
- Purkinje fibers

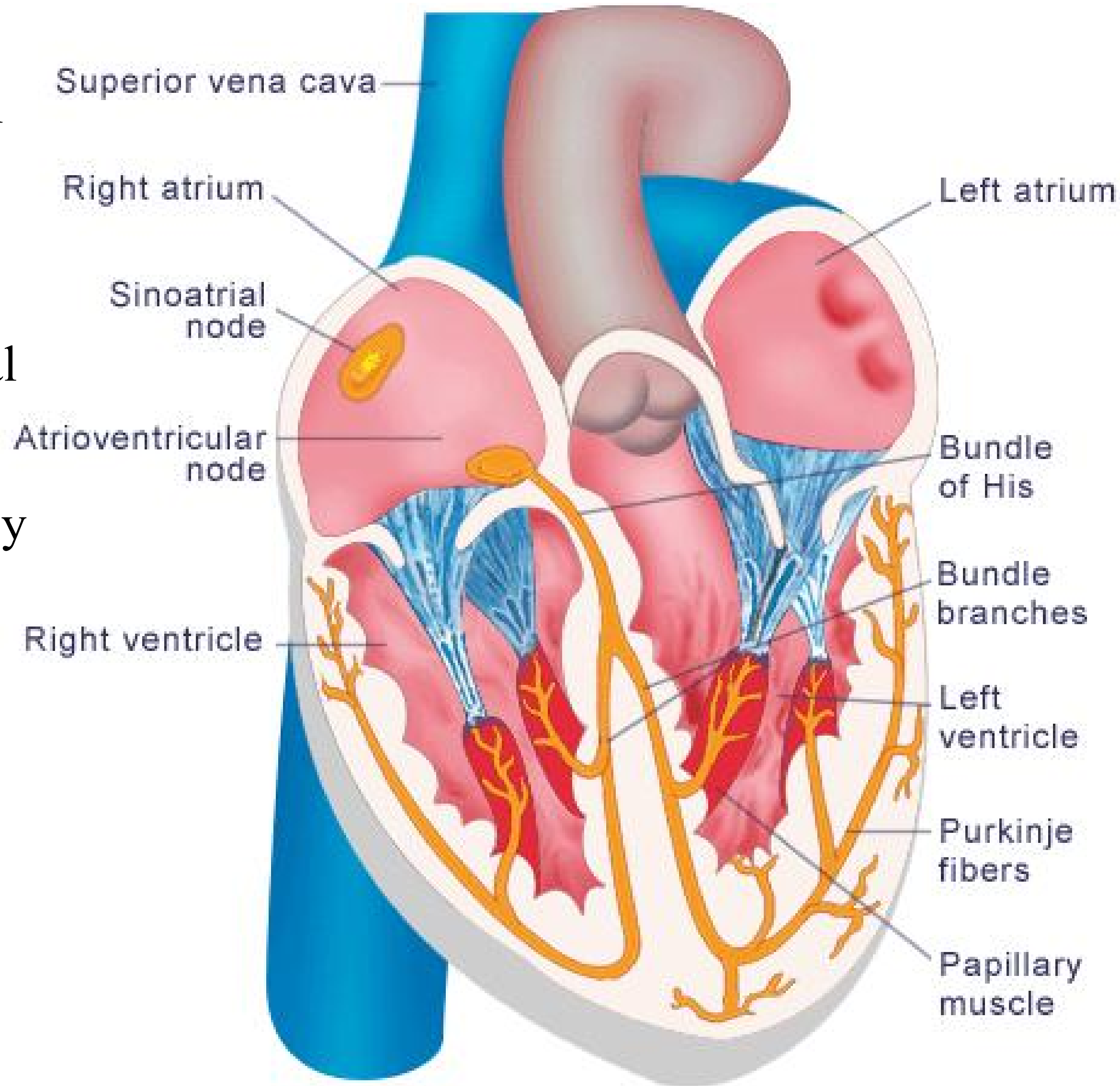
- 20 - 40 per minute

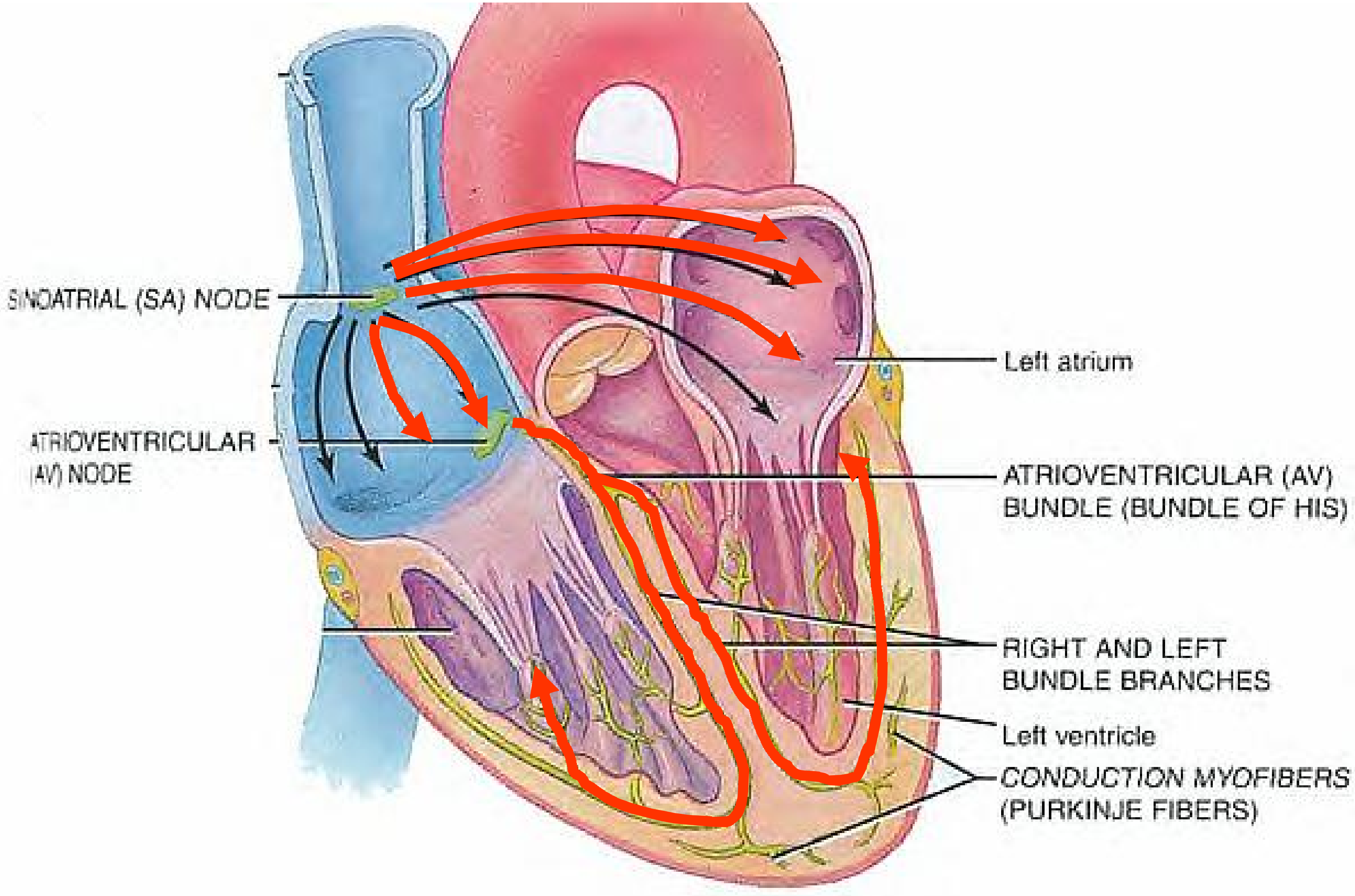


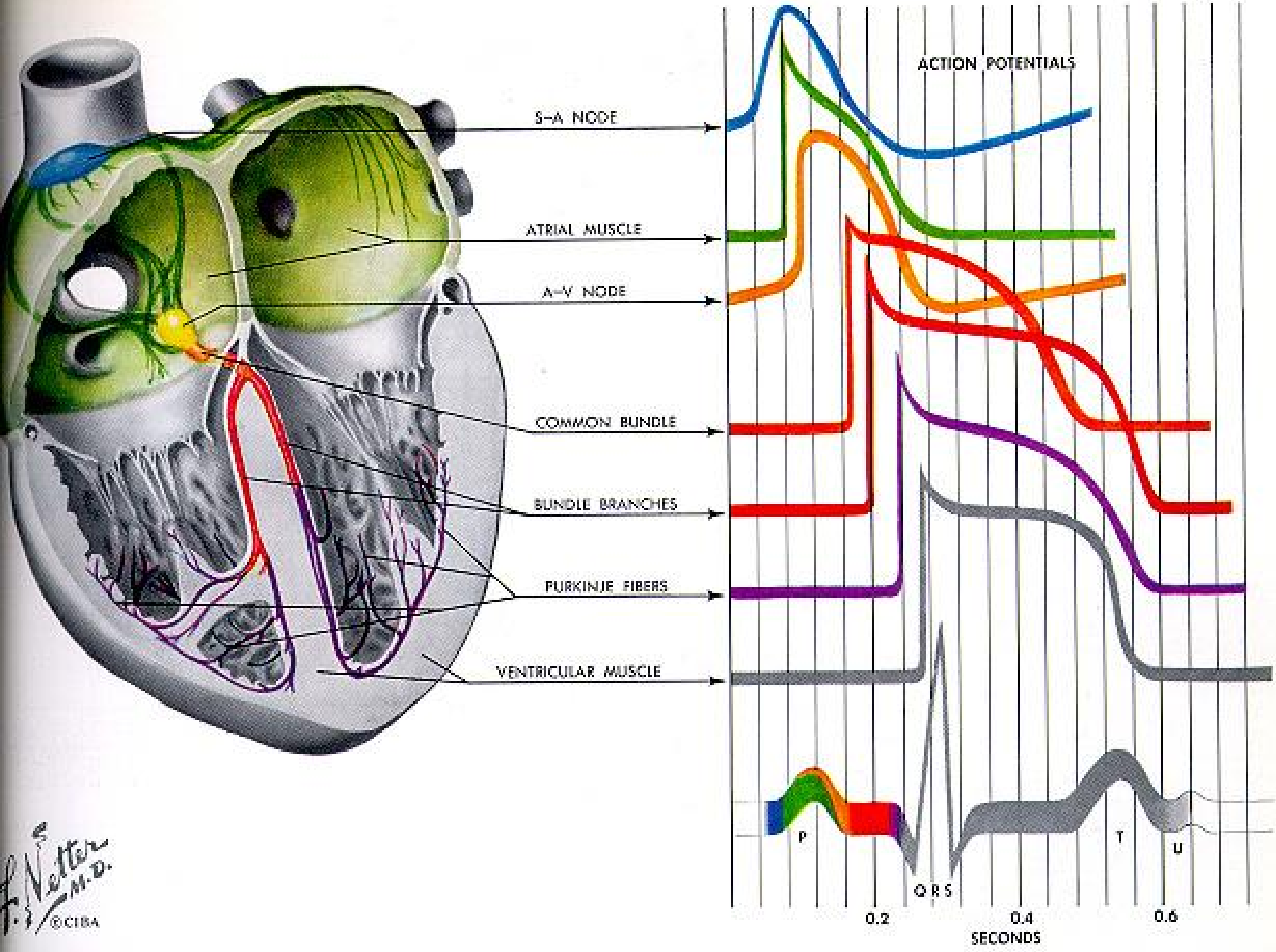


Membrane potential
of autorhythmic cell
Electrical
current
Membrane potential
of contractile cell
Contractile cells
Cells of
SA node
Intercalated disk
with gap junctions

- **Sinoatrial node-** a patch of modified myocytes in the right atrium that is the pacemaker that initiates each heartbeat and determines the heart rate.
- **Atrioventricular node-** located near the right AV valve and acts as an electrical gateway to the ventricles.
- **atrioventricular bundle** (bundle of His)- a pathway by which signals leave the AV node
- **Right and left bundle branches-** divisions of the AV bundle that enter the interventricular septum and descend toward the apex.
- **Purkinje fibers-** nervelike processes that arise from the bundle of branches that distribute the electrical excitation to the myocytes of the ventricles




SINOATRIAL (SA) NODE
ATRIOVENTRICULAR (AV) NODE
Left atrium
ATRIOVENTRICULAR (AV) BUNDLE (BUNDLE OF HIS)
RIGHT AND LEFT BUNDLE BRANCHES
Left ventricle
CONDUCTION MYOFIBERS (PURKINJE FIBERS)



ACTION POTENTIALS
S-A NODE
ATRIAL MUSCLE
A-V NODE
COMMON BUNDLE
BUNDLE BRANCHES
PURKINJE FIBERS
VENTRICULAR MUSCLE
P
QRS
T
U
0.2
0.4
0.6
SECONDS
F. Netter M.D.
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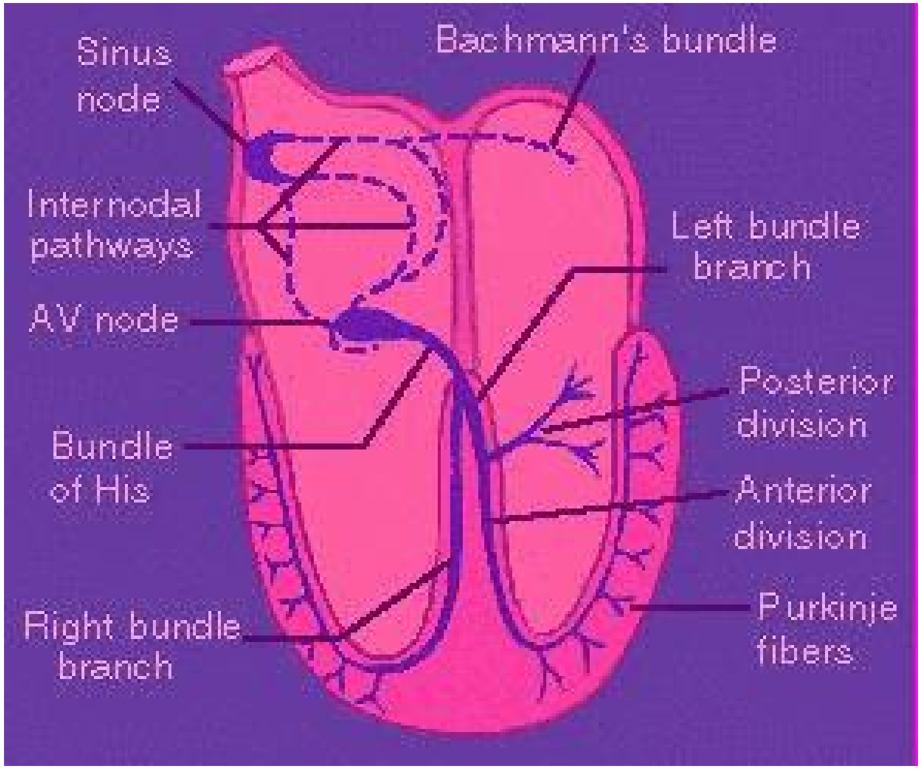
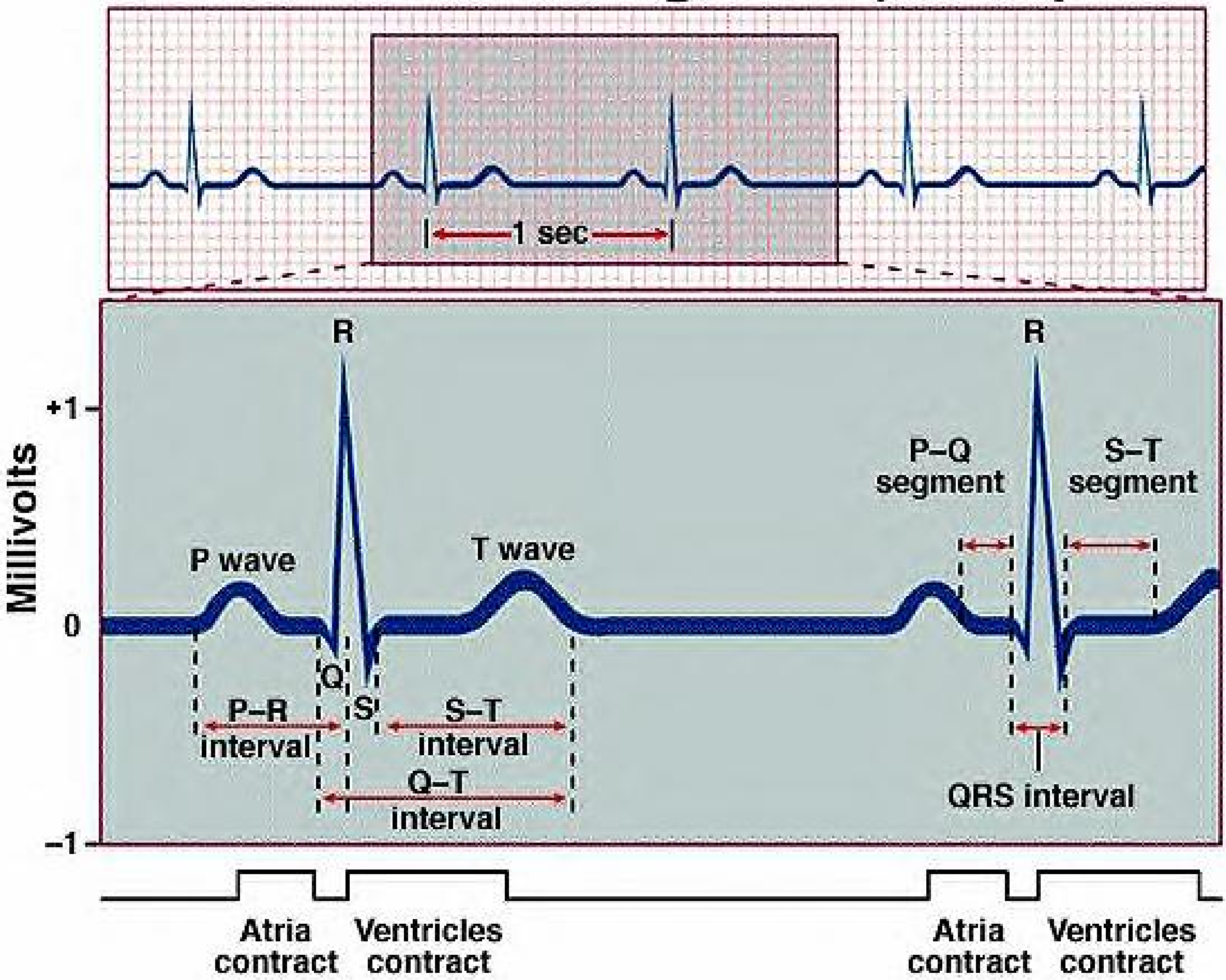
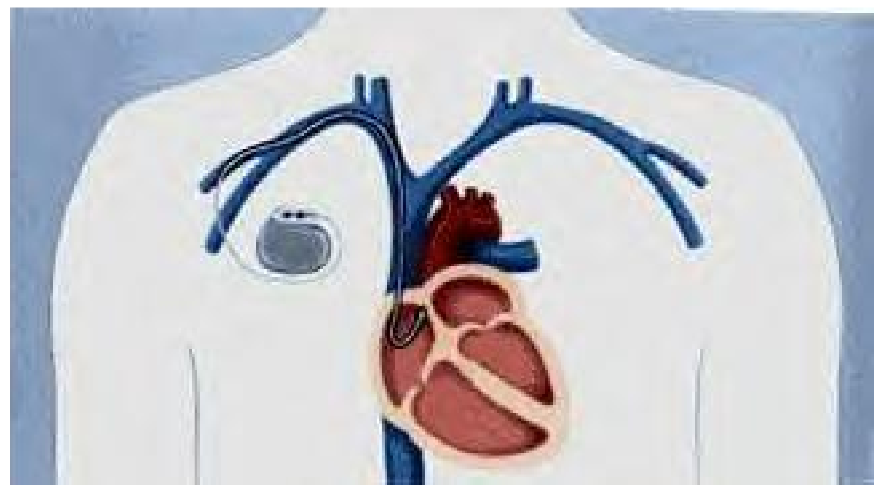
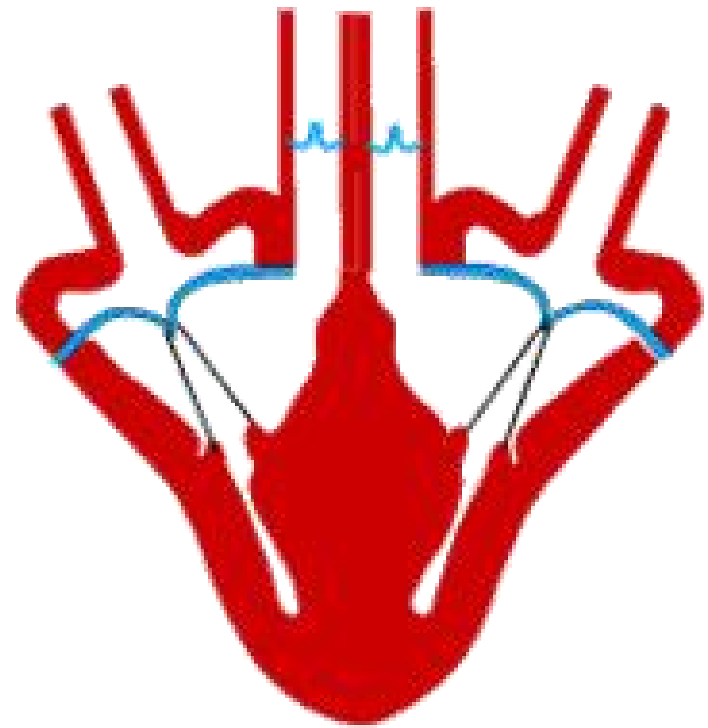

Sinus node
Bachmann's bundle
Internodal pathways
Left bundle branch
AV node
Posterior division
Bundle of His
Anterior division
Purkinje fibers
Right bundle branch

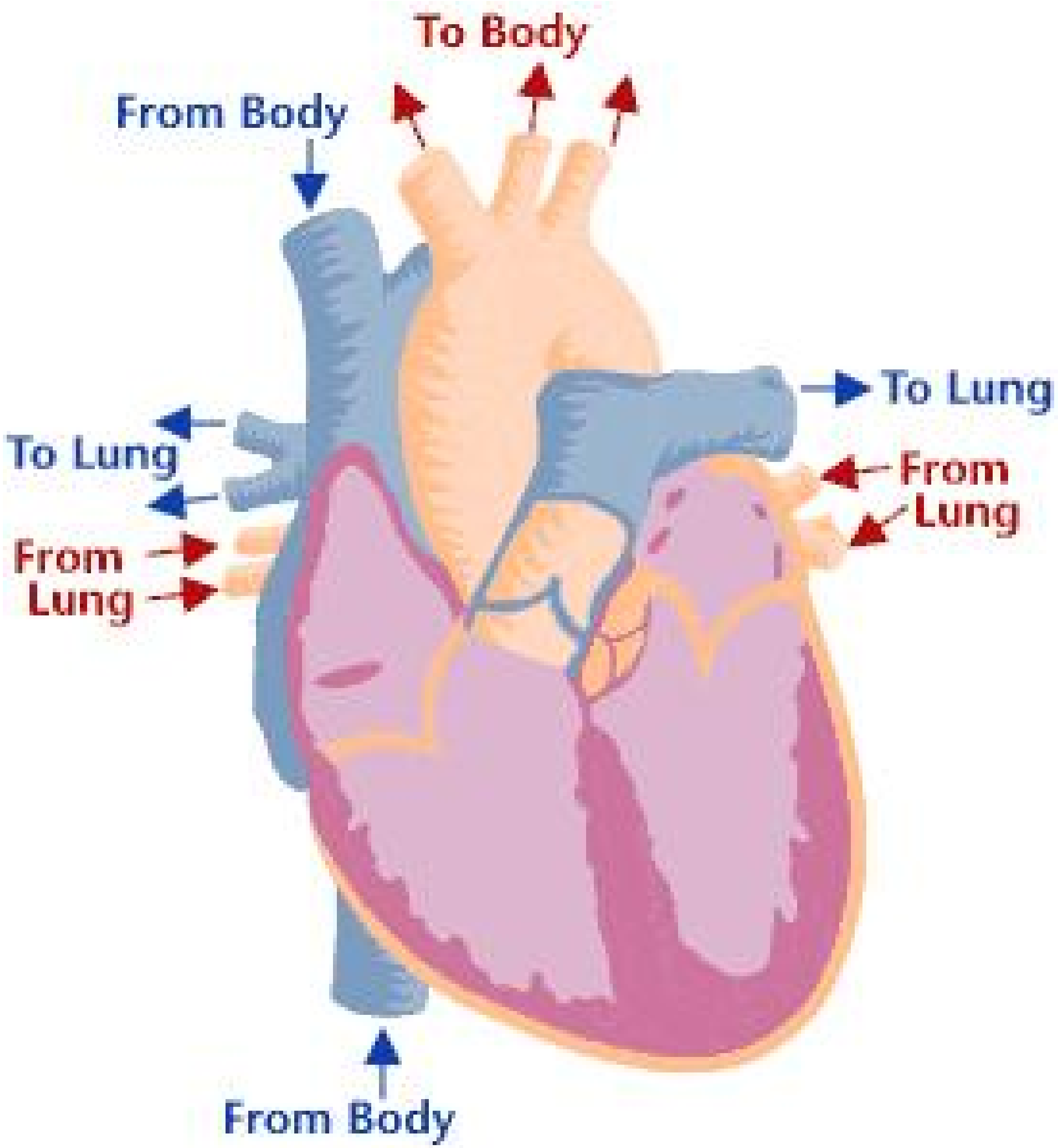
Electrocardiogram (ECG)

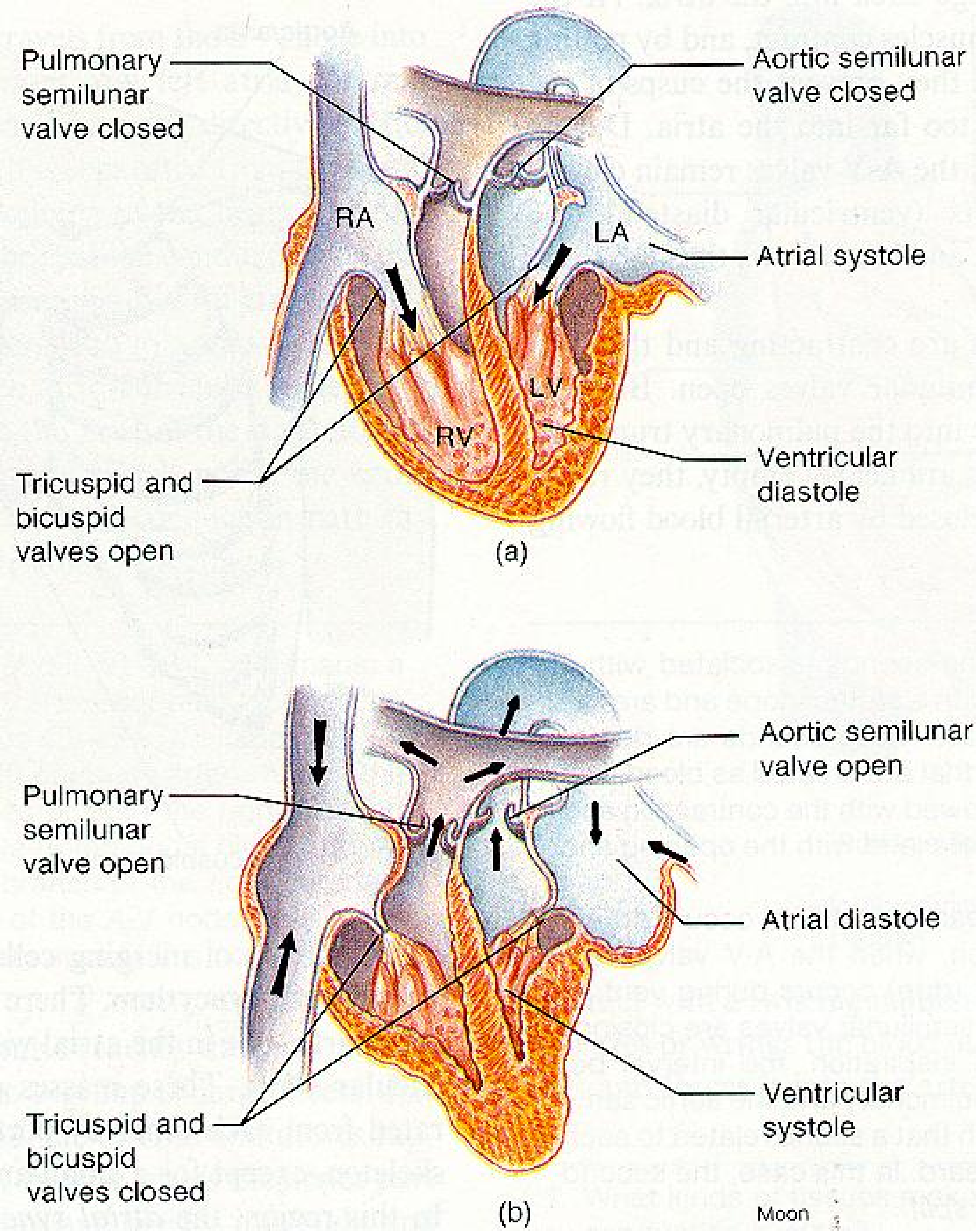




- **End diastolic volume (EDV)-** blood in the ventricles at the end of diastole
- **Ejection fraction-** fraction of the EDV that is ejected (%), used to measure heart efficiency
- **End systolic volume (EDV)-** blood that remains in the ventricle after ejection




To Body
From Body
To Lung
To Lung
From Lung
From Lung
From Body



Cardiac Cycle Phases

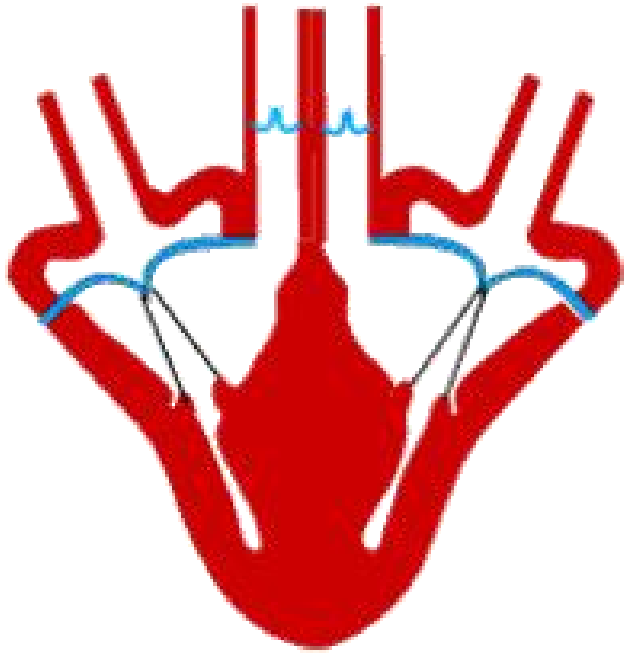
- relaxation (diastole)---dupp (S2)
- ventricular filling
- ventricular contraction (systole)---lubb (S1)

•**Heart murmur**- abnormal flow noise
•Mitral Stenosis- narrowing of the Mitral valve opening
•Mitral valve prolapse- when a portion of the valve pushes back to far into the atria upon contraction

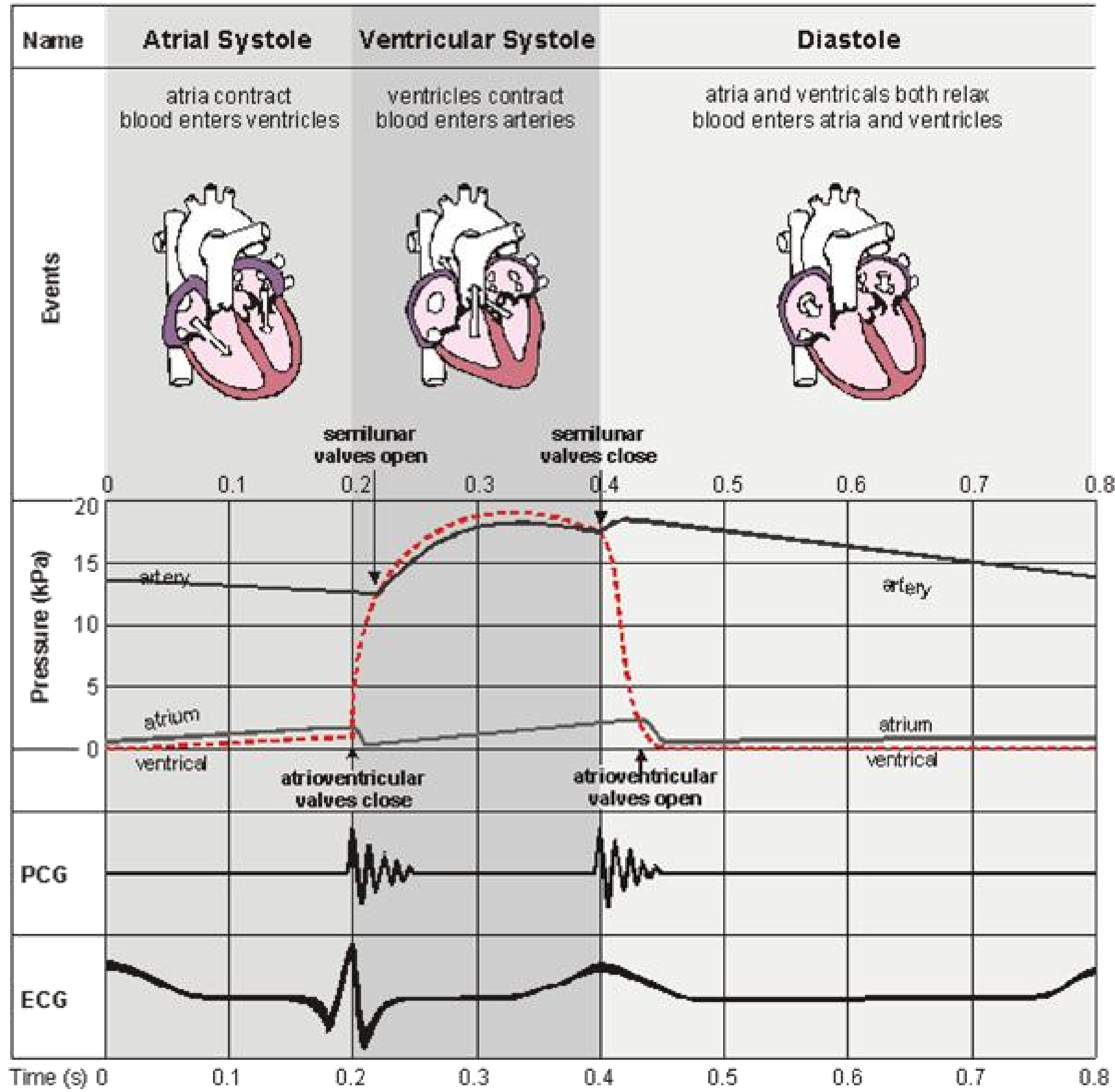
Cardiac Output- the amount of blood ejected from the heart per minute
- determined by the stroke volume (the amount of blood pumped each stroke) and the heart rate (beats per minute)

•average CO is 5.25L/min

Starlings law of the heart- the more cardiac fibers are stretched by the filling of a chamber with blood, the stronger the walls will contract to eject the blood



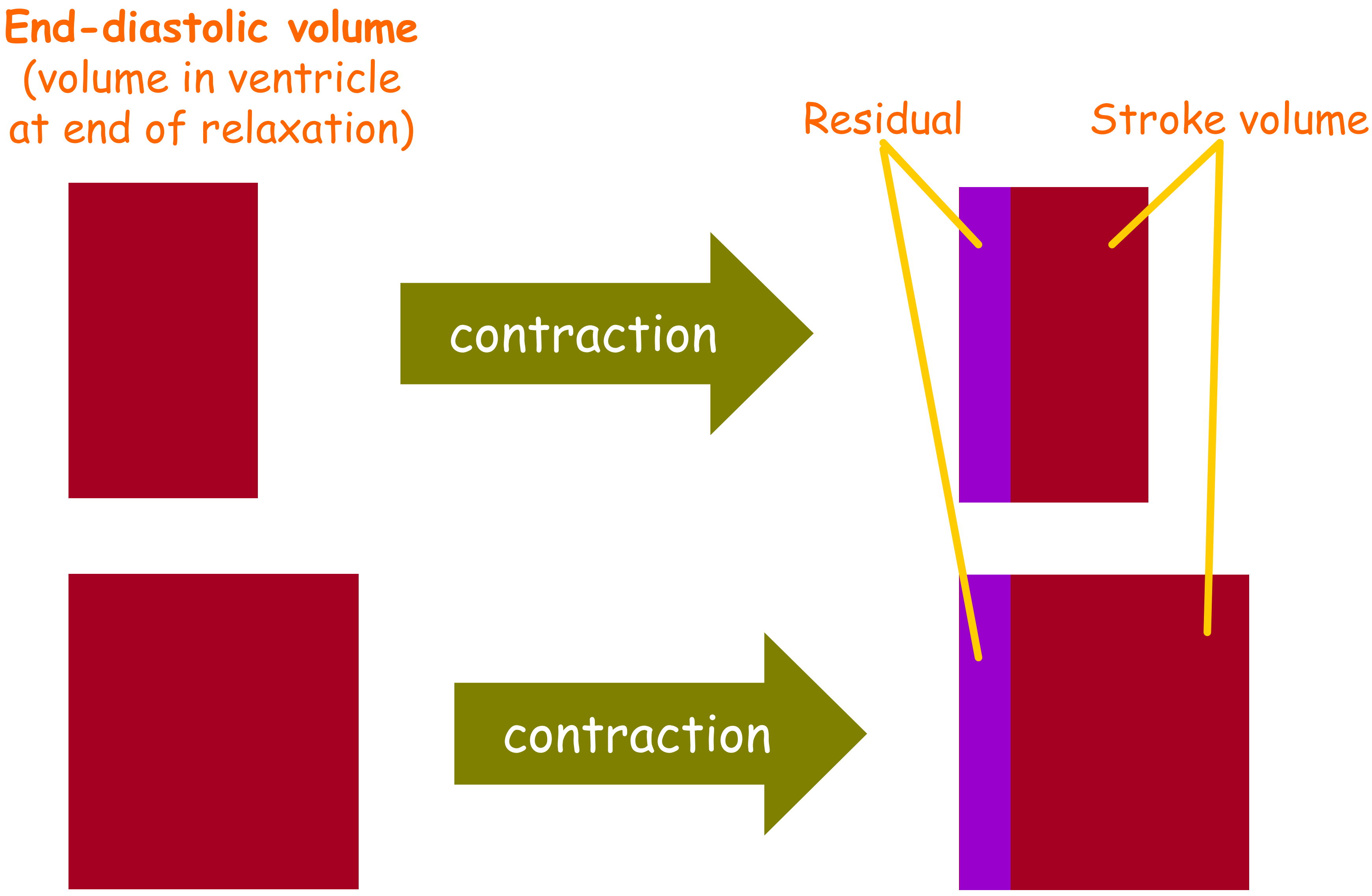
1.Ventricular filling
2.Ventricular contraction
   a. av valves close (S1)
   b.isovolumetric contraction
   c. semilunar valves open
3. Ejection
4.Begin diastole
5.Similunar valves close (S2)
6.Isovolumetric relaxation
7.Av valves open

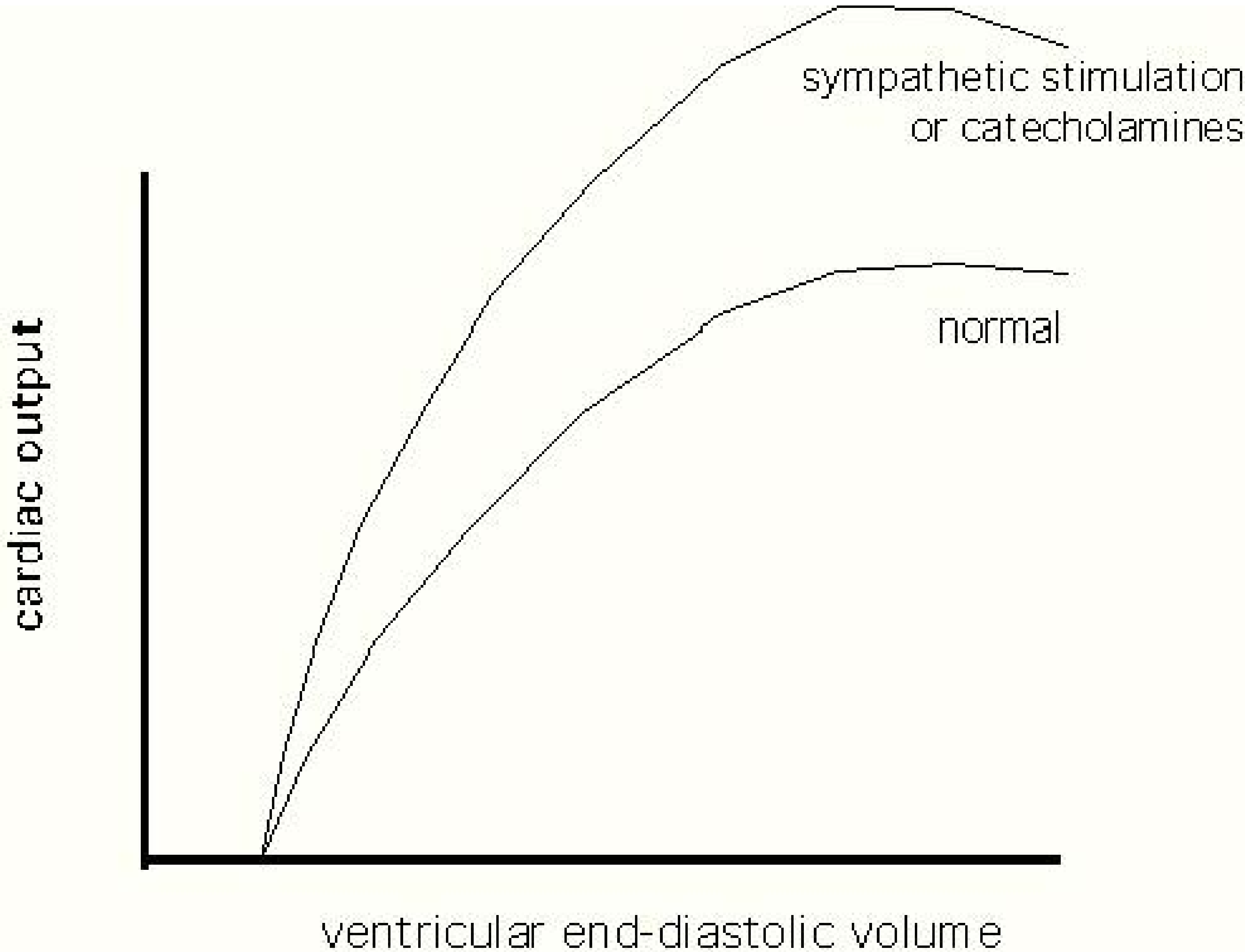


Stroke Volume

- Governed by preload, contractility, and afterload
- **Preload**- the work imposed on the heart before contraction begins
  - represents the amount of blood that the heart must pump with each beat
    - determined by venous return and the accompanying stretch of the muscles fibers
  - established on Frank-Starling law of the heart-
    - based on the fact that there is an optimal anatomic arrangement of the actin and myosin filaments (when the fibers are stretched 2 ½ times there normal resting length) that generates maximum contraction.

Starling's Law of the Heart




sympathetic stimulation
or catecholamines
normal
cardiac output
ventricular end-diastolic volume

After load- the work presented to the heart after the contraction has commenced

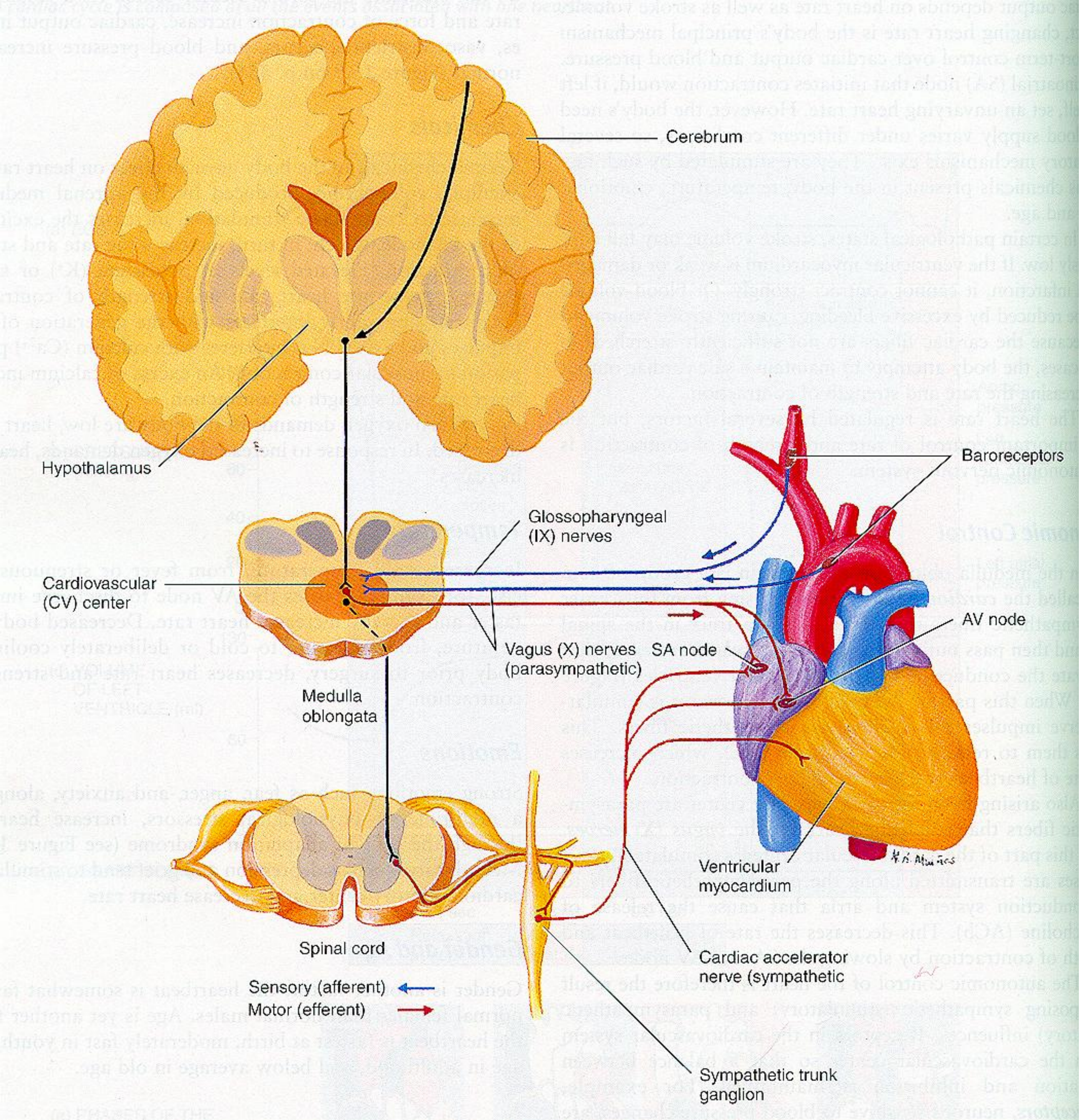
- represents the pressure that the heart must generate to move blood into the aorta
- The systemic arterial blood pressure is the main source of afterload work on the left heart and the pulmonary artery pressure for the right heart.

- **Contractility**- refers to the ability of the heart to change its force of contraction without changing its resting fiber (diastolic) length.
- The state of the muscle is strongly influenced by the number of calcium ions that are available to participate in the contraction process.
- **Inotropic** influence is one that modifies the contractile state of the myocardium independent of Frank-Starling mechanism.
  - ex: sympathetic stimulation produces a positive inotropic effect by increasing the calcium that is available for interaction between the actin and myosin filaments

Heart Rate

- Determines the frequency with which blood is ejected from the heart
- As heart rate increases, cardiac output tends to increase
- As the HR increases the time spent in diastole is reduced and there is less time for ventricular filling but the time spent in systole remains fairly constant
- This leads to a decrease in stroke volume at high heart rates
  - ex: one of the dangers of **ventricular tachycardia** is a reduction in cardiac output because the heart does not have time to fill adequately.

- **Tachycardia**- adult heart rate above 100 bpm
- **Bradycardia**- adult heart rate below 60 bpm
- **Positive chronotropic agents-** factors that raise the heart rate
- **Negative chronotropic agents-** factors that lower the heart rate



<u>Heart rate control</u>

sympathetic
parasympathetic
chemical- K^+, Na^+, Ca^{++}
temperature
emotions
gender/age

Chronotropic Effects of the Autonomic Nervous System

- The nervous system only modulates the heart beat but does not initiate it.

1. cardiac center of the medulla consist of two neuronal pools
   - **cardioacceleratory center-** sends signals by way of the sympathetic cardiac accelerator nerves to the SA node, AV node, and myocardium.
   - These nerves secrete norepinephrine, which bind to B-adrenergic receptors that tend to increase heart rate and contractility

Chronotropic Effects of the Autonomic Nervous System

2. Cardioinhibitory center- sends signals by way of the parasympathetic fibers in the vagus nerves to the SA and the AV nodes]
    - the right vagus innervates mainly the SA node and the left vagus, the AV node
    - nerve secretes acetylcholine which binds to muscarinic receptors to opens K+ channels (K+ leaves the cell) to hyperpolarize the cell which causes the cell to fire less frequently, thereby slowing the heart rate.
    - vagal tone- continuous background vagal input to the nodes that holds the heart rate between 70 and 80 bpm.
        - maximal vagus stimulation can reduce the heart rate to as low as 20 bpm
        - severing the vagus allows the SA node to fire at its own intrinsic frequency of about 100 bpm

Input to the Cardiac Centers

- Sensory and emotional input via the cerebral cortex, limbic system, and hypothalamus
- **Proprioceptors-** in the muscles and joints inform the cardiac center of changes in physical activity
- **Baroceptors** (pressure receptors)- pressure sensors in the aorta and internal carotid arteries
- **Chemoreceptors-** sensitive to blood pH, carbon dioxide, and oxygen concentration are found in the aortic arch, carotid arteries, and medulla oblongata
  - respond to **hypercapnia** (excess CO2) and **acidosis** (increased H+) and **hypoxia** (oxygen deficiency)

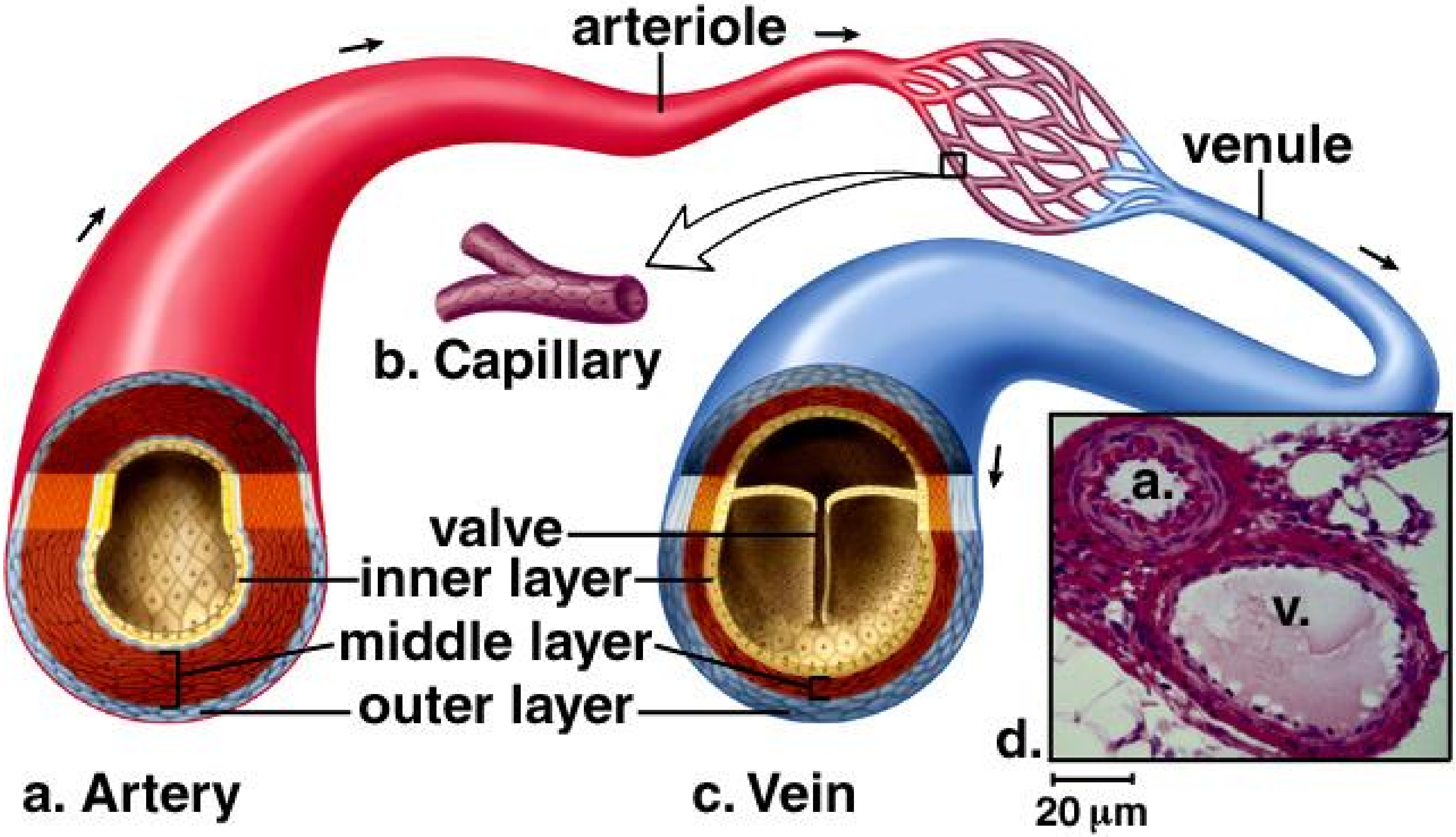
Chronotropic Effects of Chemicals

- The catecholamines, Epinephrine and norepinephrine, are potent cardiac stimulants
  - they act through cAMP
- Caffine and the related stimulants in coffee, tea, and chocolate produce positive chronotropic effects by inhibiting the breakdown of cAMP
- Nicotine accelerates heart rate by stimulating catecholamine secretion
- Thyroid hormone increases the number of adrenergic receptors in the cardiac muscles, thereby making the more responsive to sympathetic stimulation (hyperthyroidism causes tachycardia)

Chronotropic Effects of Chemicals

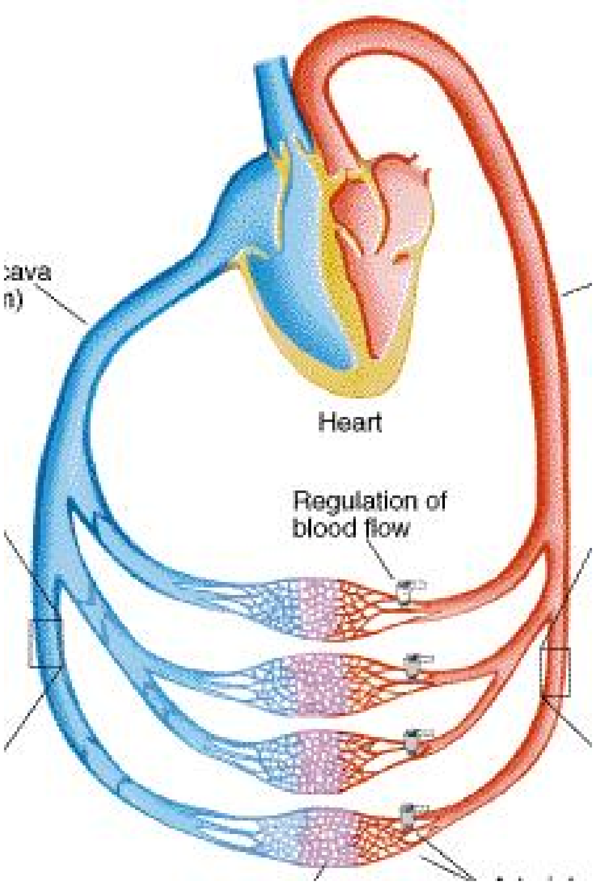
- **Hyperkalemia** (excess K+)
  - rapid rise makes the myocardium unusually excitable and subject to systolic arrest (ventricles contract and fail to rest)
  - slow rise makes it less excitable than normal; the heart rate becomes slow and irregular and may arrest in diastole
- **Hypokalemia** (K+ defficiency)- myocytes become hyperpolarized which makes it more difficult to stimulate the cells to threshold
- **Hypercalcemia**- reduces the heart rate and strengthens contraction strength
- **Hypocalcemia**- increases the heart rate and weakens contraction

Blood vessels



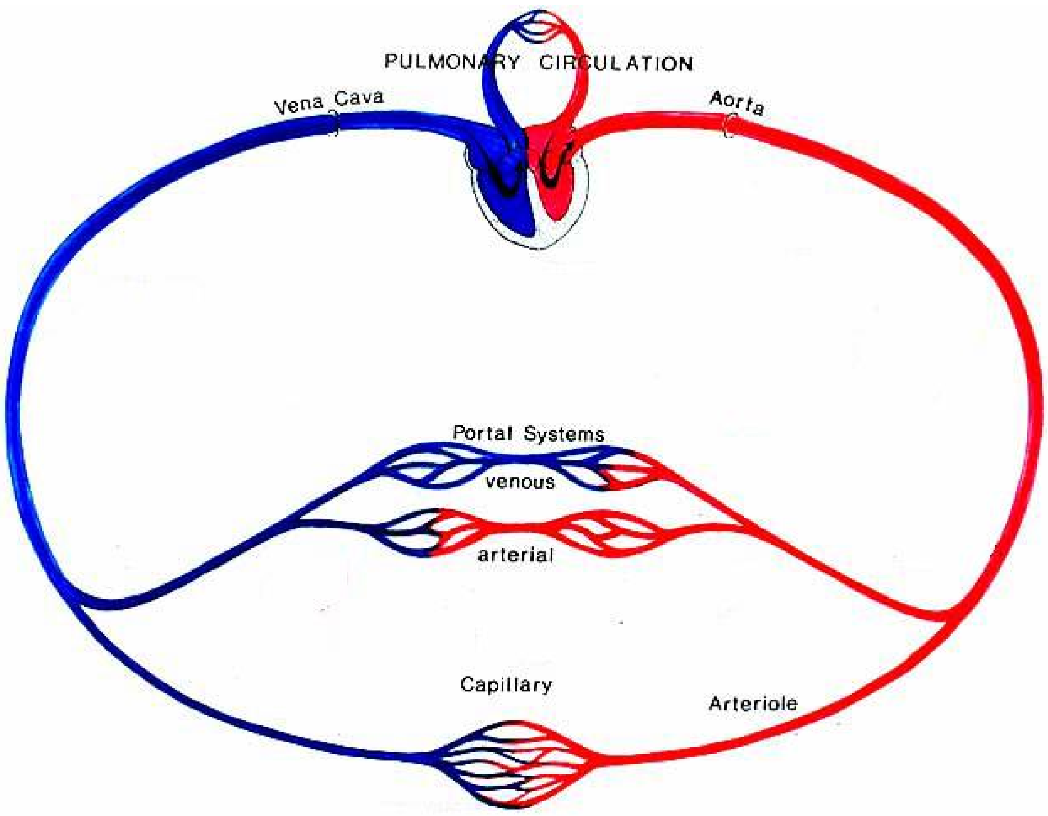
Circulatory Routes

- Usual route of blood is
  - heart
  - arteries
  - arterioles
  - capillaries
  - venules
  - veins
  - heart



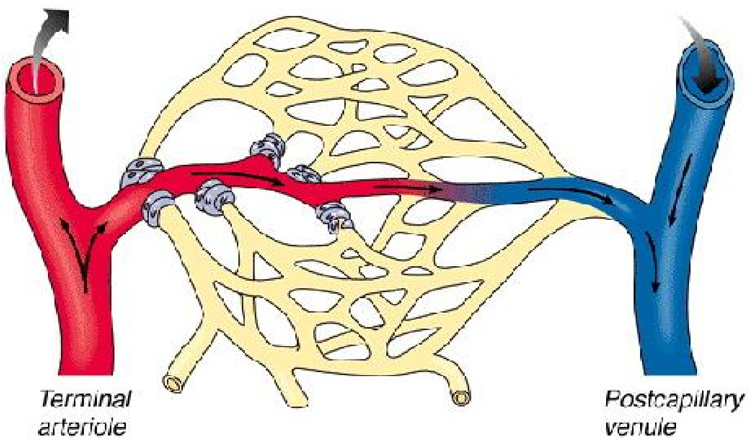
Circulatory Routes

- Portal system- blood flows through two consecutive capillary beds before returning to the heart

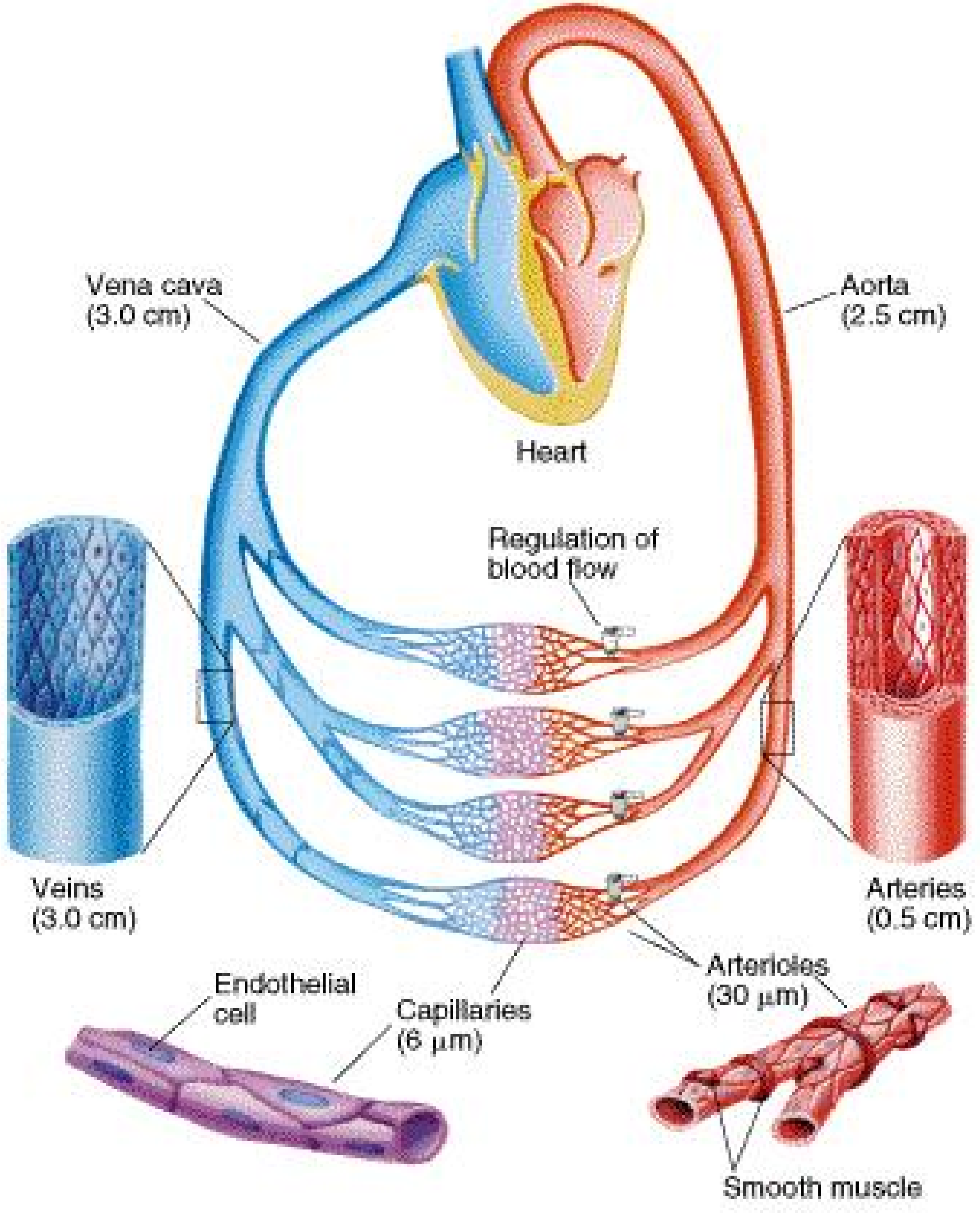


Circulatory Routes

- **Anastomosis**- a point where two blood vessels merge
- **Arteriovenous anastomosis (shunt)-** when blood flows from an artery directly into a vein and bypasses the capillaries
  - occurs in cold weather in fingers, palms, toes, and ears when body is trying to conserve h eat
  - makes areas more susceptible to frostbite
- **Arterial anastomosis-** when two arteries merge and provide collateral (alternative) routes of blood supply to a tissue
  - common around joints where movement may temporarily obstruct one pathway
- **Venous anastomosis-**
  - are more common
  - provide several alternative routes of drainage from an organ, therefore, venous blockage is rarely as life-threatening as arterial blockage



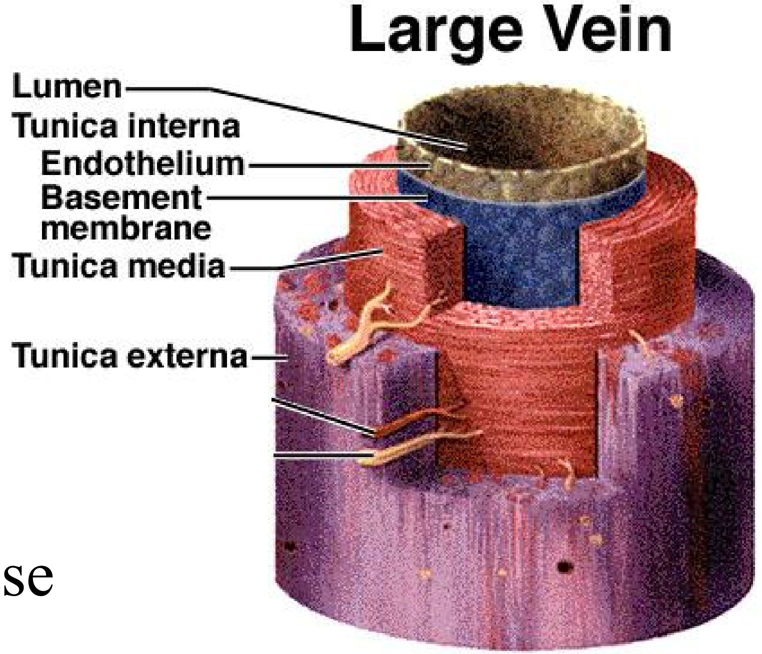
(b) Sphincters closed

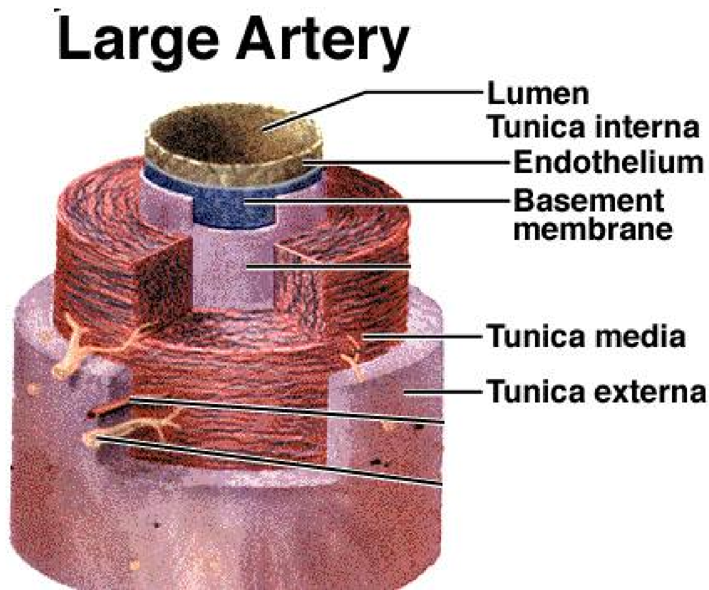

Vena cava
(3.0 cm)
Aorta
(2.5 cm)
Heart
Regulation of
blood flow
Veins
(3.0 cm)
Arteries
(0.5 cm)
Arterioles
(30 µm)
Endothelial
cell
Capillaries
(6 µm)
Smooth muscle

The Vessel Wall

Vessel walls has three layers (tunics)

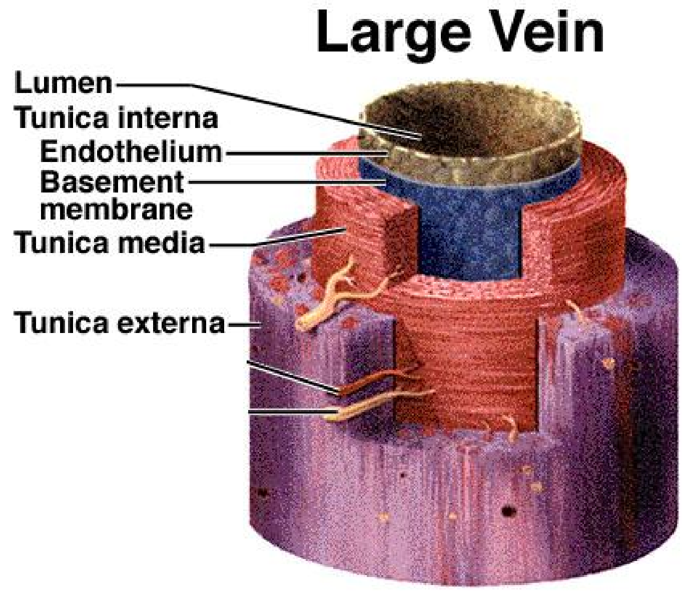
- **tunica externa (adventitia)-**
  - outer most layer that consist of loose c.t. that anchors the vessel
  - provides passage for small nerves, lymphatics, and smaller blood vessels (**vasa vasorum**) that supply blood to outer half of wall
  - inner half nourished by diffusion of luminal blood

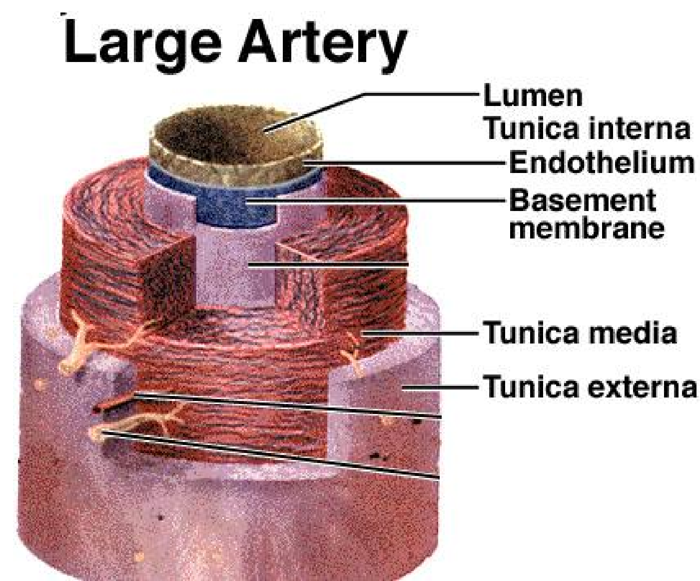




The Vessel Wall

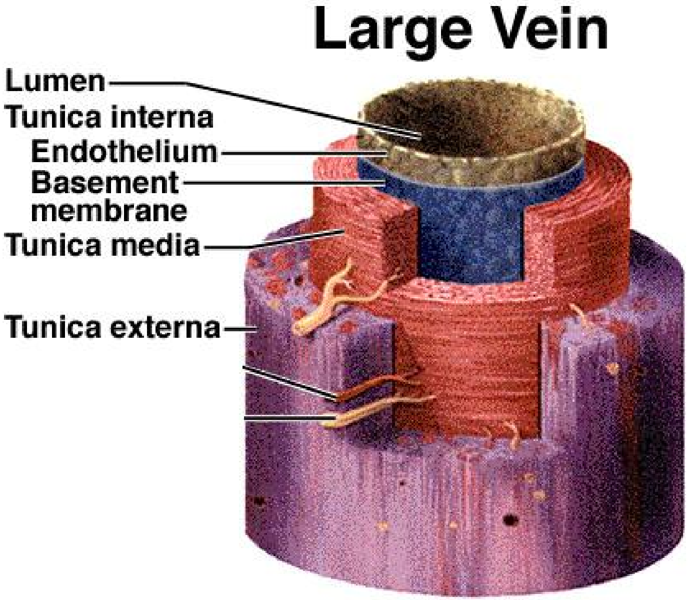
- Tunica media-
  - the middle layer
  - usually the thickest layer
  - consist of smooth muscle, collagen, and sometimes elastic tissue
  - smooth muscle responsible for vasoconstriction and vasodilation

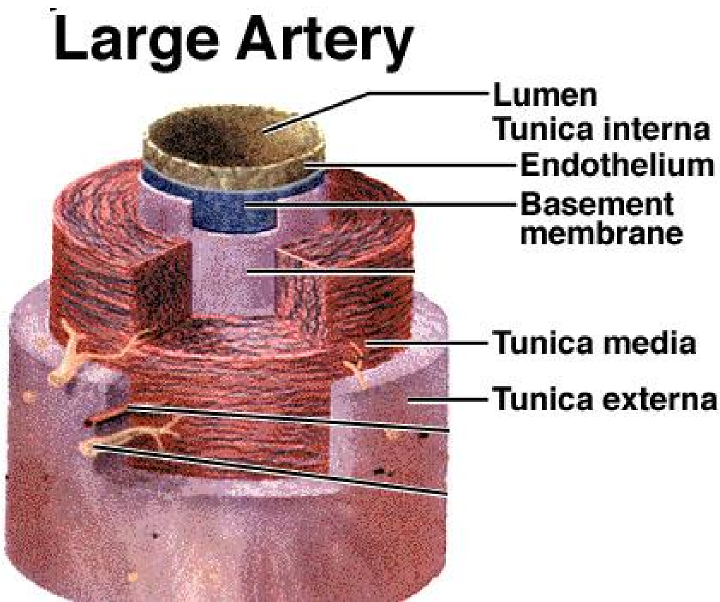




The Vessel Wall

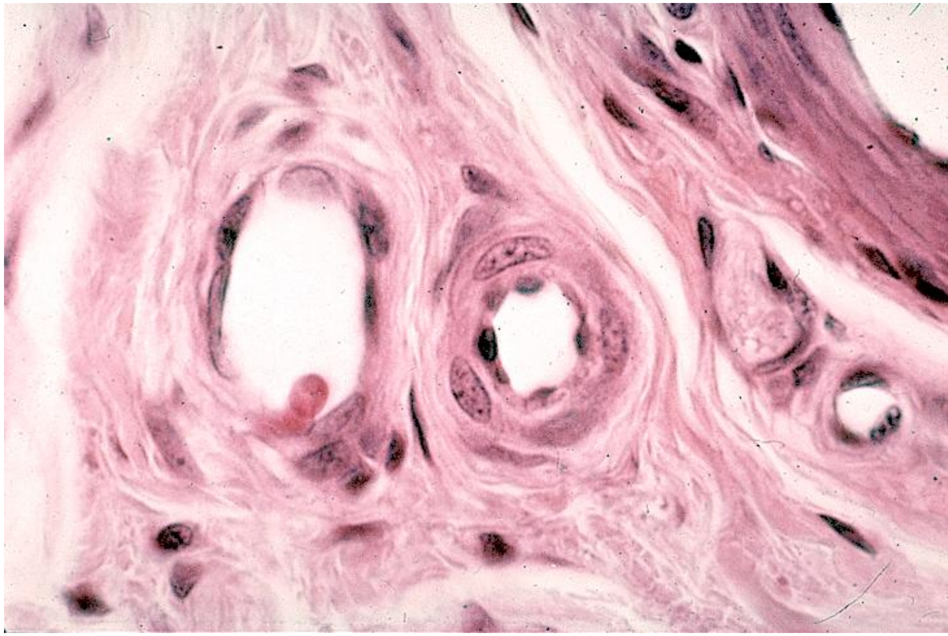
- **Tunica intima (tunica interna)-** inner layer that is exposed to blood
  - consists of a simple squamous endothelium overlaying a basement membrane and a sparse layer of fibrous c.t.
  - acts as a selectively permeable barrier to blood solutes
  - secretes vasoconstrictors and vasodilators
  - provides a smooth inner lining that repels blood cells and paltelets
    - platelets adhere to damaged endothelium
    - during inflammation, leukocytes adhere to endothelium by means of **cell-adhesion molecules** produced by the endothelium cells





Arteries and Metarterioles

- Arteries are constructed to withstand surges of blood pressure generated by the heart
  – more muscular than veins and appear relatively round in tissue sections
- Arteries are divided into three categories by size
  – conducting (elastic)
  – distributing (muscular)
  – resistance (small)



Arteries and Metarterioles

- **Conducting (elastic) arteries-**
  - are the largest (pulmonary, aorta, common cartotids)
  - tunica media consist of lots of elastic tissue and smooth muscle
  - expand when the ventricles pump blood into them during systole and recoil during diastole

Arteries and Metarterioles

- **Distributing (muscular) arteries**
  - are smaller branches farther away from the heart that distribute blood to specific organs
  - smooth muscle layers consist of ¾ of the wall thickness
  - most arteries to which names are given are of this class (as well as conducting arteries)
    - brachial, femoral, etc.
- **Resistance (small) arteries-** are usually too variable in number and location to be given names
  - lots of smooth muscle in tunica media
  - the smallest of these are the arterioles
  - are the primary points at which the body controls the relative amounts of blood directed to various organs

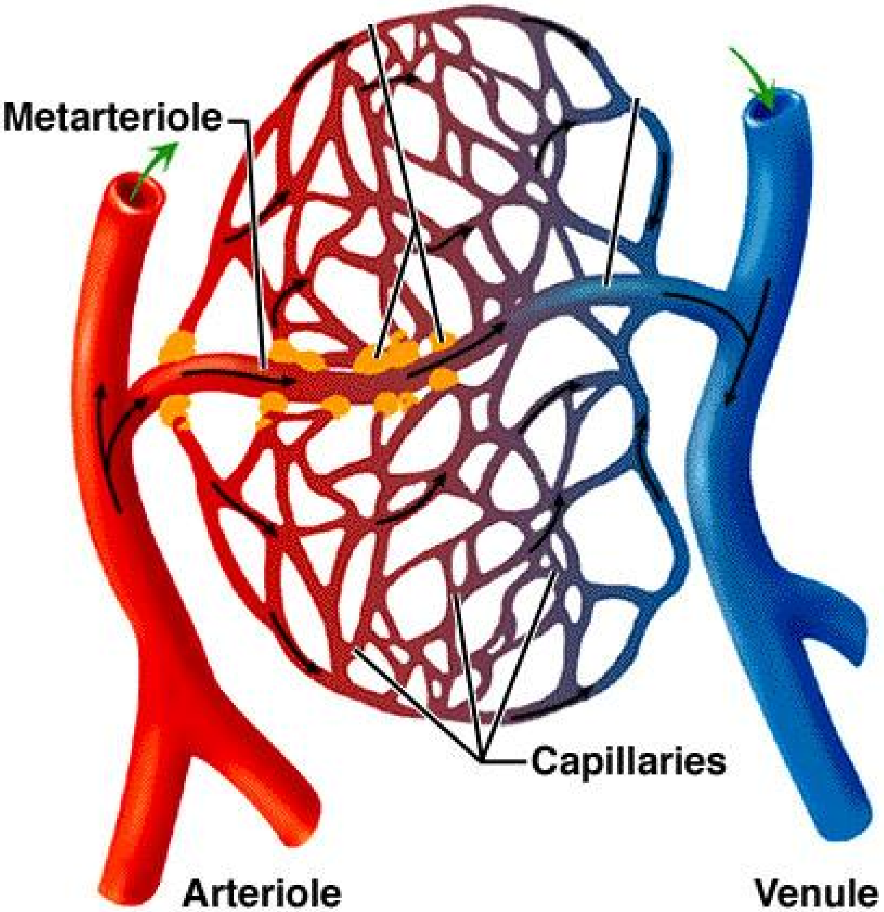
Metarterioles & Capillaries

Metarterioles

- short vessels that link arterioles and capillaries
- have smooth muscle pre-capillary sphincter that encircles the entrance to a capillary
- continues through the capillary bed as a thoroughfare channel leading directly to the venule

Capillaries

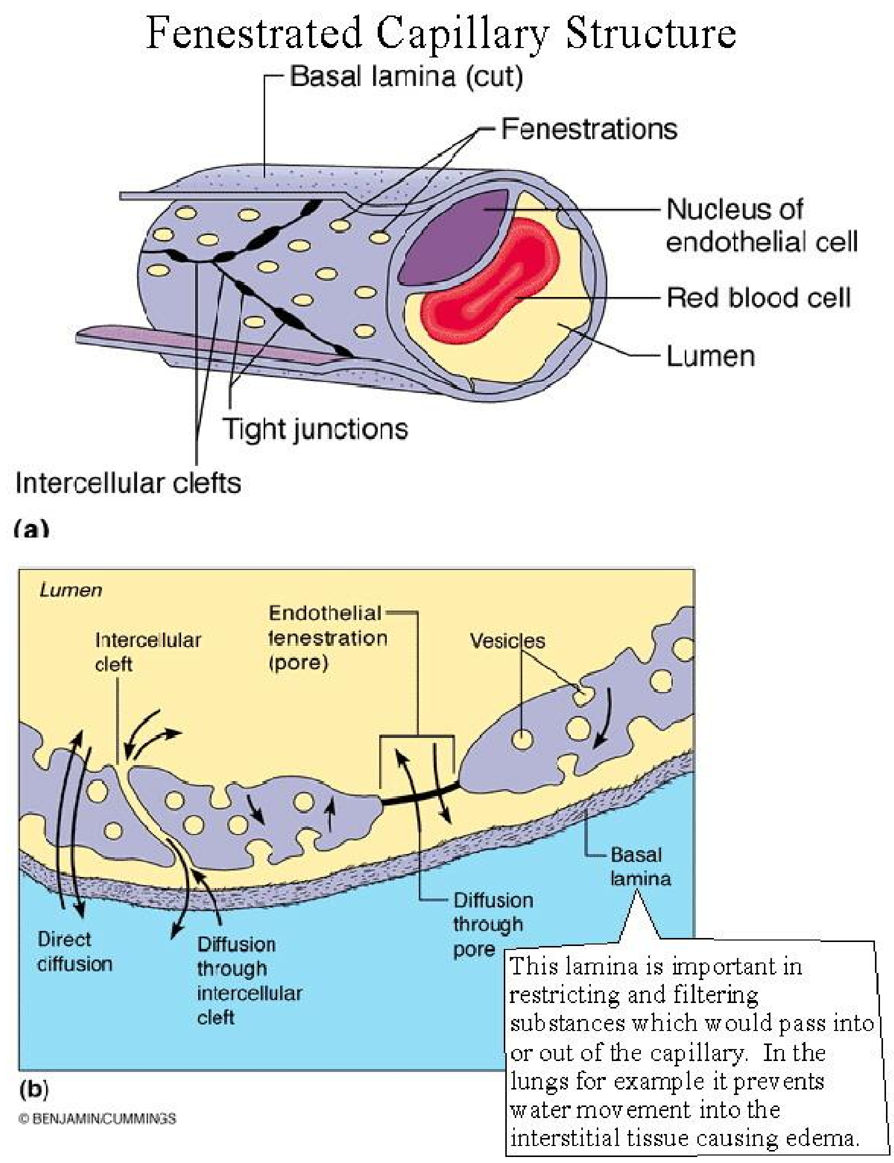
- only point where materials are exchanged between blood and tissue
- consist of only endothelium (one cell thick) and basement membrane
- has very large total surface area (6,300 m^2)



Types of Capillaries

Continuous capillaries

- occurs in most tissues
- endothelial cells held togeth by tight junctions
- cells have narrow intercellul clefts which can pass small solutes such as glucose, but large particles (plasma prote are held back
  - capillaries of the blood brain barrier lack intercellular cleft: and more complete tight junc

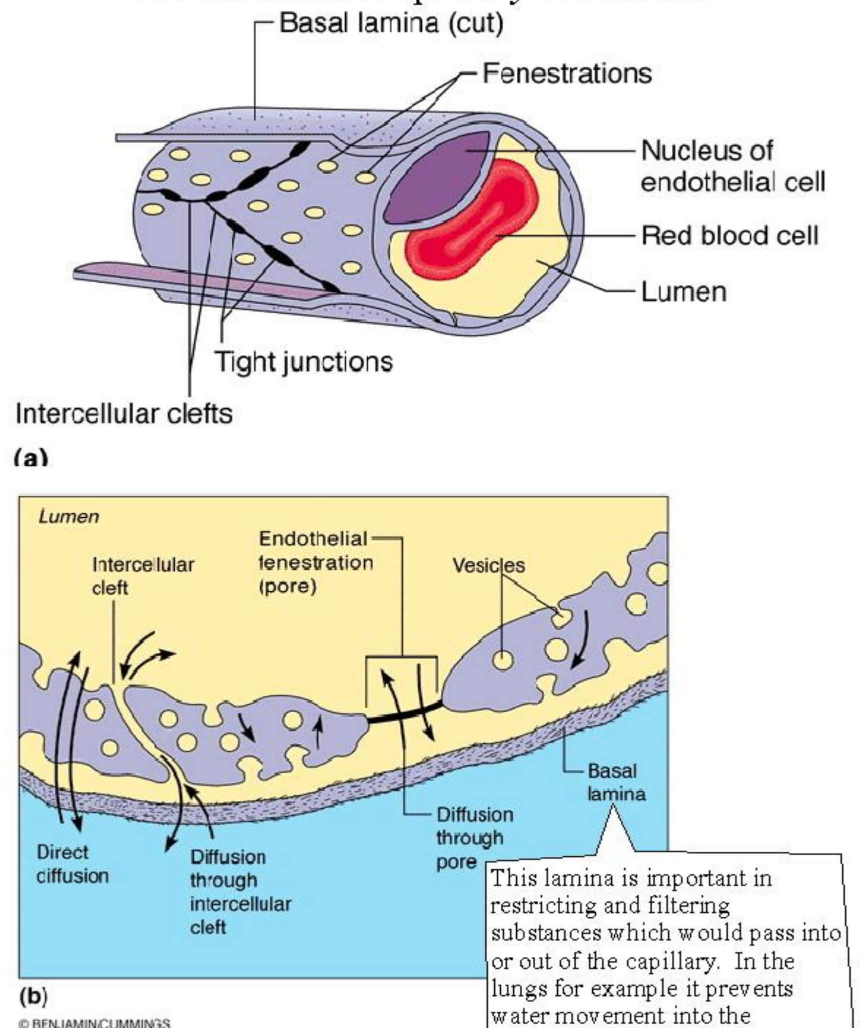


Types of Capillaries

Fenestrated capllaries

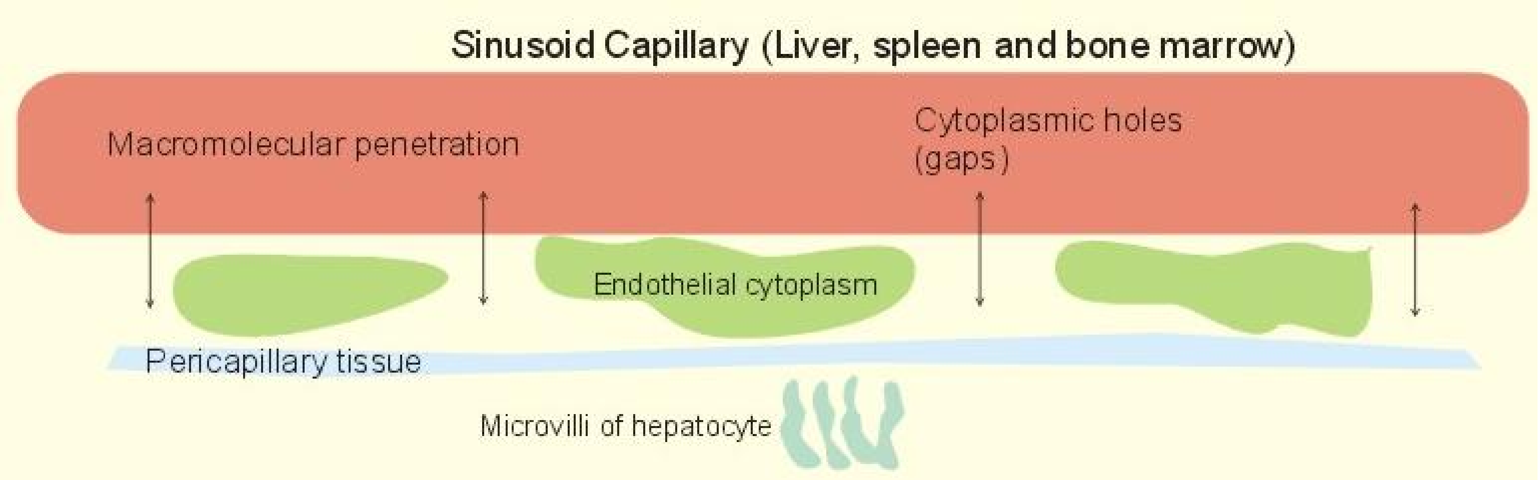
- cells are riddled with holes called fenestrations (filtration pores)
- fenestrations are covered by a thin mucoprotein diaphragm
- they allow for the rapid passage of small molecules but retain proteins and larger particles in the blood stream
- are important in organs that engage in rapid absorption or filtration (kidneys, endocrine glands, small intestine, choroid plexus of brain)

Fenestrated Capillary Structure



This lamina is important in restricting and filtering substances which would pass into or out of the capillary. In the lungs for example it prevents water movement into the interstitial tissue causing edema.

Types of Capillaries

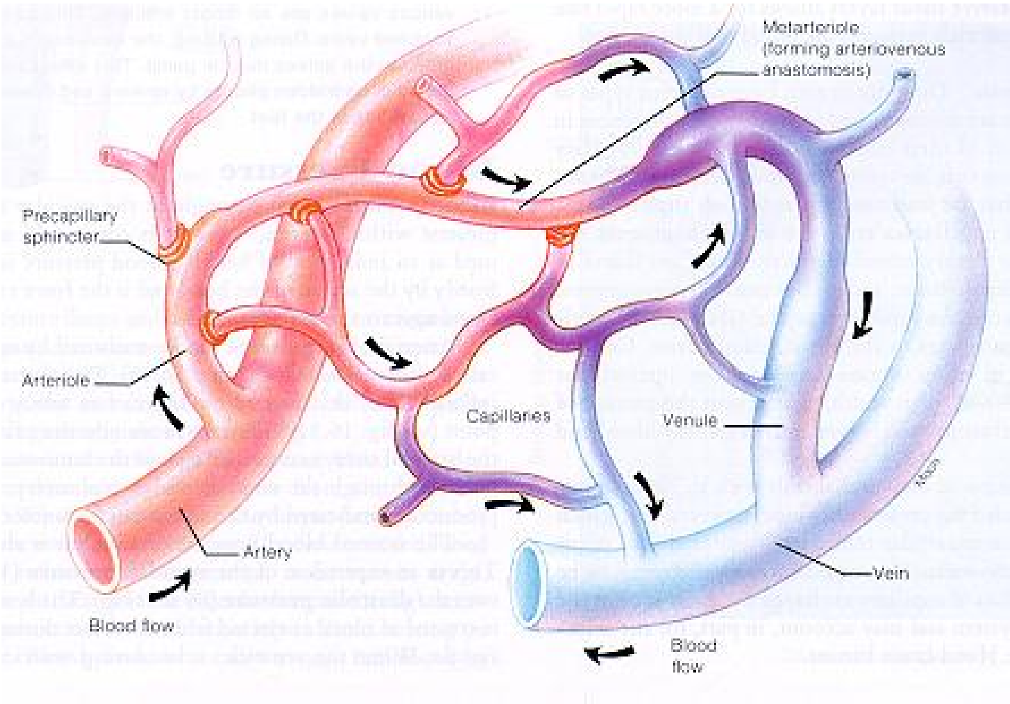


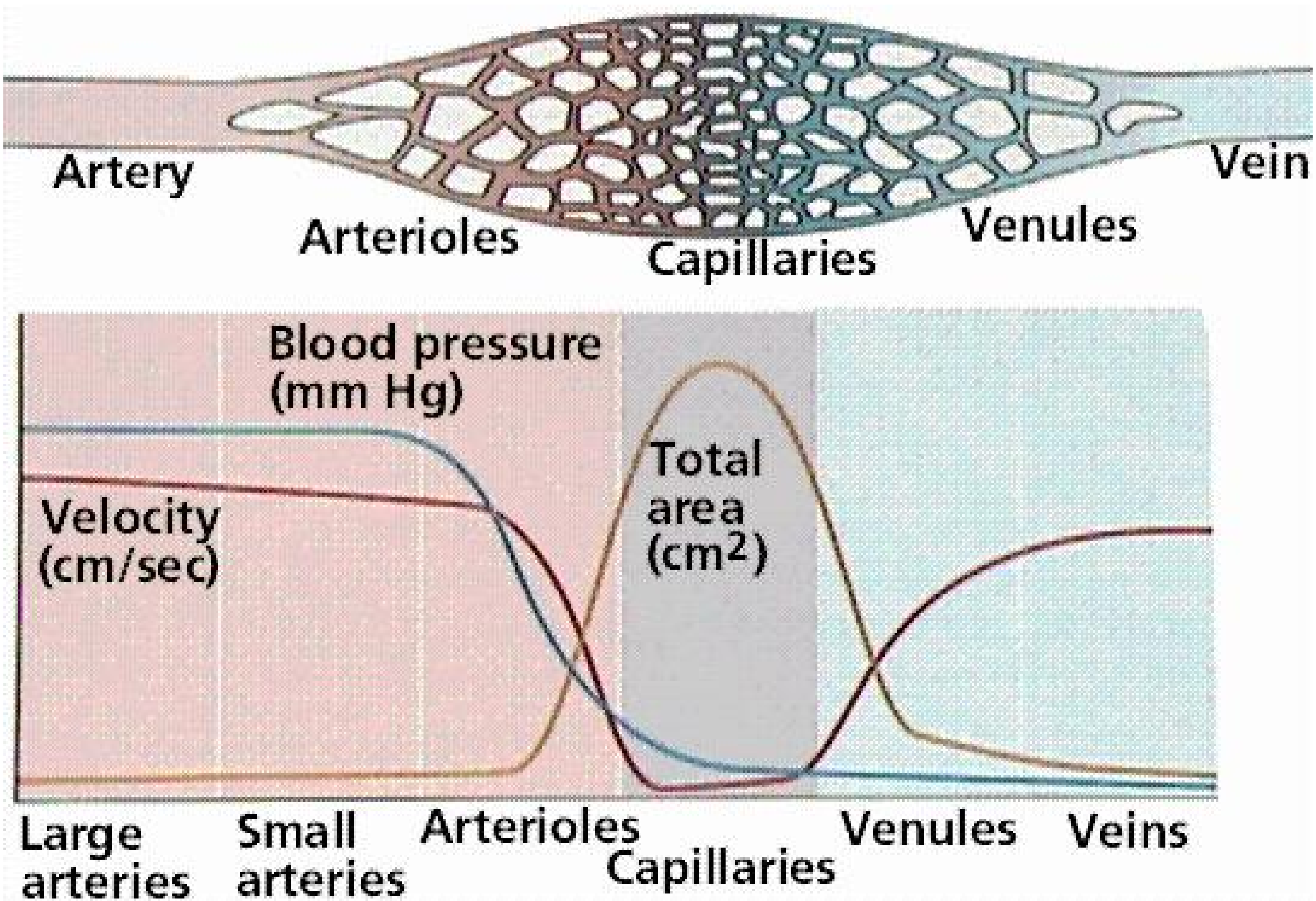
Sinusoid capillary

- irregular bllood filled spaces that serves as passageways that allow blood plasma to come into direct contact with the parivascular cells
- Pores allow passage of proteins and blood cells
  - how albumin, clotting factors, and other large proteins synthesizes by the liver enter the blood
  - how newly formed blood cells inter the circulation from the bone marrow and lymphatic organs

Veins

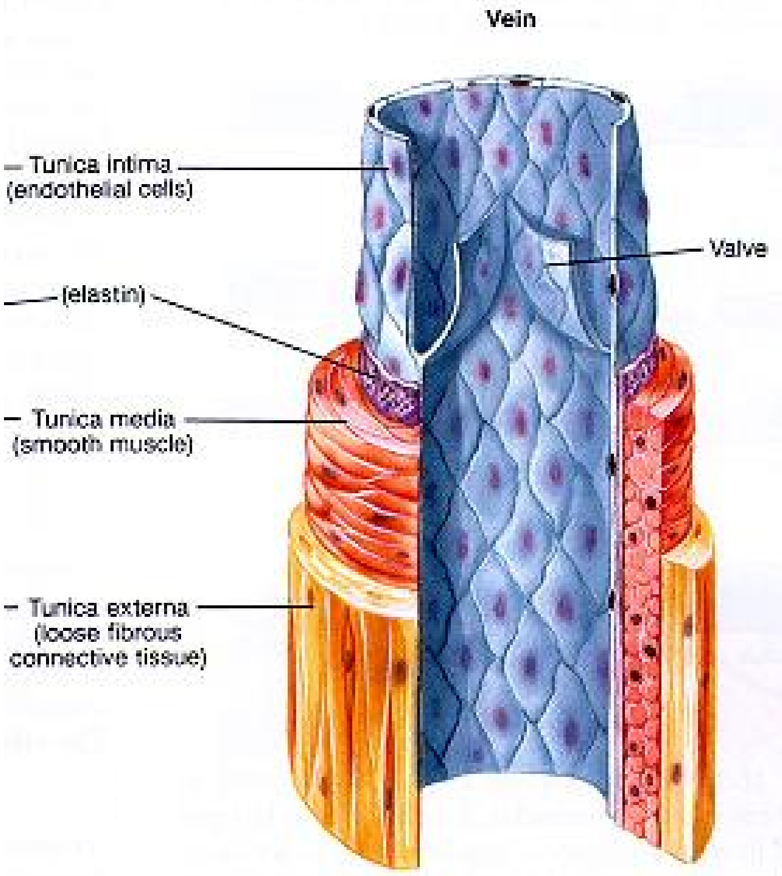
- Blood collects from the capillaries to the venules that are able to exchange fluid with the surrounding tissues
- veins have much lower blood pressure than arteries (avg. 10 mmHg vs. 100mmHg)
- Have thinner walls than arteries with less muscular and elastic tissue
- They collapse when empty and look flattened or irregular in histologic sections
- Expand more easily and accommodate more blood than do arteries
  - approx. 54% of the blood is found in the systemic veins at rest (called **capacitance vessels**)

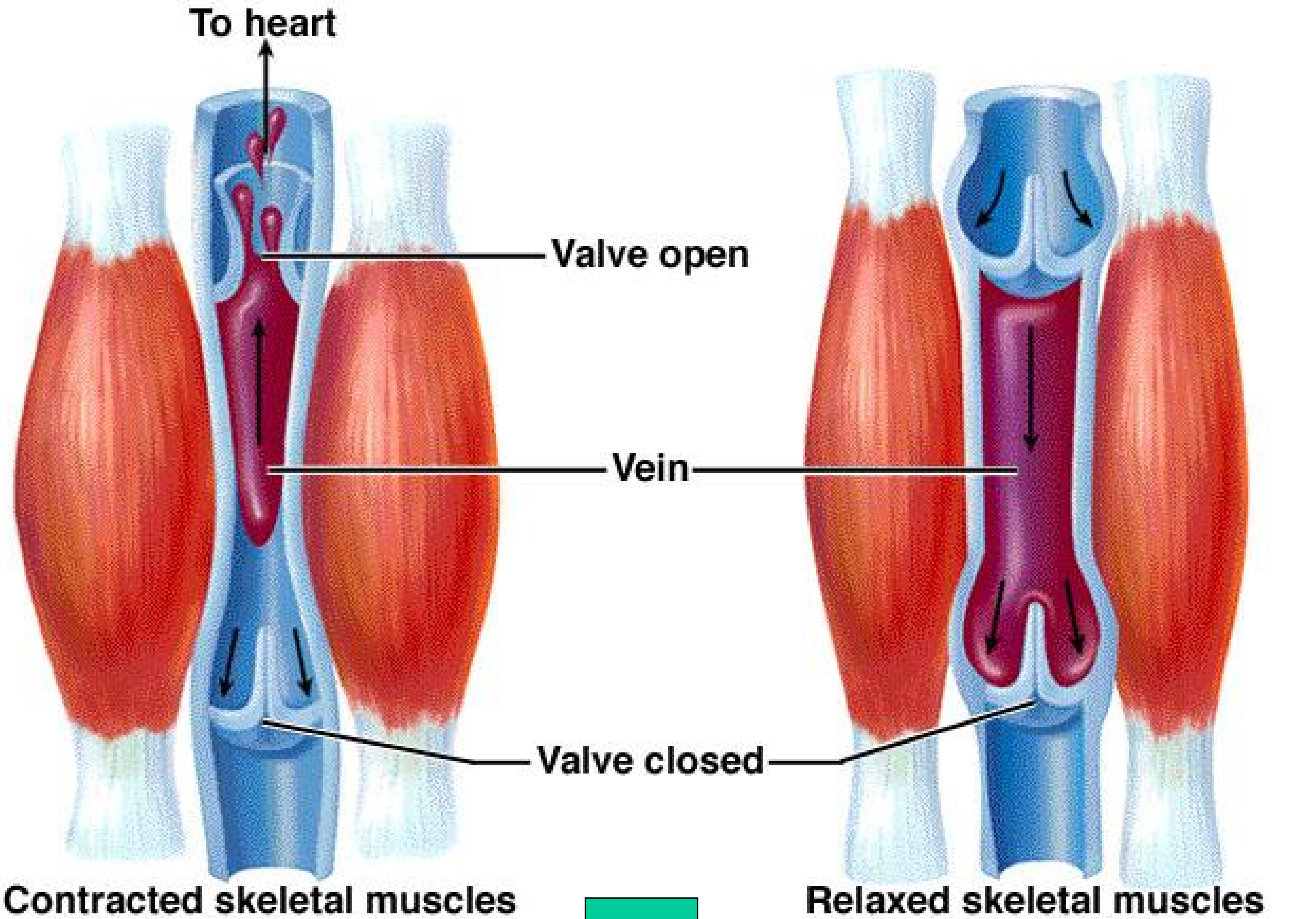



Artery
Arterioles
Capillaries
Venules
Vein
Blood pressure
(mm Hg)
Velocity
(cm/sec)
Total
area
(cm2)
Large
arteries
Small
arteries
Arterioles
Capillaries
Venules
Veins

Veins

- Pressure in the veins is not high enough to push blood upward against gravity to the heart
- flow of blood back to the heart depends on the
  - **messaging action of skeletal muscle**
  - **one-way valves** that keep blood from dropping down again when the muscles relax
  - **thoracic (respiratory) pump**
  - **cardiac suction-** chordae tendeneae pulls AV valves cusps downward, slightly expanding the atrial space, creating a slight suction
  - **gravity-** blood flow from head
- Valves occur especially in medium sized veins of the arms and legs
- They are absent from very small and very large veins of the ventral body cavity and brain





To heart
Valve open
Vein
Valve closed
Contracted skeletal muscles
Relaxed skeletal muscles

Circulatory Shock

- Is any state in which cardiac output is insufficient to meet the body's metabolic needs
- All forms of shock fall in to two categories
  - **cardiogenic shock-** caused by inadequate pumping by the heart usually as result of myocardial infarction

Circulatory Shock

- **low venous return (LVR) shock** has three principal forms
  - hypovolemic shock-
    - most common form
    - produced by a loss of blood volume as a result of hemorrhage, trauma, bleeding ulcers, burn, or dehydration
  - Obstructed venous return shock
    - occurs when something compresses vein and impedes its blood flow
      - ex: a growing tumor or aneurysm

Circulatory Shock

- Venous pooling (vascular) shock-
  - occurs when the body has a normal total blood volume, but too much of it accumulates in the limbs
  - can result from long periods of standing or sitting or from widespread vasodilation
  - neurogenic shock- form of venous pooling caused by a sudden loss of vasomotor tone, allowing the vessels to dilate
    - can be cause by severe brainstem trauma or emotional shock

Circulatory Shock Caused by Both Venous Pooling and Hypovolemic Shock

- **Septic shock-** occurs when bacterial toxins trigger vasodilation and increased capillary permeability
- **Anaphylactic shock-** results from exposure to an antigen to which a person is allergic which triggers release of histamine causing generalized vasodilation and increased capillary permeability

Principles of Blood flow

Blood flow is determined by two factors

- a pressure difference between the two ends of a vessel or group of vessels
- the resistance that blood must overcome as it moves through the vessel or vessels
- The relationship between pressure, resistance, and flow is expressed by the equation

$$F=P/R$$

F is the blood flow, P is the difference in pressure between the two ends of the system, and R is the resistance to flow through the system

Principles of Blood flow

- Peripheral resistance is the resistance that the blood encounters in the vessels as it travels away from the heart
- It results from the friction of blood against the walls of the vessels and is proportional to three variables
  - blood viscosity
  - vessel length
  - vessel radius

Principles of Blood flow

Blood viscosity

- thickness of the blood
- due mainly to erythrocytes and albumin
- A deficiency of red blood cells (anemia) or albumin (hypoproteinemia) decreases peripheral resistance and speeds up blood flow
- Viscosity increases as a result of polycythemia or dehydration, therefore, resistance increases and flow declines

Principles of Blood flow

Vessel length

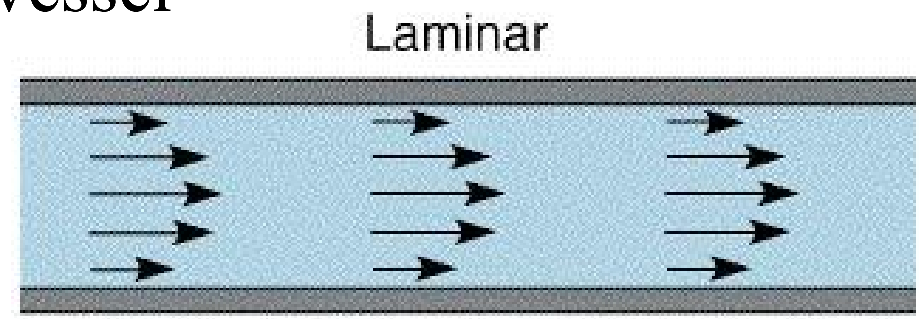
- The farther a liquid travels through a tube, the more cumulative friction it encounters (in the body the length is constant)

Vessel Radius

- Is the only significant way of controlling peripheral resistance
- vasomotion- a change in vessel radius
  - vasoconstriction- smooth muscle contraction
  - vasodilation- smooth muscle relaxation

Principles of Blood flow

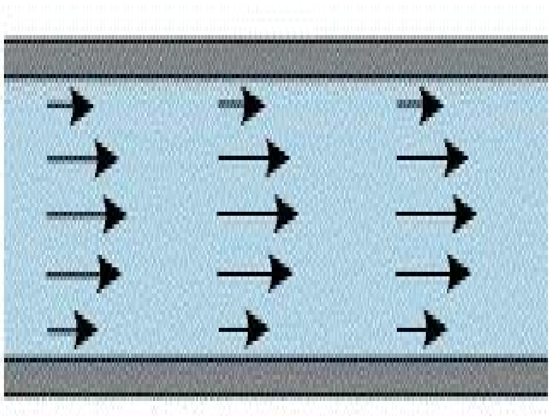
- The effects of vessel radius on blood flow is related to the friction of the moving blood against the walls of the vessel

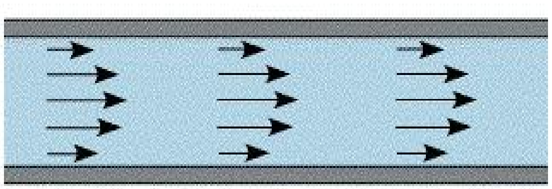


- Blood flow is laminar, meaning, it flows in layers that is faster near the center of the vessel where it encounters less friction, and slower near the walls where it drags against the vessel.

Principles of Blood flow

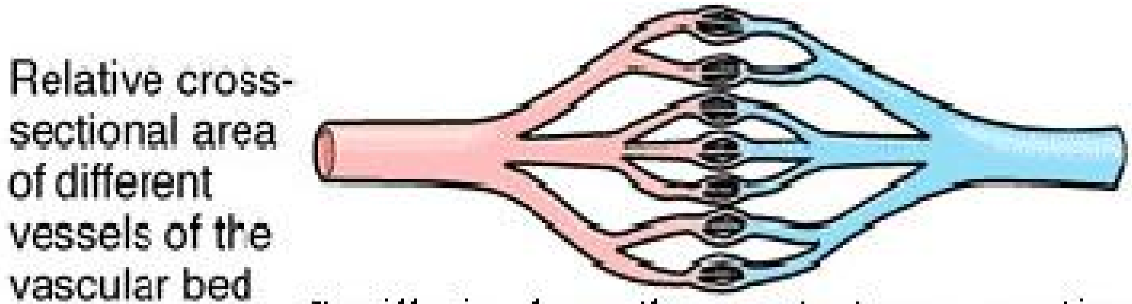
- When a blood vessel dilates, a greater portion of the blood is in the middle of the stream and the average flow is swift
- When the vessel constricts, more blood is closer to the wall and average flow is slower
- Blood flow is proportional to the fourth power of the radius, making a slight change in diameter resulting in a great change in flow



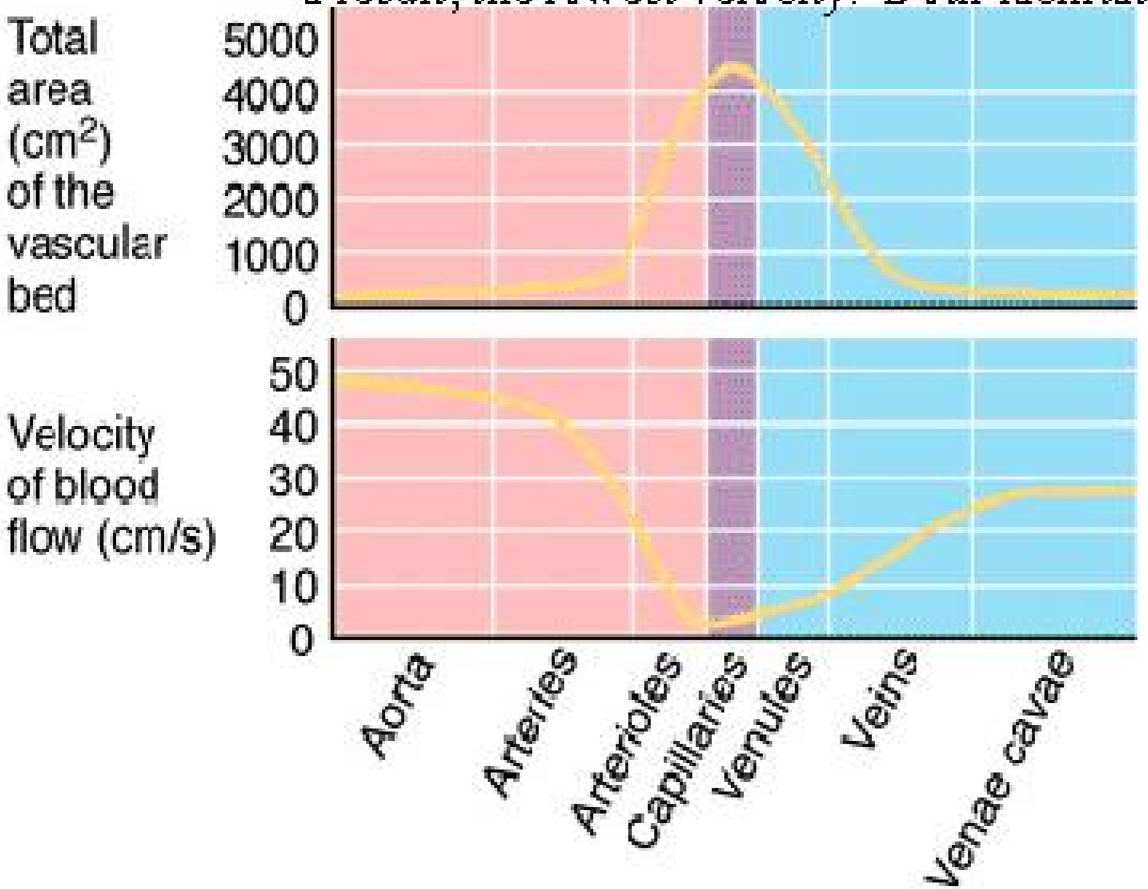


ex: r= 2 mm   F= 16 mm/sec

r= 3 mm   F= 81 mm/sec



Capillaries have the greatest cross-sectional area, and as a result, the lowest velocity. Both facilitate transport.



Regulation of Blood Pressure and Flow

Local control

- **Autoregulation-** the ability of tissue to regulate their own blood supply according to its metabolic needs

Ex: in inadequately perfused tissue, waste products accumulate (CO_2, H^+, K^+, lactic acid) which stimulates vasodilation which tend to increase perfusion.

- Established through **vasoactive chemicals** secreted by blood platelets, endothelial cells, and the perivascular tissue.
  - Ex: vasodilators- histamine, bradykinin, prostaglandins in inflammation, trauma, and exercise
  - endothelial cells secrete prostacyclin and nitric oxide – vasodilators and **endothelins**- vasoconstrictors

Regulation of Blood Pressure and Flow

Local control (cont.)

- **Reactive hyperemia-** increase flow above normal to a tissue when flow is cut off for a time
  - due an accumulation of metabolites during the period of ischemia]
    - ex: when skin flushes after a person comes in from the cold
- **Angiogenesis-** the process where a tissue increases its own perfusion by the growth of new blood vessels
  - three situations in which this is demonstrated
    - regrowth of the uterine lining after menstruation
    - generation of blood vessels in the muscles of well-conditioned athletes
    - growth of arterial bypasses around obstruction in the coronary circulation
    - malignant tumors secrete growth factors to provide more nourishment

Regulation of Blood Pressure and Flow

Neural control

- control by hormones and the autonomic nervous system
- vasomotor center-
  - give off sympathetic fibers stimulate most blood vessels to constrict but they dilate the vessels of skeletal and cardiac muscle.
  - integrating center for autonomic reflexes
    - barorefexes
    - chemoreflexes
    - medullary ischemic reflex- response to a drop in perfusion to the brain
      - increase in heart rate and contraction force
      - widespread vasoconstriction

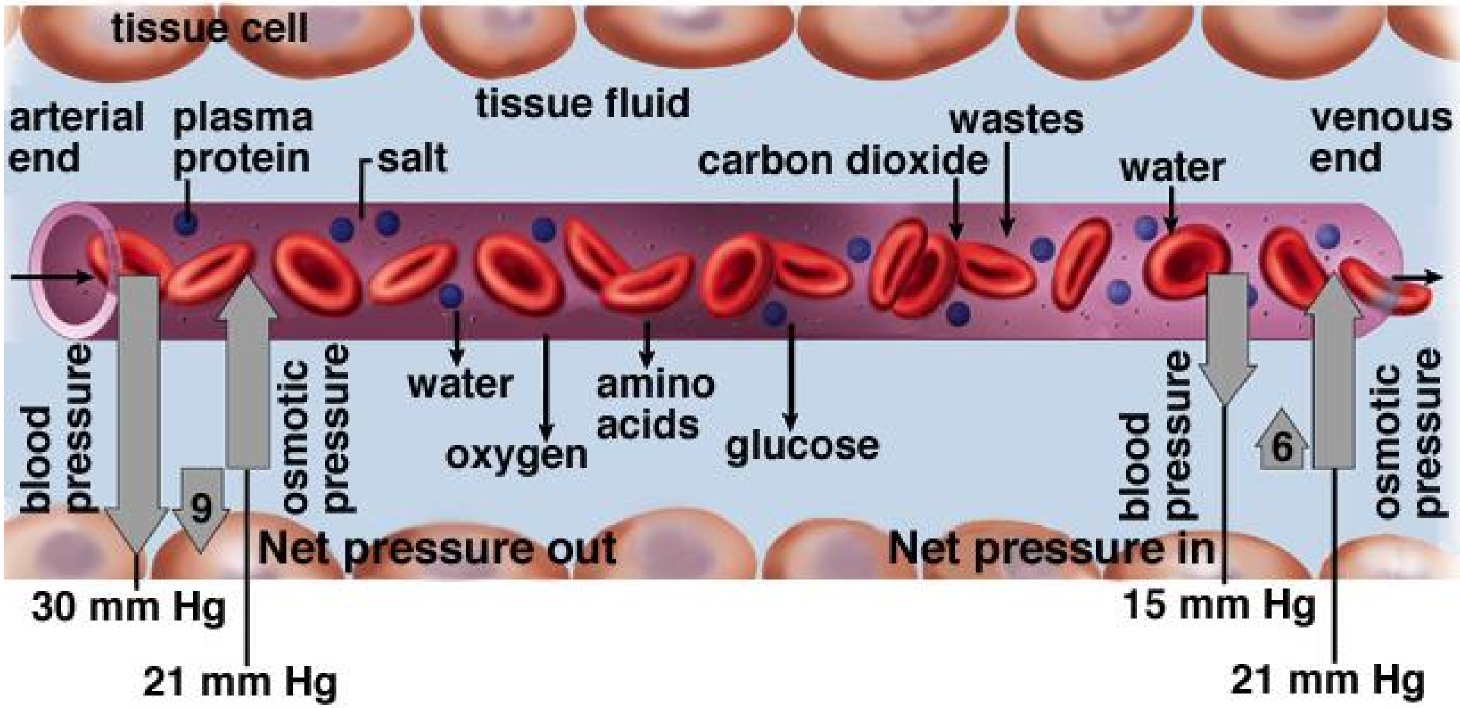
Hormonal Control of Blood Pressure

- **Angiotensin II-** potent vasoconstrictor produced by angiotensin converting enzyme (ACE)
  - hypertension often treated with ACE inhibitors
- **Aldosterone-** salt retaining hormone
  - promotes Na+ retention by the kidney along with water following
- **Atrial natriuretic peptice** (ANP)- is secreted by the heart and antagonizes aldosterone
  - it increases Na+ excretion by the kidney, thus reducing blood volume and pressure
  - also has a generalized vasodilator effect
- **Antidiuretic hormone** (ADH)- promotes water retention but at very high concentrations causes vasoconstriction (hence the name vasopressin)
- **Epinephrine and norepinephrine-** adrenal and sympathetic catecholamine that bind to alpha- adrenergic receptors on smooth muscles of vessels, causing vasoconstriction
  - in skeletal muscles and coronary vessels, they bind to beta- adrenergic receptors causing vasodilation, resulting in increased blood flow to the myocardium

Capillary Exchange

- Substances pass between the blood and tissue fluid by three routes
  - through the intercellular clefts between endothelial cells
  - through the fenestrations (pores) of fenestrated capillaries
  - through the endothelial cell cytoplasm
- The mechanisms of exchange involve
  - diffusion
  - transcytosis
  - filtration
  - reabsorption

Capillary Exchange



Diffusion

- most important mechanism for exchange
- glucose and oxygen diffuse from vessels to tissue
- CO_2 and other wastes products diffuse from tissue to vessels

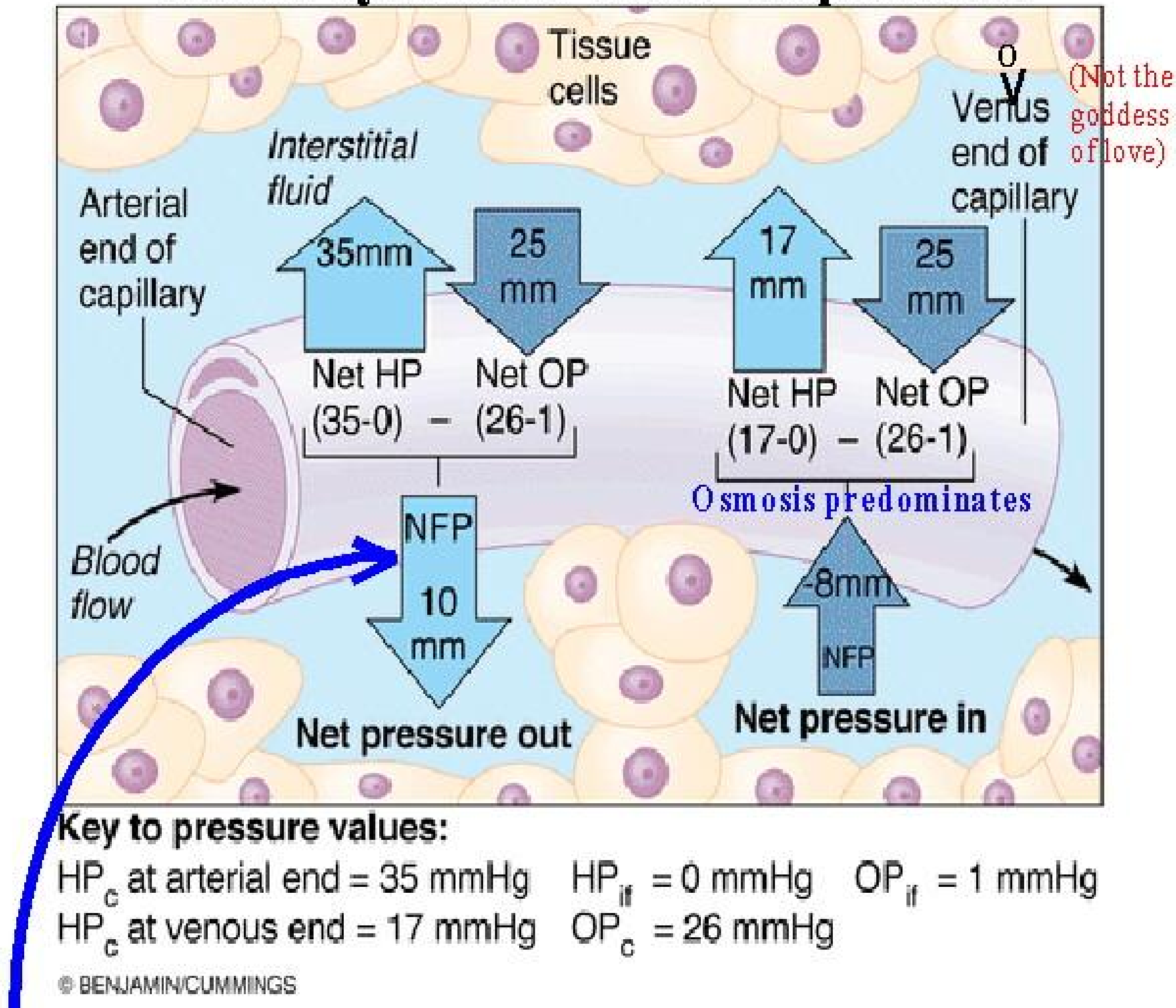
Other forces in capillary fluid dynamics

•blood pressure (**hydrostatic pressure**) causing filtration

•**Oncotic pressure-** the difference between the interstitial pressure (colloid osmotic pressure of the tissue) and the colloid osmotic pressure of the plasma

•Pressures change from arterial end to venous end

Fluid Dynamics inthe Capillaries

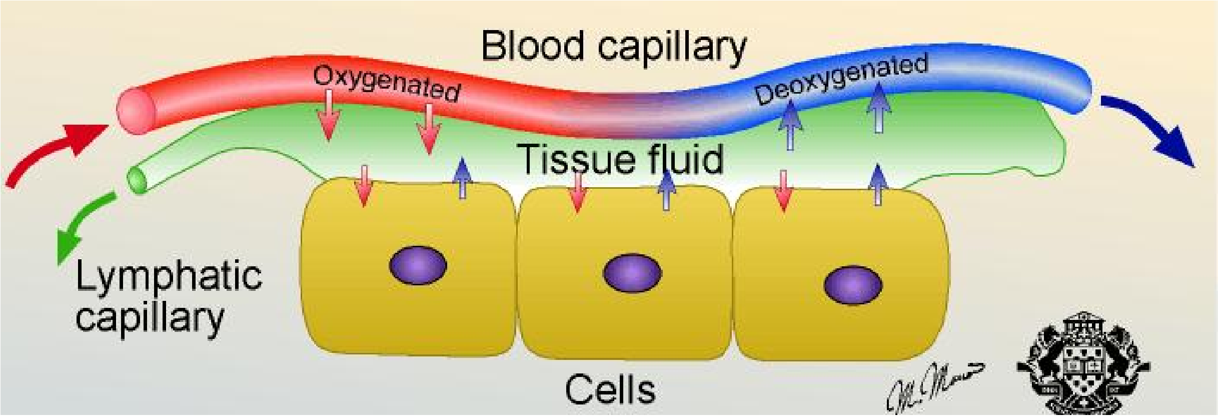


Filtration - movement of water and dissolved substances out of the capillary due to hydrostatic pressure

HP = hydrostatic pressure (blood pressure)

OP = osmotic pressure

Edema

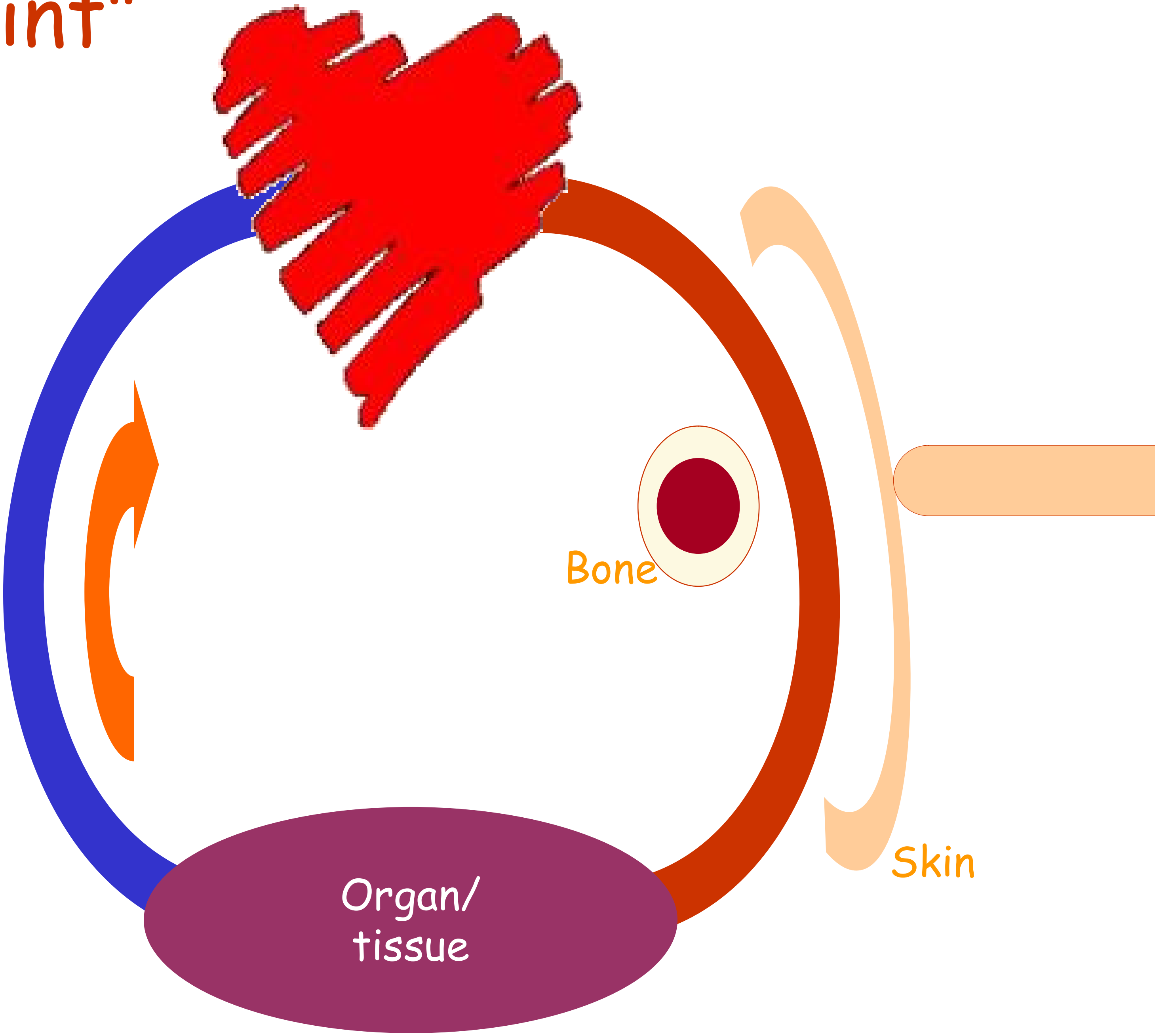


- the accumulation of excess fluid in a tissue causes by
  - increased capillary filtration caused by increased permeability or blood pressure
    - poor venous return causes back pressure
      - congestive heart failure, incompetent heart valves
    - prolonged confinement to bed or wheelchair (insufficient muscular activity)
    - kidney failure- causing water retention and hypertension
- Reduced capillary reabsorption caused by a reduction in oncotic pressure
  - hypoproteinemia caused by liver damage
- Obstructed lymphatic drainage or surgical removal

Edema

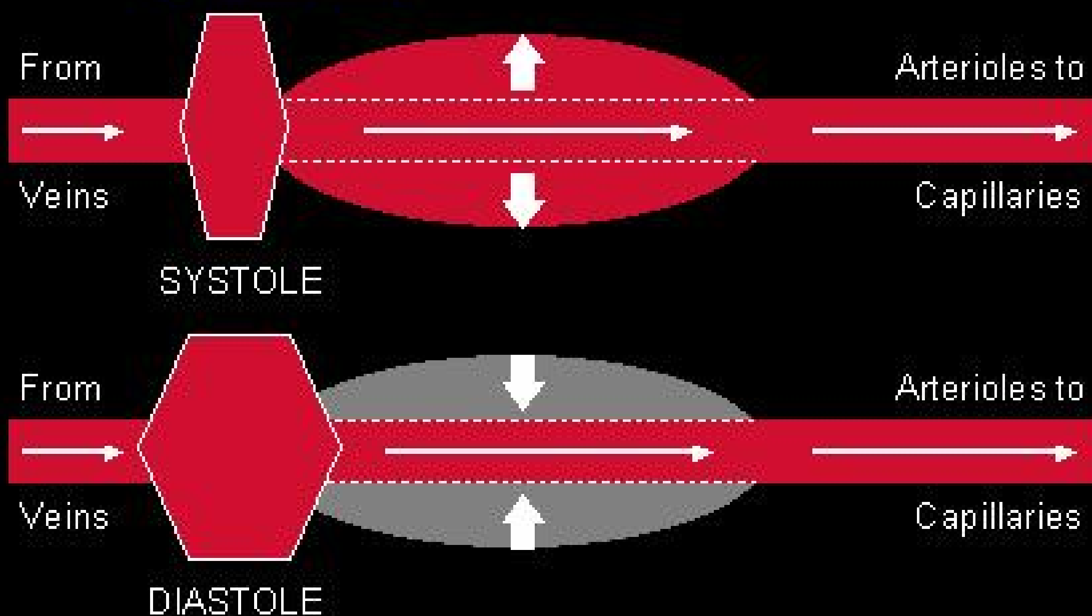
- Severe edema
  - may lead to circulatory shock too much of a transfer of fluid from vessels to tissues
  - As the tissue becomes swollen with fluid, oxygen delivery and waste removal are impaired leading to tissue necrosis
  - Pulmonary edema presents a threat of suffocation
  - cerebral edema can produce headaches, nausea, seizures, and coma

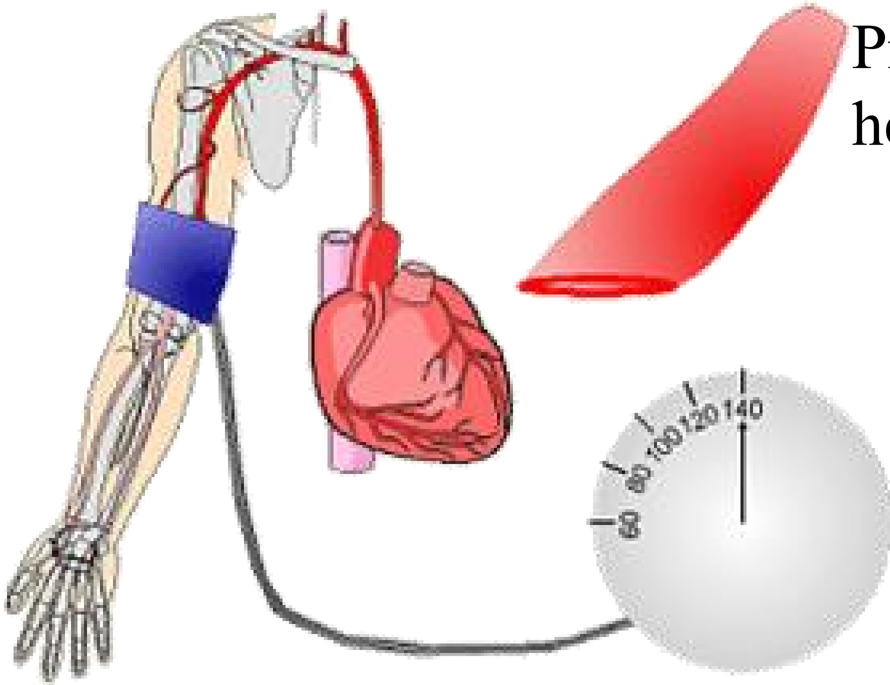
“pulse point”



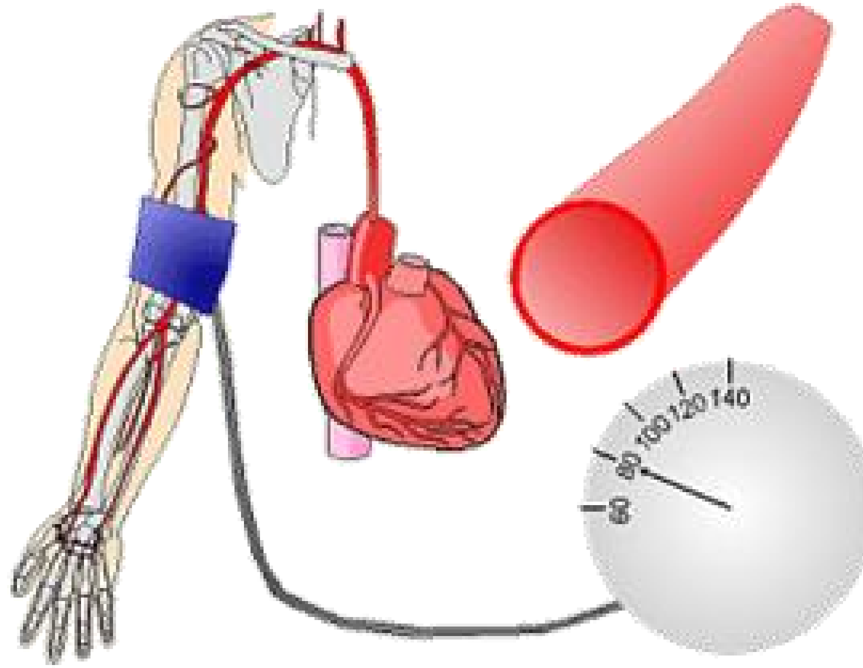
Arteries

- Low resistance, rapid transit passageways
- Muscle & elastic connective tissue in walls
  - *elastic recoil*

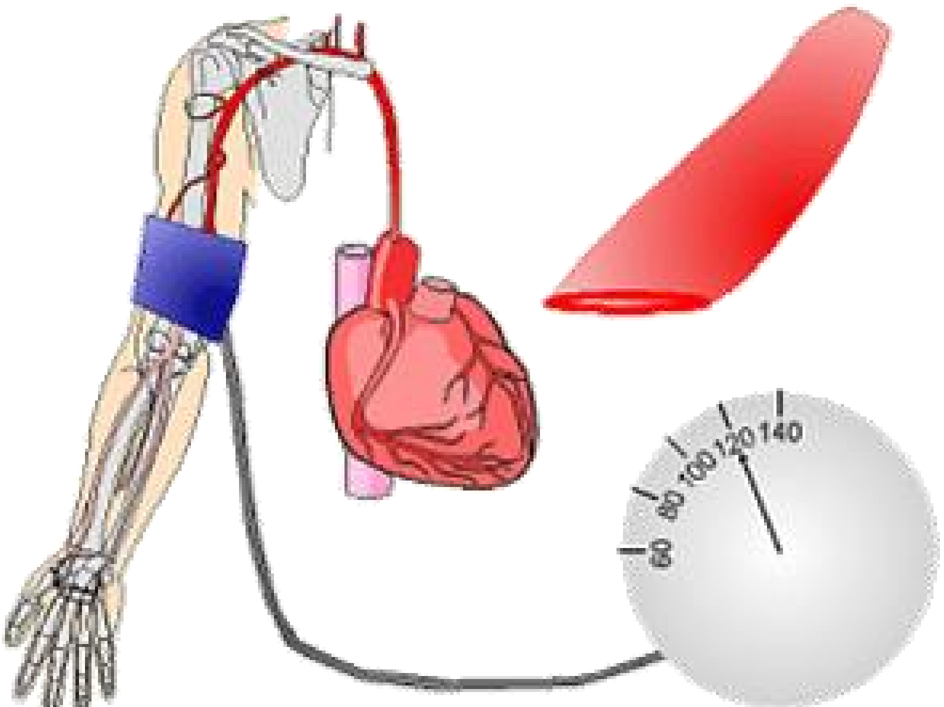




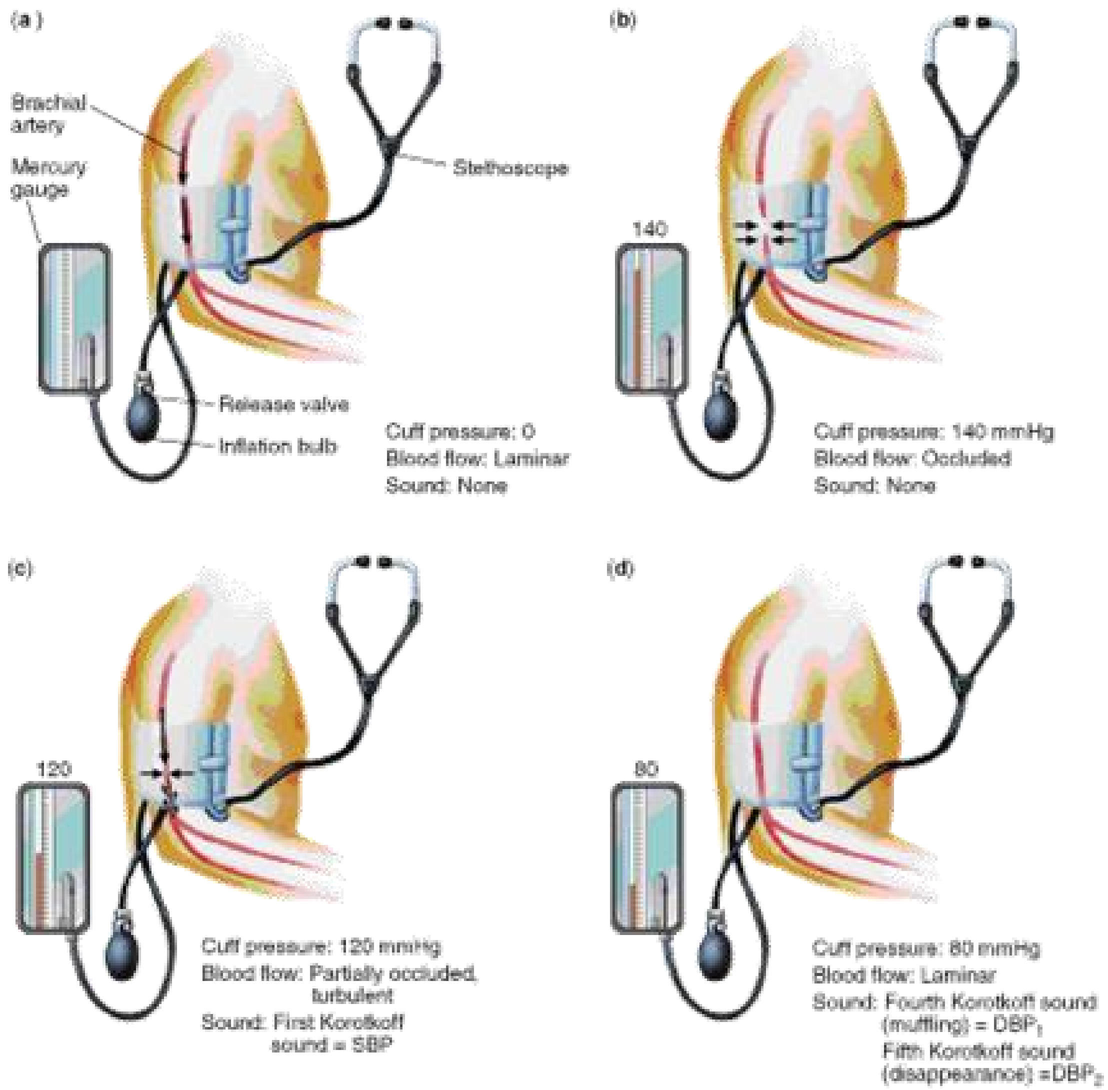
Pressure of cuff > than heart systolic press



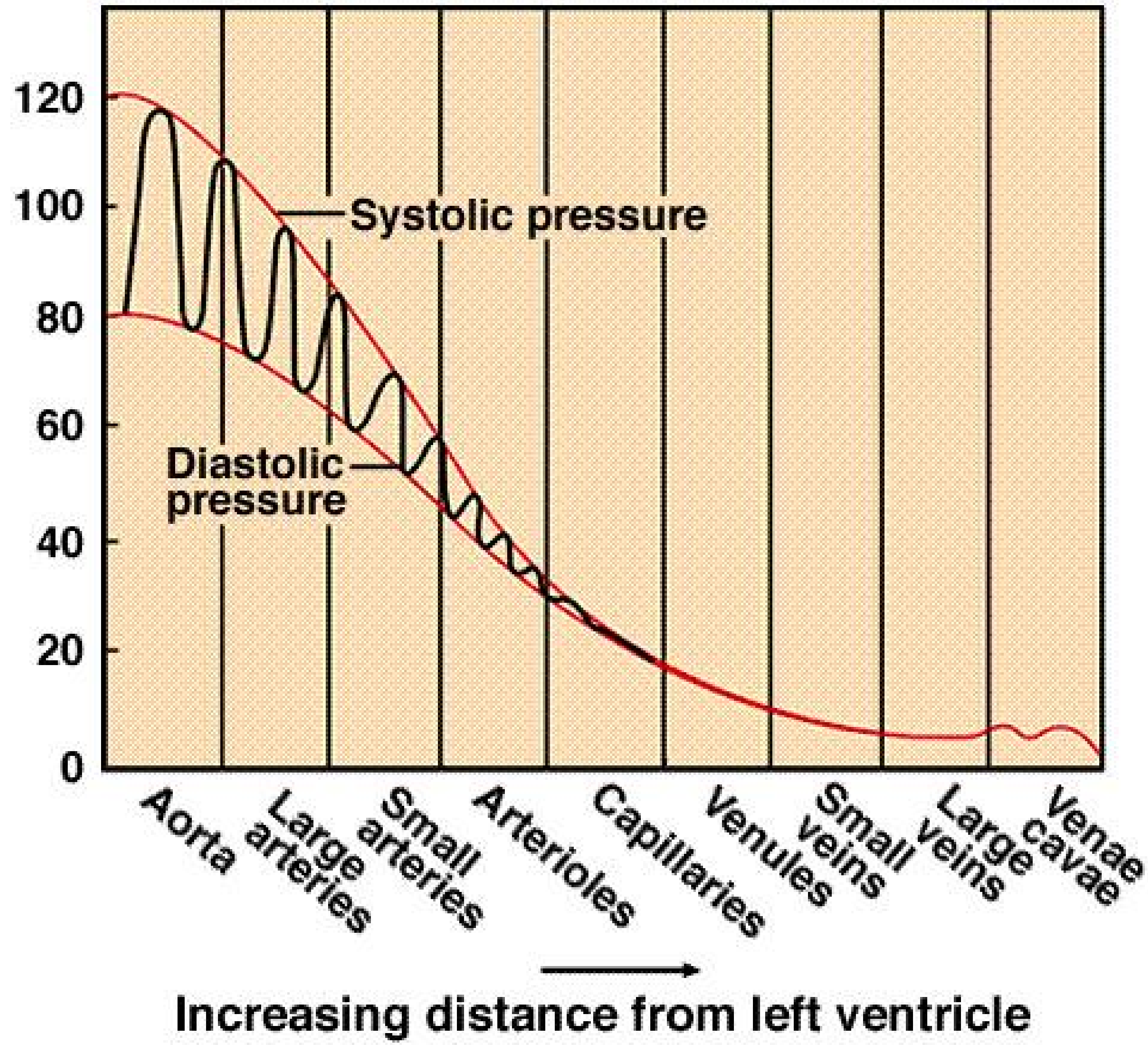
Heart pressure > cuff (both systolic and diastolic)



Heart pressure > cuff but cuff > diastolic pressure


(a)
Brachial artery
Mercury gauge
Stethoscope
Release valve
Inflation bulb
Cuff pressure: 0
Blood flow: Laminar
Sound: None
(b)
140
Cuff pressure: 140 mmHg
Blood flow: Occluded
Sound: None
(c)
120
Cuff pressure: 120 mmHg
Blood flow: Partially occluded, turbulent
Sound: First Korotkoff sound = SBP
(d)
80
Cuff pressure: 80 mmHg
Blood flow: Laminar
Sound: Fourth Korotkoff sound (muffling) = DBP1
Fifth Korotkoff sound (disappearance) =DBP2

Blood Pressure and Distance



CARDIOVASCULAR ANIMATIONS

Conditions Procedures

- Atherosclerosis
- Angiography
- Heart Attack
- Angioplasty with Stent
- Stroke
- Coronary Artery Bypass Graft
- Abdominal Aortic Aneurysm
- Valve Replacement