CIRCULATORY SYSTEM

The circulatory system is a mass flow system, moving substances form one part of the body (**source**) to another (**sink**).

It is linked by exchange surfaces.

DOUBLE CIRCULATION

- The RHS of the heart pumps deoxygenated blood to the lungs and oxygenated blood returns to the LHS of the heart. (**pulmonary system**)
- The LHS of the heart pumps the oxygenated blood to the tissues. Deoxygenated blood then returns to the heart. (**systemic system**)
- So blood passes through the heart twice in each circuit of the body.
- This is called a **double circulatory system**.

- **pulmonary system**

  a smaller circuit than the systemic system

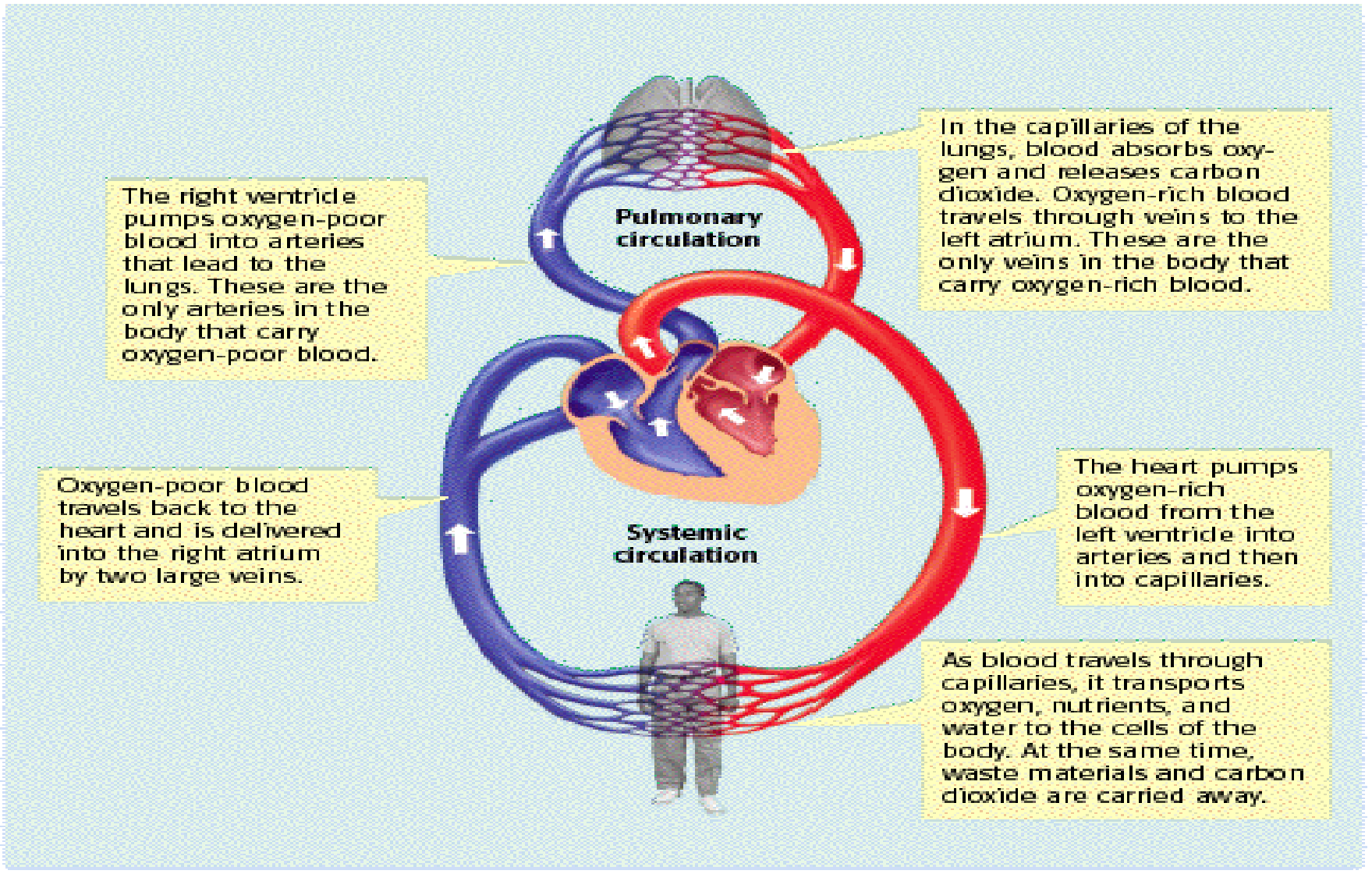
  blood pressure lower to allow blood to pass slowly through the capillaries of the lungs, giving more time for gas exchange
- **systemic system**

  higher pressure to ensure blood is pumped to all organs of the body to efficiently deliver metabolites and remove waste

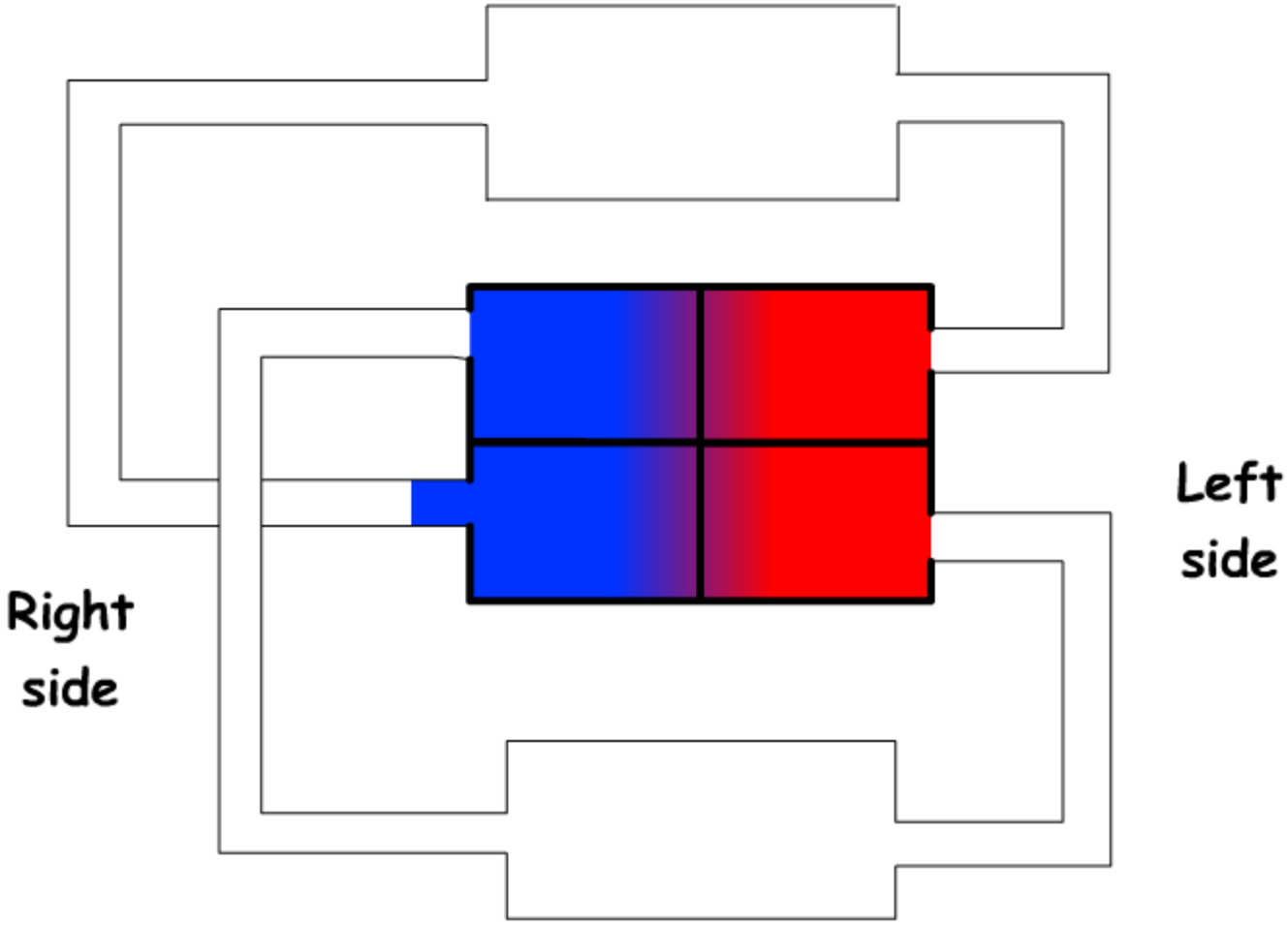
  high pressure also maintains blood/tissue fluid balance in each organ

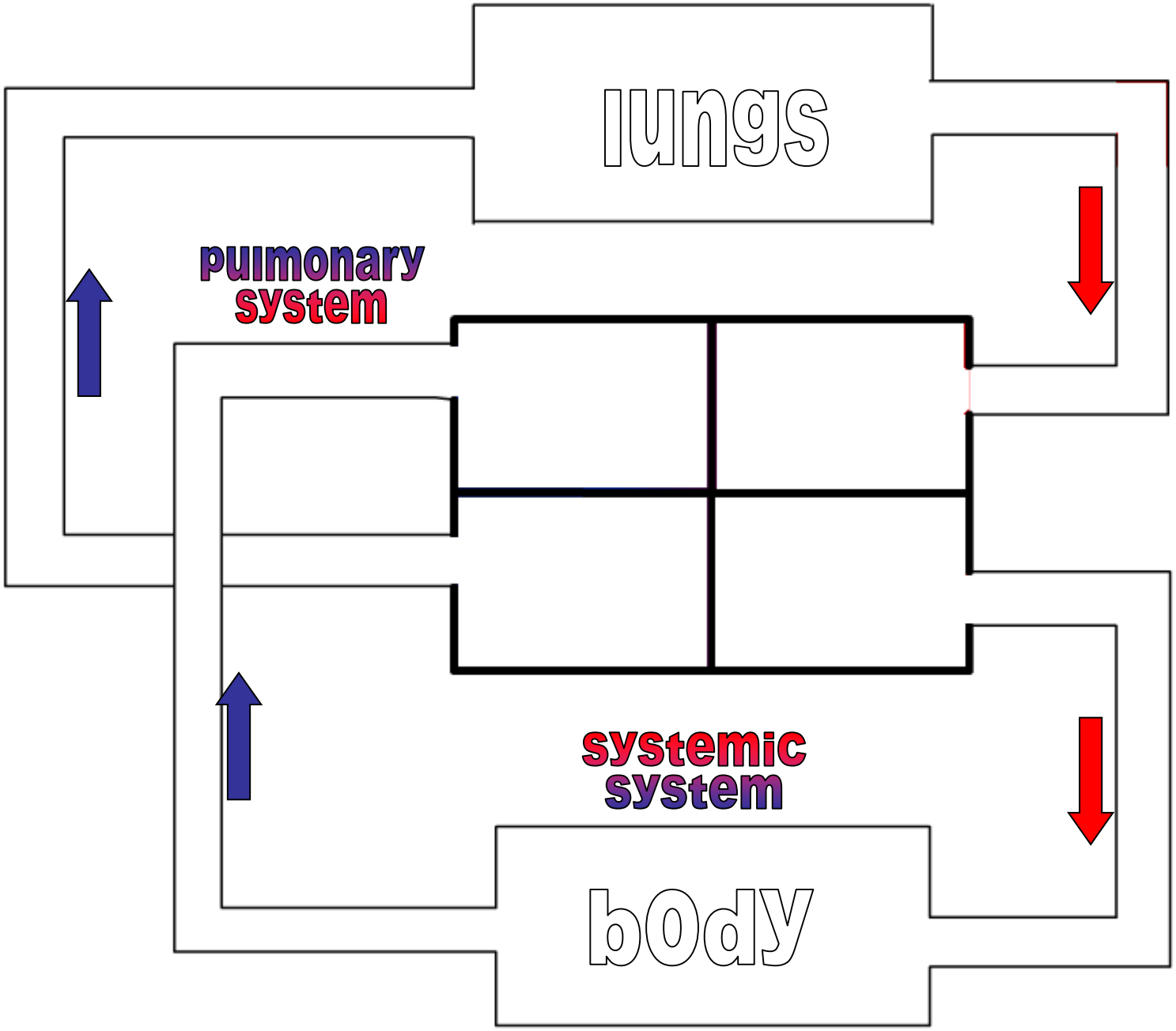
You need to click on properties and click play as yes to get this to work

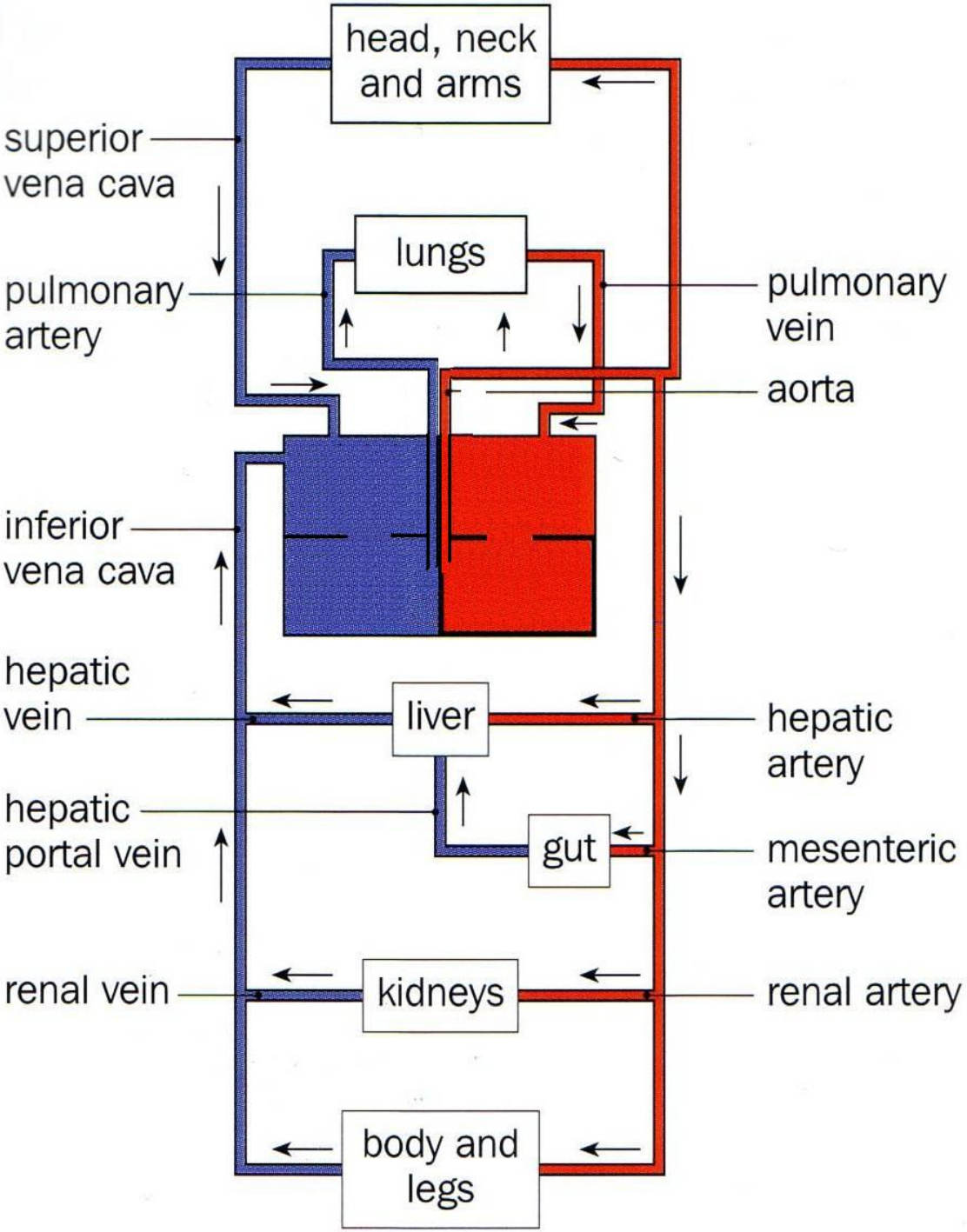
The Flow of Blood Through the Body



Double Circulatory System



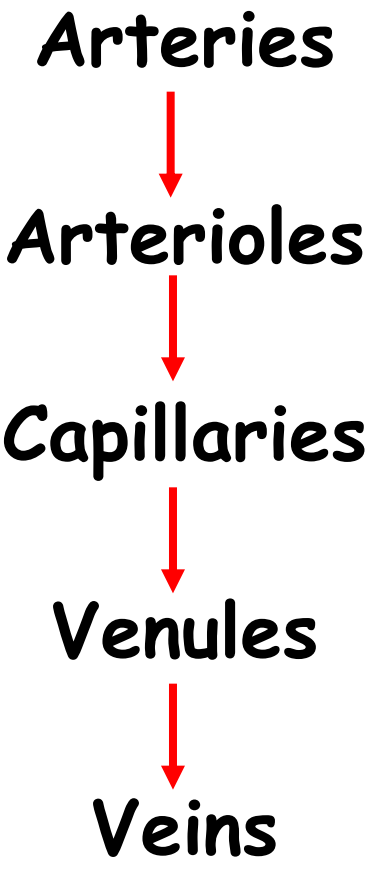

lungs
pulmonary system
systemic system
body

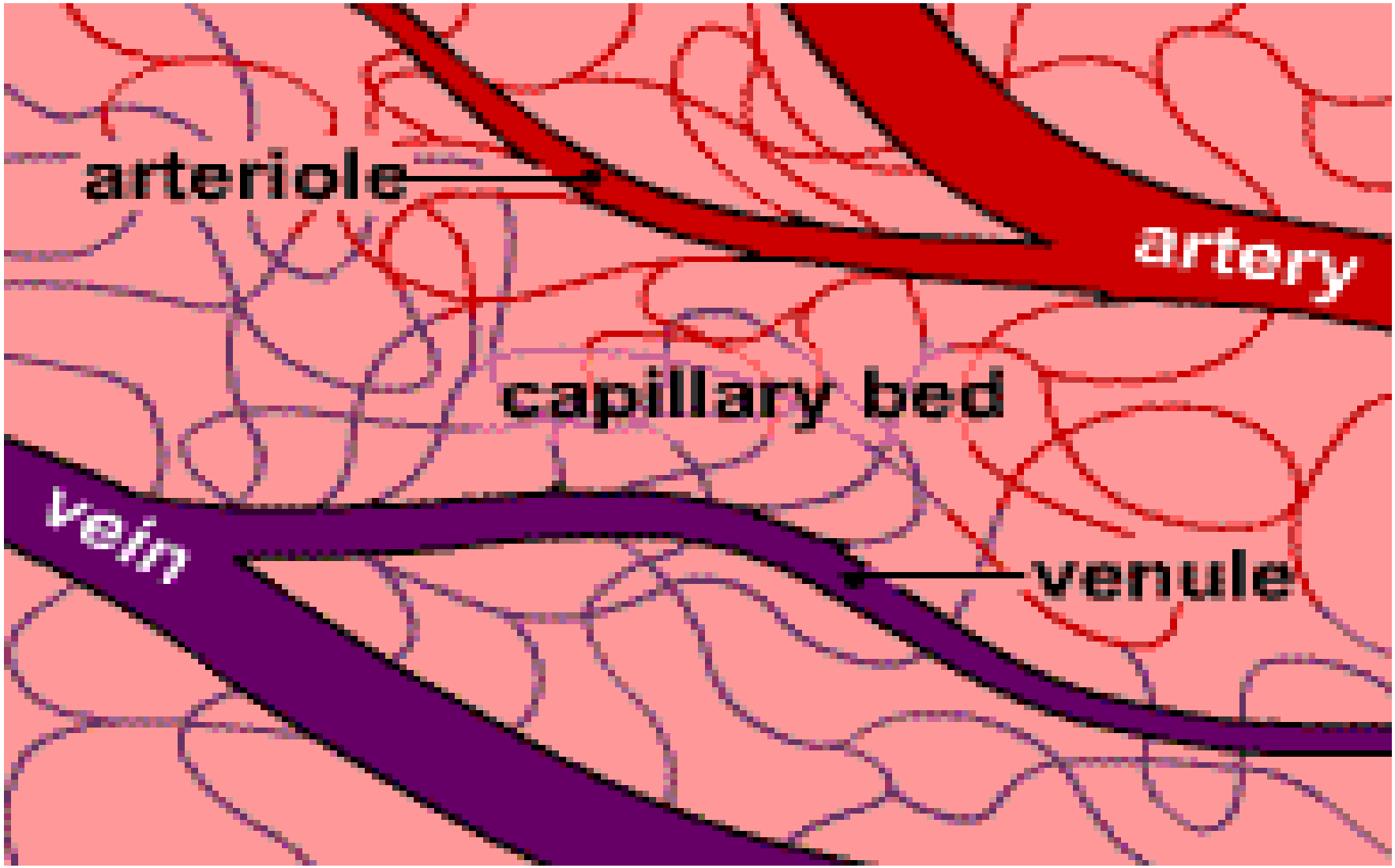


Carotid artery
Jugular vein

BLOOD VESSELS

- **A**rteries carry blood **a**way from the heart. They branch to form smaller arterioles. Arterioles sub divide into capillaries.
- Capillaries join up to form venules. Venules join to form veins which return blood to the heart.




arteriole
artery
capillary bed
vein
venule

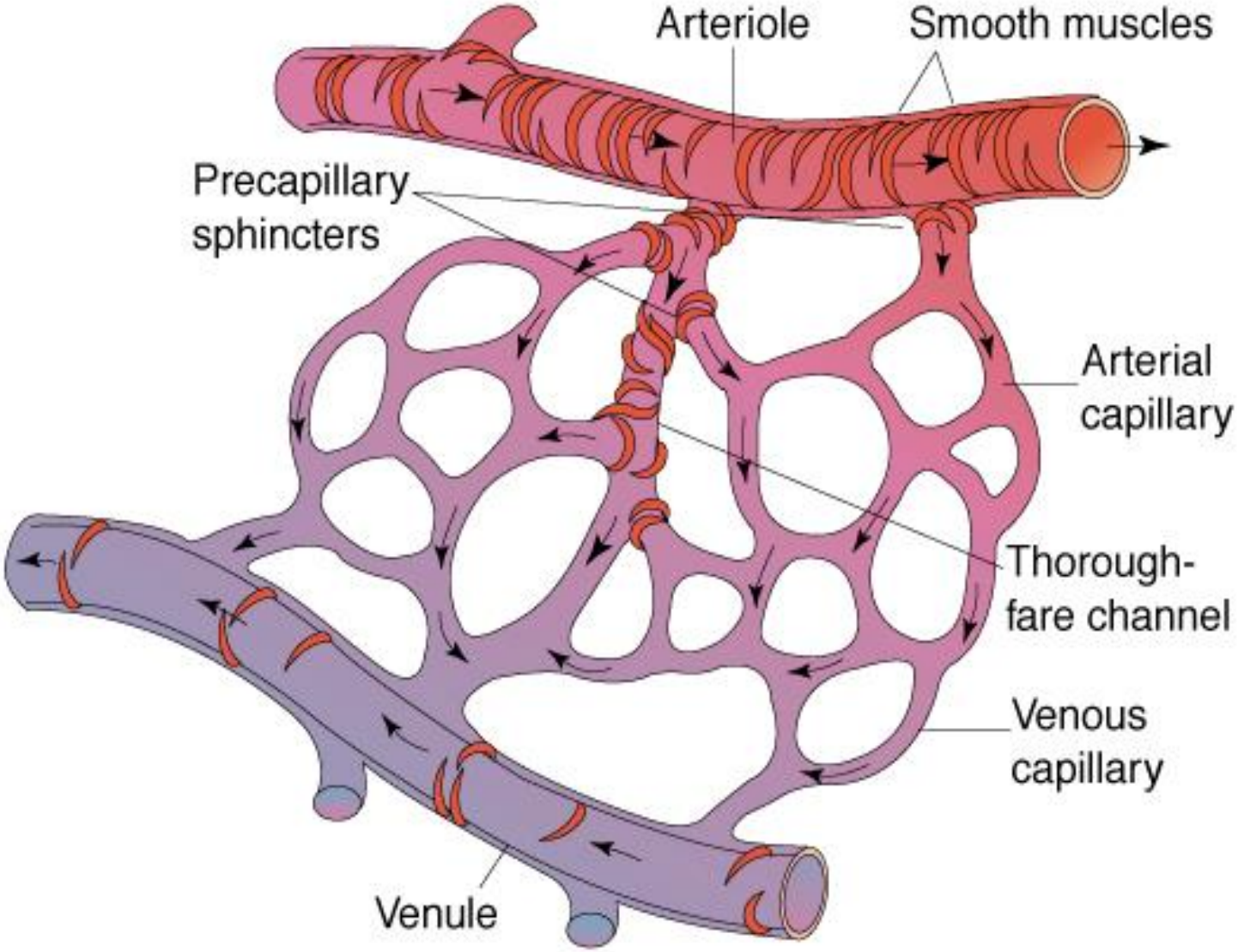
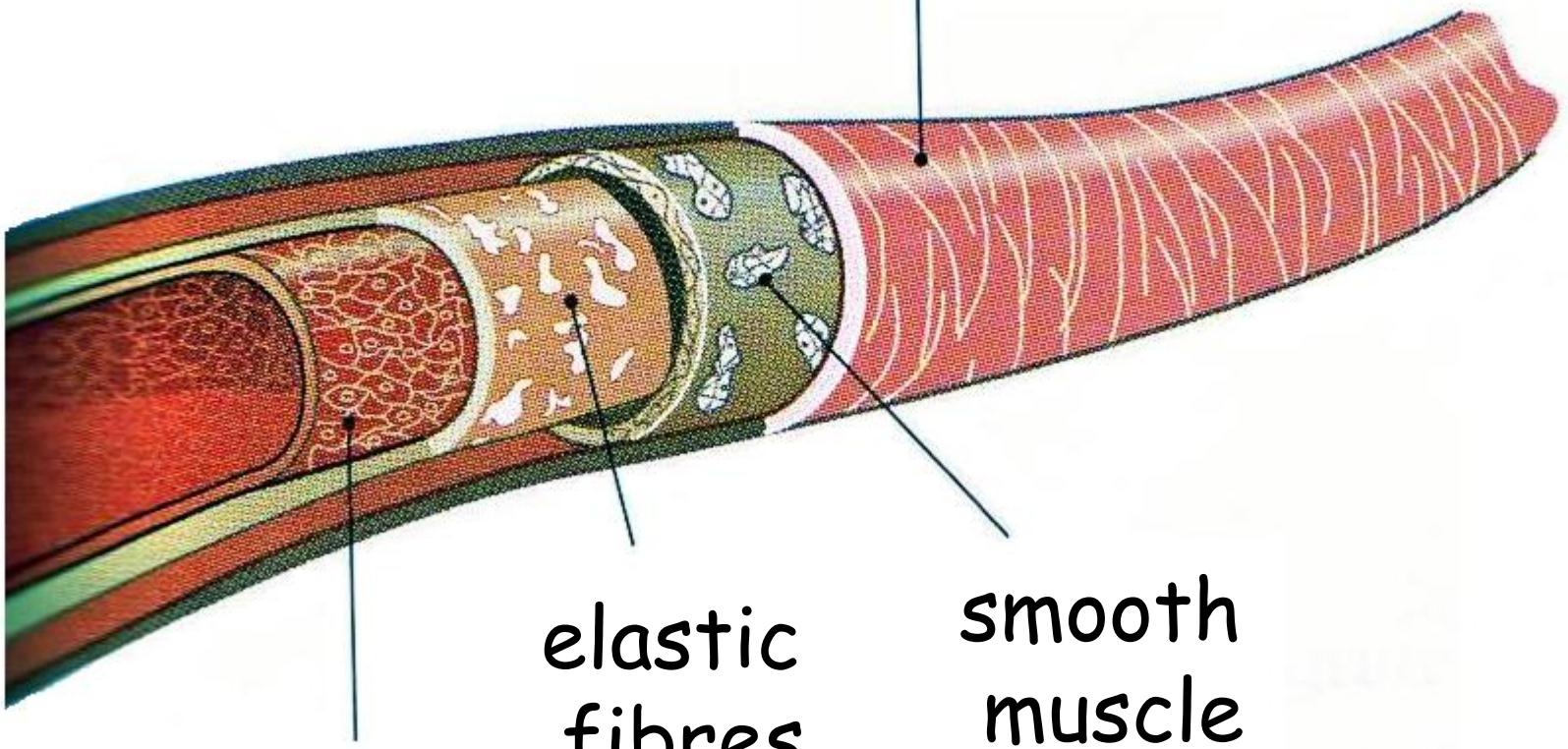


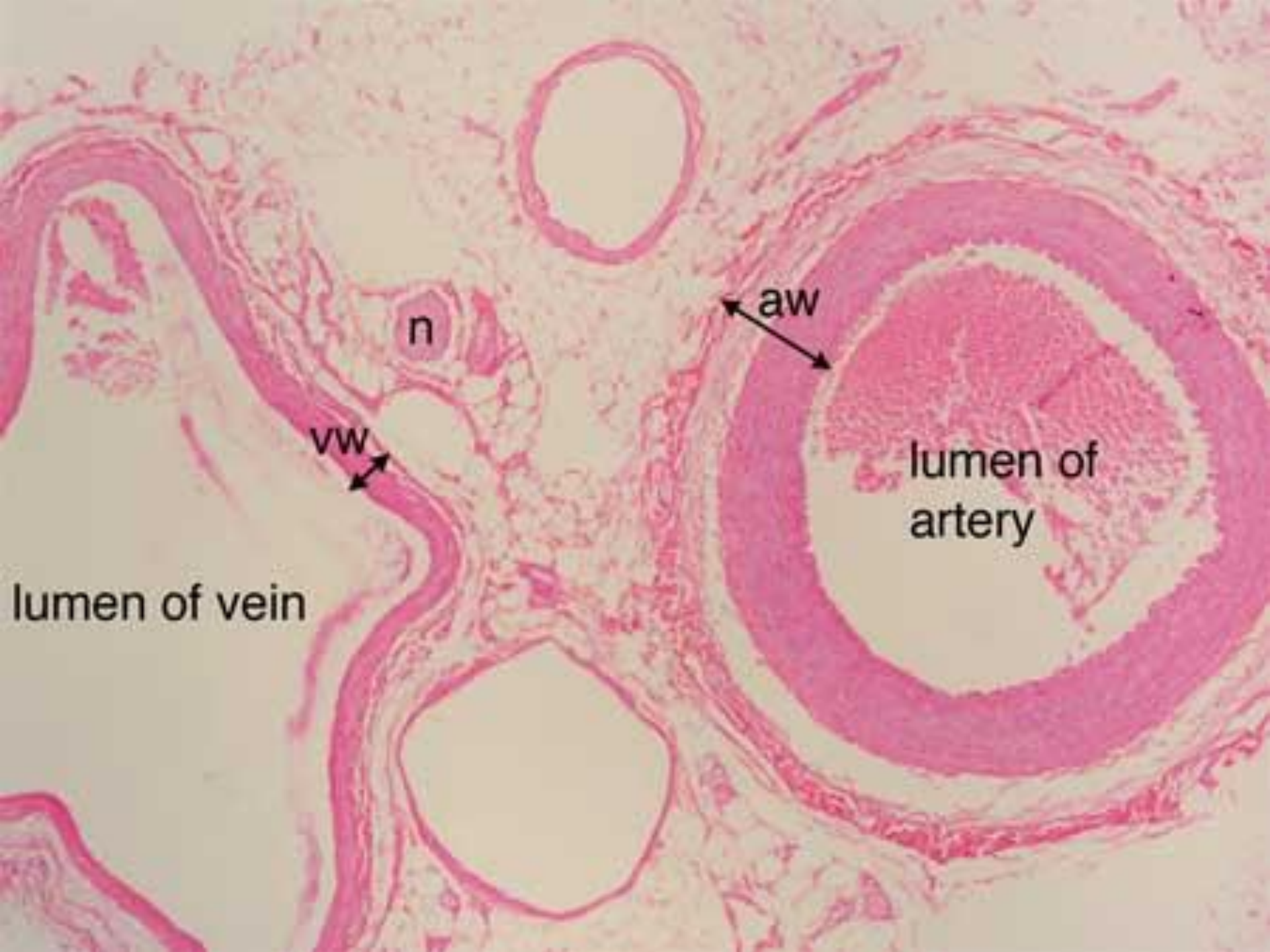
Figure 23-23 Capillary bed. Precapillary sphincters control the flow of blood through the capillary network. Thoroughfare channels (*i.e.*, arteriovenous shunts) allow blood to move directly from the arteriole into the venule without moving through nutrient channels of the capillary.

ARTERIES

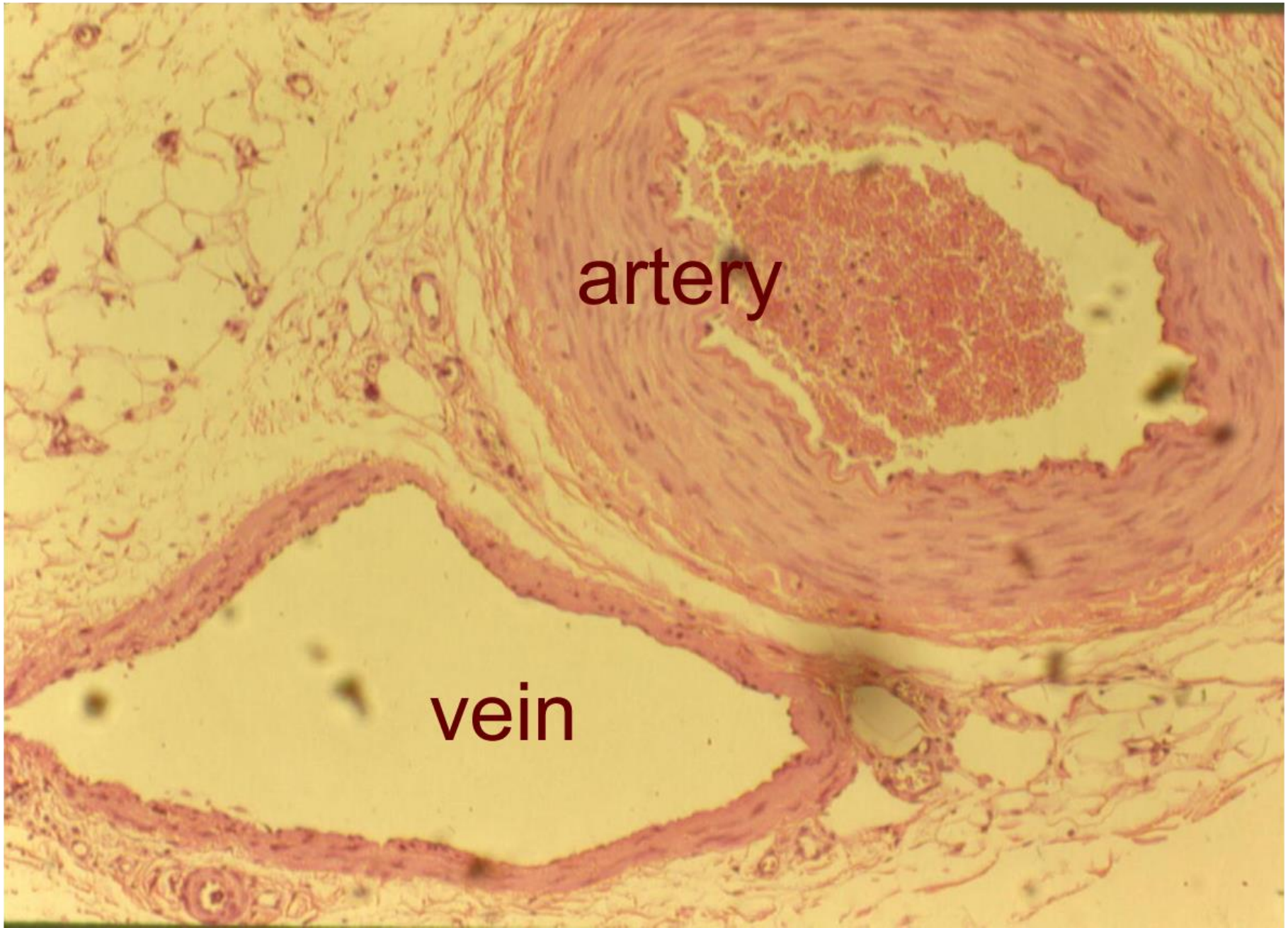
- Contain numerous **elastic fibres** which allow the vessel walls distend (stretch and recoil) as blood surges through from the heart. This develops a pulse.
- **Smooth muscle** allows arteries to constrict or dilate controlling the blood supply to specific organs.
  - **Vasodilation** allows more blood to flow to the organ
  - **Vasoconstriction** reduces blood flow.

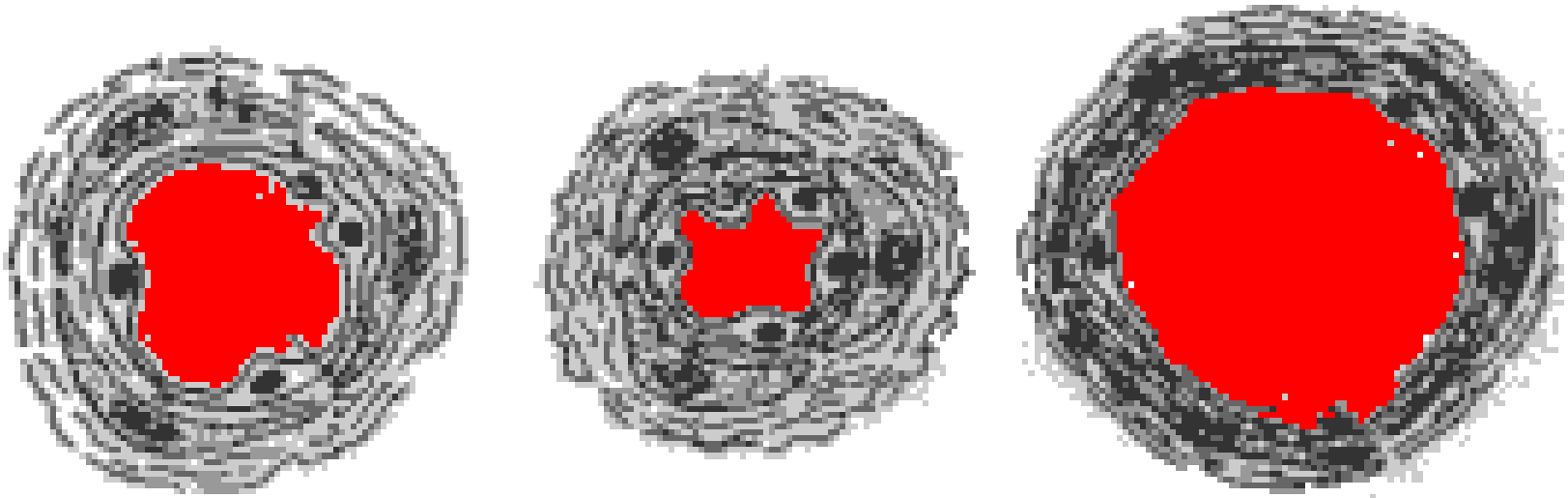
structure of an artery




n
aw
vw
lumen of artery
lumen of vein

Artery and Vein Comparison



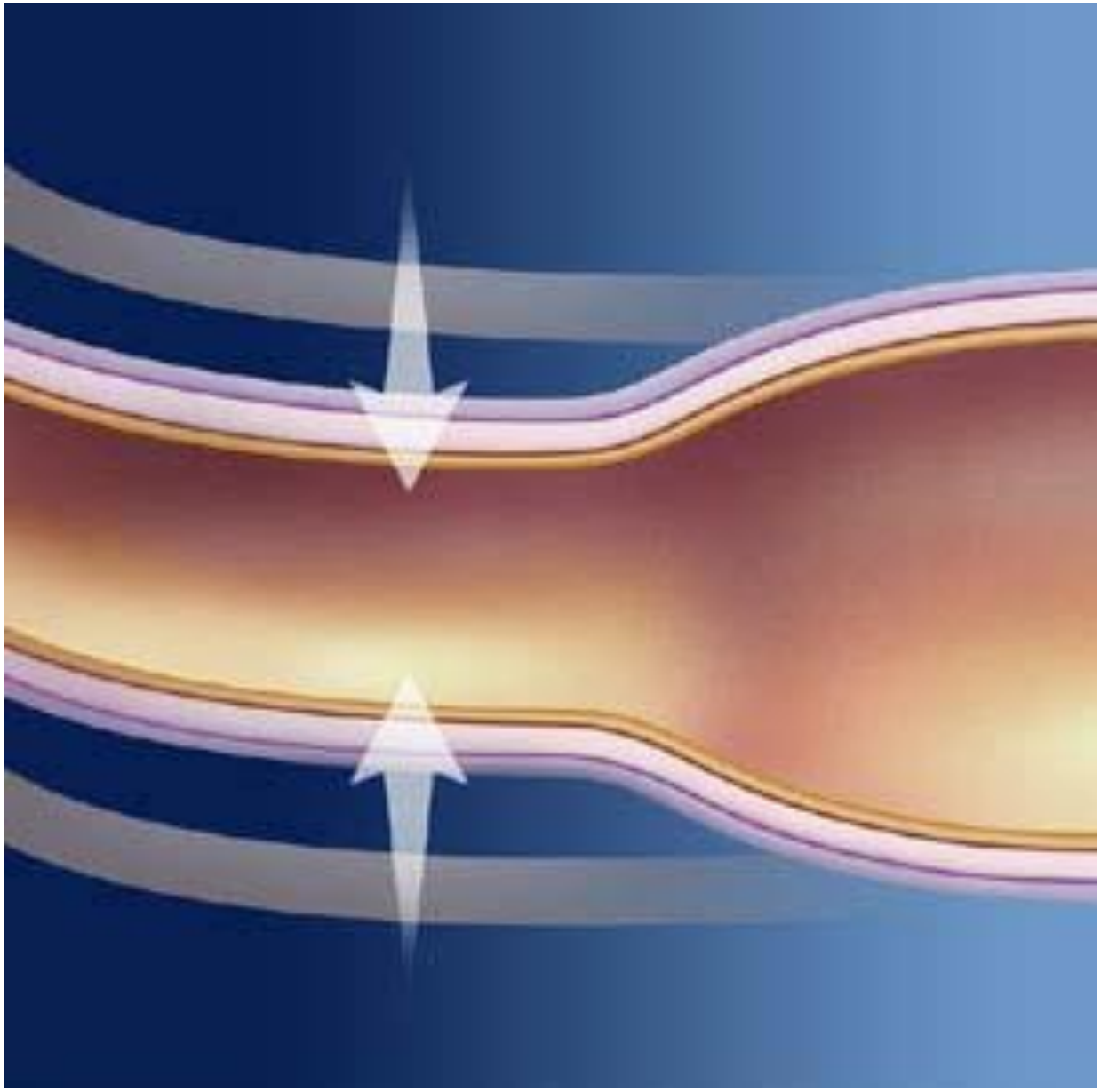


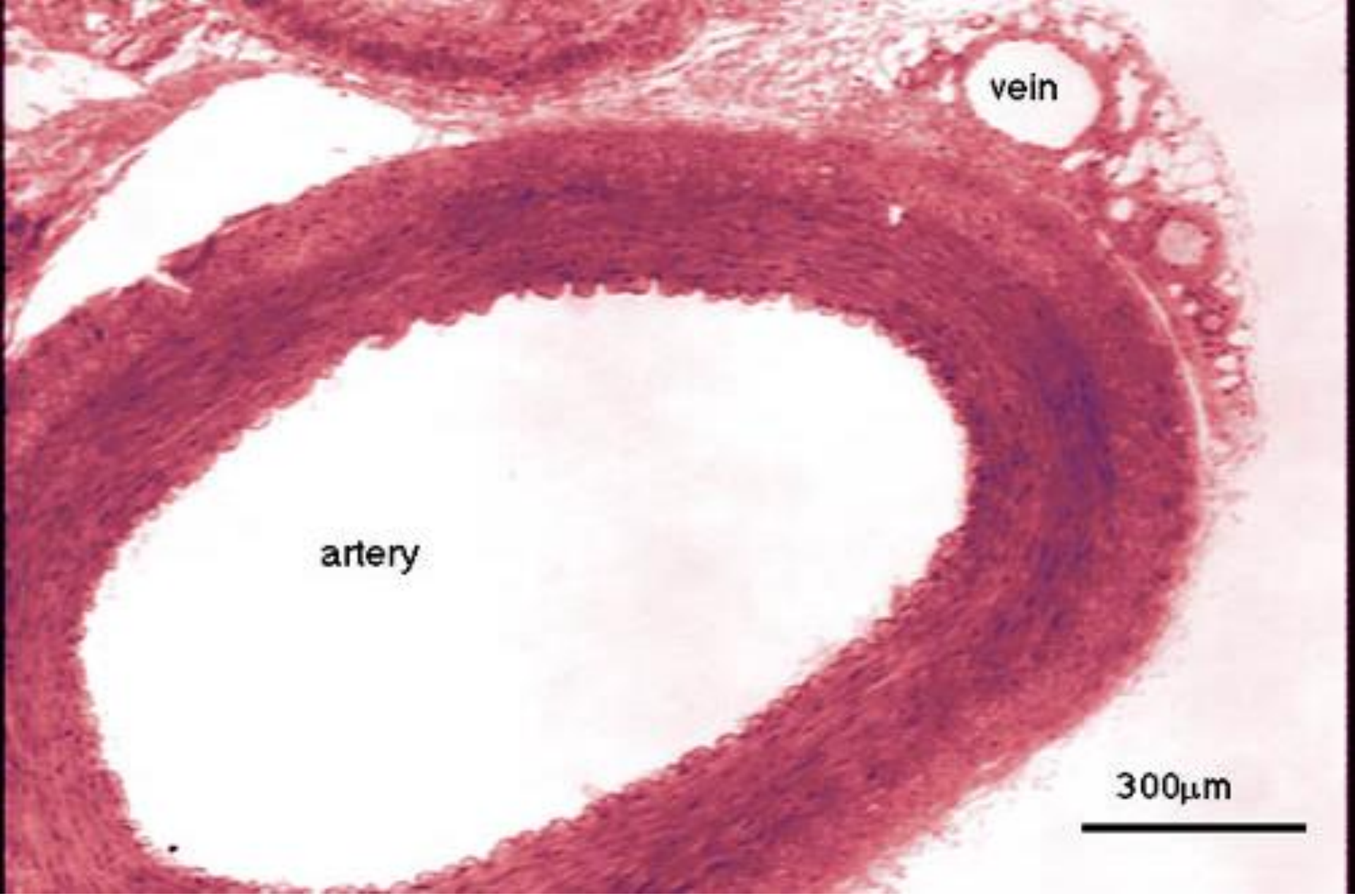
vasoconstriction

Smooth muscle contracted
less blood gets to capillaries in organs

vasodilatation

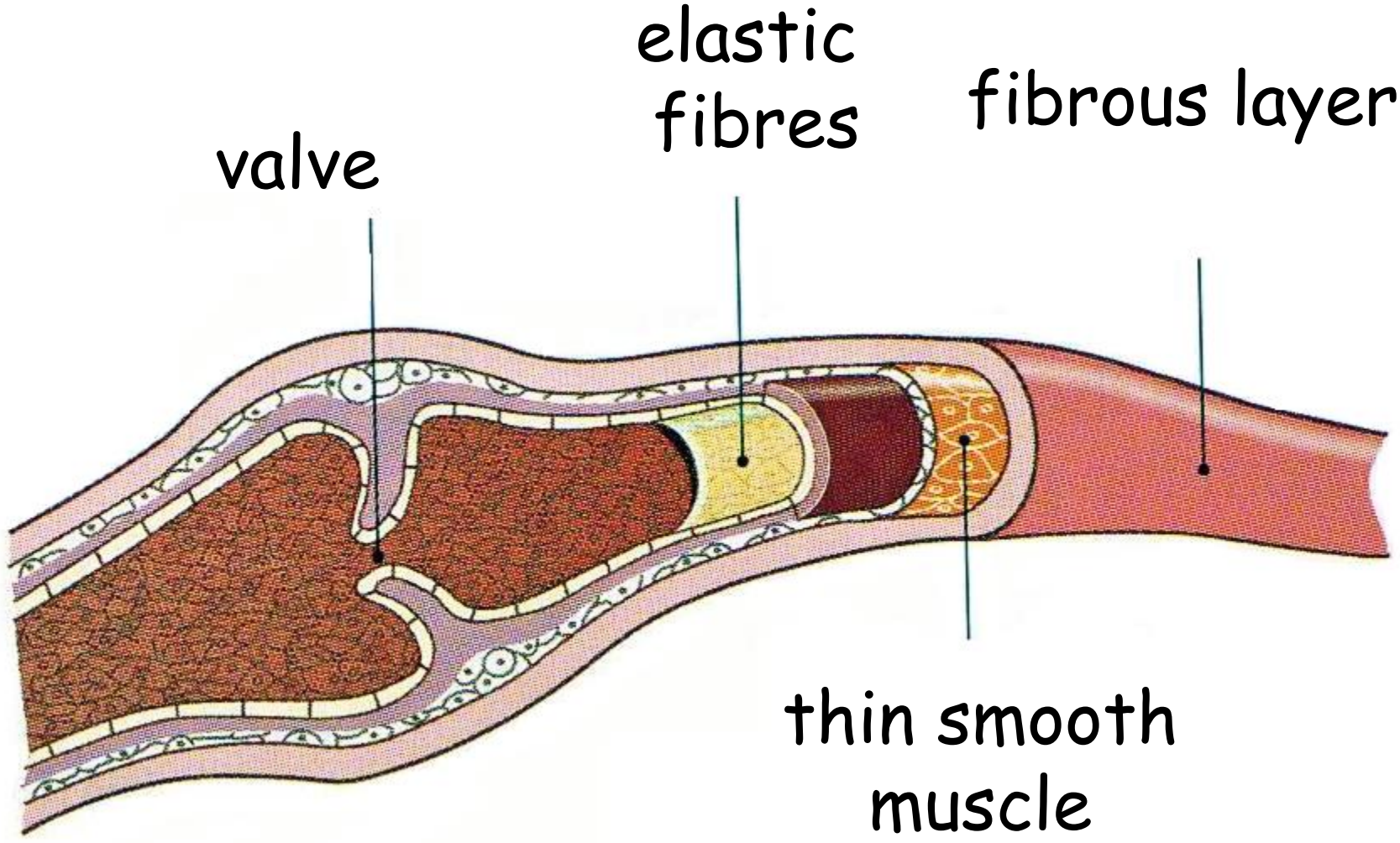
Smooth muscle relaxed
more blood gets to capillaries in organs





How would you calculate the magnification?

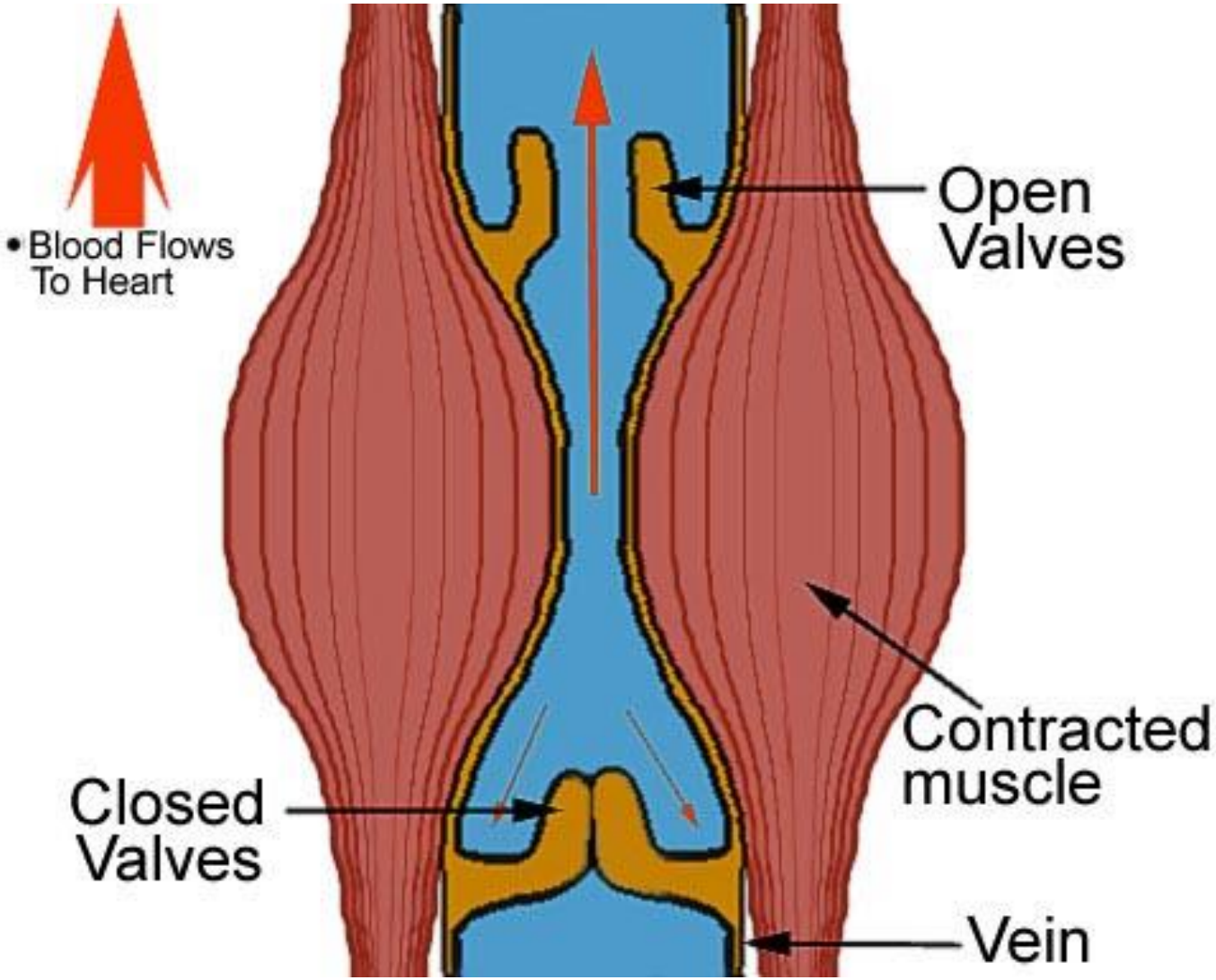
structure of a vein

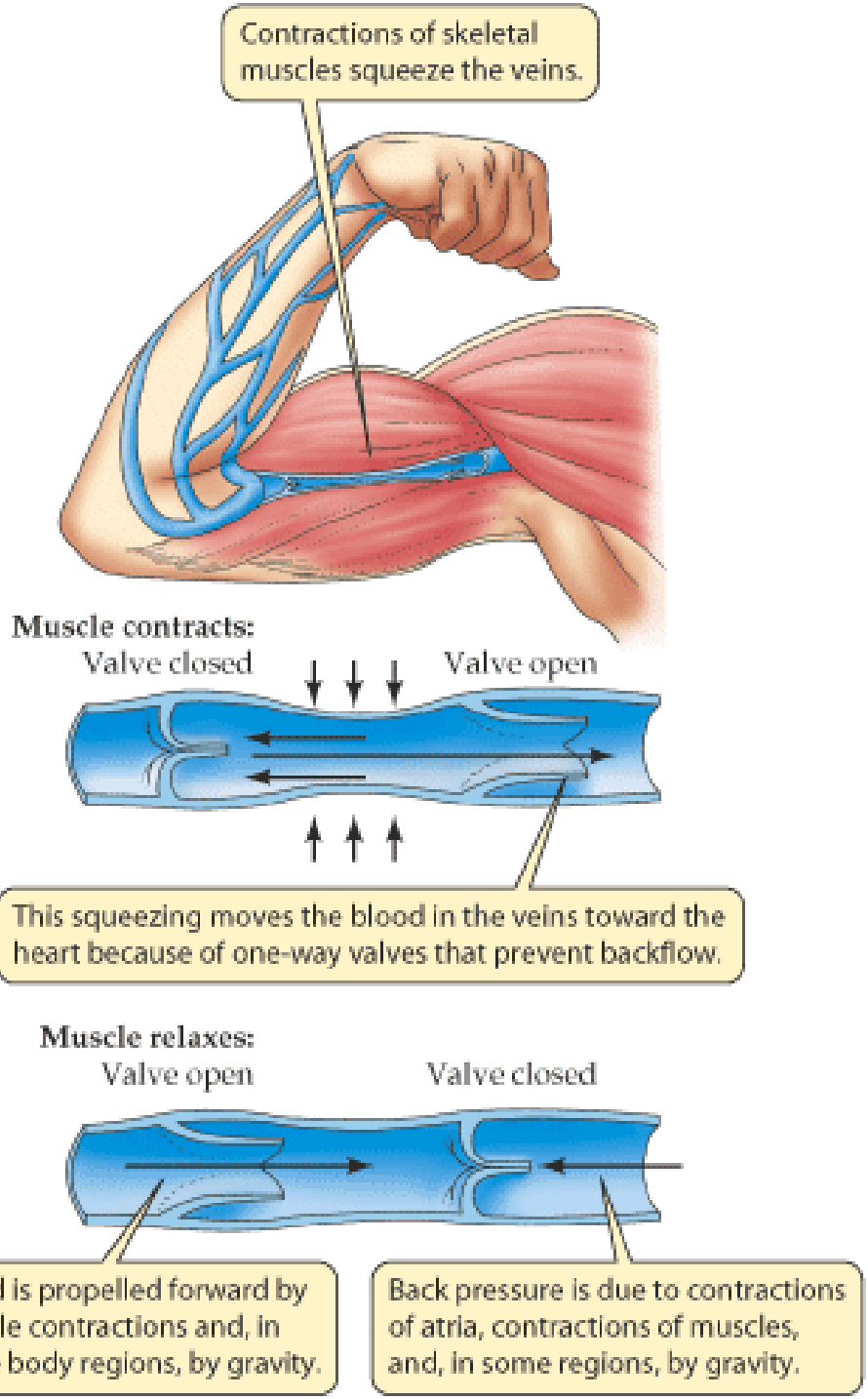


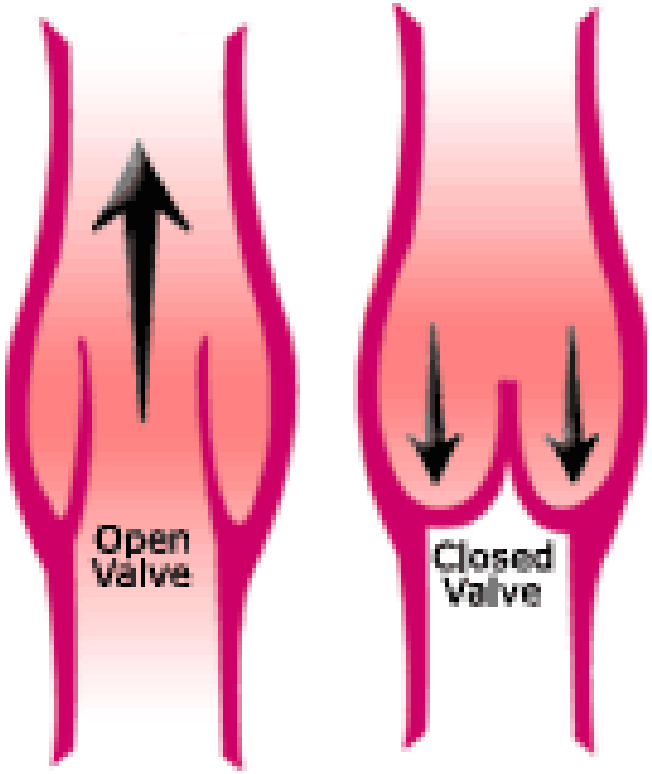
VEINS

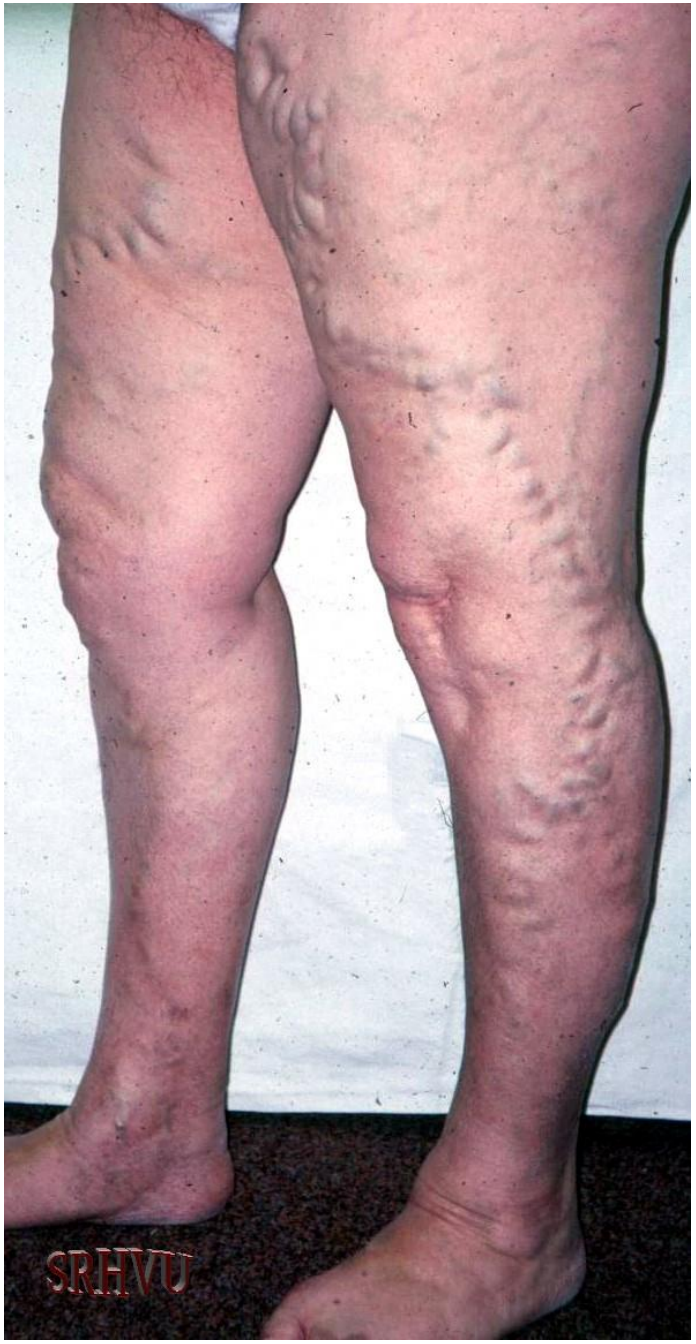
- The flow of blood is aided by contraction of nearby muscles which push on the veins and cause blood to move forward therefore they contain lots of fibrous tissue for protection
- Very little elastic tissue because the blood flow smoothes out as it passes through capillaries
- Large lumen reduces wall contact area with the blood to facilitate the return of blood to the heart.
- Semilunar valves prevent backflow of blood. This is needed because the blood pressure is low.

valves in veins



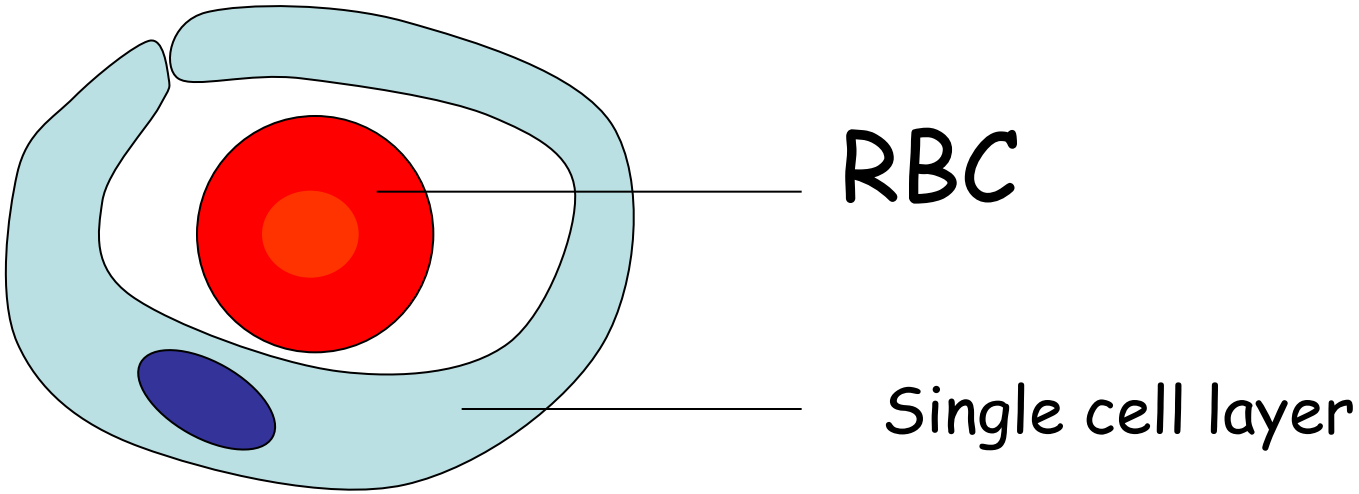

Contractions of skeletal muscles squeeze the veins.
Muscle contracts:
Valve closed
Valve open
This squeezing moves the blood in the veins toward the heart because of one-way valves that prevent backflow.
Muscle relaxes:
Valve open
Valve closed
Blood is propelled forward by muscle contractions and, in some body regions, by gravity.
Back pressure is due to contractions of atria, contractions of muscles, and, in some regions, by gravity.

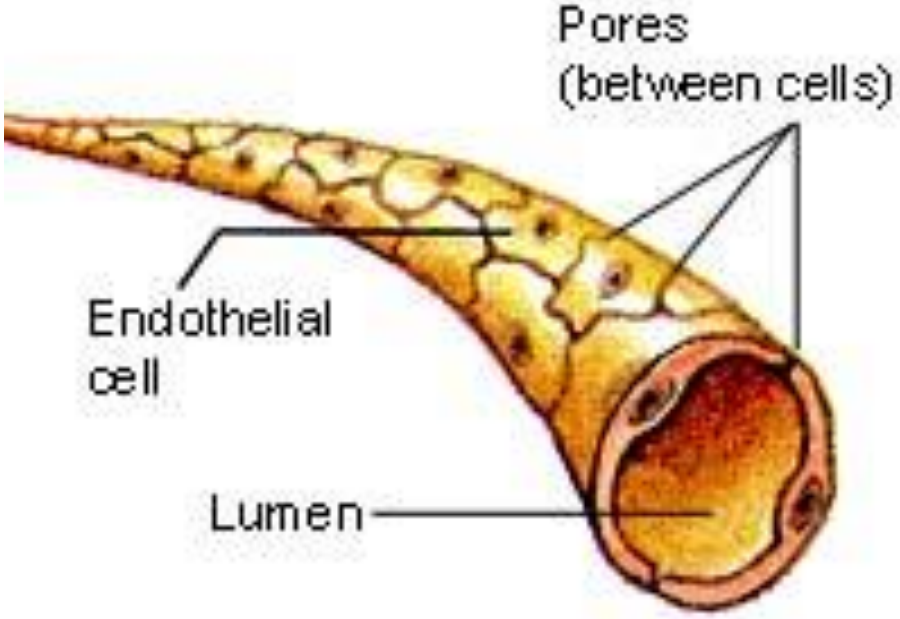

Open
Valve
Closed
Valve

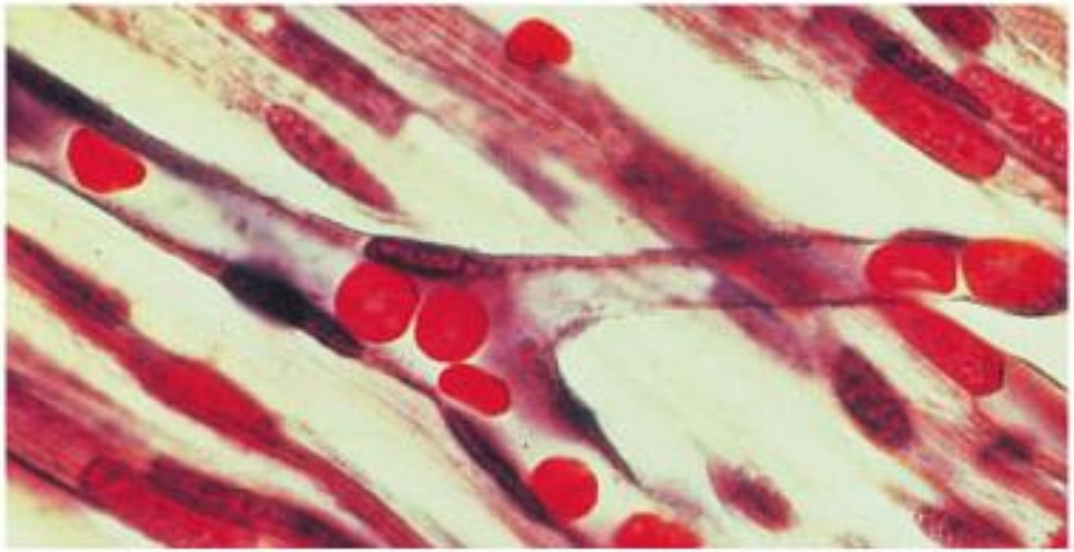

SRHVU

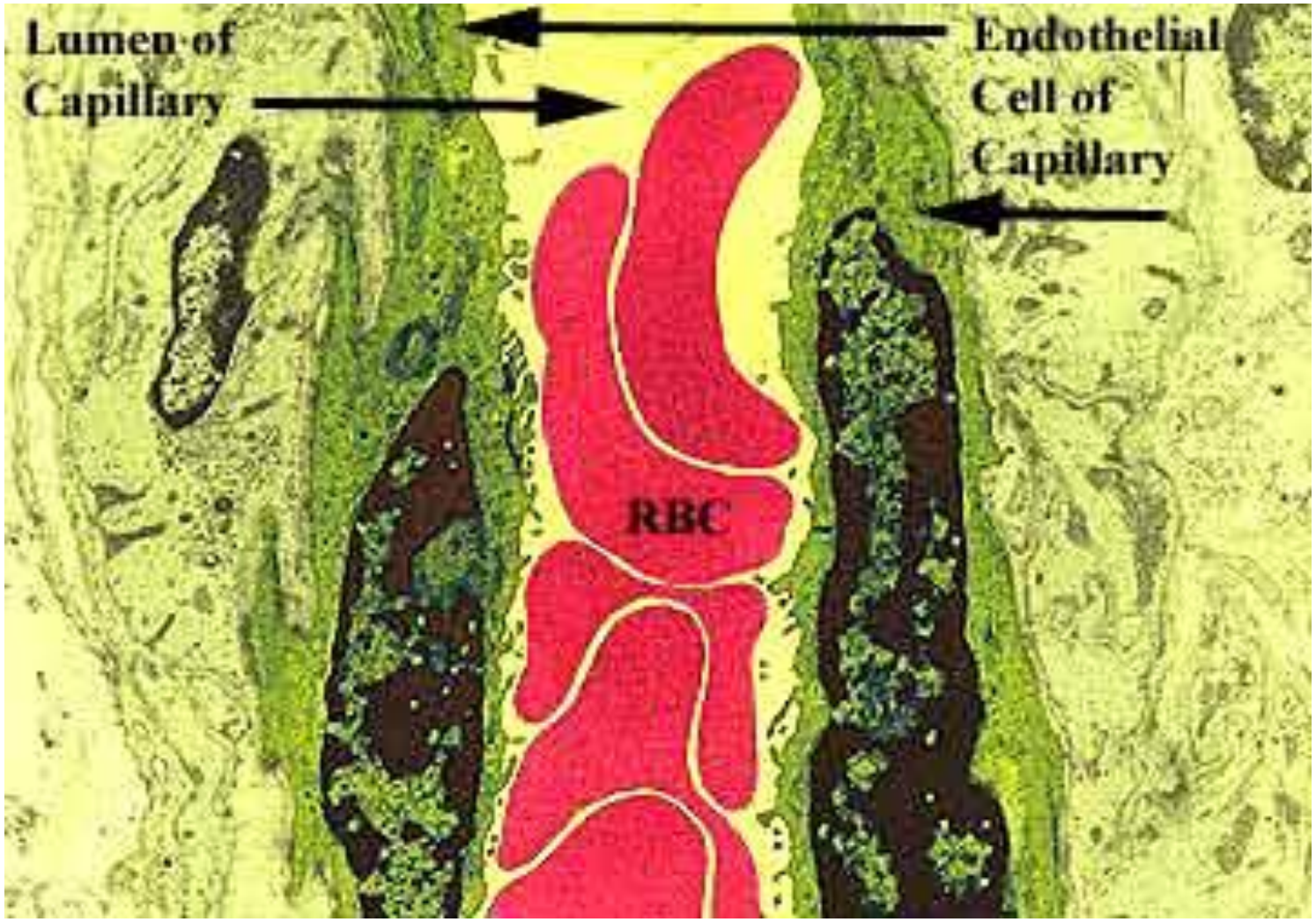
CAPILLARIES

- No elastic or muscle tissue
- Composed of a single layer of squamous endothelial cells which are flattened in shape and do not fit tightly together, leaving gaps which substances can move through



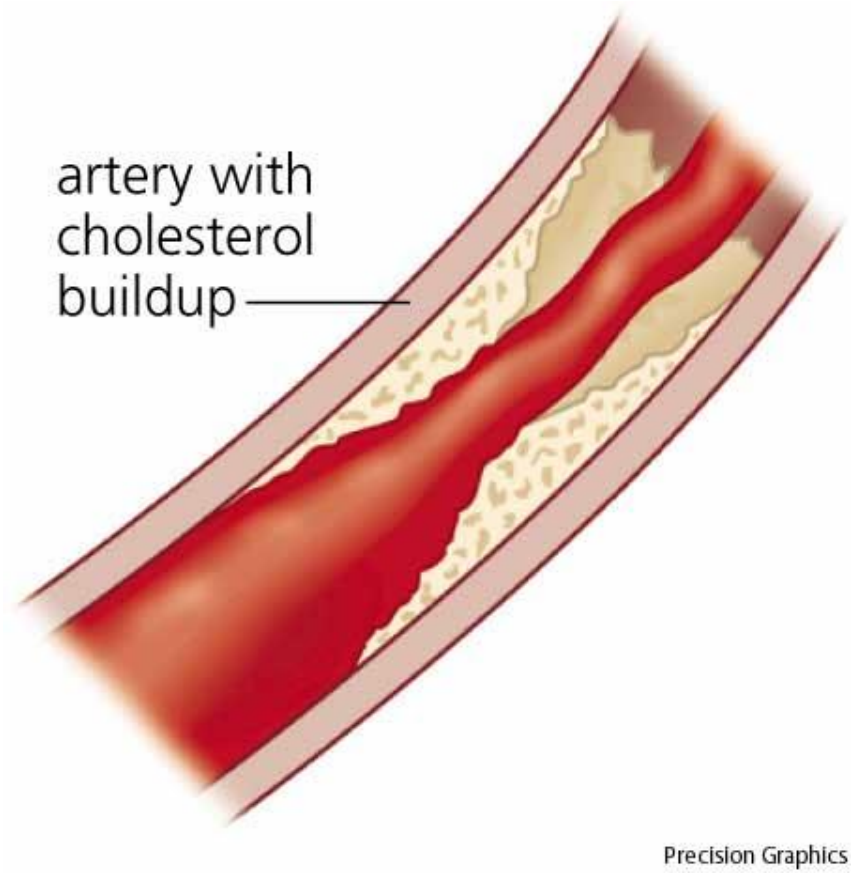

Pores
(between cells)
Endothelial
cell
Lumen



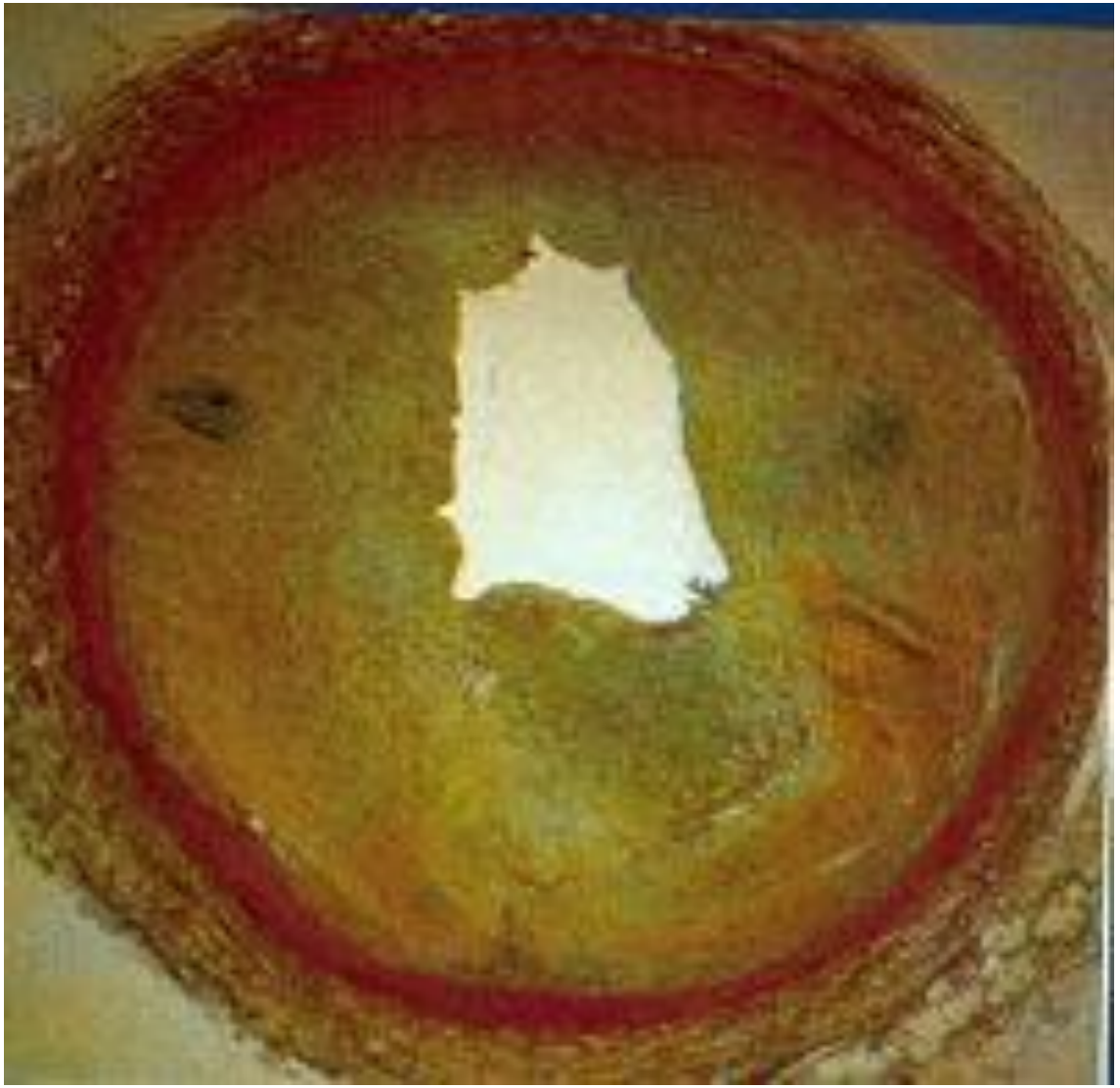

Lumen of Capillary
Endothelial Cell of Capillary
RBC

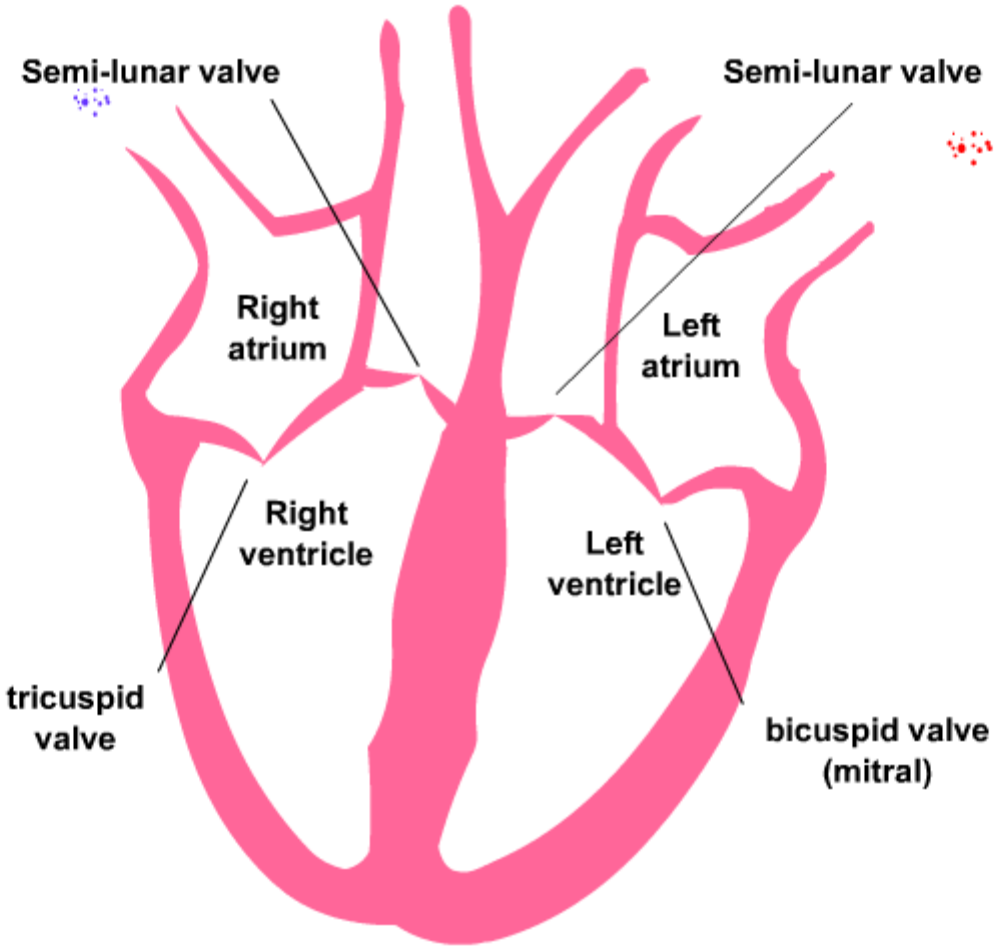
Atherosclerosis

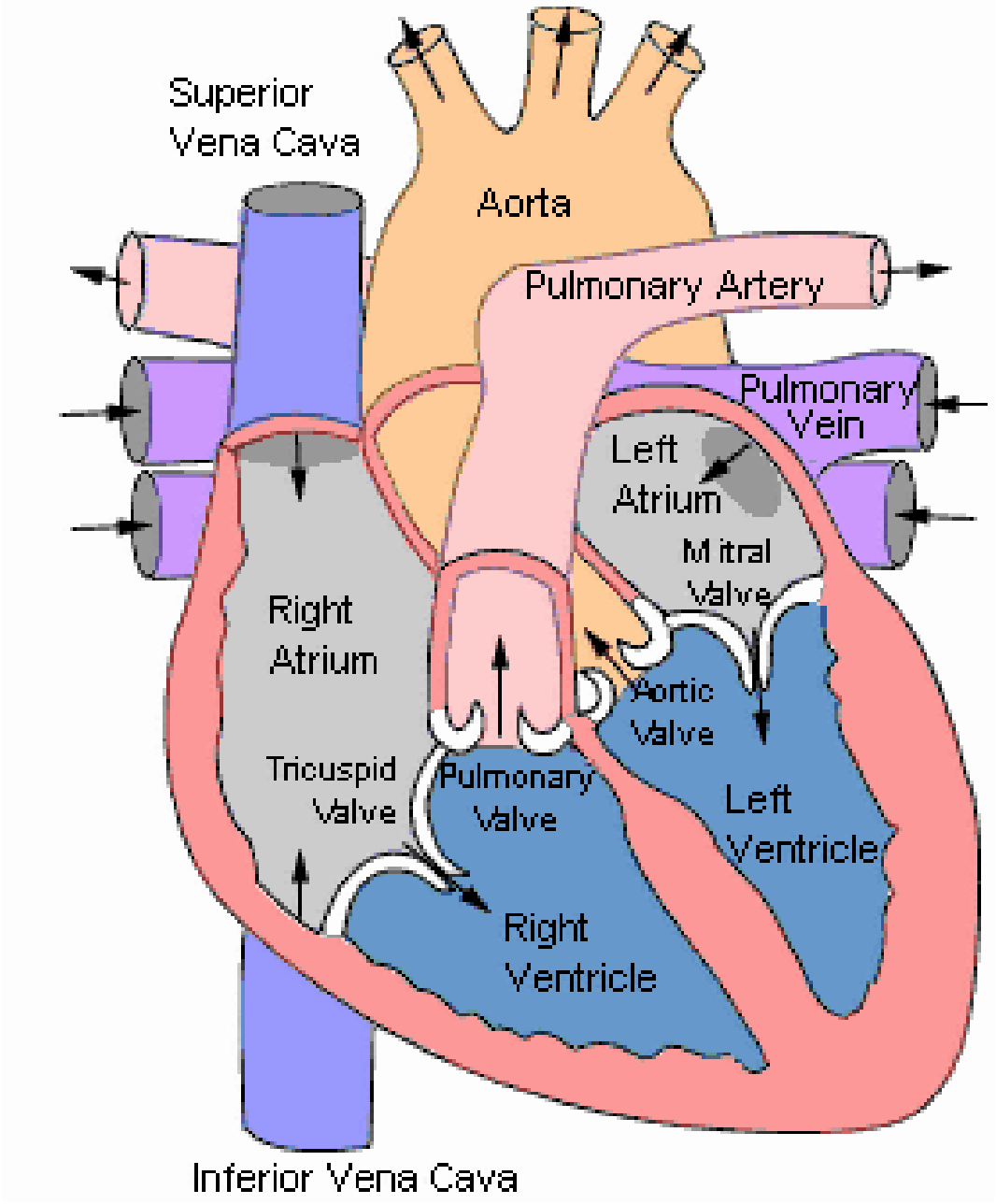
- Plaques containing cholesterol and lipids, called **atheromas**, build up on the innermost layer of the walls of large and medium-sized arteries.
- When it affects the coronary arteries, it can cause angina, heart attack or sudden death

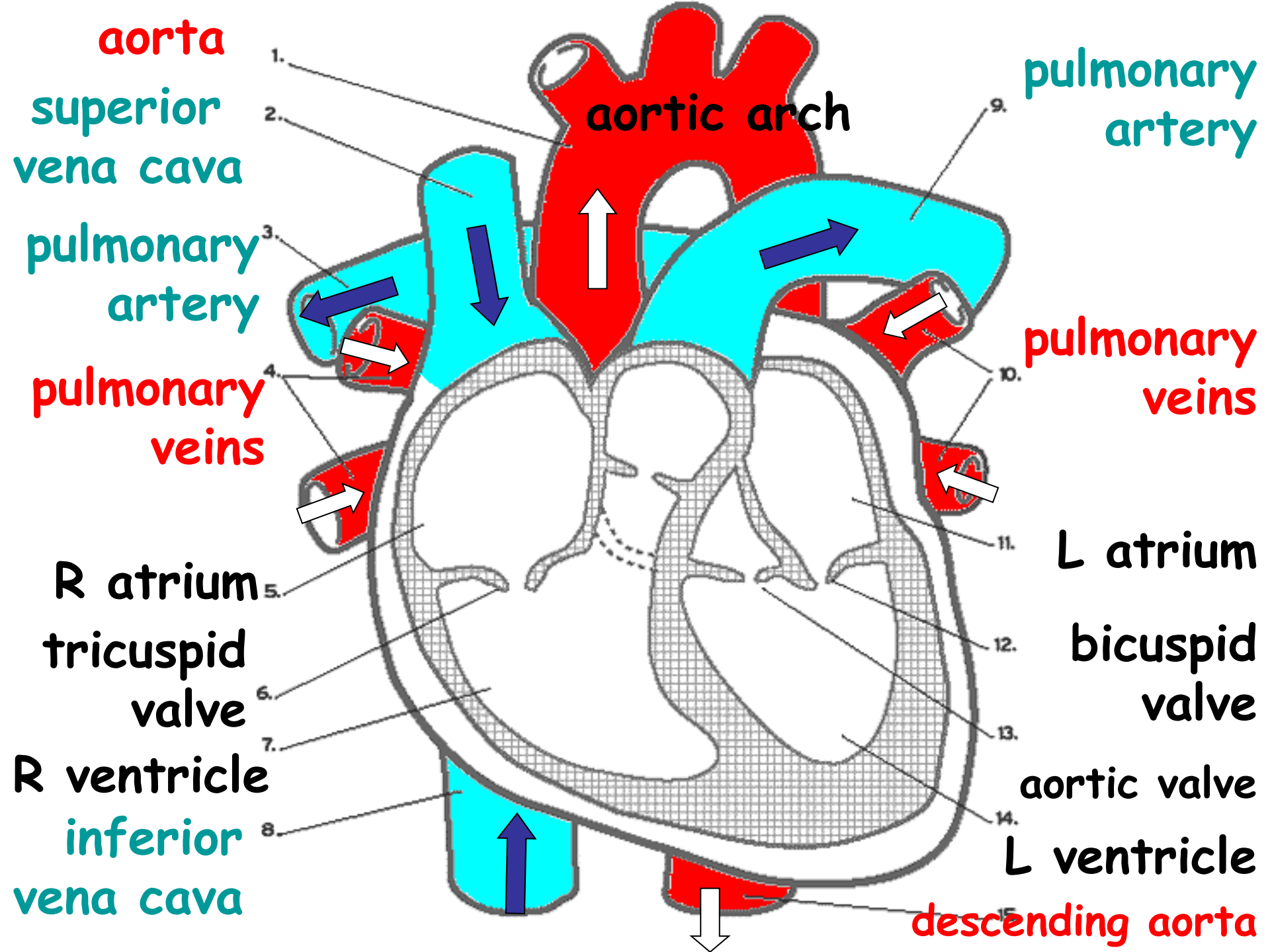


Atherosclerosis




Semi-lunar valve
Semi-lunar valve
Right atrium
Left atrium
Right ventricle
Left ventricle
tricuspid valve
bicuspid valve (mitral)


Superior
Vena Cava
Aorta
Pulmonary Artery
Pulmonary
Vein
Left
Atrium
Mitral
Valve
Right
Atrium
Aortic
Valve
Tricuspid
Valve
Pulmonary
Valve
Left
Ventricle
Right
Ventricle
Inferior Vena Cava


aorta
superior vena cava
pulmonary artery
pulmonary veins
R atrium
tricuspid valve
R ventricle
inferior vena cava
aortic arch
pulmonary artery
pulmonary veins
L atrium
bicuspid valve
aortic valve
L ventricle
descending aorta
1.
2.
3.
4.
5.
6.
7.
8
9.
10.
11.
12.
13.
14.
15

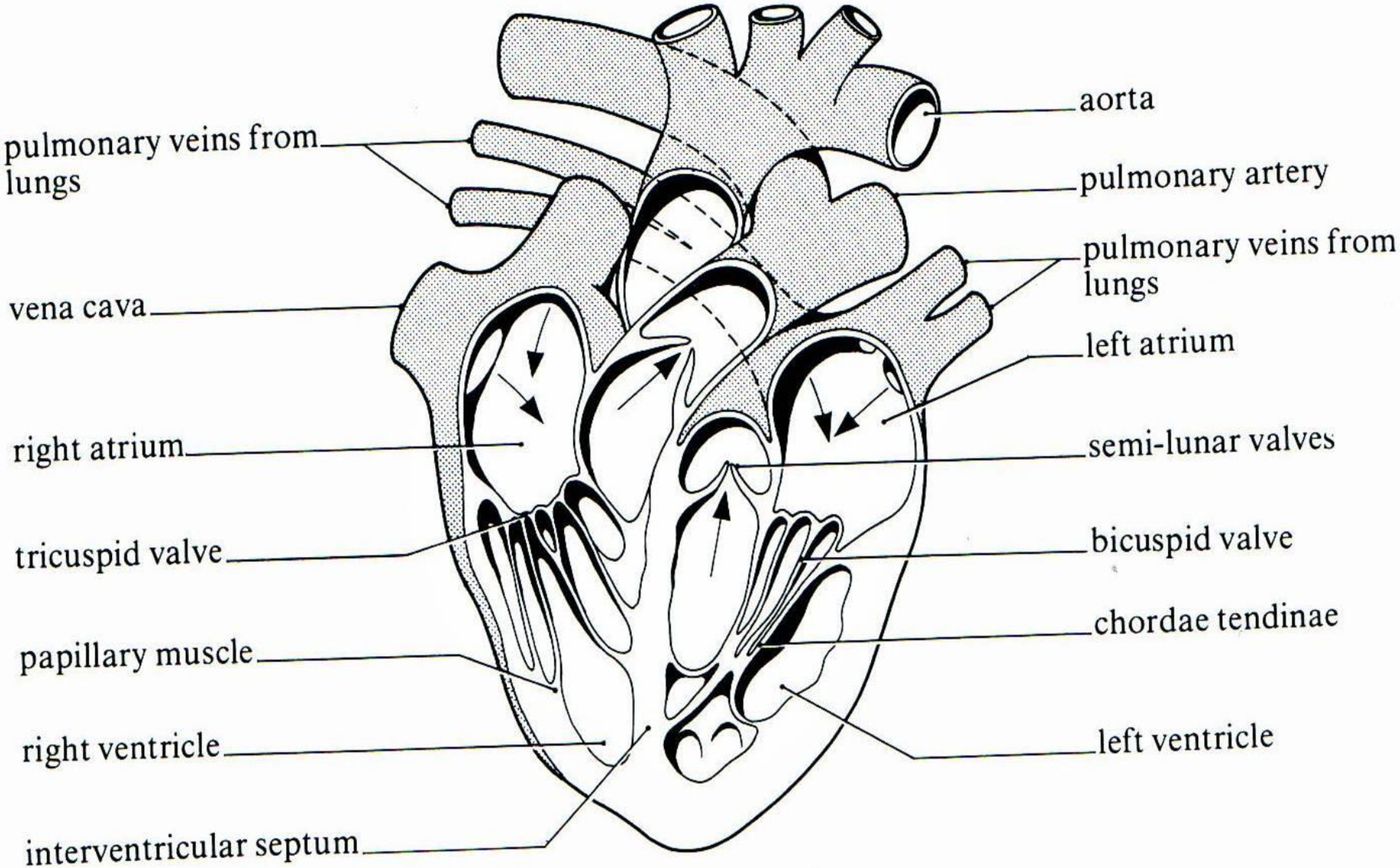


Fig 14.50 *Section through mammalian heart*

Structure and function of the heart

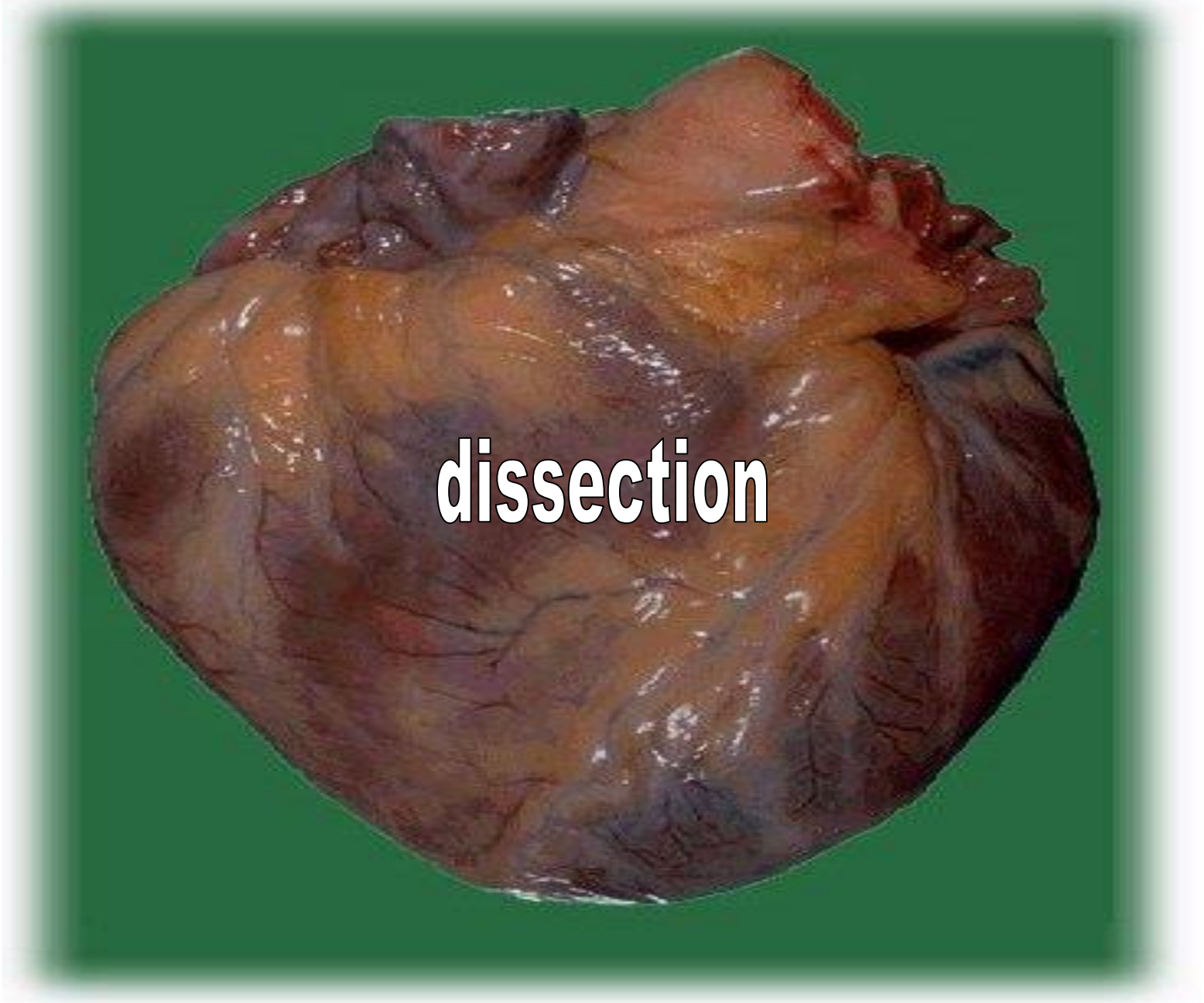
- **Atria**
- **Ventricles**
- **Atrio-ventricular valves:**
  - **found between the atria and ventricles i.e. tricuspid (RHS) & bicuspid valves**
- **Semi-lunar valves:**
  - **found in the arteries leaving the ventricles i.e. aortic valve and pulmonary valve**
- **Papillary muscles:**
  - **anchor the AV valves to the ventricle muscle wall**
- **Chordae tendinae:**
  - **link papillary muscles to the AV valves**

STRUCTURE AND FUNCTION OF THE HEART

- **papillary muscles** – the area of the ventricle which the tendons are attached to - add to your diagram
- **chordae tendinae** these are thin, fibrous chords that lead from the valves to the small papillary muscles within the heart muscle wall and contribute to the support of the tricuspid and bicuspid valves.

PAPILLARY MUSCLE & TENDONS

vnantpap[1]
Quicktime animation in file


dissection

Structure of the heart

- The heart has a high metabolic rate
- To supply metabolites necessary for respiration and muscle contraction the heart muscle has its own blood supply
- Coronary artery branches off the aorta as it leaves the heart
- Coronary vein returns blood from the coronary circulation to the vena cava.

Cardiac Cycle

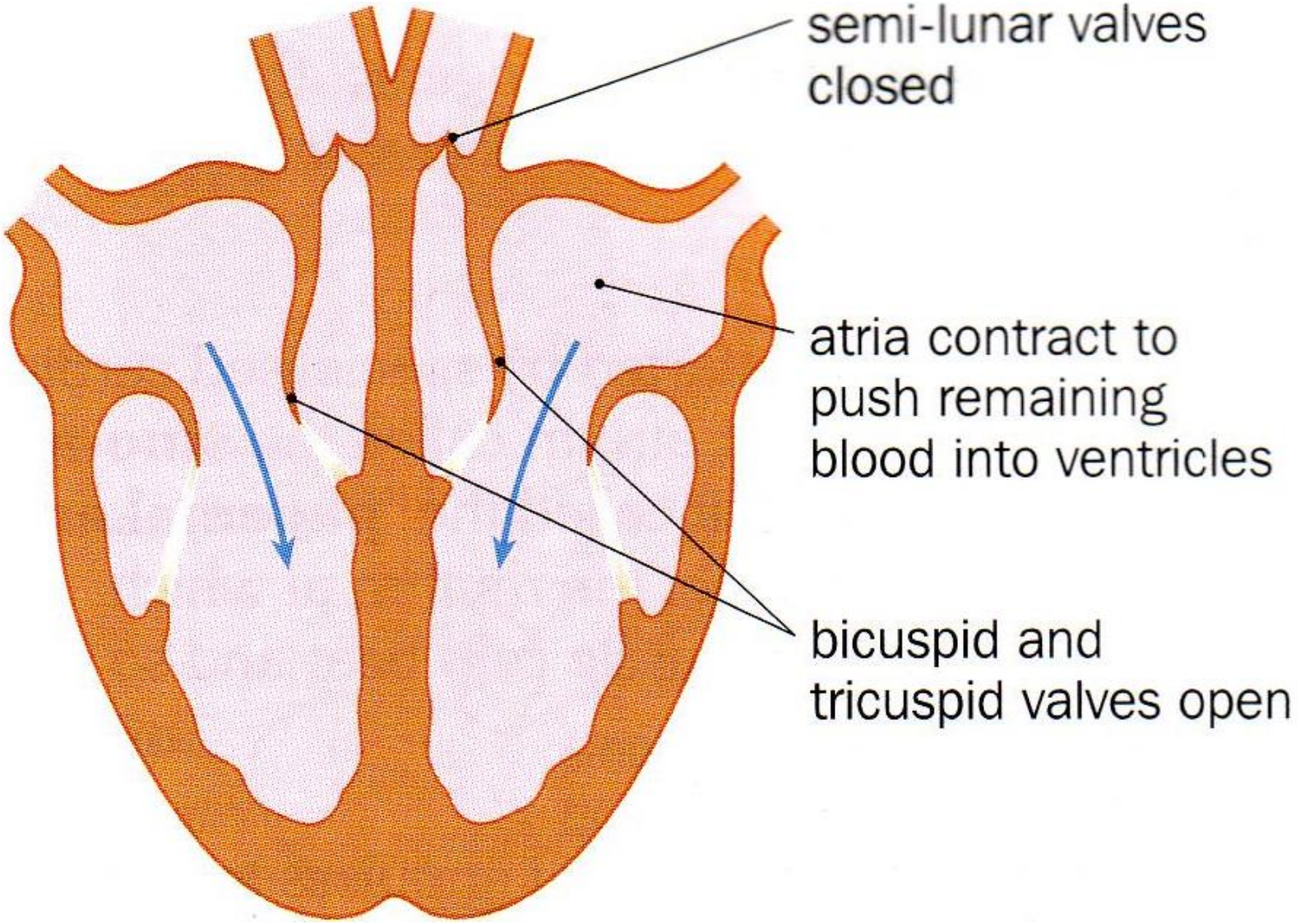
Loading

- Cardiac cycle represents the filling and emptying of the heart as it pumps blood to the lungs and body
- The beating of the two sides is synchronised
- The heart goes through stages of contraction, called systole, and relaxation, diastole.
- There are 3 stages in each cardiac cycle

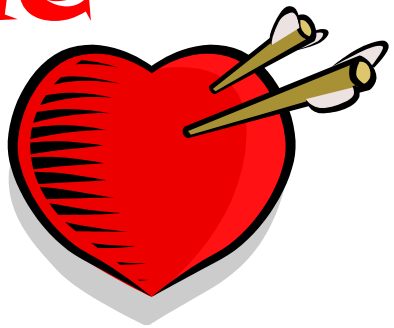
Atrial Systole

- Heart is full of blood
- Ventricles relaxed
- Both atria contract
- Leads to increased pressure in atria
- Blood forced into ventricles
- Atrio-ventricular (AV: tri and bicuspid) valves open due to pressure of blood against them

Atrial systole

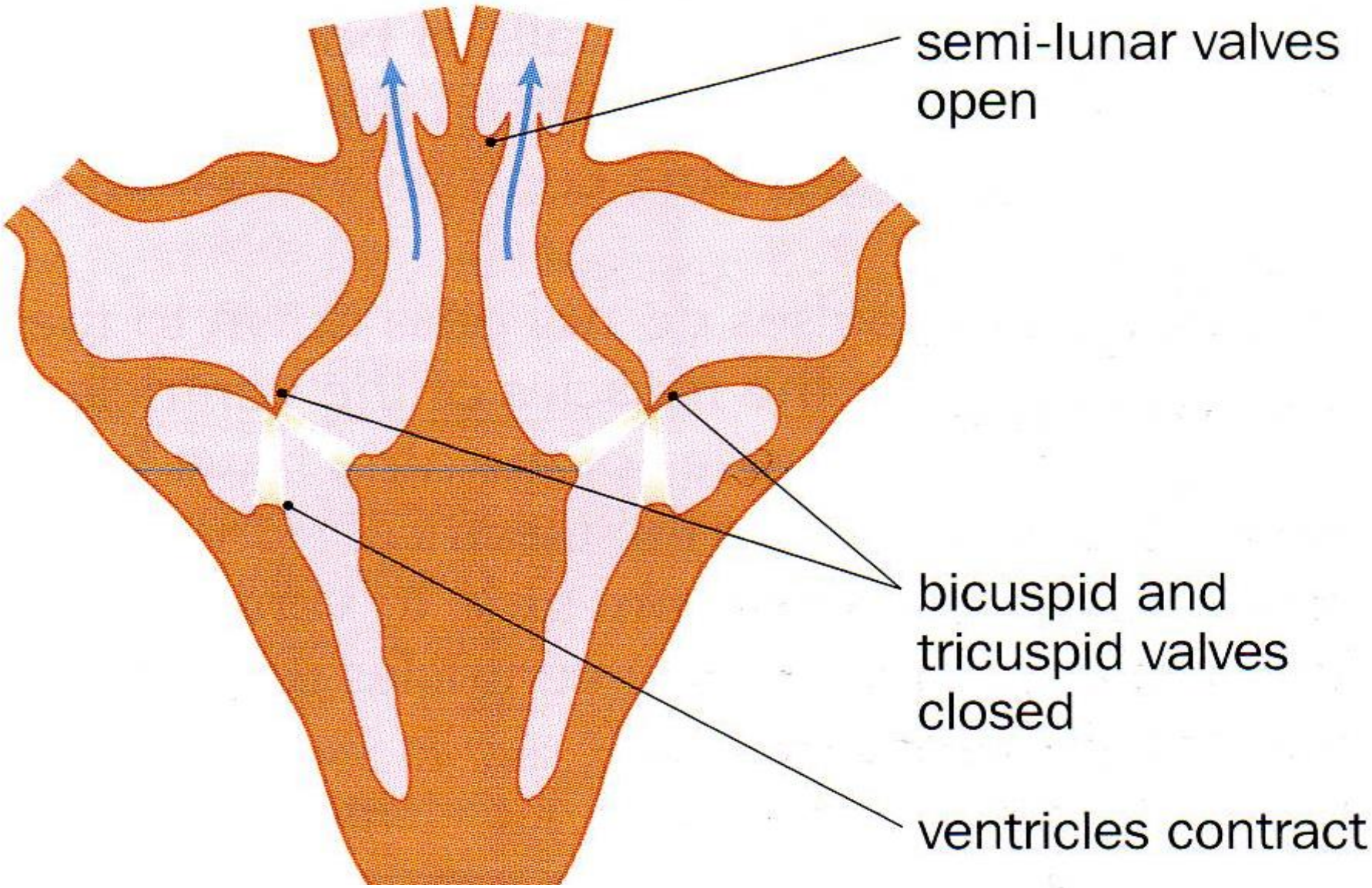


Ventricular Systole



- Atria relax
- Ventricles contract
- Increased pressure in ventricles
- AV valves shut as there is a greater pressure in the ventricles than in the atria. The chordae tendinae prevent the AV valves from blowing open and so prevents blood going back to atria
- Semi-lunar (SL) valves open as there is a greater pressure in the ventricles than in the arteries leaving the heart
- Blood forced out of heart into pulmonary artery and aorta

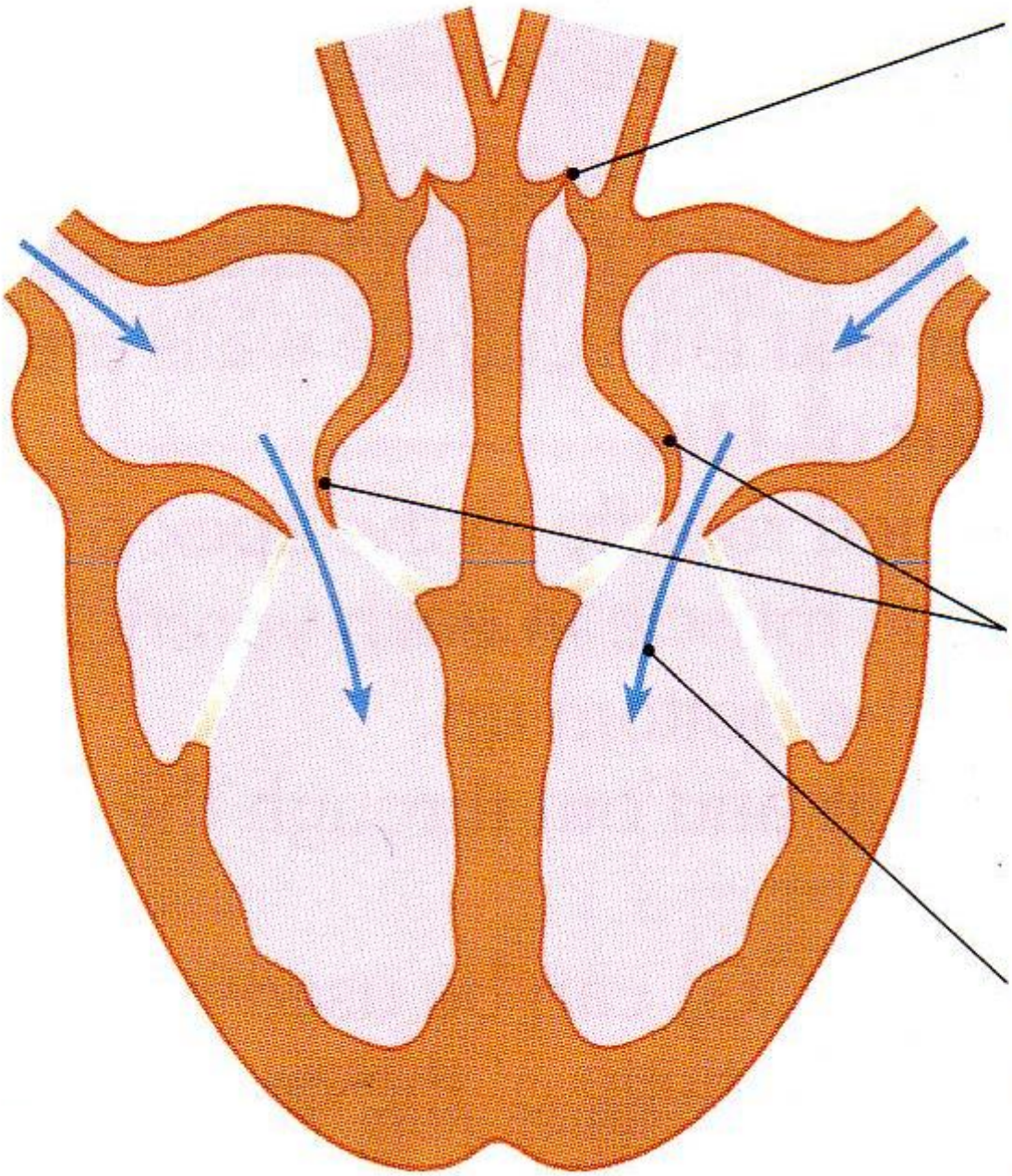
Ventricular systole



Diastole

- Ventricles & Atria relax
- Pressure in ventricles drops below that in arteries
- This causes SL valves to close – prevents blood flow back to ventricles
- All heart muscle relaxes
- Blood from vena cava and pulmonary vein enters the atria
- Increased atrial pressure
- Pushes open AV valves
- Blood moves passively into ventricles

Diastole



semi-lunar valves closed

bicuspid and tricuspid valves open

relaxation of ventricles draws blood from atria

HEART BEAT

VALVES IN THE HEART

Valves open and close due to pressure changes

AV valves OPEN when P in atria > ventricles

ie when atria contract

AV valves CLOSE when P in ventricles > atria

ie when ventricles contract

SL valves OPEN when P in ventricles > arteries

(aorta + pulmonary artery) ie when ventricles contract

SL valves CLOSE when P in arteries > ventricles

ie when ventricles relax + artery walls recoil

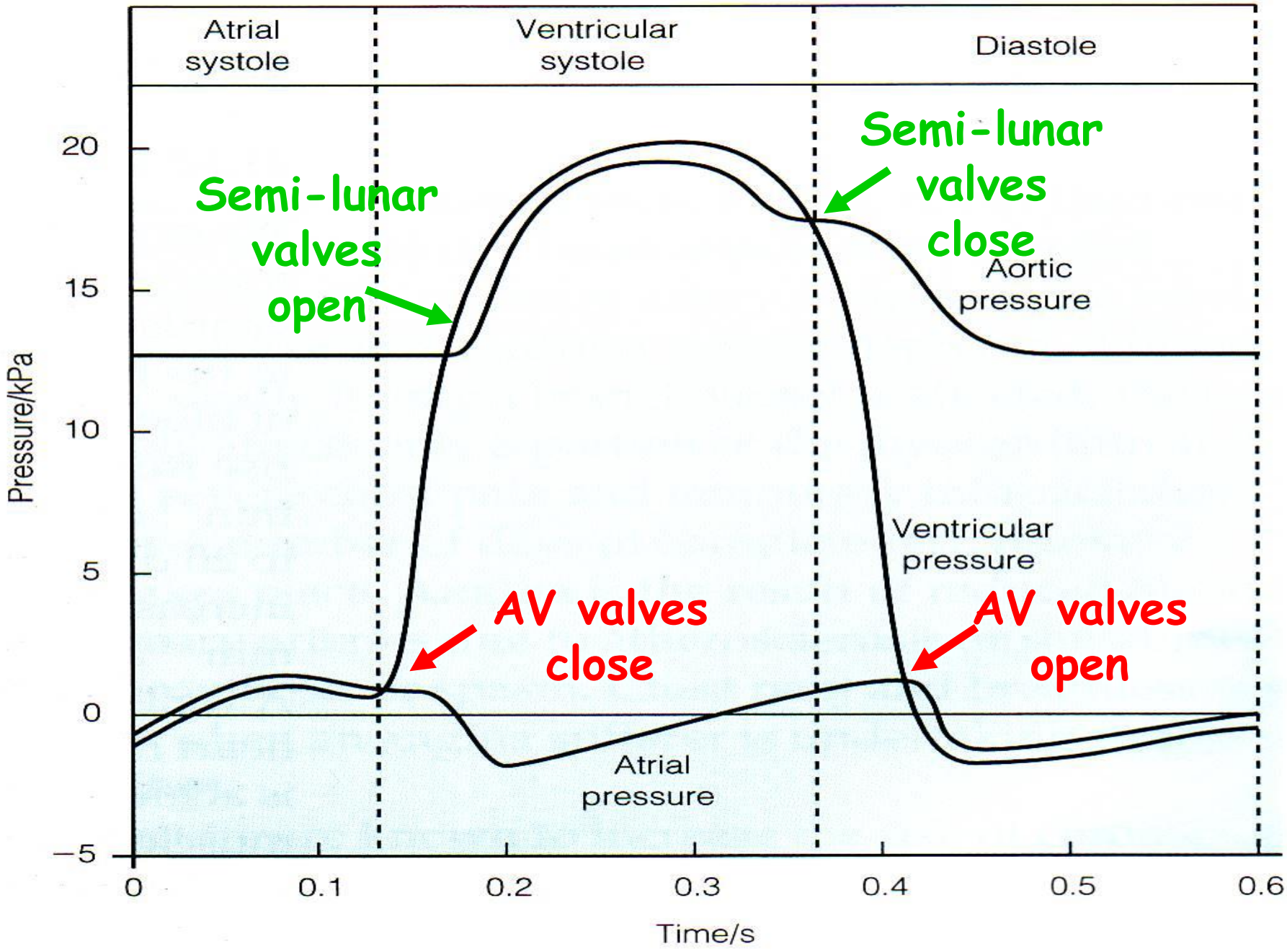
HEART VALVES

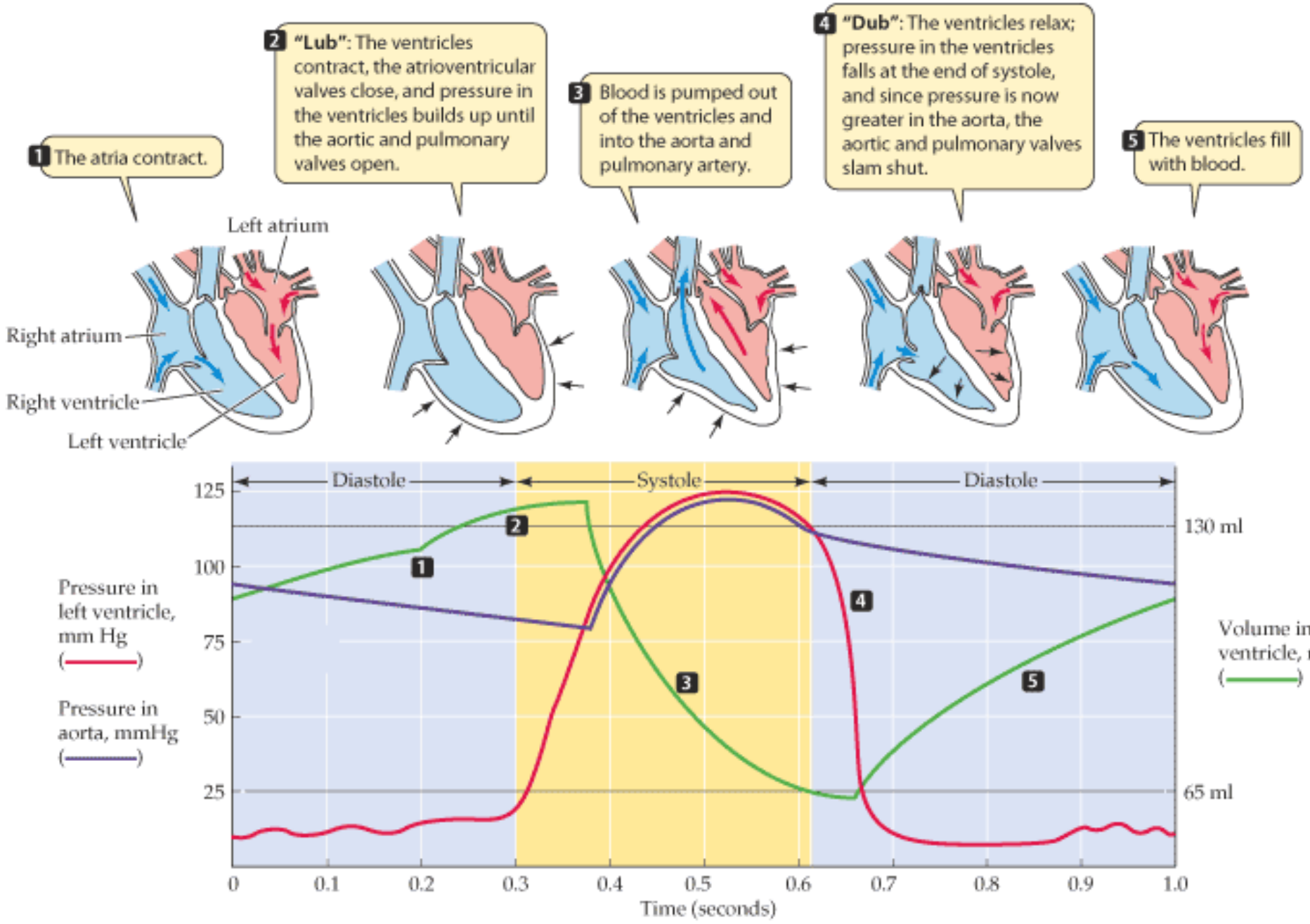
VALVE

Heart valves

http://nhscience.lonestar.edu/biol/ap2int.htm

http://www.visibleheart.com/videoLibrary.shtml#education


Atrial systole
Ventricular systole
Diastole
Semi-lunar valves open
Semi-lunar valves close
Aortic pressure
Ventricular pressure
AV valves close
AV valves open
Atrial pressure
Pressure/kPa
20
15
10
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
Time/s


1 The atria contract.
2 "Lub": The ventricles contract, the atrioventricular valves close, and pressure in the ventricles builds up until the aortic and pulmonary valves open.
3 Blood is pumped out of the ventricles and into the aorta and pulmonary artery.
4 "Dub": The ventricles relax; pressure in the ventricles falls at the end of systole, and since pressure is now greater in the aorta, the aortic and pulmonary valves slam shut.
5 The ventricles fill with blood.
Left atrium
Right atrium
Right ventricle
Left ventricle
Diastole
Systole
Diastole
125
100
75
50
25
130 ml
65 ml
Pressure in left ventricle, mm Hg
Pressure in aorta, mmHg
Volume in left ventricle, ml
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Time (seconds)

Control of Heartbeat

Cardiac muscle is MYOGENIC

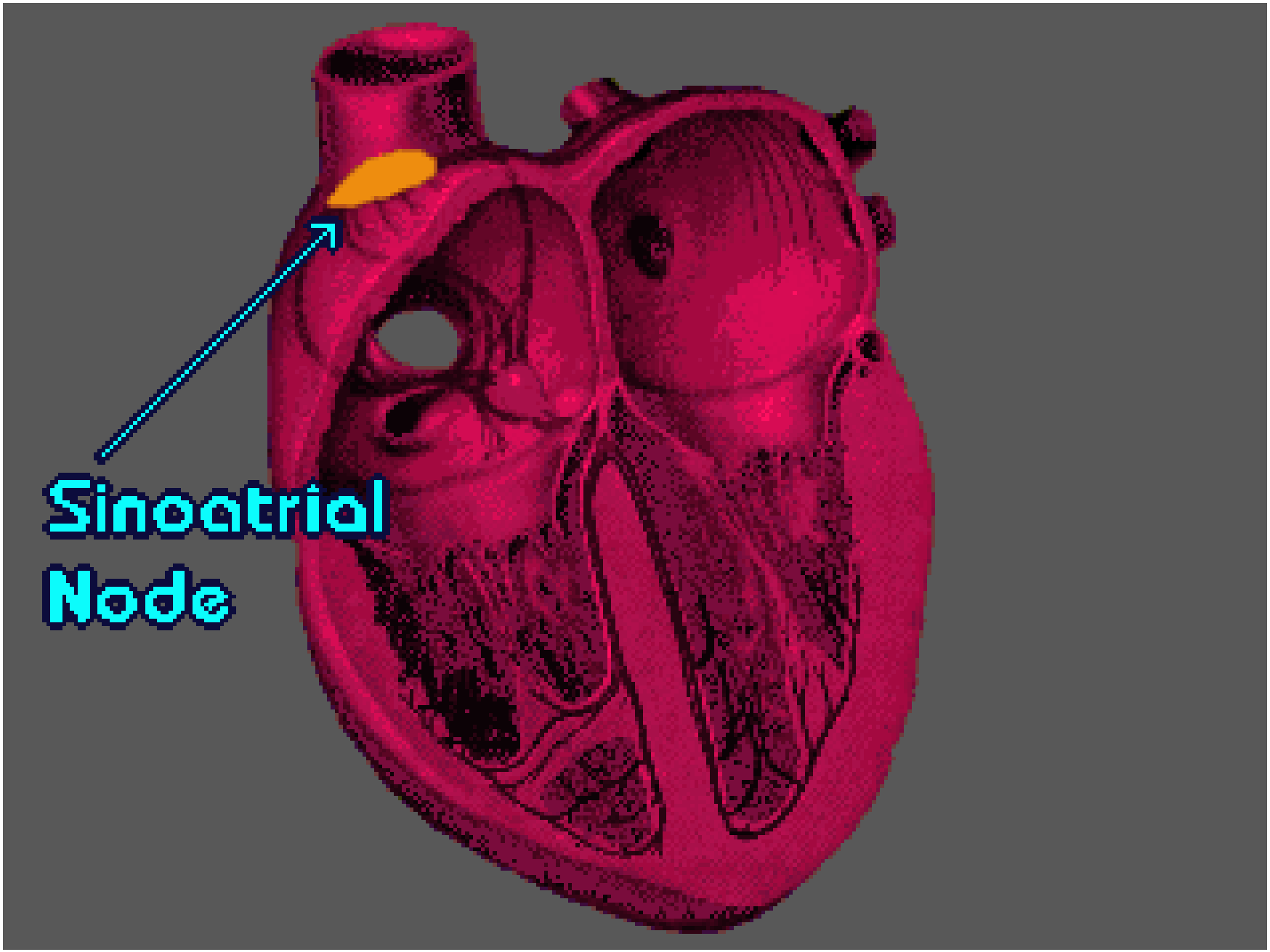
this means it contracts and relaxes without receiving impulses from the nervous system

The heartbeat starts with an electrical signal from an area of specialised cardiac muscle the R atrium wall known as the SINOATRIAL NODE (pacemaker) SAN.

SAN sets the **rhythm** at which all the other cardiac muscle cells beat and so controls the speed of the cardiac cycle.

It does this by sending a wave of electrical excitation through the heart muscle.

Drugs which affect these cells will slow or speed up the heart rate.


Sinoatrial
Node

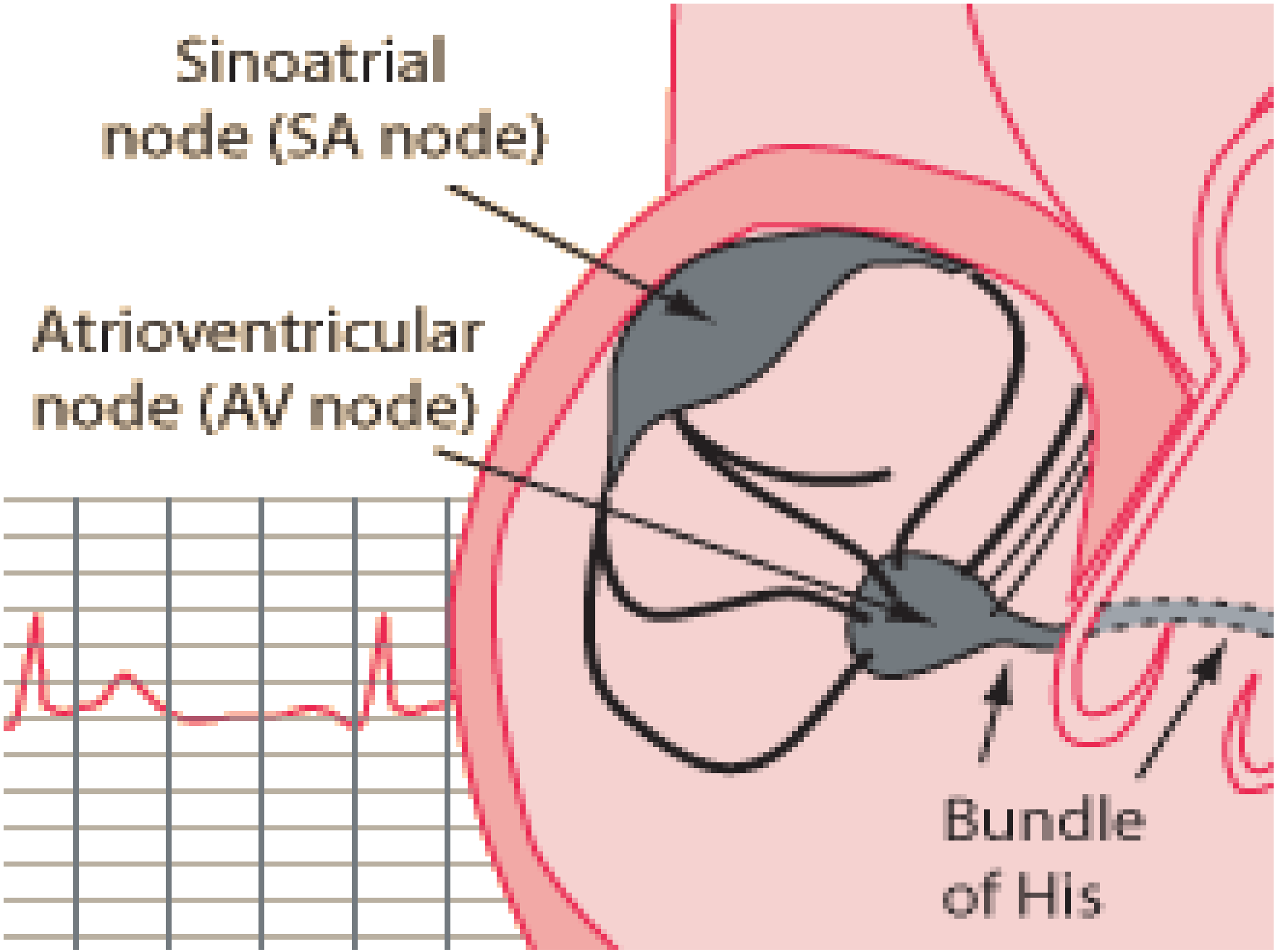
Atrial Contraction

- Impulses spread out from SAN in a wave over the atrial walls
- Cardiac muscle cells in the atrial walls contract in time with the impulses form SAN
- Both atria contract at the same time

- Impulses do not pass to the ventricles
- The atria must finish contracting first
- A band of **collagen fibres** between the atria and ventricles prevent passage of the impulses to the ventricles
- This delay ensures that the ventricles do not contract until they are full of blood.

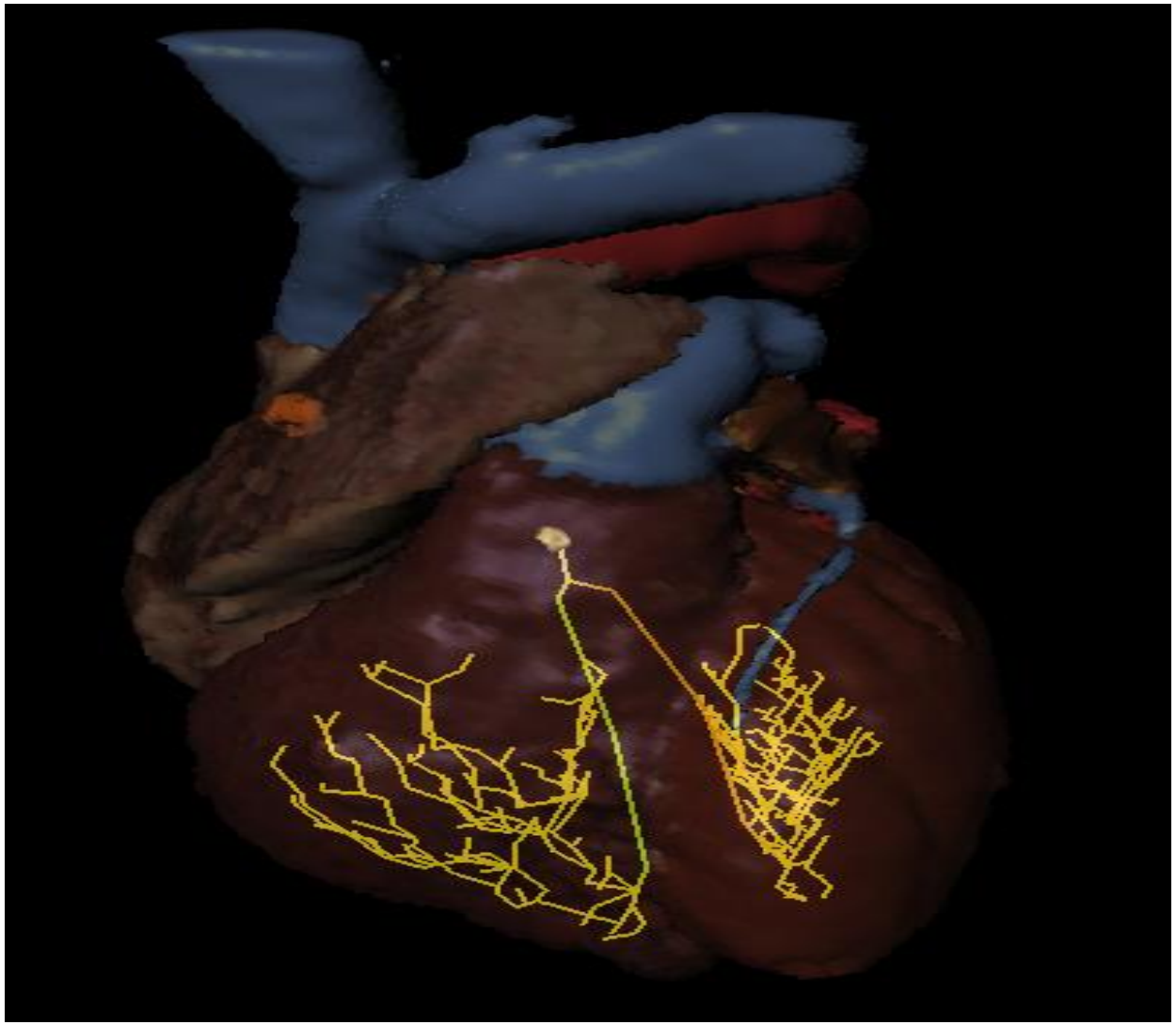
Ventricular Contraction

- A 2nd node the ATRIO-VENTRICULAR NODE also found in the R atrium picks up the impulses from SAN
- This responds by transmitting the impulse to the ventricles

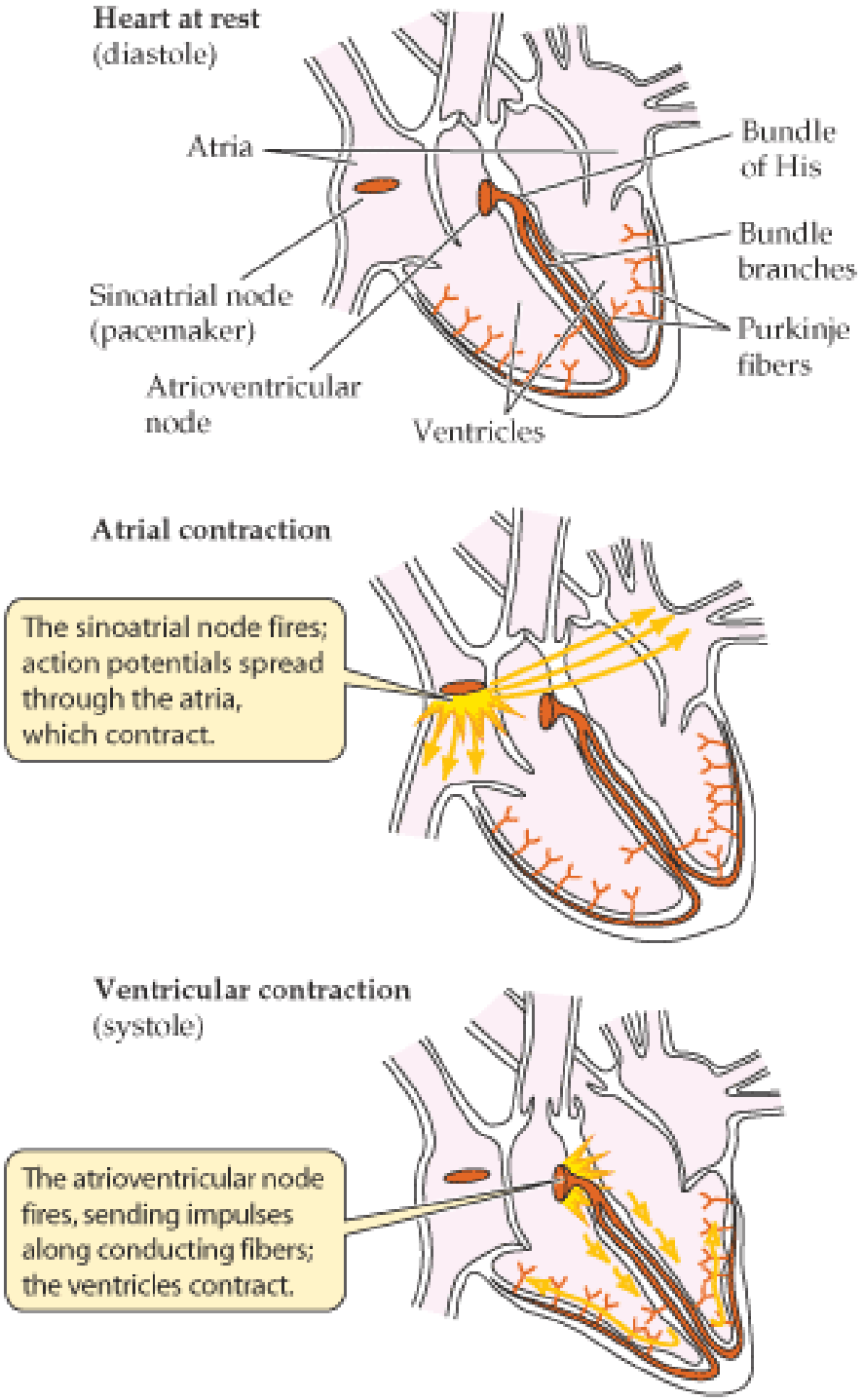

Sinoatrial
node (SA node)
Atrioventricular
node (AV node)
Bundle
of His

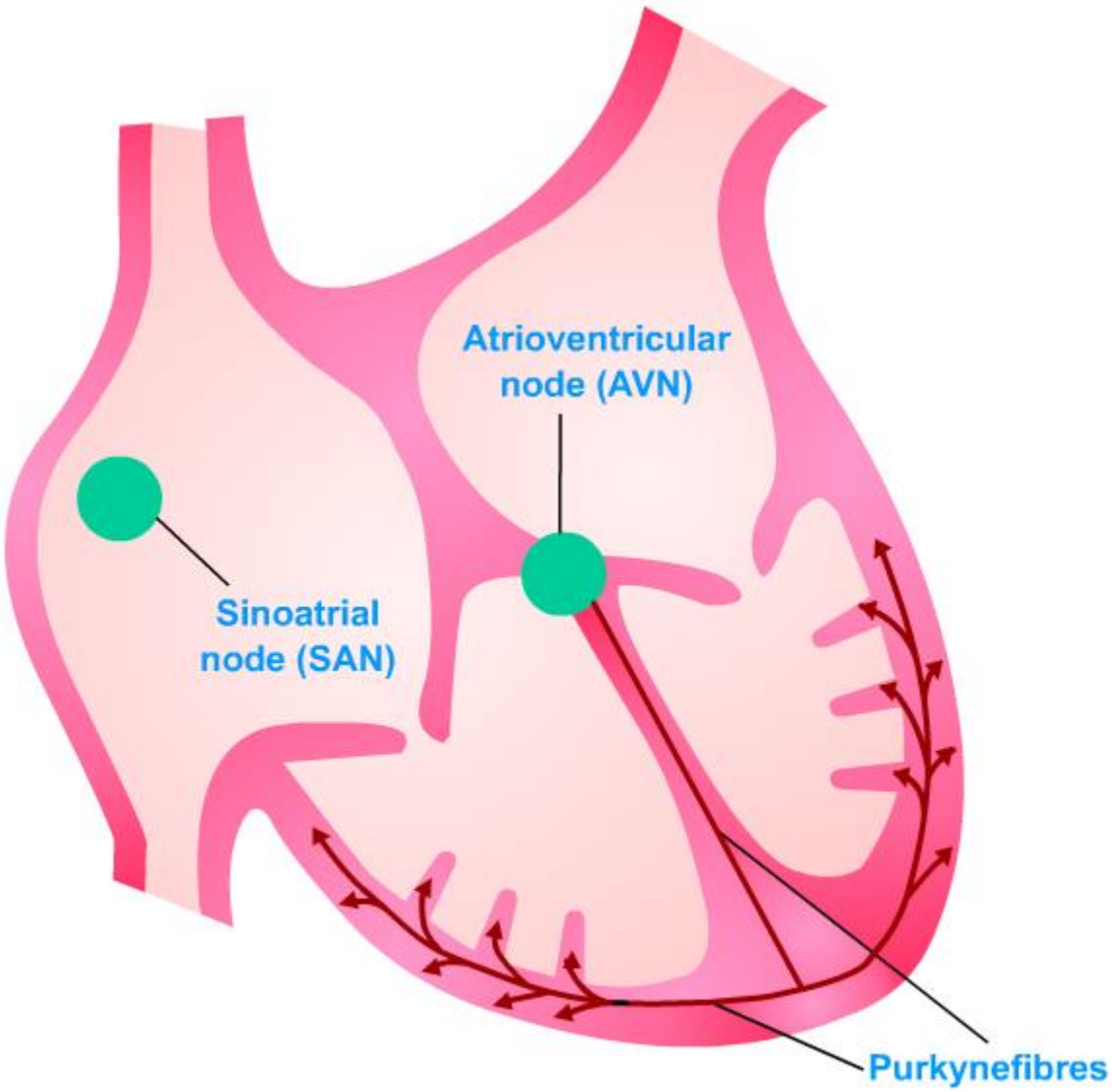
- The impulses travel from AVN down the septum along specialised muscle fibres – THE PURKINJE FIBRES
- The fibres are collectively known as THE BUNDLE OF HIS
- At the apex of the ventricles the purkinje fibres spread out into the walls of the L and R ventricles

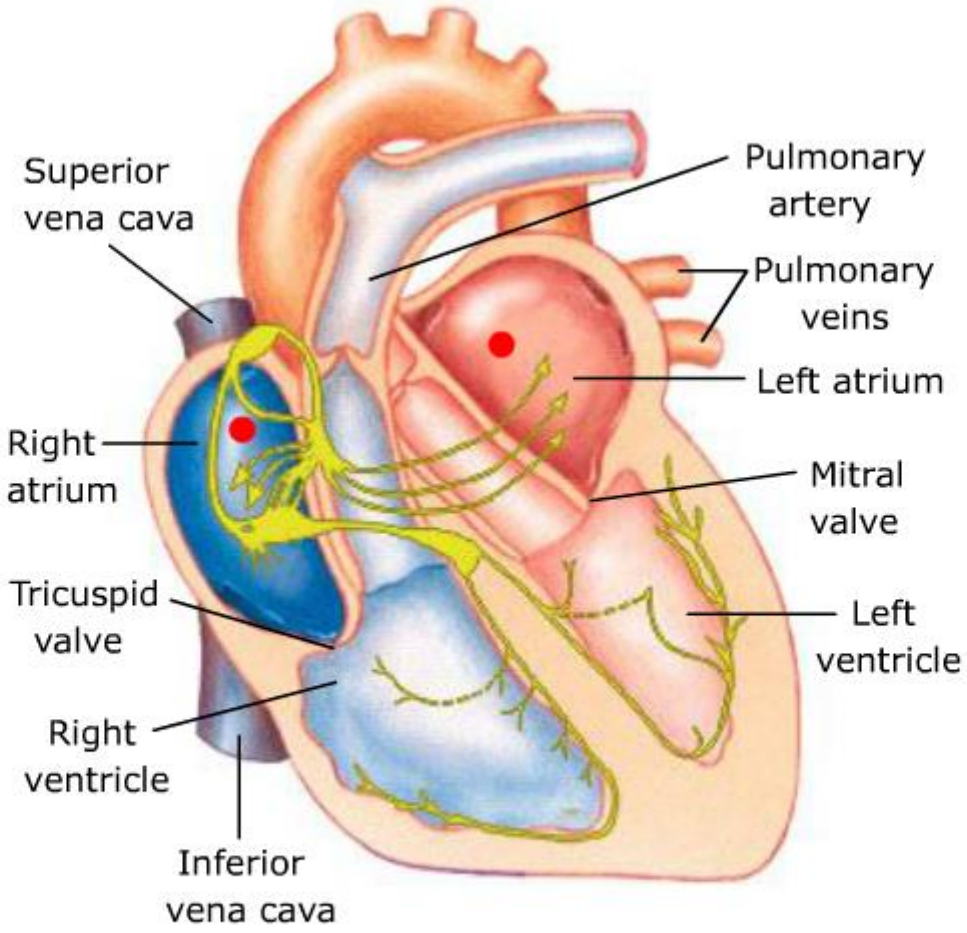
Purkinje fibres and Bundle of His



- Impulses are carried rapidly to the apex (tip) of the ventricles
- Causing the cardiac muscle in the ventricles to contract from the bottom up
- Blood is squeezed up and out of the arteries

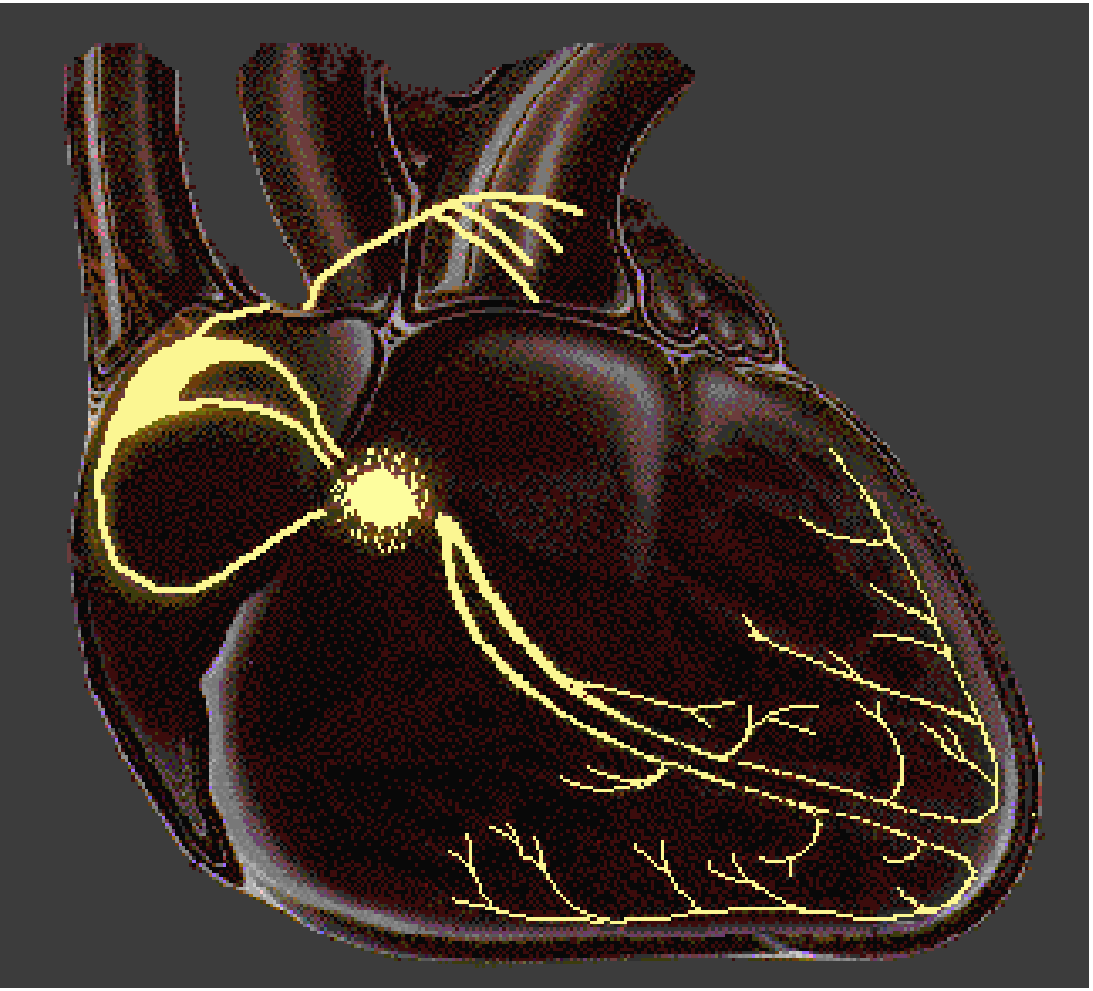

Heart at rest
(diastole)
Atria
Bundle
of His
Bundle
branches
Purkinje
fibers
Sinoatrial node
(pacemaker)
Atrioventricular
node
Ventricles
Atrial contraction
The sinoatrial node fires;
action potentials spread
through the atria,
which contract.
Ventricular contraction
(systole)
The atrioventricular node
fires, sending impulses
along conducting fibers;
the ventricles contract.


Atrioventricular
node (AVN)
Sinoatrial
node (SAN)
Purkynefibres



Play Animation Pause

The conduction system of the heart



Where are the

SA node?

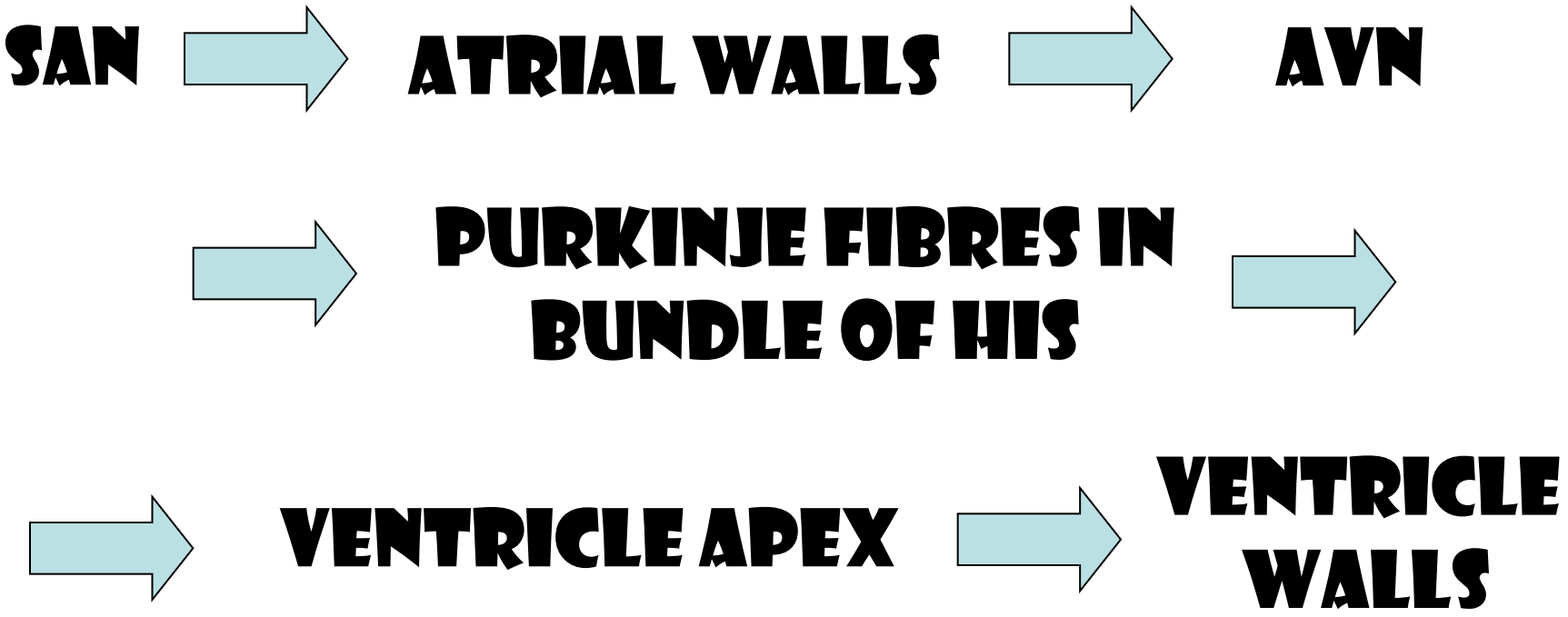
AV node?

Bundle of His?

Purkinje fibres?

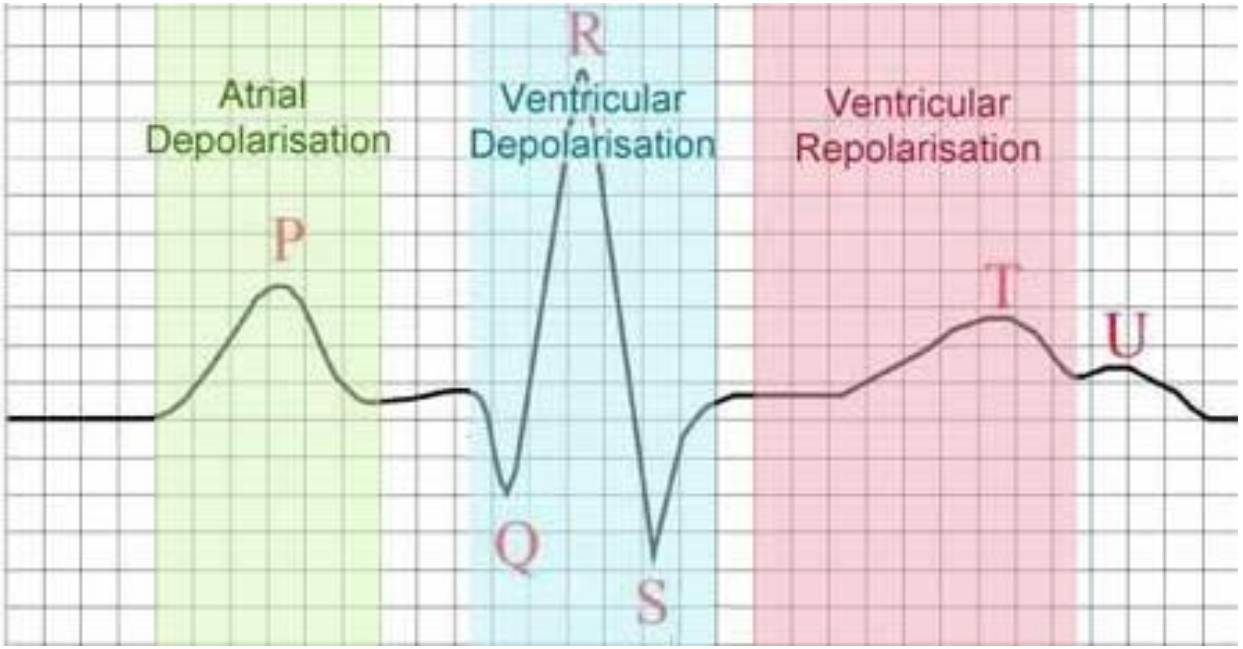
Bundle branches?

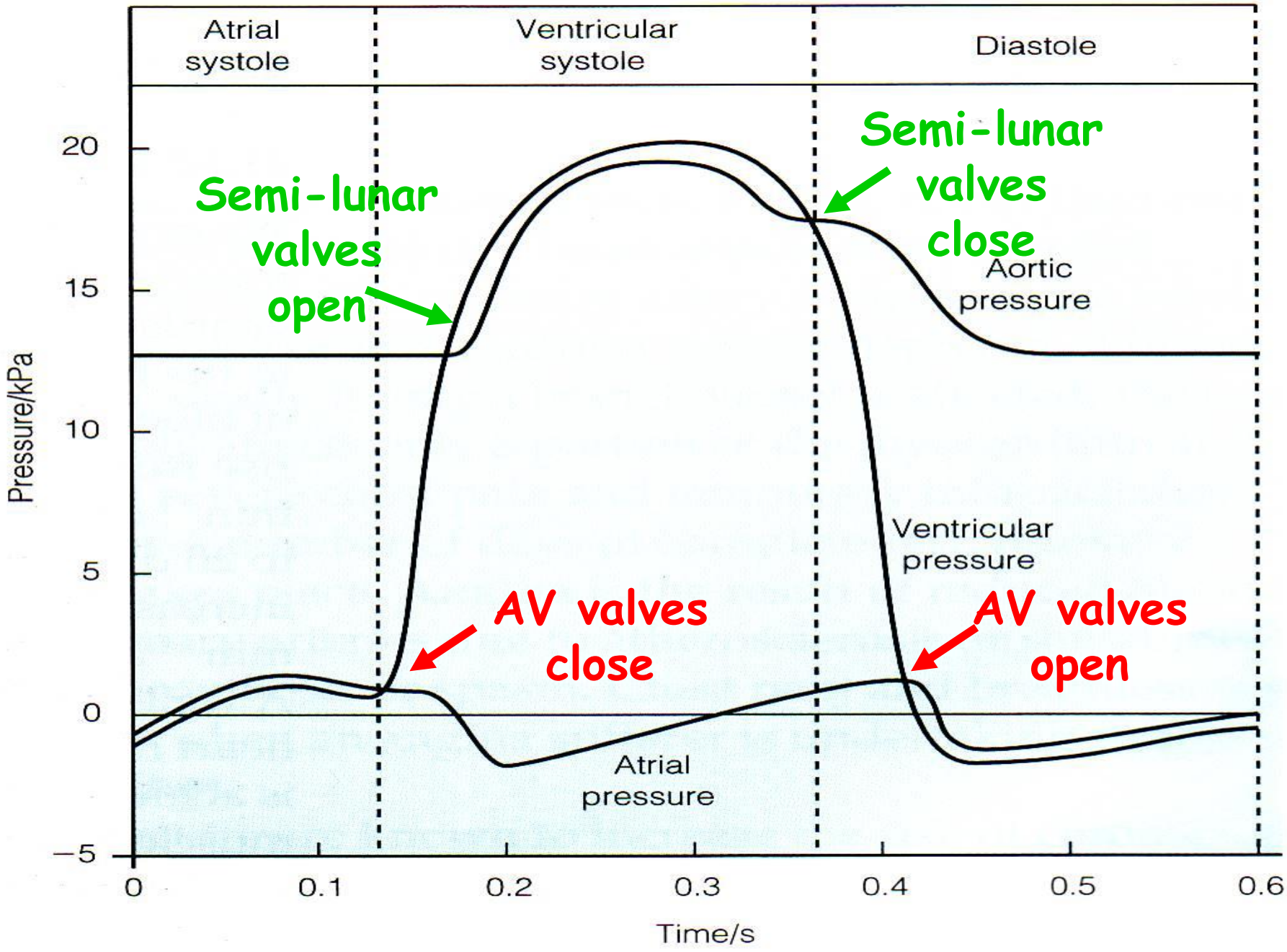
Draw a flow chart showing how the cardiac impulse flows through the heart



ELECTROCARDIOGRAM

- An ECG is used to detect changes in the electrical activity of the cardiac cycle.
- The wave represents the excitation wave travelling across the atria and ventricles.




Atrial systole
Ventricular systole
Diastole
Semi-lunar valves open
Semi-lunar valves close
Aortic pressure
Ventricular pressure
AV valves close
AV valves open
Atrial pressure
Pressure/kPa
20
15
10
5
0
−5
0
0.1
0.2
0.3
0.4
0.5
0.6
Time/s

HEART SOUNDS

- There are 2 sounds associated with the cardiac cycle. LUB, DUB

- **Lub** = AV valves closing during ventricular systole (= point A on ECG)

- **Dub** = semilunar valves shutting during diastole (= point C on ECG)

The Blood

FUNCTIONS

- Transports materials
- Distributes heat around the body to maintain a constant body temperature
- Acts as a buffer
- Provides pressure for some organs to work
- Defence against disease

Components of the Blood

RED BLOOD CELLS

(Erythrocytes)

Their function is to transport oxygen from the lungs to the respiring tissues

- Biconcave discs
- Gives a big surface area to volume ratio

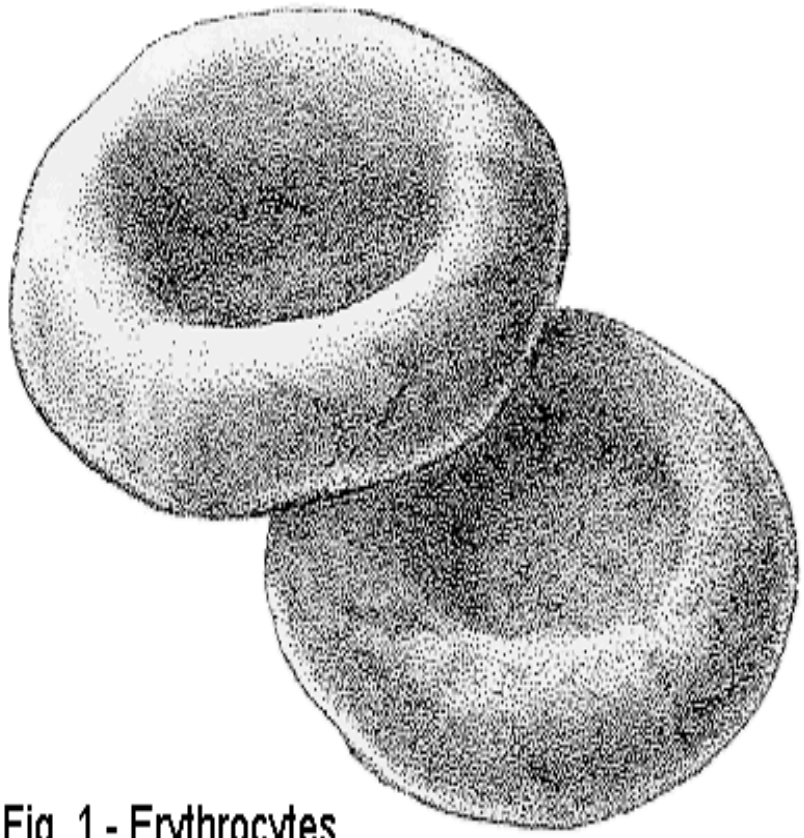


Fig. 1 - Erythrocytes

- Full of haemoglobin
- A red globular protein which transports oxygen
- RBCs have no nucleus, mitochondria or ER – more room for Hb
- RBCs are flexible to move along small capillaries; there is more contact with capillary walls so increased rate of gas exchange

- Very small
- Only last about 120 days
- New cells are constantly being made in the bone marrow

White Blood cells

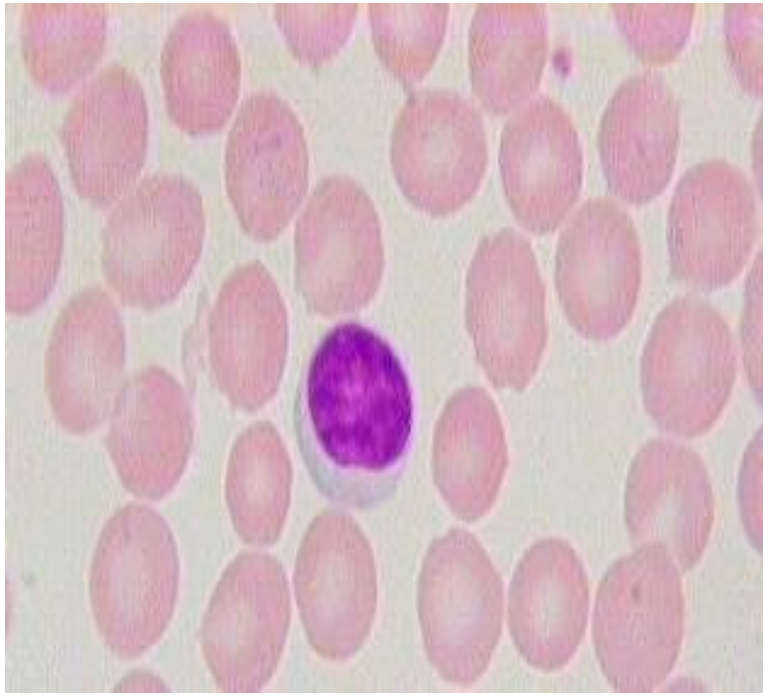
Common Features

- Have a nucleus
- Spherical or irregular in shape
- Much bigger than red cells
- Occur in smaller numbers

3 main types

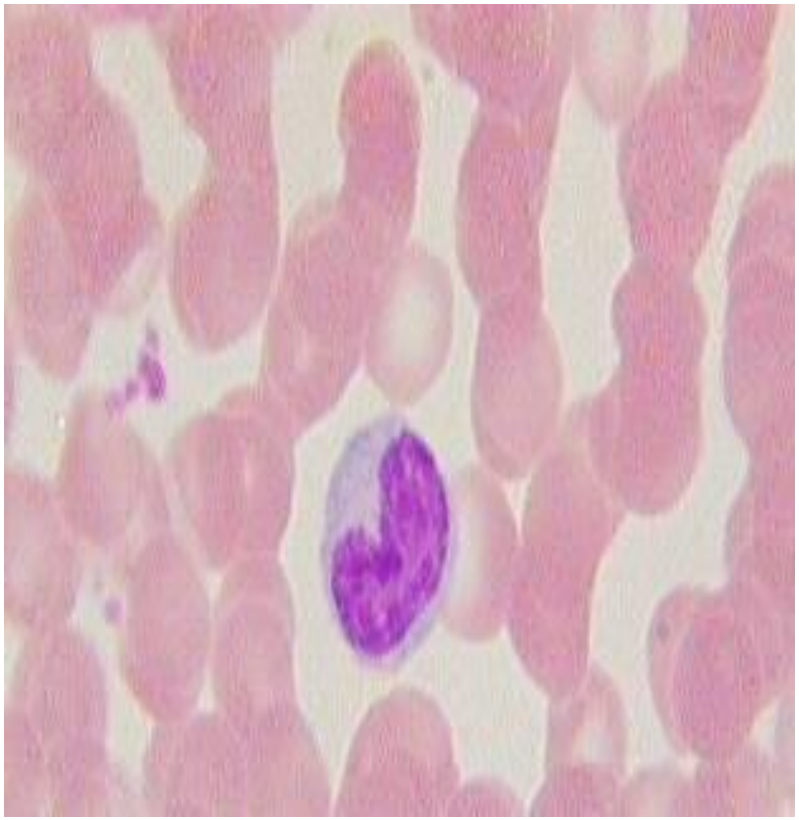
Lymphocytes

- Have a large round nucleus and a small amount of cytoplasm
- Some (B cells) secrete antibodies
- Some kill infected cells (T cells)
- Some control other aspects of immunity



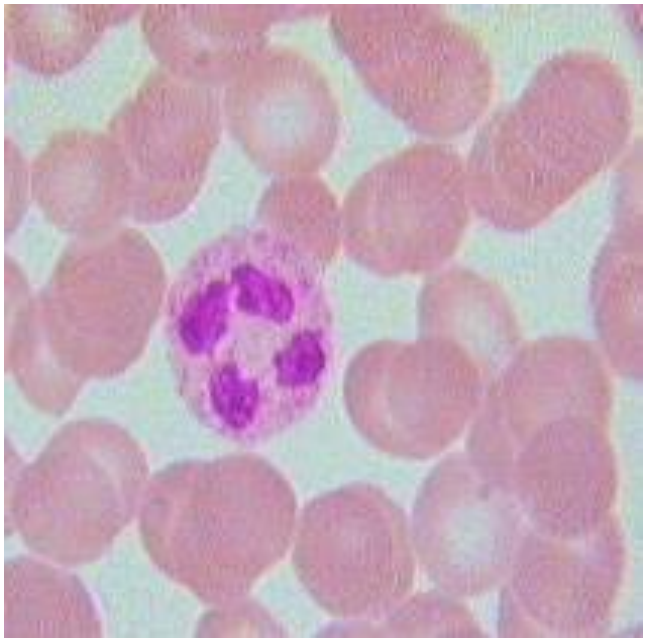
Monocytes

- Large kidney shaped nucleus
- Develop into macrophages
- Engulf bacteria- phagocytic

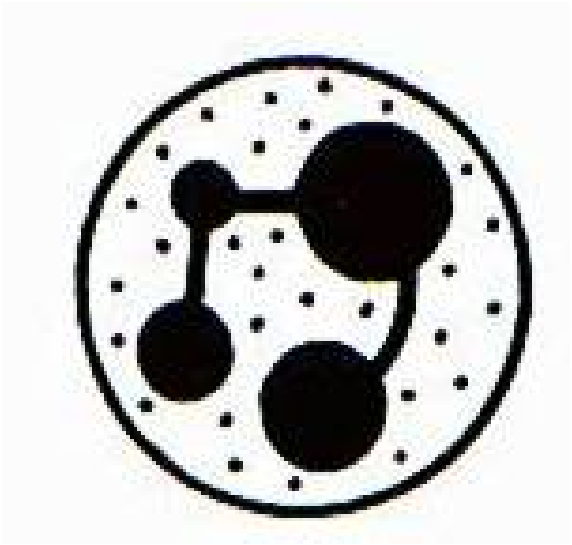


polymorphs
(granulocytes or microphages)

- Have lobed nuclei
- Develop into microphages
- Have granular cytoplasm
- Engulf bacteria
- Involved with allergies and inflammation

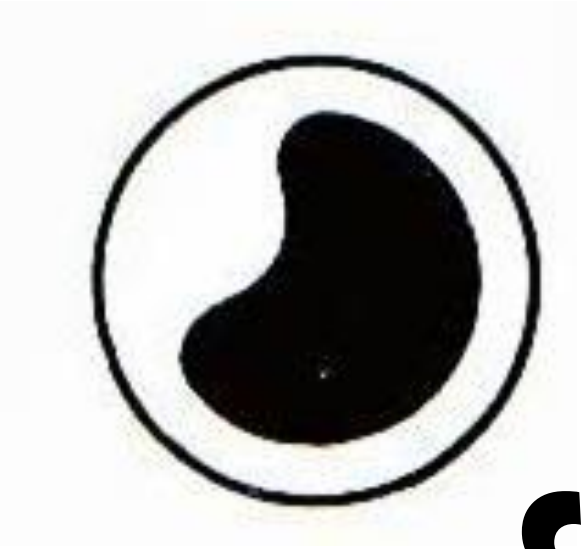


Give the name and function of each cell type



A

B



C


plasma

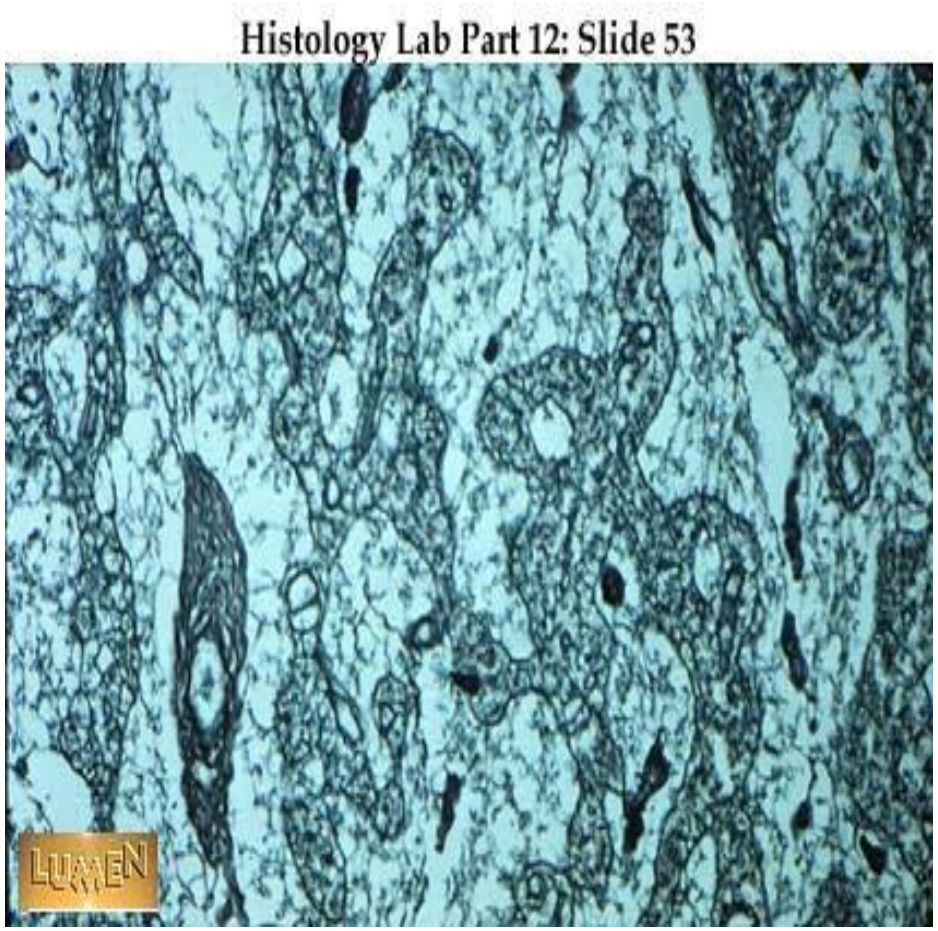
The liquid component of the blood involved in the transport of:

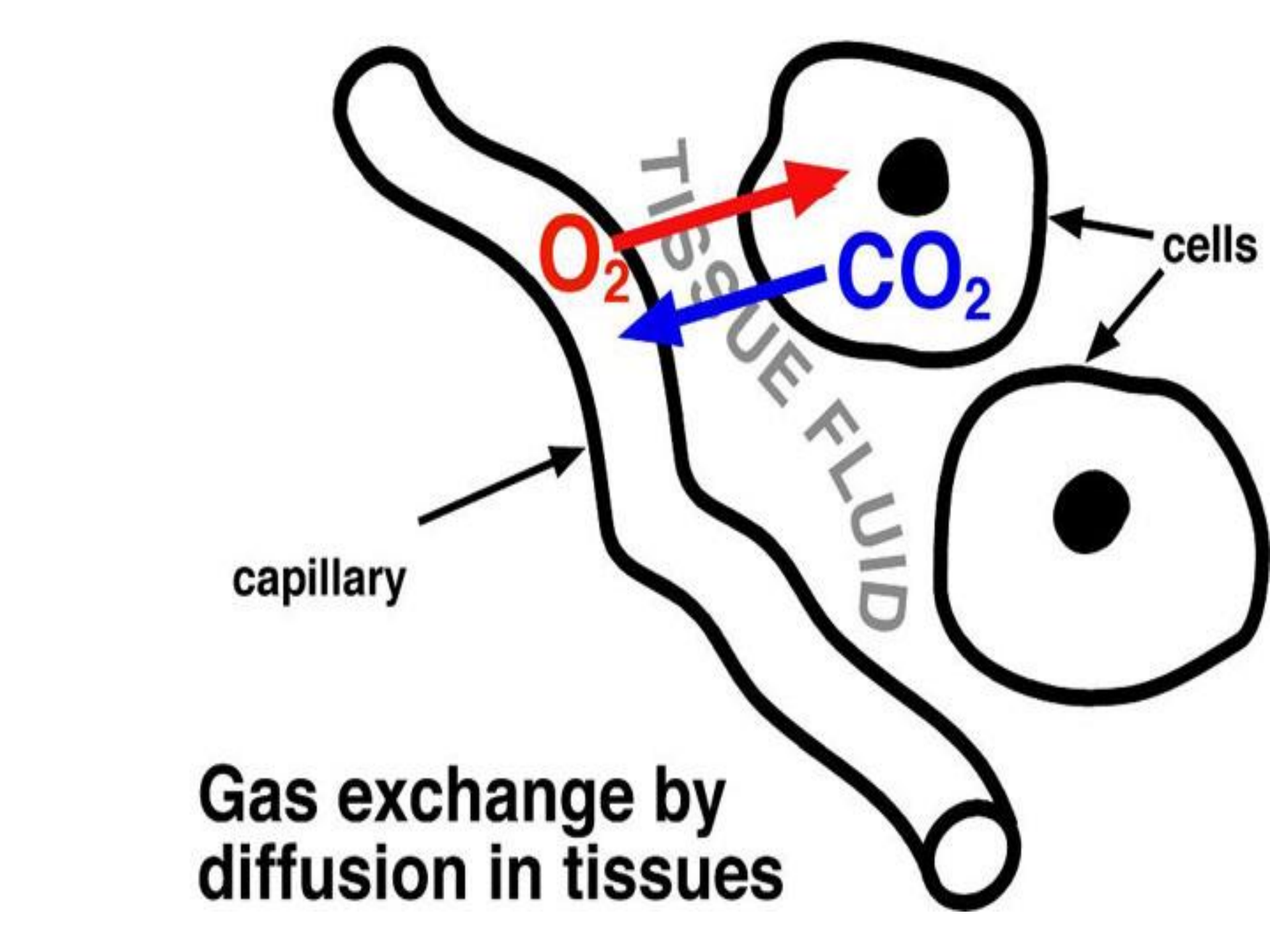
- products of digestion (amino acids, glucose, vitamins, minerals etc)
- Ions (HCO_3^-)
- Carbon dioxide
- Urea
- Heat
- Prothrombin , fibrinogen and clotting factors
- hormones

Not constant in composition

TISSUE FLUID

- Liquid medium which bathes all cells within tissues.
- Involved in exchange of metabolites with tissues.

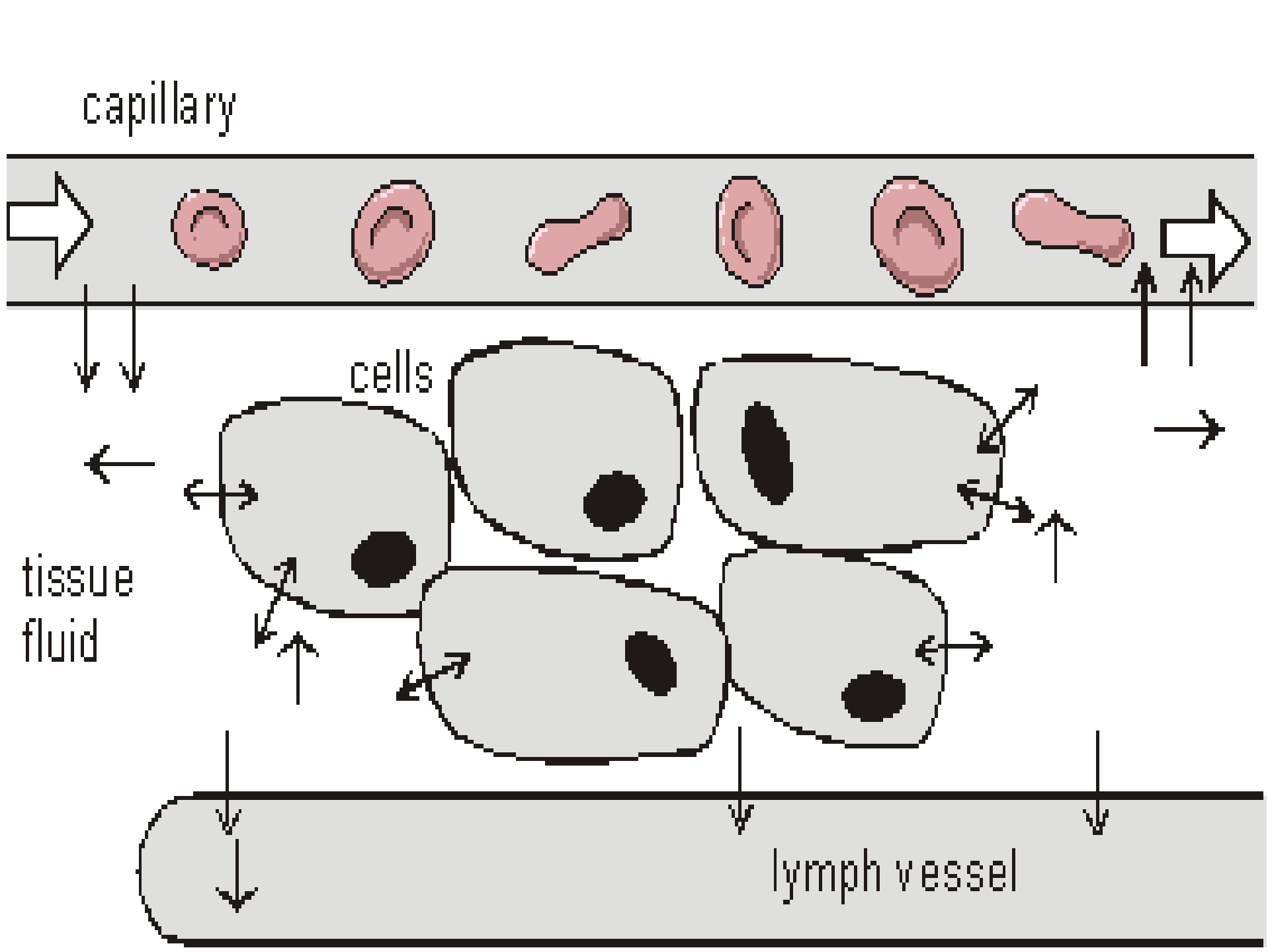




Gas exchange by diffusion in tissues

TISSUE FLUID

- Substances do not actually move directly between the blood and the cell: they first diffuse into the tissue fluid that surrounds all cells, and then diffuse from there to the cells.
- Two forces are involved in the formation of tissue fluid: hydrostatic pressure and the osmotic gradient.
- Hydrostatic pressure is caused by the pumping action of the heart.
- Osmotic gradient is caused when there is a difference in the concentration of dissolved substances in the blood and the tissue fluid


capillary
cells
tissue fluid
lymph vessel

TISSUE FLUID FORMATION

1. At the arterial end of the capillary bed the blood still has a high hydrostatic pressure. The osmotic gradient between the blood and tissue fluid is low (water moved into blood)

The difference between the water potential of the blood and the tissue fluid is small, so there is a low osmotic gradient. As the HP is greater than the osmotic gradient blood plasma is squeezed out through the permeable walls of the capillary.

Cells and proteins are too big to leave the capillary, so they remain in the blood.

2. This fluid now forms tissue fluid surrounding the cells. Materials are exchanged between the tissue fluid and the cells by all four methods of transport across a cell membrane. Gases and lipid-soluble substances (such as steroids) cross by **lipid diffusion**; water crosses by **osmosis**, ions cross by **facilitated diffusion**; and glucose and amino acids cross by **active transport**.

3. At the venous end of the capillary bed the blood is at low pressure, since it has lost so much plasma. The removal of fluid has decreased the water potential of the blood remaining in the capillary so the osmotic gradient between the tissue fluid and blood in the capillary is high.

When the osmotic gradient exceeds the hydrostatic pressure water returns from the tissue fluid to the blood by osmosis.

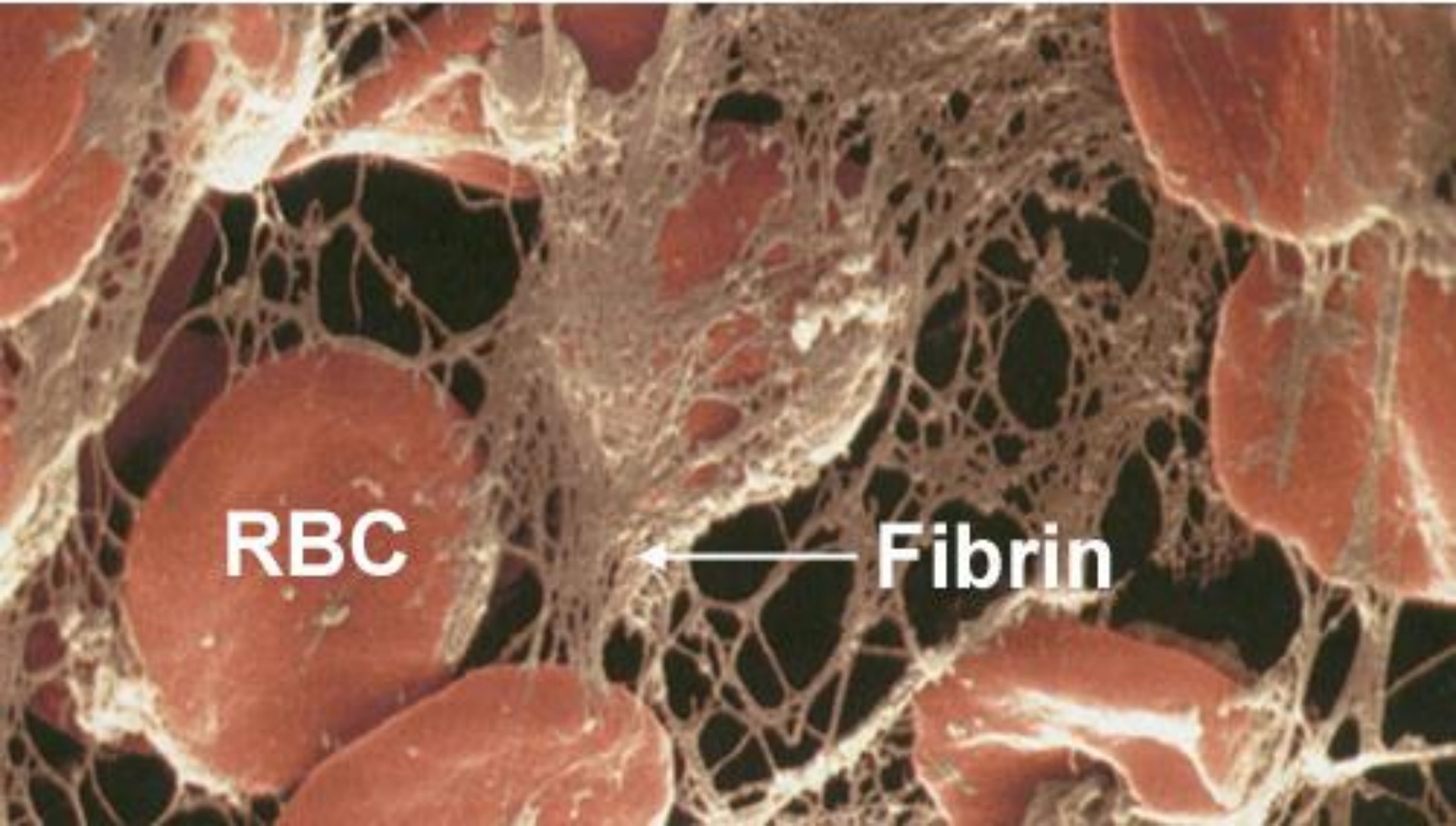
Solutes (such as carbon dioxide, urea, salts, etc) enter the blood by diffusion, down their concentration gradients.

4. Not all the plasma that left the blood returns to it, so there is excess tissue fluid. This excess drains into **lymph vessels**, which are found in all capillary beds. Lymph vessels have very thin walls, like capillaries, and tissue fluid can easily diffuse inside, forming **lymph.**

Tissue fluid formation

- Read page 193 Froggy
- Draw diagrams

Blood clotting



CLOTTING

- Injury to the lining of a blood vessel exposes **collagen** fibres.
- **Thrombocytes (platelets)** stick to these and swell up releasing **thromboplastins**.
- Thromboplastins attract **clotting factors** to the injury site (e.g. factor VIII, Vitamin K).

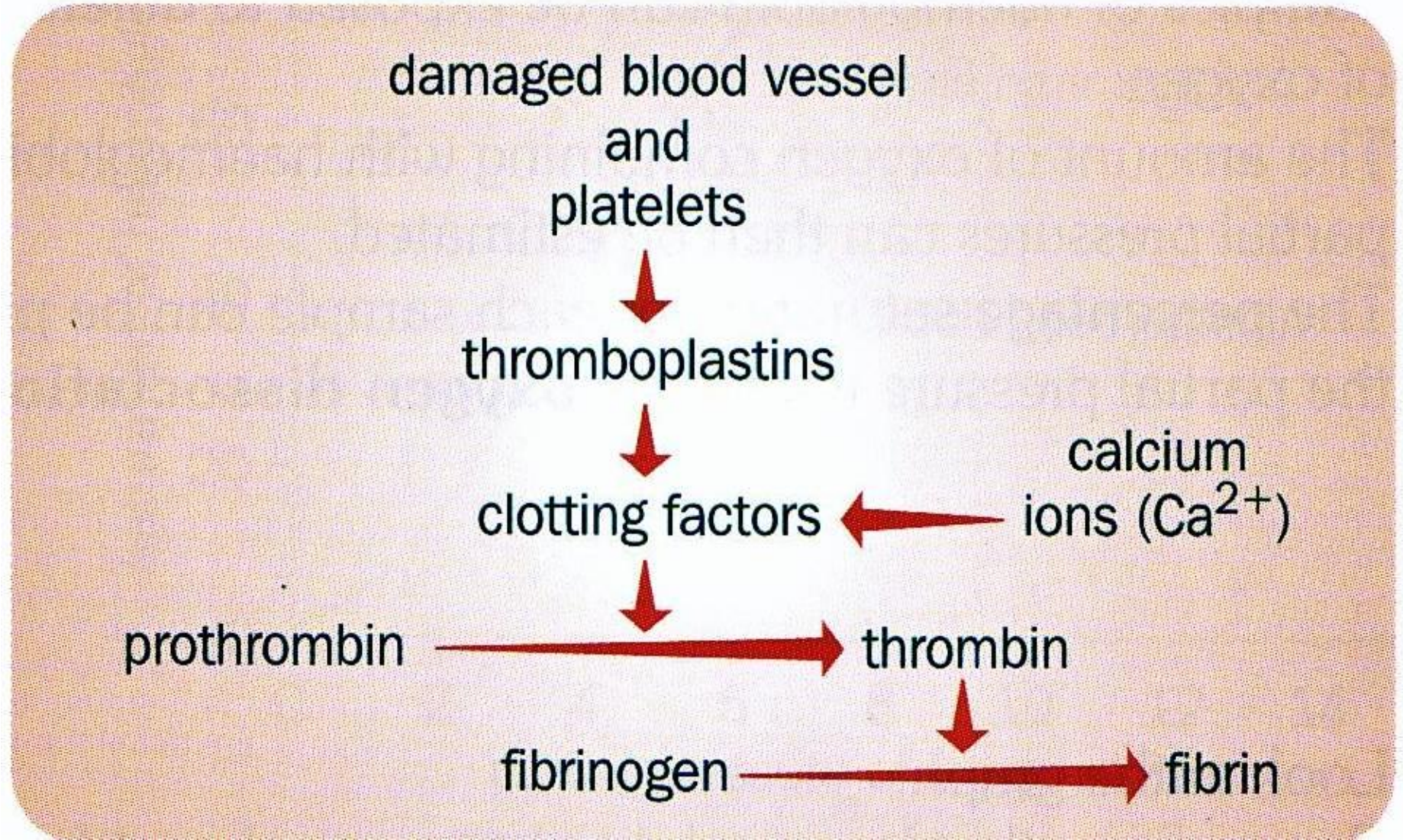
- In the presence of **Ca^{2+} ions** the clotting factors cause the inactive plasma protein **prothrombin** to be converted to **thrombin**.

- Thrombin then converts soluble **fibrinogen** into insoluble **fibrin** which forms a mesh of fibres across the wound, trapping RBCs.

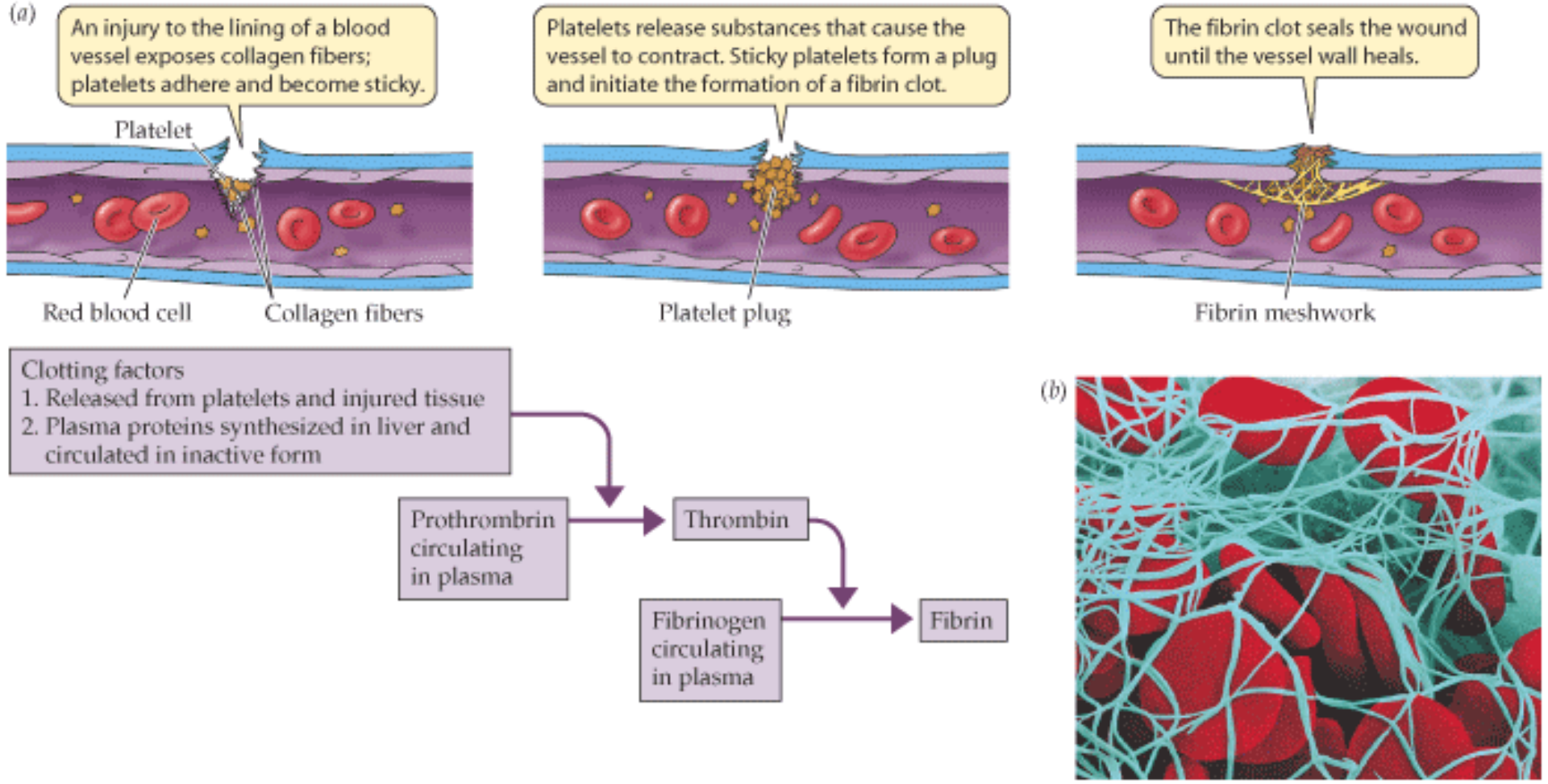
- These dry to form a **clot** in which the protein fibres contract pulling the edges of the wound together

- The clot which forms prevents entry of bacteria, further loss of blood allowing the wound to heal.

Role of thrombocytes in the clotting mechanism



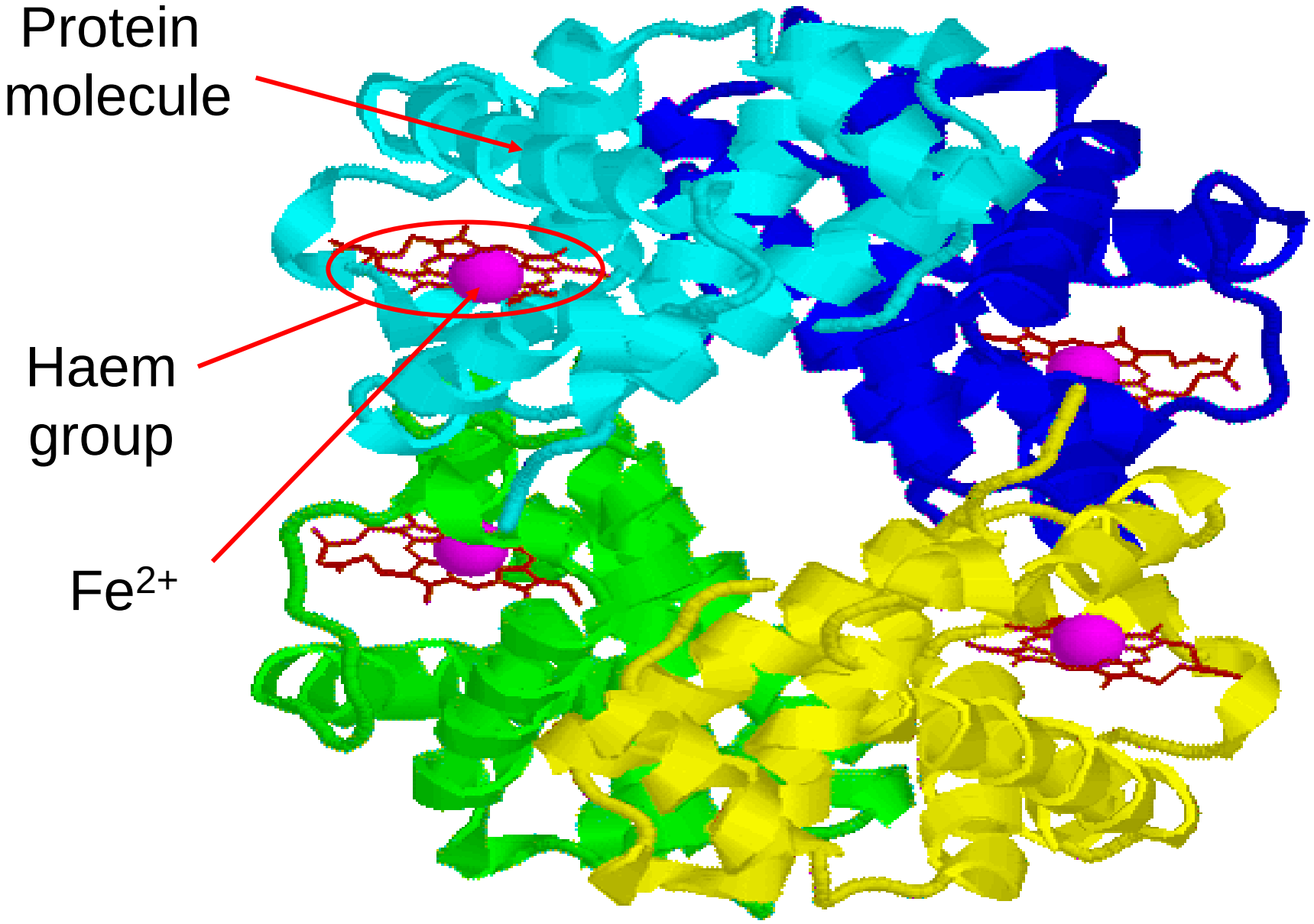
- Vitamin K is required for the protein prothrombin to be produced.
- Warafarin is a vitamin K antagonist and prevents blood clotting.

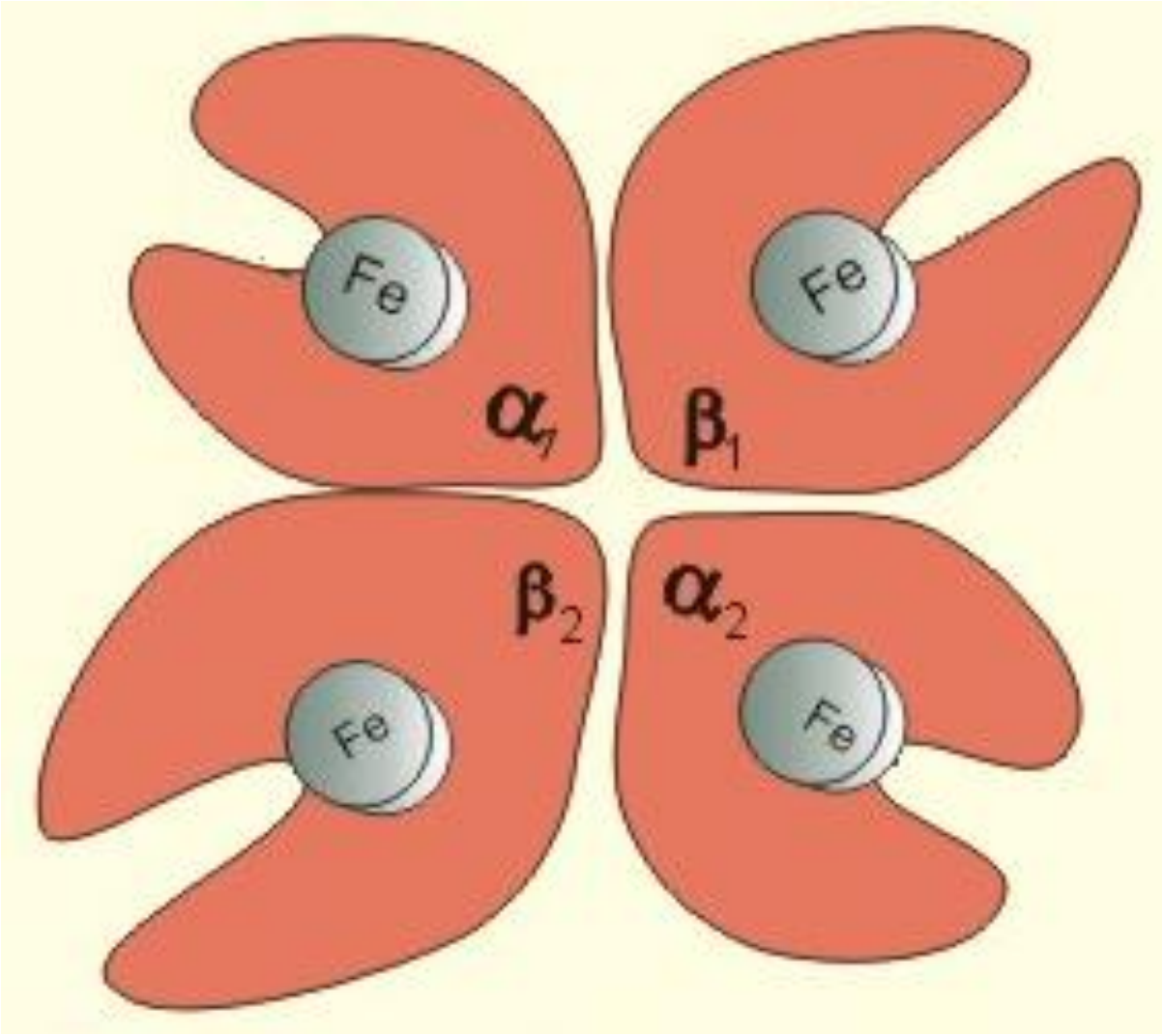

(a)
An injury to the lining of a blood vessel exposes collagen fibers; platelets adhere and become sticky.
Platelet
Red blood cell
Collagen fibers
Platelets release substances that cause the vessel to contract. Sticky platelets form a plug and initiate the formation of a fibrin clot.
Platelet plug
The fibrin clot seals the wound until the vessel wall heals.
Fibrin meshwork
Clotting factors
1. Released from platelets and injured tissue
2. Plasma proteins synthesized in liver and circulated in inactive form
Prothrombrin circulating in plasma
Thrombin
Fibrinogen circulating in plasma
Fibrin
(b)

HAEMOGLOBIN

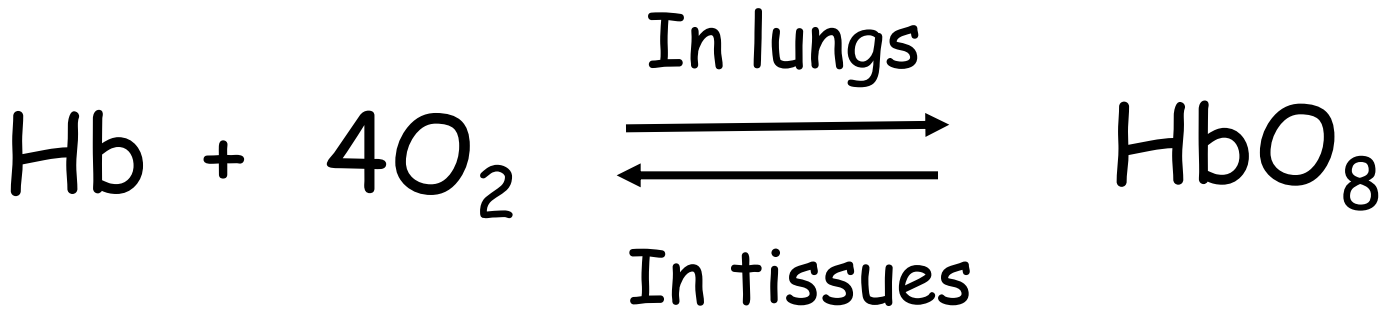
- Conjugated proteins consist of a protein molecule attached to another non-protein structure, called a prosthetic group.
- Haemoglobin is a **conjugated protein** made of
- 4 protein molecules (2 α, 2 β)
- and a prosthetic group **haem**.
- Haem contains **Fe^{2+}** (iron).
- Each Hb molecule contains 4 haem groups.
- Each RBC contains thousands of Hb molecules

HAEMOGLOBIN




Fe
Fe
α1
β1
β2
α2
Fe
Fe

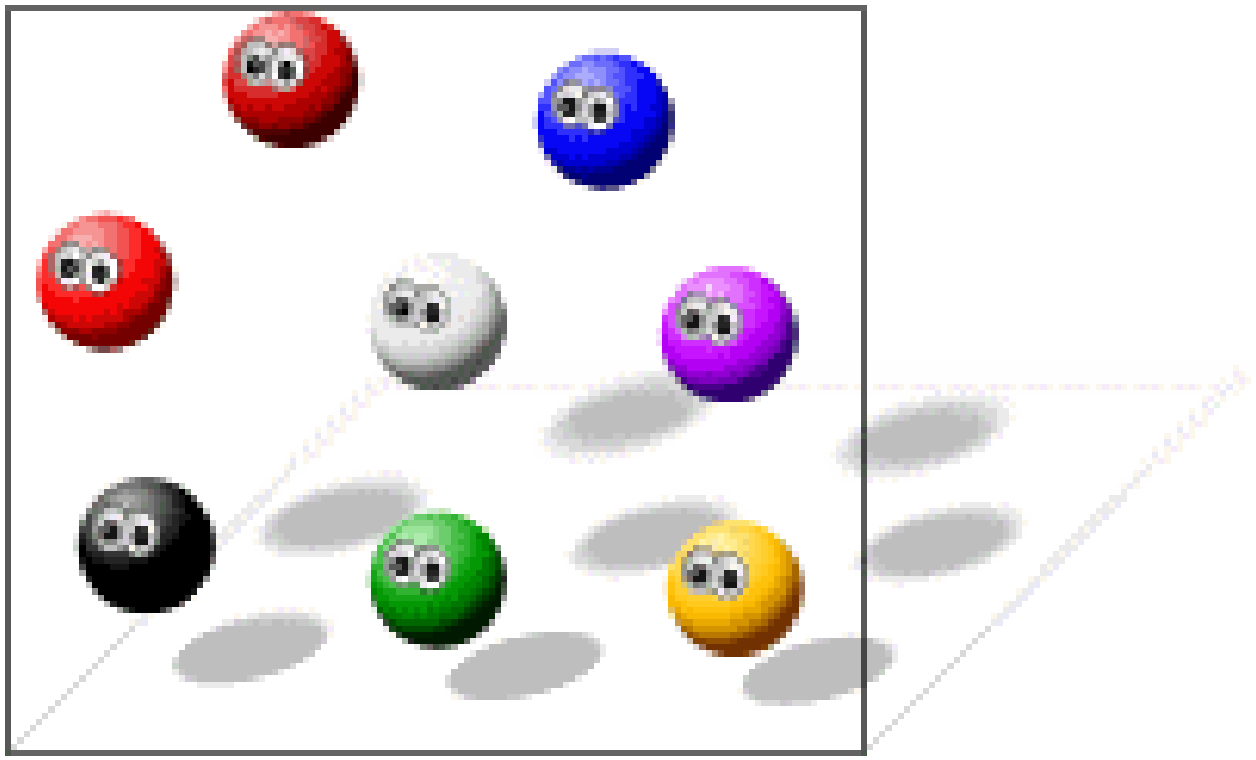
EQUATION



EACH HAEM GROUP CAN TRANSPORT 4 MOLECULES OF OXYGEN

Oxygen combines with haemoglobin to form oxyhaemoglobin

Partial pressure of gases



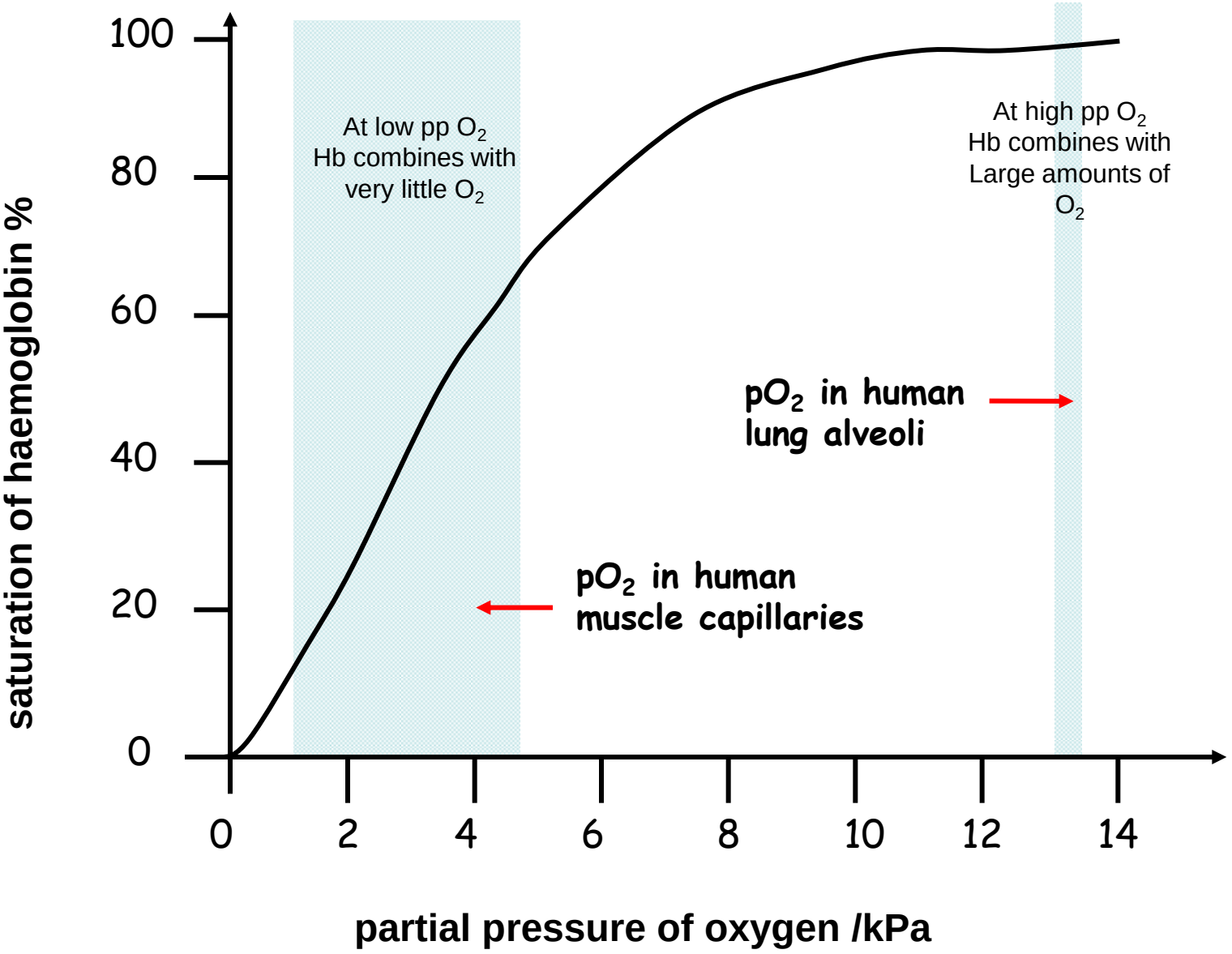
PARTIAL PRESSURE (pp)

- The pp of oxygen is the measure of oxygen concentration.
- Haemoglobin combines with oxygen at high oxygen partial pressures and becomes **saturated** (can't take up any more)
- This is called **oxygen association**. (Where does this happen?)
- RBCs carry oxygen as oxyhaemoglobin to the respiring tissues.
- Here the pp of O_2 is low at the respiring tissues . The oxyhaemoglobin breaks down releasing the oxygen for use in respiration. This is called **oxygen dissociation**.

OXYGEN DISSOCIATION CURVE

- This shows the percentage of Hb which is saturated with oxygen at different partial pressures of oxygen.

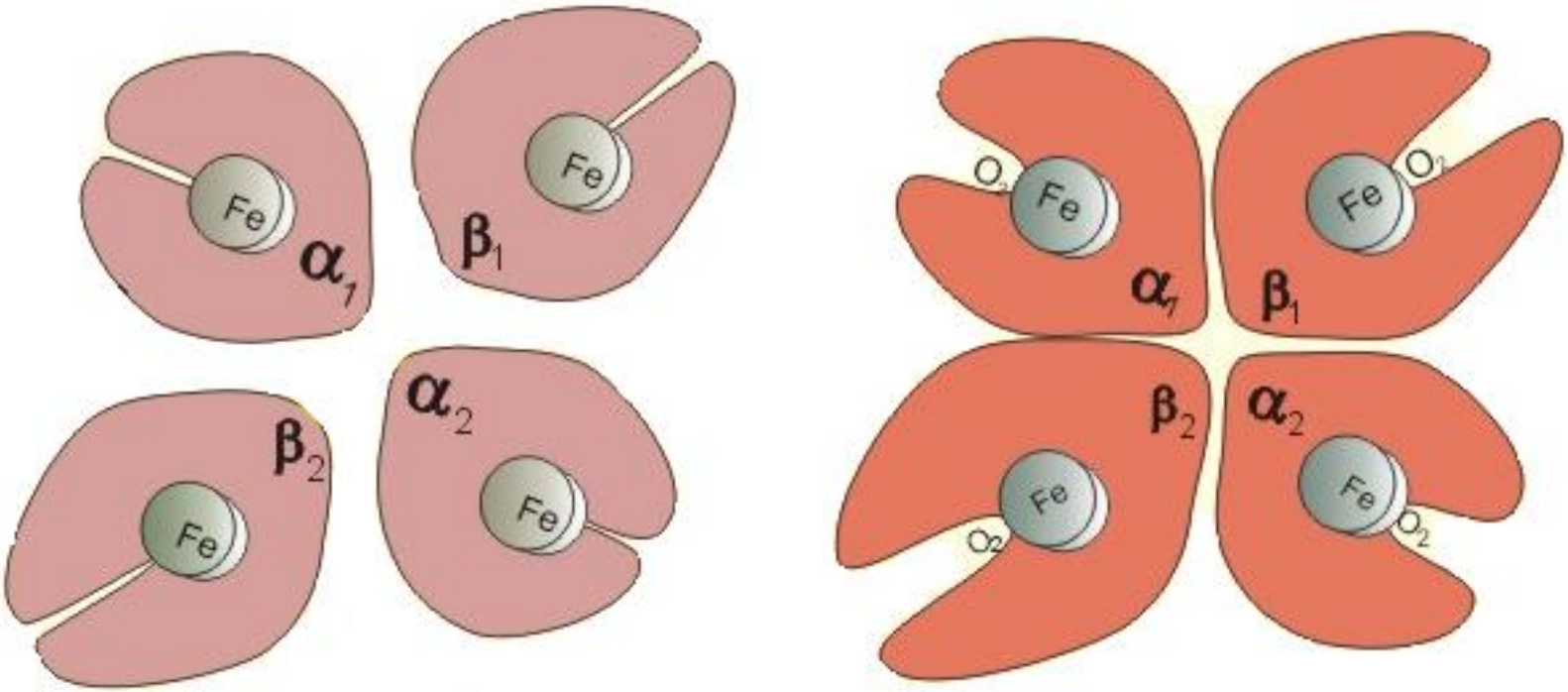
- The graph is sigmoidal / **S shaped**


saturation of haemoglobin %
100
80
60
40
20
0
0
2
4
6
8
10
12
14
partial pressure of oxygen /kPa
At low pp O_2
Hb combines with
very little O_2
At high pp O_2
Hb combines with
Large amounts of
O_2
pO_2 in human
lung alveoli
pO_2 in human
muscle capillaries

Why is the graph S shaped?

- When the first molecule of oxygen combines with the first haem group the haemoglobin changes shape. This makes it easier for the next and subsequent oxygen molecules to bind with other haem groups.

High O_2
partial pressure



Low O_2
partial pressure

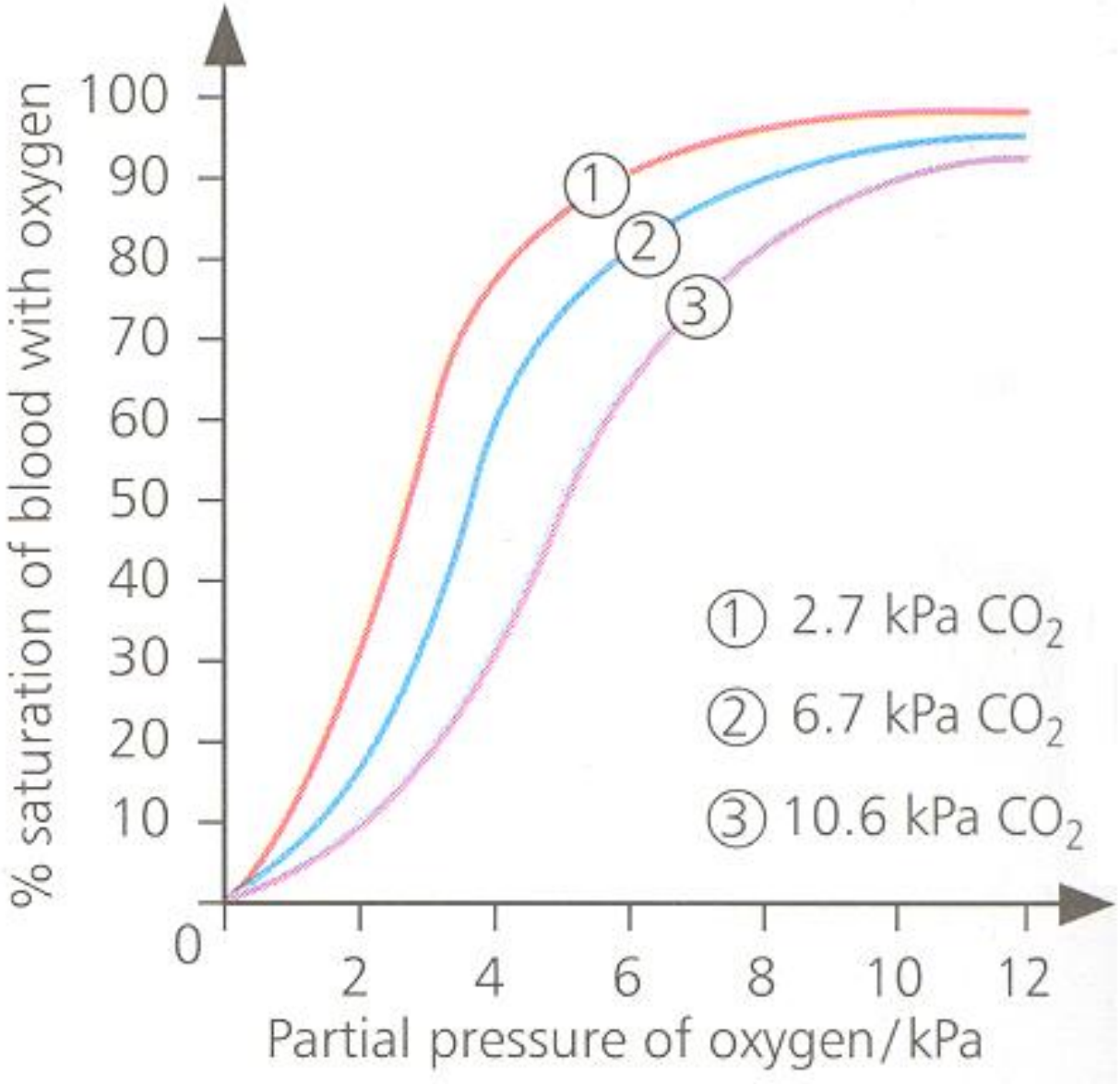
THE BOHR EFFECT

- The amount of oxygen carried by Hb depends not only on the pp of O_2 but also on the pp of CO_2 and temperature
- Oxygen does not combine as well with haemoglobin at high CO_2 pp and high temperatures
- Both increase the dissociation of oxygen from oxyHb

- Therefore during exercise when CO_2 production and temperature increases there will be a greater dissociation of oxygen from haemoglobin
- This provides more oxygen for respiration and energy release needed for exercise to continue.

NOTE

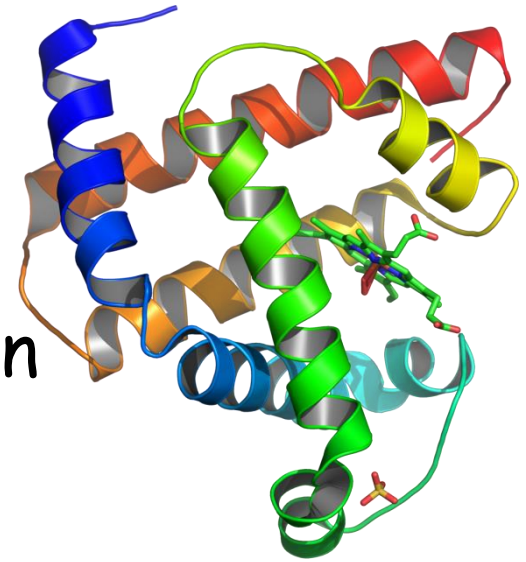
- Increased CO_2/temperature shifts the oxygen dissociation curve to the right.



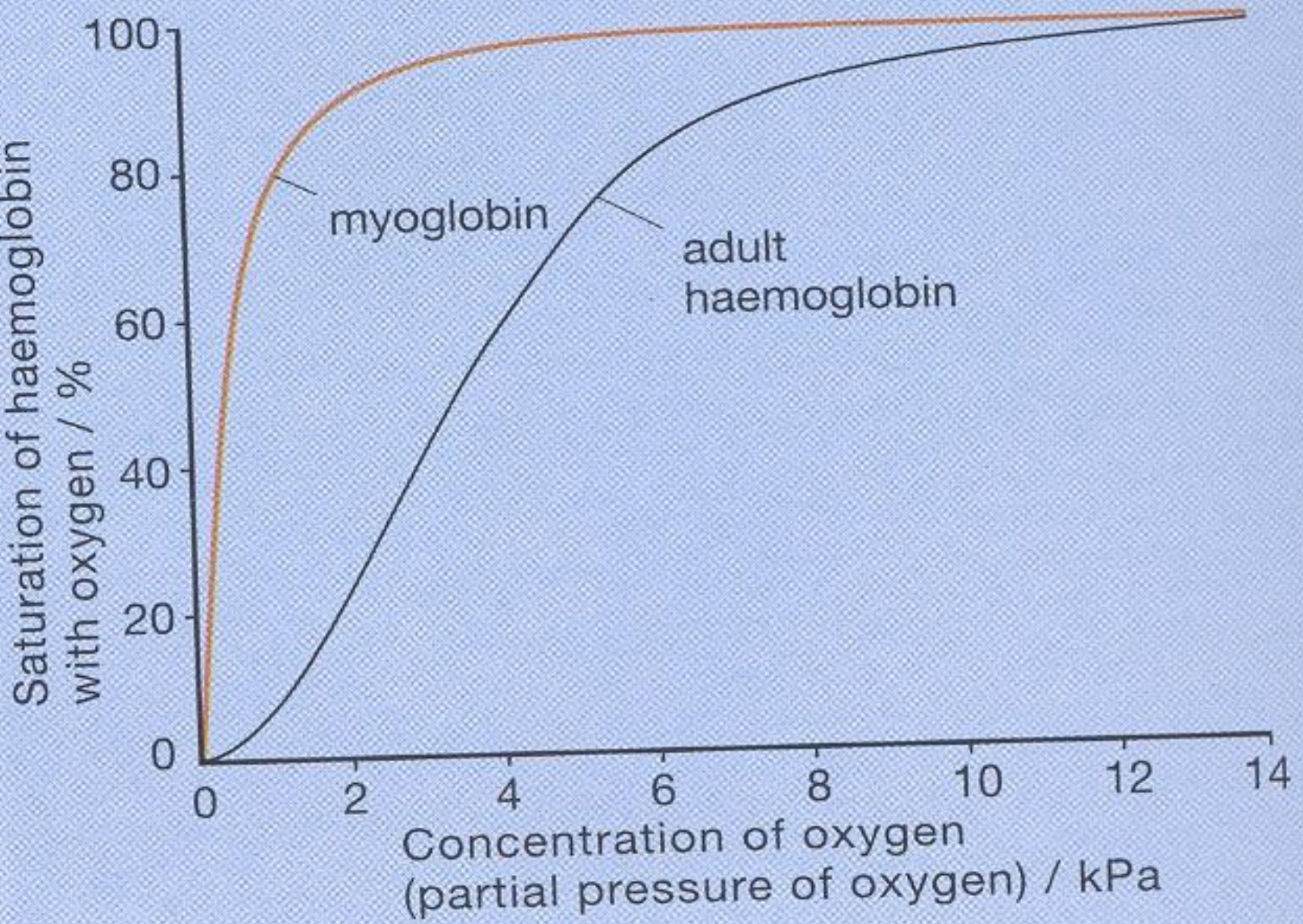
As the proportion of carbon dioxide increases, the Hb curves move downwards and to the right. This is known as the BOHR SHIFT

MYOGLOBIN

- Myoglobin is a dark red pigment found in muscle.
- It is not found in the blood and therefore has no role in oxygen **transport**.
- It has a greater affinity for oxygen than haemoglobin and becomes saturated at very low partial pressures of oxygen
- This enables it to act as an oxygen store because it only dissociates at very low pp of oxygen



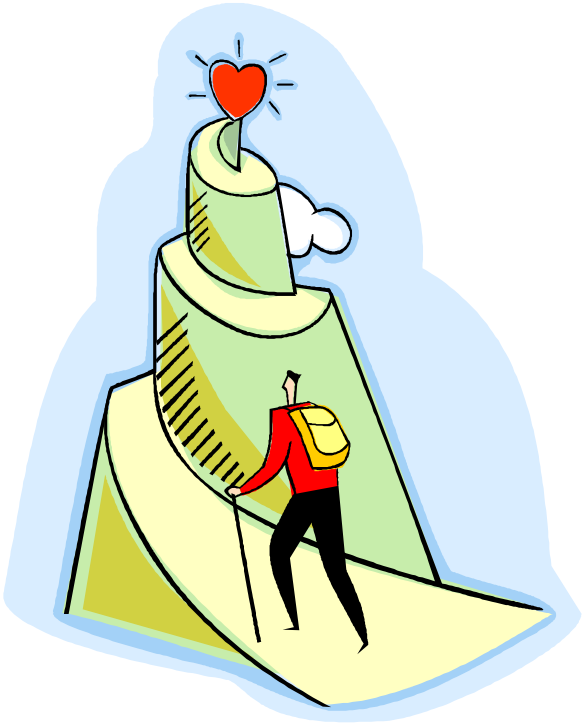
Myoglobin


100
80
60
40
20
0
Saturation of haemoglobin with oxygen / %
myoglobin
adult haemoglobin
0
2
4
6
8
10
12
14
Concentration of oxygen (partial pressure of oxygen) / kPa

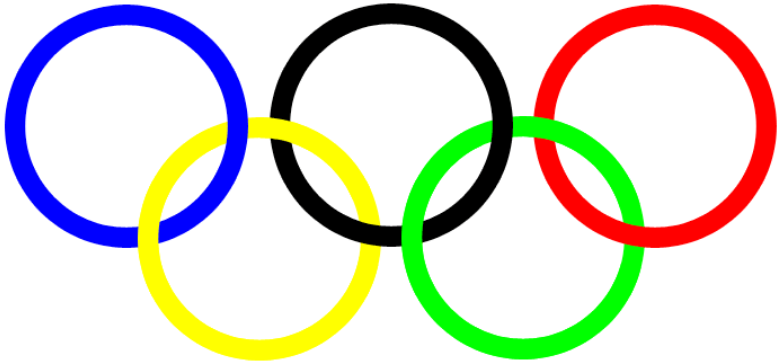
- Myoglobin does not give up its oxygen easily- it only releases oxygen when the oxygen levels in very active muscle tissue get extremely low and carbon dioxide levels are very high.
- This enables aerobic respiration to continue for longer and delays the onset of anaerobic respiration.

Effect of altitude on oxygen transport by haemoglobin

- At altitude there is lower pp of O_2 there will be less O_2 delivered to muscles.
- The Hb of people who live at high altitude saturates with oxygen at lower pp O_2 than the Hb of lower altitude dwellers.



- When the body of someone who lives at low altitude is exposed to altitude it responds by releasing RBCs stored in the spleen.
- It also increases the rate at which RBCs are formed.
- 1968 Olympics were held in Mexico City (high altitude)
- Athletes who normally live at high altitude did well and won many endurance races.
- Athletes who trained near sea level performed poorly.



- 1968 Olympics where in Mexico City (altitude).
- Athletes who normally lived at high altitude did well and won many endurance races e.g. 10,000 metres.
- Athletes who trained near sea level performed poorly.