Meccanismi funzionali di adattamento all’ambiente

UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA
1998 | 2023

Francesco Lodola
(francesco.lodola@unimib.it)

Meccanismi funzionali di adattamento all’ambiente

- ✓ 3 CFU (21h)

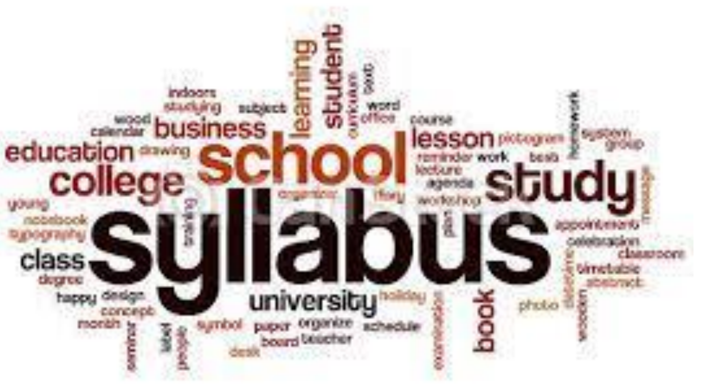
- ✓ Orario
  - Lunedì 10.30-12.30
  - Giovedì 8:30-10.30
  - Venerdì 10.30-12.30

- ✓ Francesco Lodola
  - francesco.lodola@unimib.it
  - 0264483228
  - BIOS, 3° piano, stanza 3014

- ✓ Testi consigliati
  - Willmer et al., Fisiologia ambientale degli animali, Zanichelli.
  - Randall et al., Fisiologia Animale, Zanichelli.
  - Sherwood et al., Fisiologia degli animali, Zanichelli.
  - Ladd-Prosser (ed.). Comparative Animal Physiology (2 voll.)
  - Schmidt-Nielsen. Animal Physiology.

- ✓ Esame: ORALE

Course outline



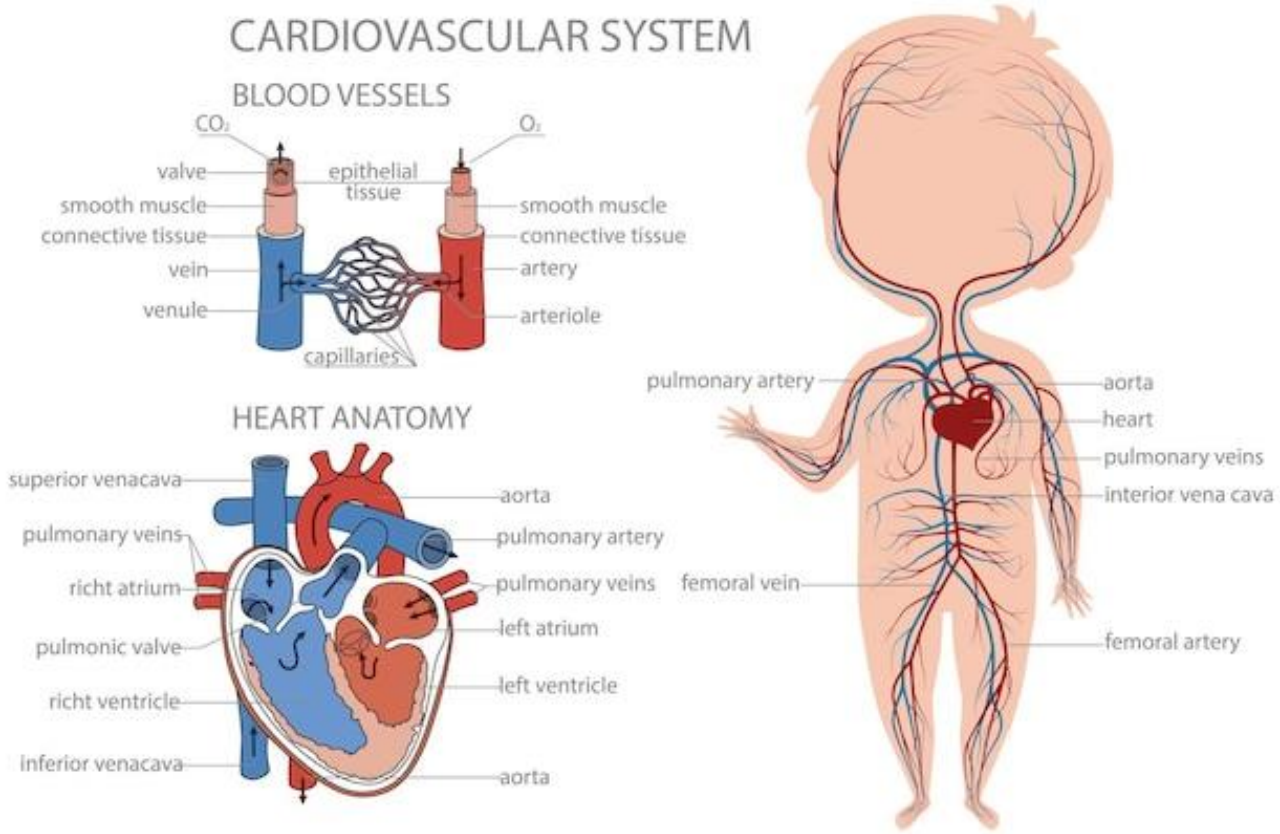
✓Circulatory system

✓Respiratory system

✓Osmoregulation and excretion

Circulatory system

Why is it called the 'circulatory system'?



Organs: Heart + vessels (these are considered to be tubular-like organs)

Functions: a pump that pushes blood around the body, delivering oxygen to respiring cells, vessels provide a transport system for blood ensuring one-way flow!

Circulatory systems have up to three distinct components: fluid, pump, and vessels

1. The fluid itself, which carries the transported molecules and cells; typically called blood or hemolymph

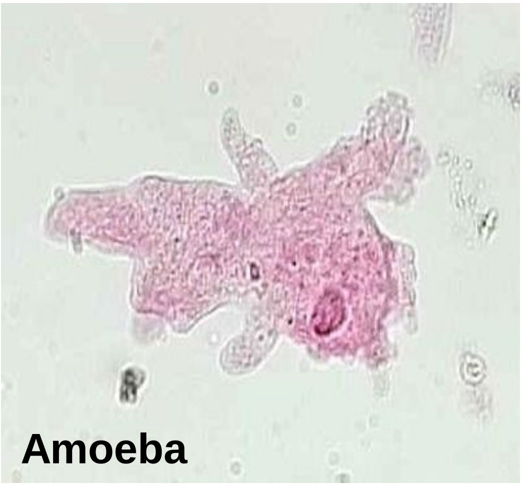
2. A pump to move the fluid; dedicated pumps are usually called hearts

3. Vascular component: vessels to carry the fluid between the pump and body tissues

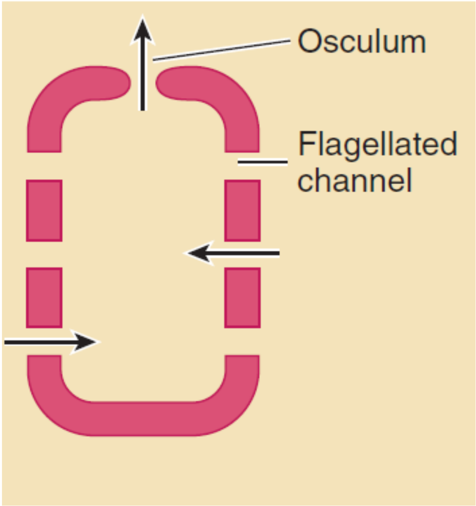
Trading Places

- Every organism must exchange materials with its environment
- Exchanges ultimately occur at the cellular level by crossing the plasma membrane
- In unicellular organisms, these exchanges occur directly with the environment

The circulatory system is used to transport nutrients and gases through the body. It varies from simple systems in invertebrates to more complex systems in vertebrates. Simple diffusion allows some water, nutrient, waste, and gas exchange into primitive animals that are only a few cell layers thick.



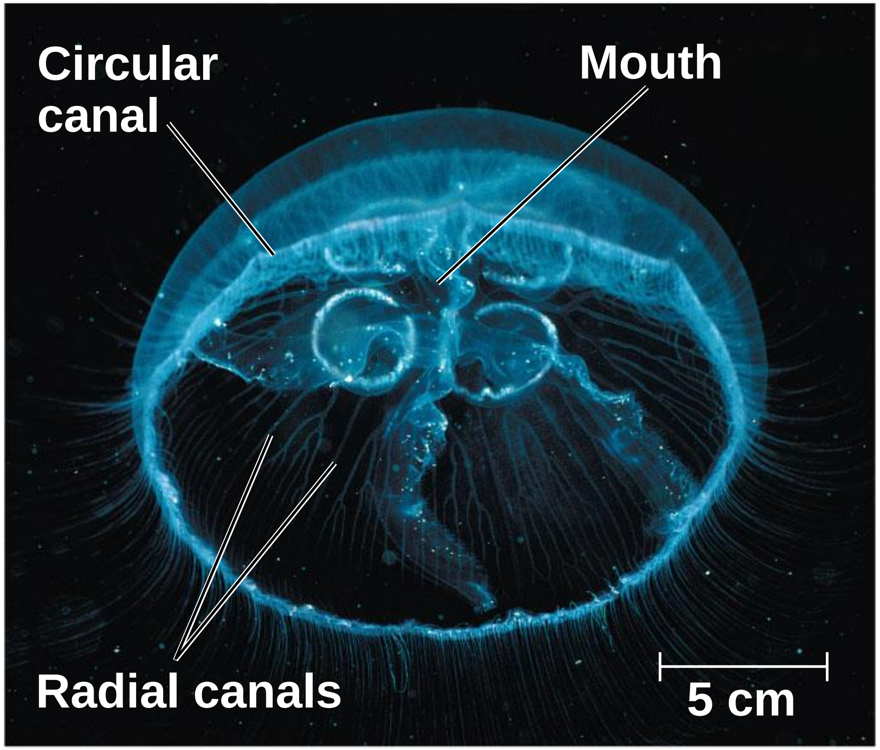
The simplest animals, such as the sponges (Porifera) and rotifers (Rotifera), do not need a circulatory system because diffusion allows adequate exchange of water, nutrients, and waste, as well as dissolved gases.



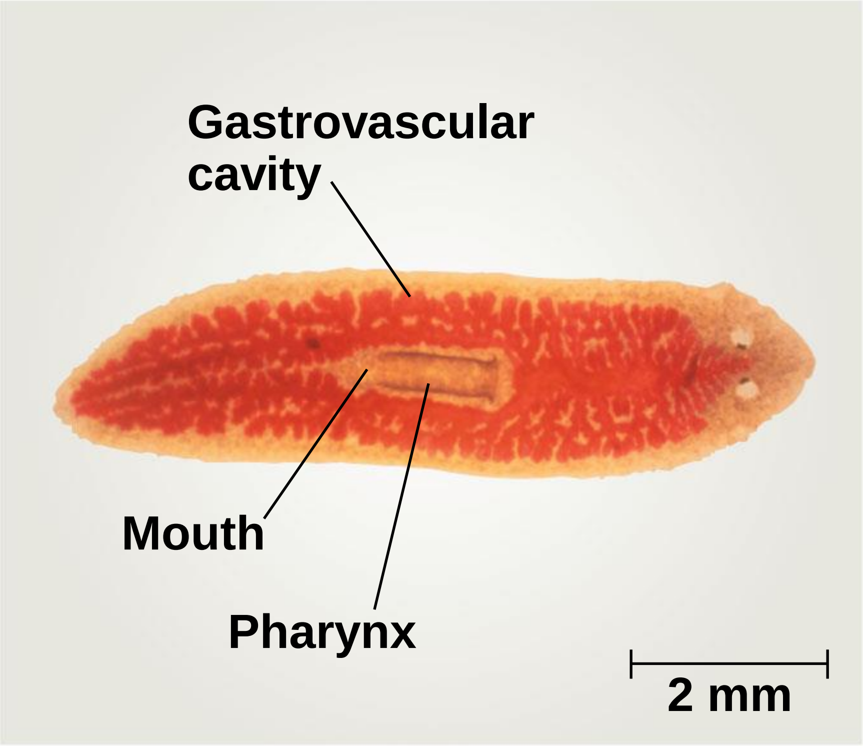
The simplest example is that of the water canal system of a sponge

Gastrovascular Cavities

- Some animals lack a circulatory system
- Some cnidarians, such as jellies, have elaborate gastrovascular cavities
- A gastrovascular cavity functions in both digestion and distribution of substances throughout the body
- The body wall that encloses the gastrovascular cavity is only two cells thick
- Flatworms have a gastrovascular cavity and a large surface area to volume ratio

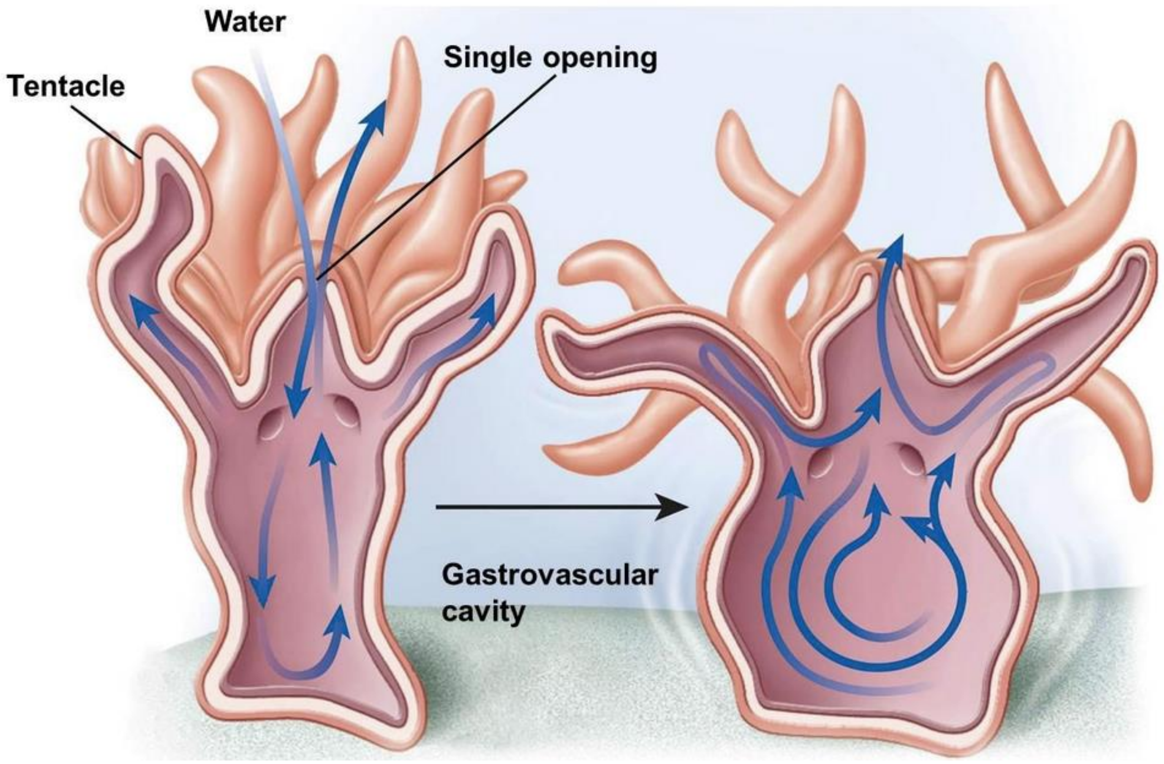


The moon jelly *Aurelia*, a cnidarian

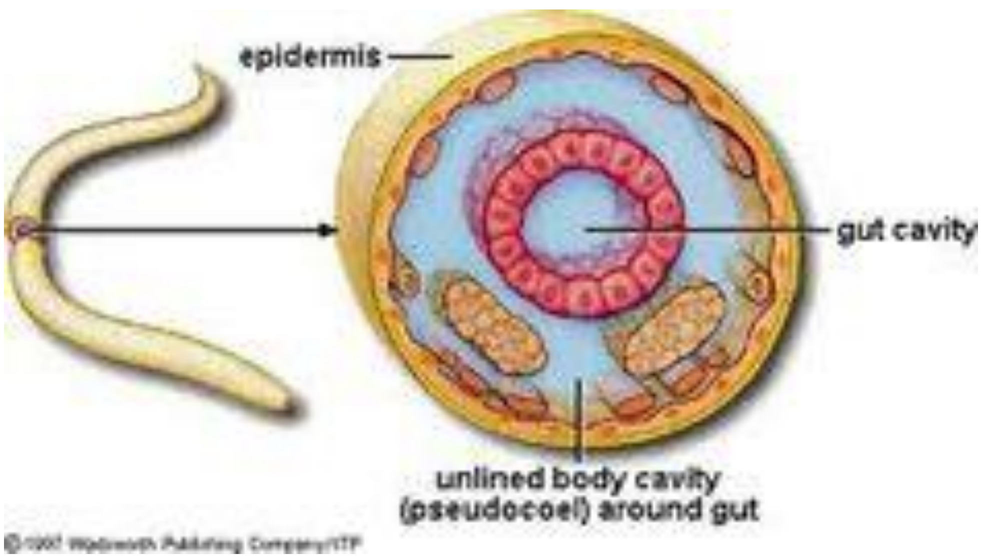


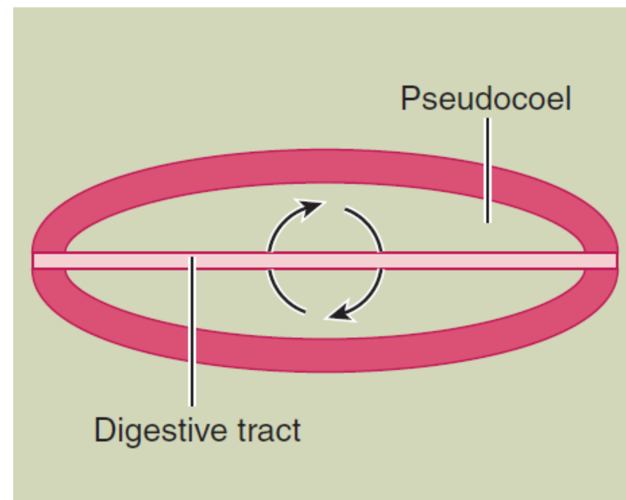
The planarian *Dugesia*, a flatworm

Organisms that are more complex but still only have two layers of cells in their body plan, such as jellies (Cnidaria) and comb jellies (Ctenophora) also use diffusion through their epidermis and internally through the gastrovascular compartment. Both their internal and external tissues are bathed in an aqueous environment and exchange fluids by diffusion on both sides. Exchange of fluids is assisted by the pulsing of the jellyfish body.



Small animals with an internal fluid-filled body cavity, such as nematodes (roundworms), may move materials through body motions that simply move the internal fluid.





Circulatory systems link exchange surfaces with cells throughout the body

- Diffusion time is proportional to the square of the distance
- Diffusion is only efficient over small distances
- Therefore, cells must either be small in size, as in the case of many prokaryotes, or be flattened, as with many single-celled eukaryotes. In small and/or thin animals, cells can exchange materials directly with the surrounding medium
- In most animals, cells exchange materials with the environment via a fluid-filled circulatory system.

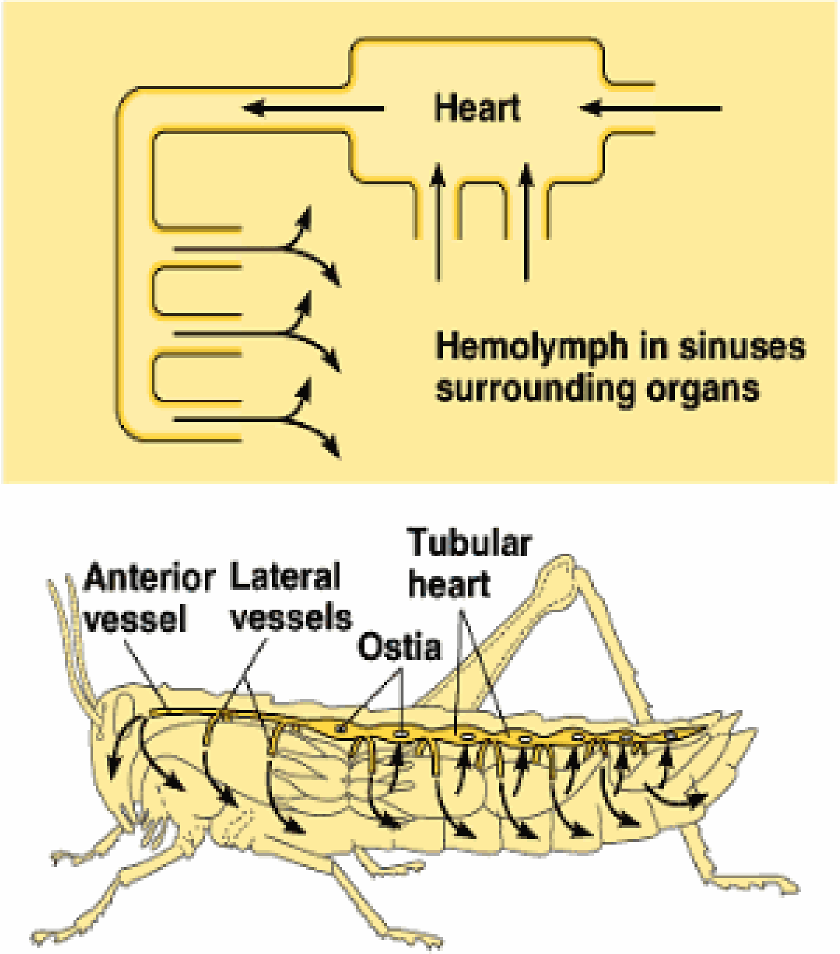
- Animals evolved thicker and larger bodies and higher metabolic rates → the need for internal circulatory systems became paramount because of diffusion limits.

- For most cells making up multicellular organisms, direct exchange with the environment is not possible
- Traditionally, internal circulation of fluids is divided into two broad categories:
  1. Open circulatory systems
  2. Closed circulatory systems

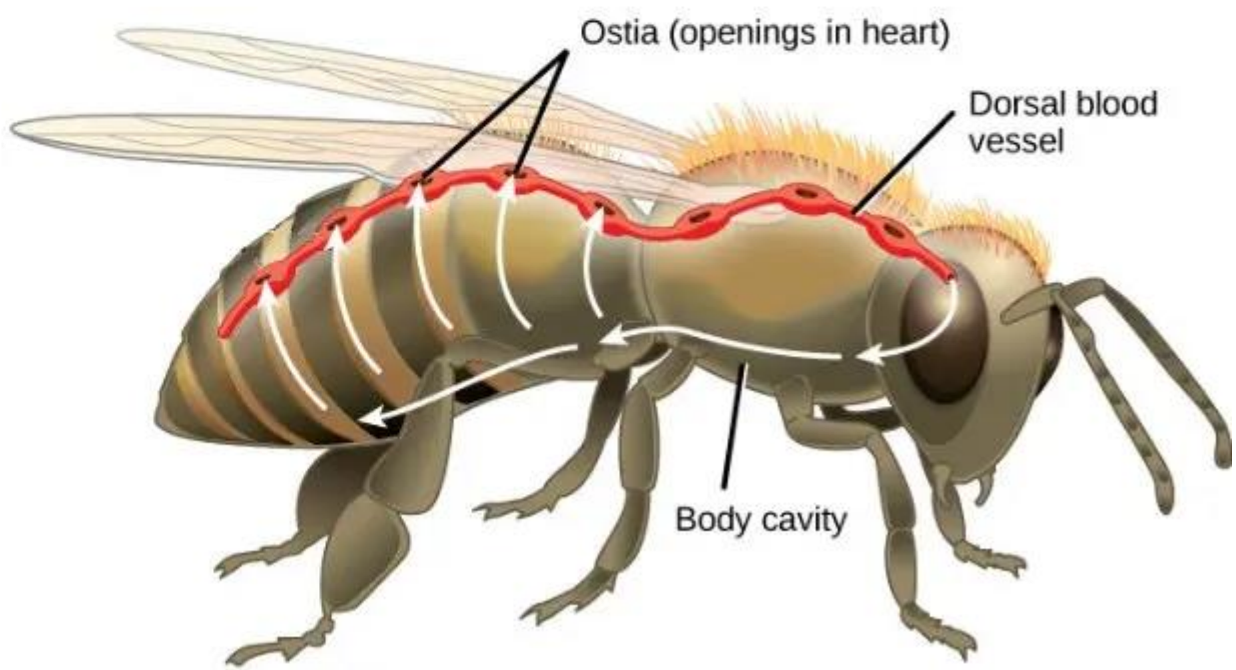
Open circulatory systems

- ✓ Open circulatory systems are systems where blood, rather than being sealed tight in arteries and veins, suffuses the body and may be directly open to the environment at places such as the digestive tract.
- ✓ Instead of a complex and closed system of veins and arteries, organisms with open circulatory systems have a “hemocoel.” This is a central body cavity found inside most invertebrate animals where both digestive and circulatory functions are performed. This hemocoel may have “arteries” through which the blood can reach tissues – but these arteries are not closed and do not circulate blood as quickly as closed, muscle-assisted arteries.

Most arthropods and many mollusks have open circulatory systems.



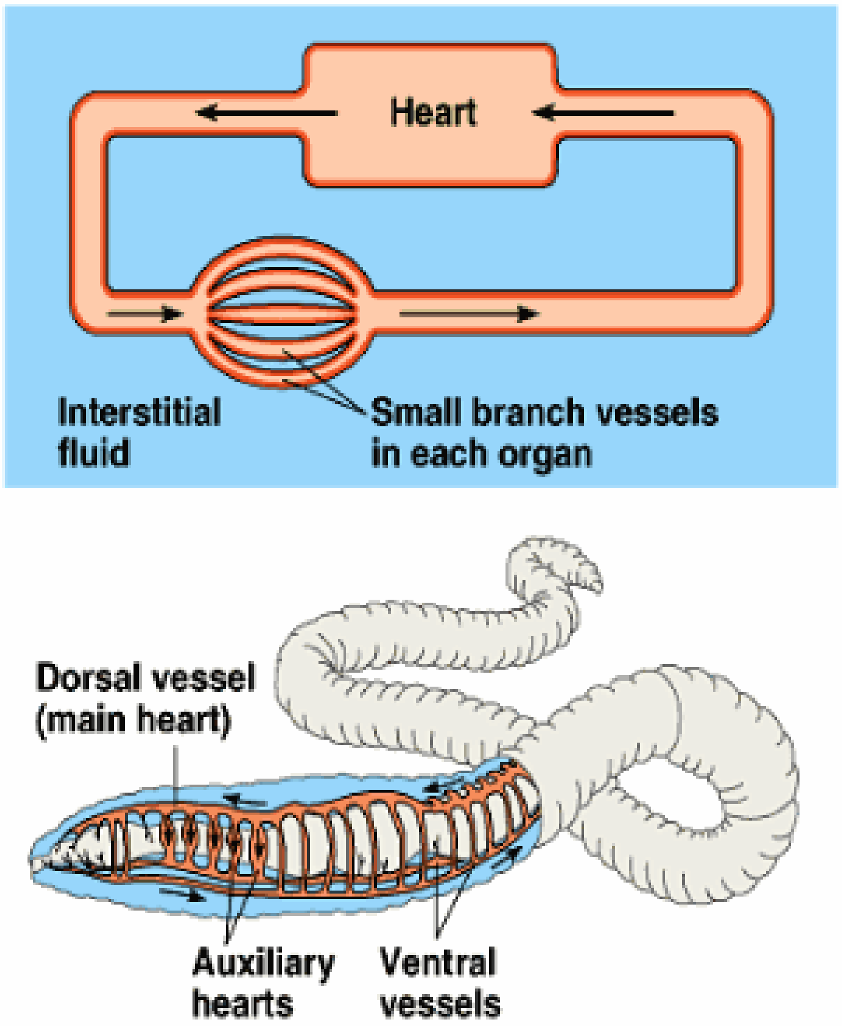
(a) Open circulatory system



L'emolinfa non è deputata generalmente al trasporto di gas, anche se in taluni gruppi possono essere presenti dei pigmenti respiratori. Essa è costituita da emociti, coinvolti nell'immunità e nella coagulazione, e plasma, una soluzione acquosa di ioni e molecole biologiche di varia natura, tra cui prodotti di scarto del metabolismo e molecole deterrenti per i predatori.

Nell'emolinfa di insetti adattati ai climi freddi possono essere presenti dei carboidrati (glicerolo e sorbitolo) che ne abbassano la temperatura di congelamento. Essa fornisce poi sostegno di natura idrostatica al corpo dell'insetto.

Closed circulatory systems are a characteristic of vertebrates

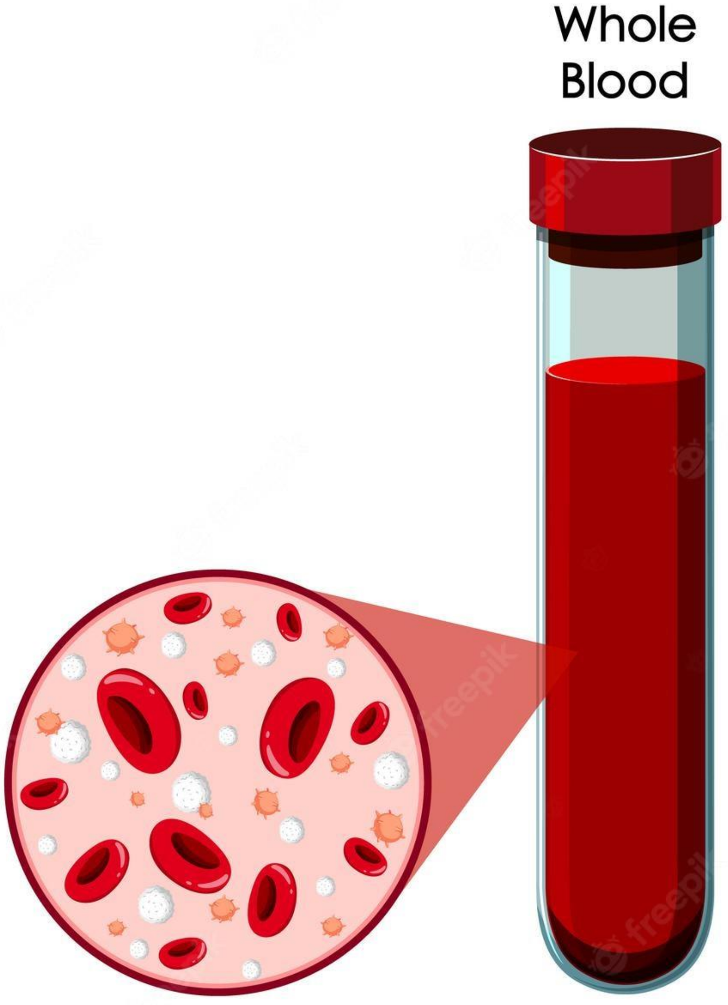


(b) Closed circulatory system

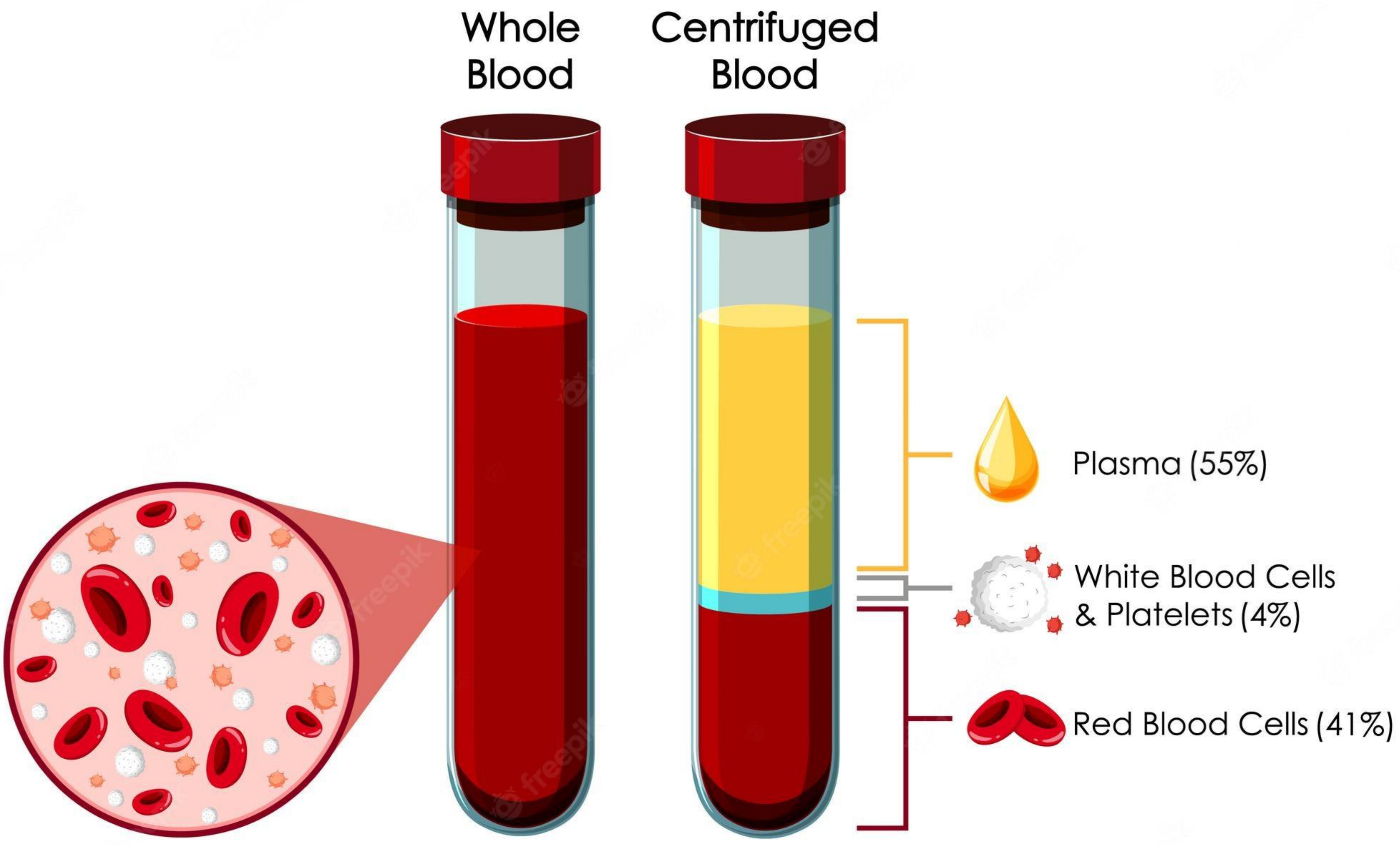
In a **closed circulatory system**, blood is contained inside blood vessels and circulates unidirectionally from the heart around the systemic circulatory route, then returns to the heart again.


A bloody investigation

COMPOSITION OF BLOOD



COMPOSITION OF BLOOD



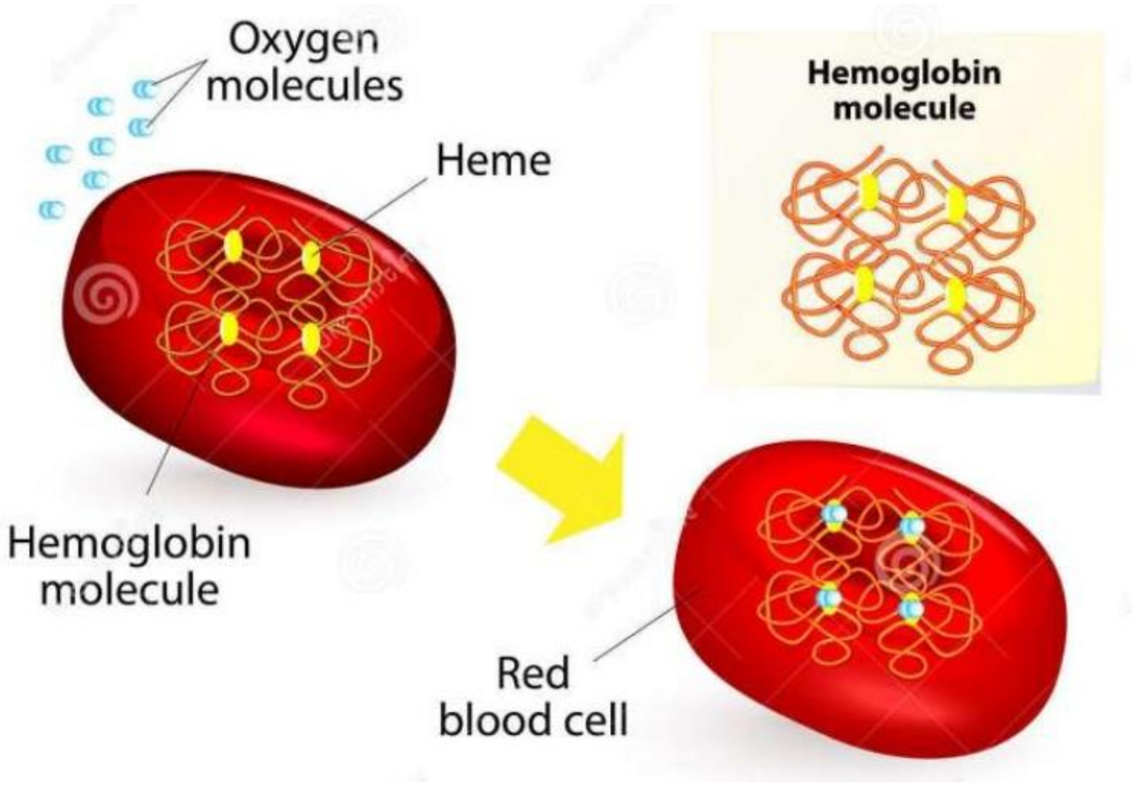
Red Blood Cells

Carry oxygen from the lungs to the tissues for respiration

- In mammals, biconcave disc shape increases surface area
- No nucleus
- Contains haemoglobin, which binds to oxygen to form oxyhaemoglobin

Haemoglobin + Oxygen ⟶ Oxyhaemoglobin

Haemoglobin + Oxygen → Oxyhaemoglobin



The mammalian red cell's small size and shape is thought to aid O2 transport by:

1) providing a larger surface area for diffusion of O2 across the membrane than would a spherical cell of the same volume

2) enabling O2 to diffuse rapidly between the exterior and innermost regions of the cell due to its thinness;

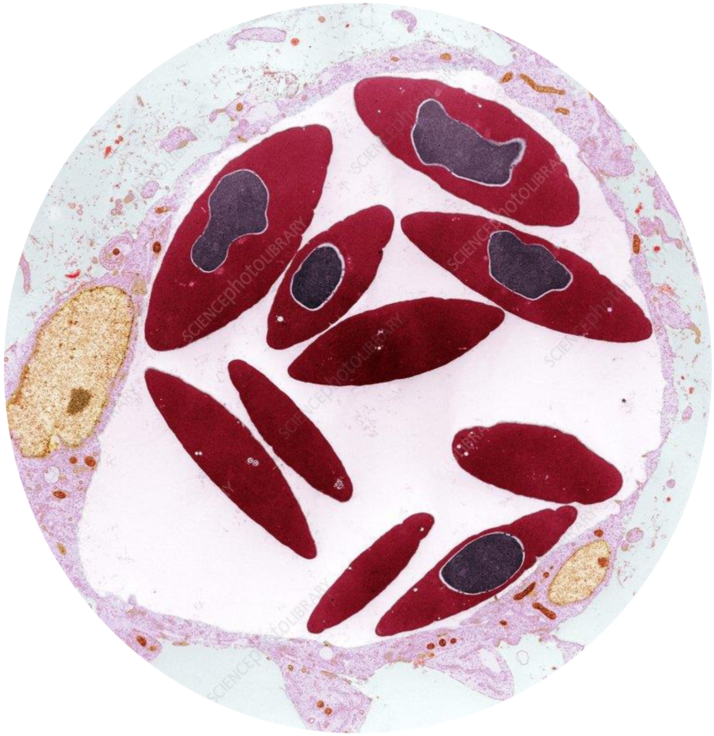
3) having more room for hemoglobin due to the lack of a nucleus;

4) allowing the cell to squeeze through mammalian capillaries, which are the narrowest among all vertebrates (this narrowness presumably evolved to support the high metabolism of mammals).

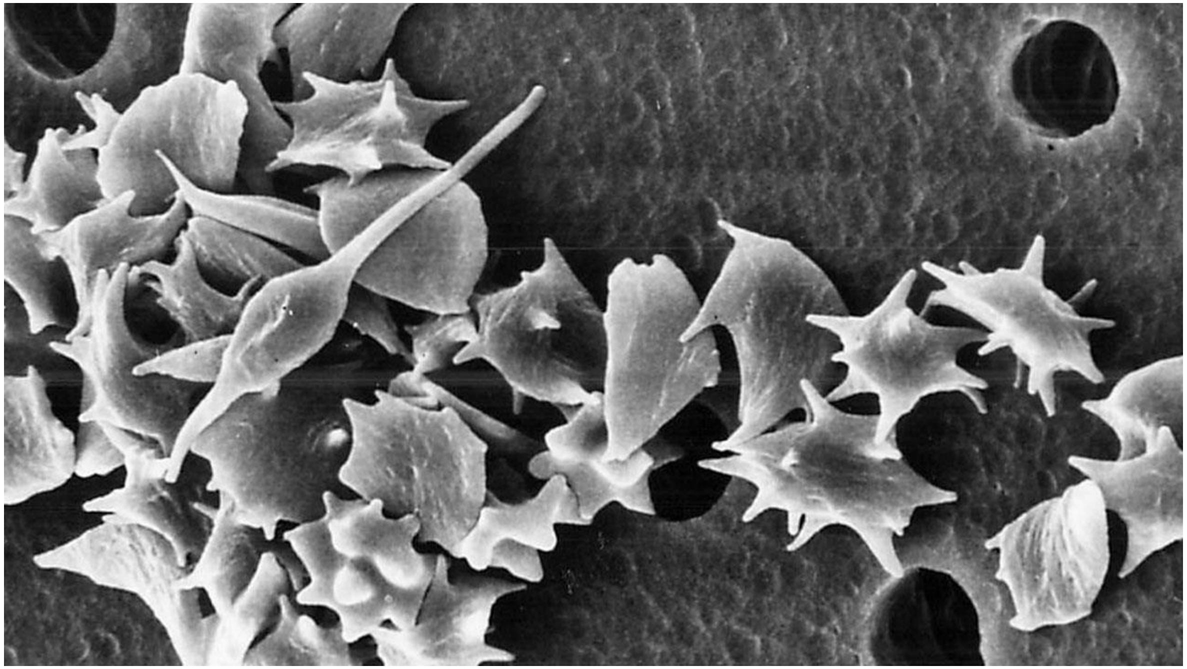
The cells, each with a diameter of 6 µm, can deform amazingly without rupturing as they squeeze single file through capillaries as narrow as 3 µm in diameter.

In other vertebrates, erythrocytes are at lower densities, have a larger ovoid shape, and keep their nuclei, although in aging birds the red cells become progressively condensed (and unused).

In birds, which typically have higher oxygen requirements than mammals, have ovoid red cells twice the diameter of mammalian ones. Correspondingly, bird capillaries, though smaller than those of most vertebrates, are twice as wide as mammals’. Yet oxygen delivery obviously functions quite well in birds.

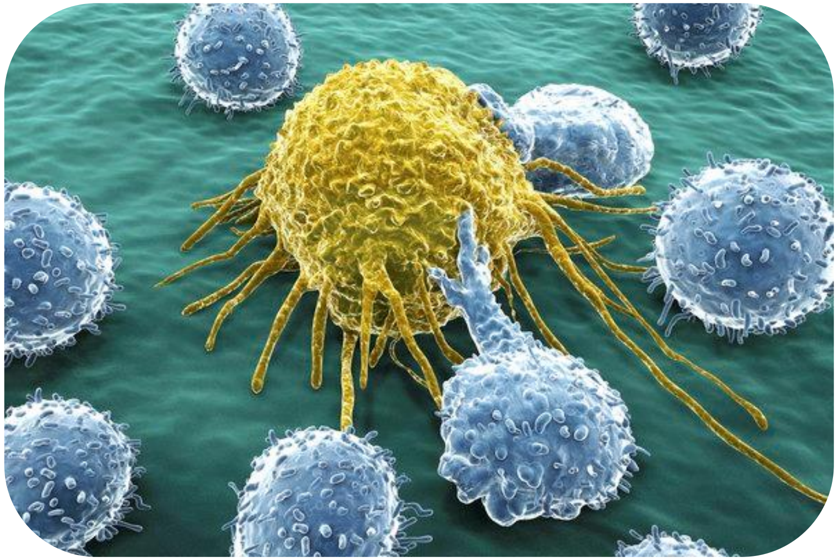


170-year-old mystery solved: Why deer have deformed blood cells just like some people



Nat Ecol Evol. 2018 February ; 2(2): 367–376. doi:10.1038/s41559-017-0420-3.

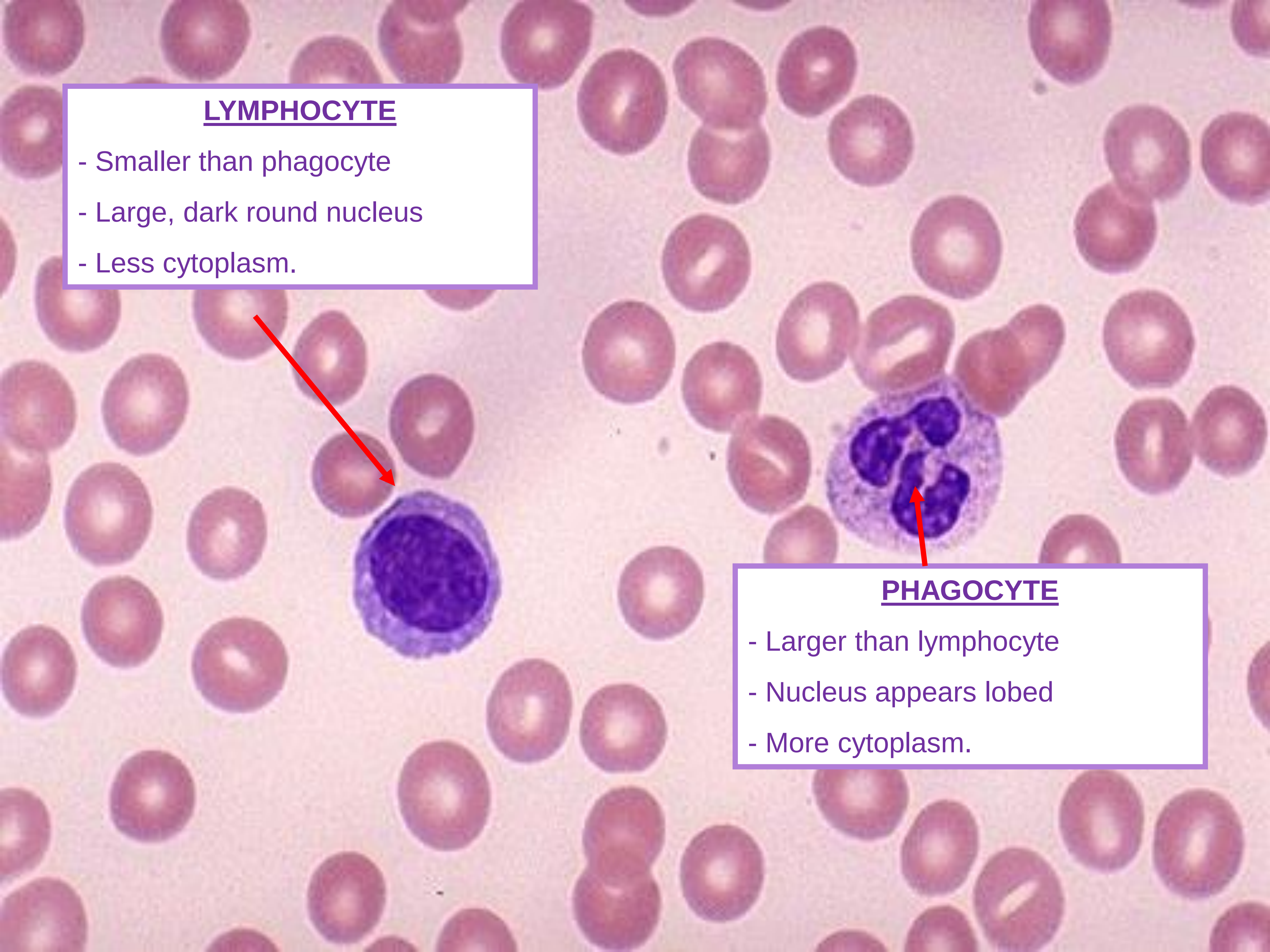
White blood cells



- Larger than red cells, but fewer of them, no fixed shape
- Many different types, which respond to different antigens on the surface of pathogens (molecules that trigger the immune system):

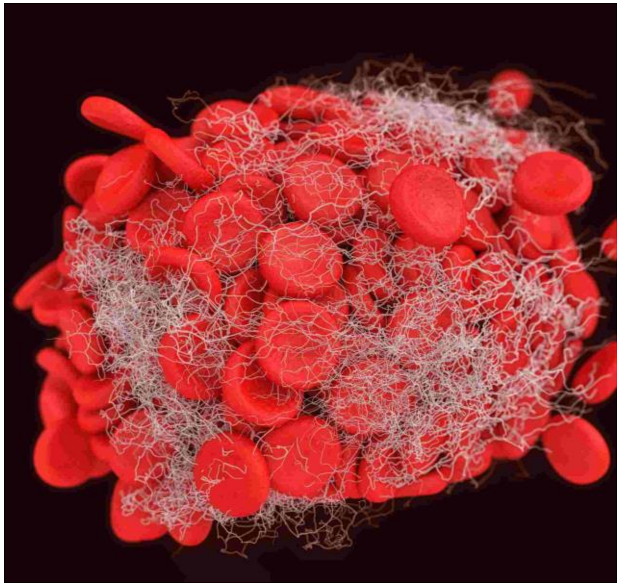
✓ **phagocytes**, which engulf pathogens and digest them

✓ **lymphocytes**, which are made by lymph glands, and are involved in antibody production when fighting infection

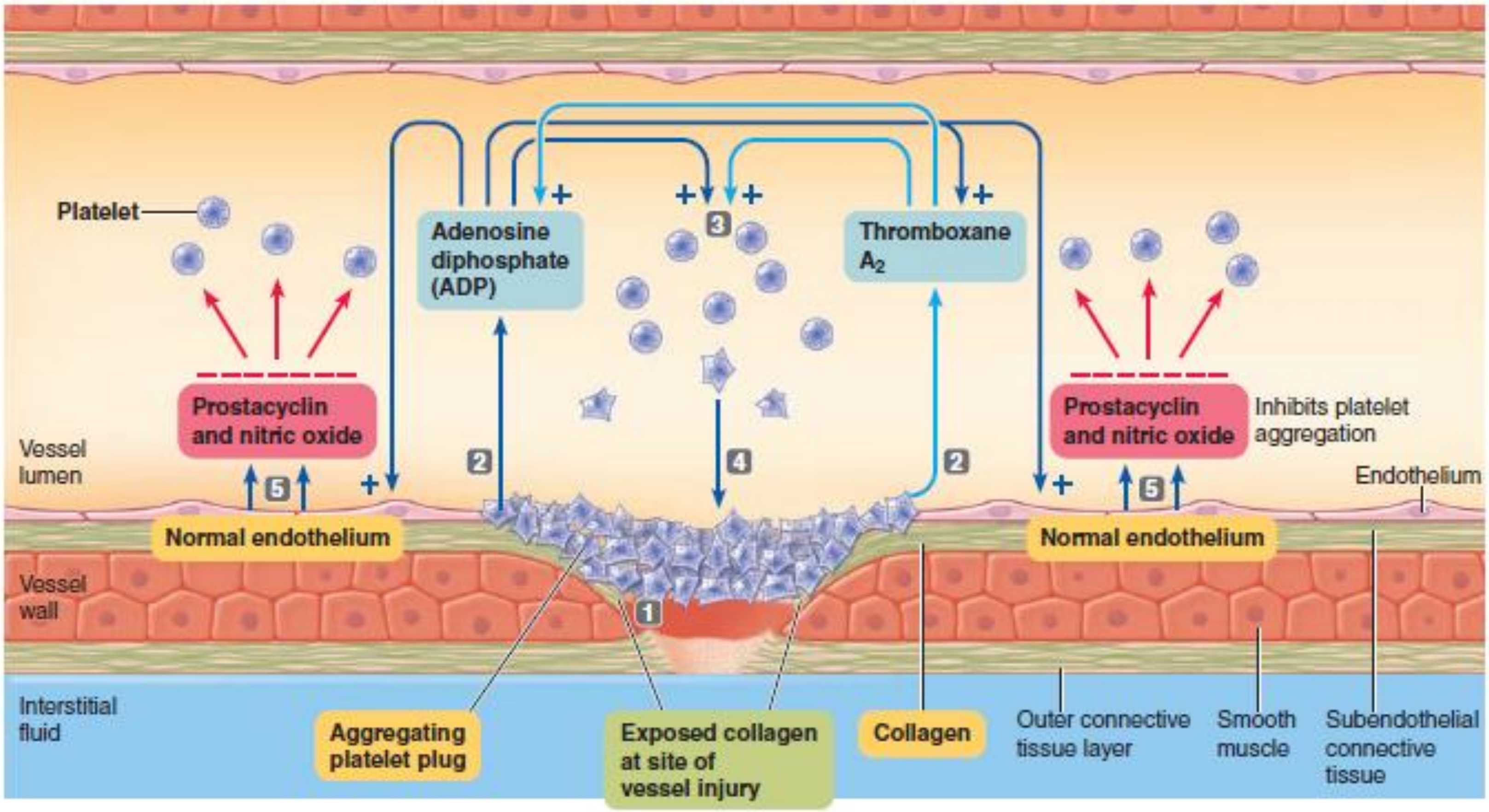

LYMPHOCYTE
- Smaller than phagocyte
- Large, dark round nucleus
- Less cytoplasm.
PHAGOCYTE
- Larger than lymphocyte
- Nucleus appears lobed
- More cytoplasm.

Thrombocytes and platelets

- Thrombocytes are cells found in all vertebrates except mammals; these cells circulate in an inactive state, and when activated by an injury to nearby tissue, they begin to break up into platelet-like fragments.
- Platelets are involved in the clotting process
- Help prevent blood loss, but also the entry of pathogens when blood vessels are damaged
- Use Ca^{2+} to convert the soluble protein **fibrinogen** into the insoluble protein **fibrin** – it is this which forms the mesh/clot



Formation of a platelet plug



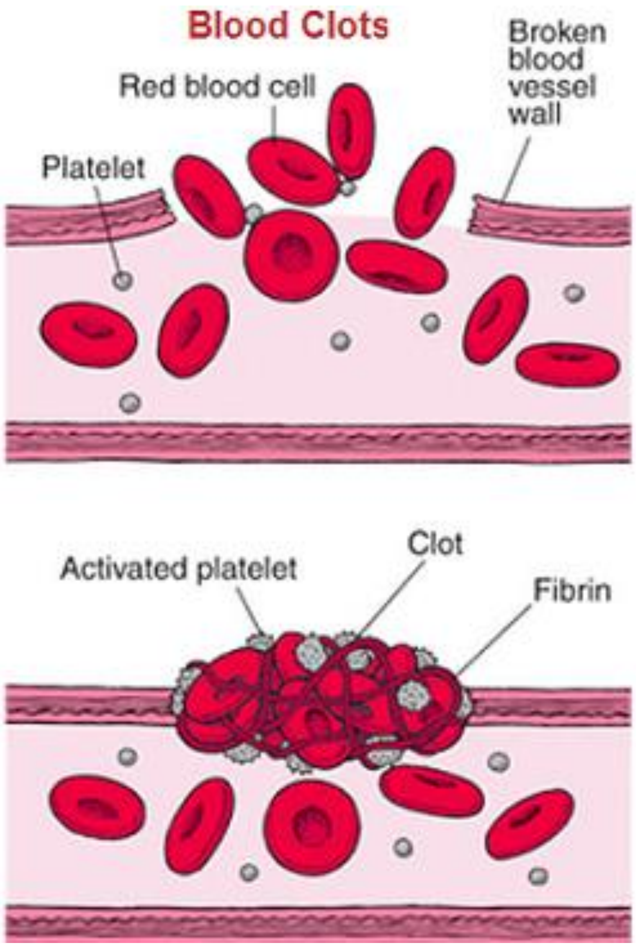
1 Platelets adhere to and are activated by exposed collagen at the site of vessel injury.

2 Activated platelets release ADP and thromboxane A_2.

3 These chemical messengers work together to activate other platelets passing by.

4 Newly activated platelets aggregate onto growing platelet plug and release even more platelet-attracting chemicals.

5 Normal (uninjured) endothelium releases prostacyclin and nitric oxide, which inhibit platelet aggregation, so platelet plug is confined to site of injury.


Blood Clots
Red blood cell
Broken blood vessel wall
Platelet
Activated platelet
Clot
Fibrin

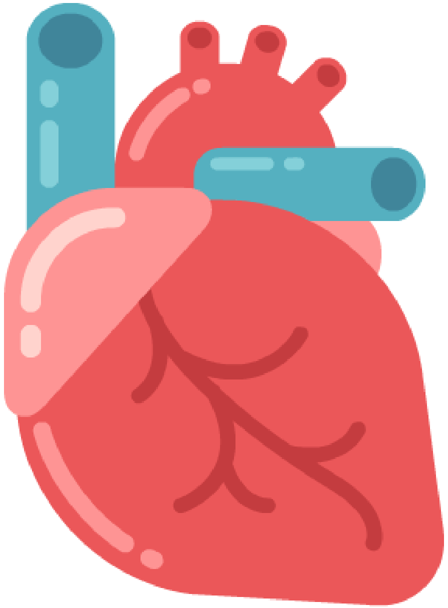
There are certain animals whose survival depends on thwarting hemostasis

These are the external parasites and predators that latch onto the outer surface of another (usually larger) animal and suck its blood as a source of nutrition.

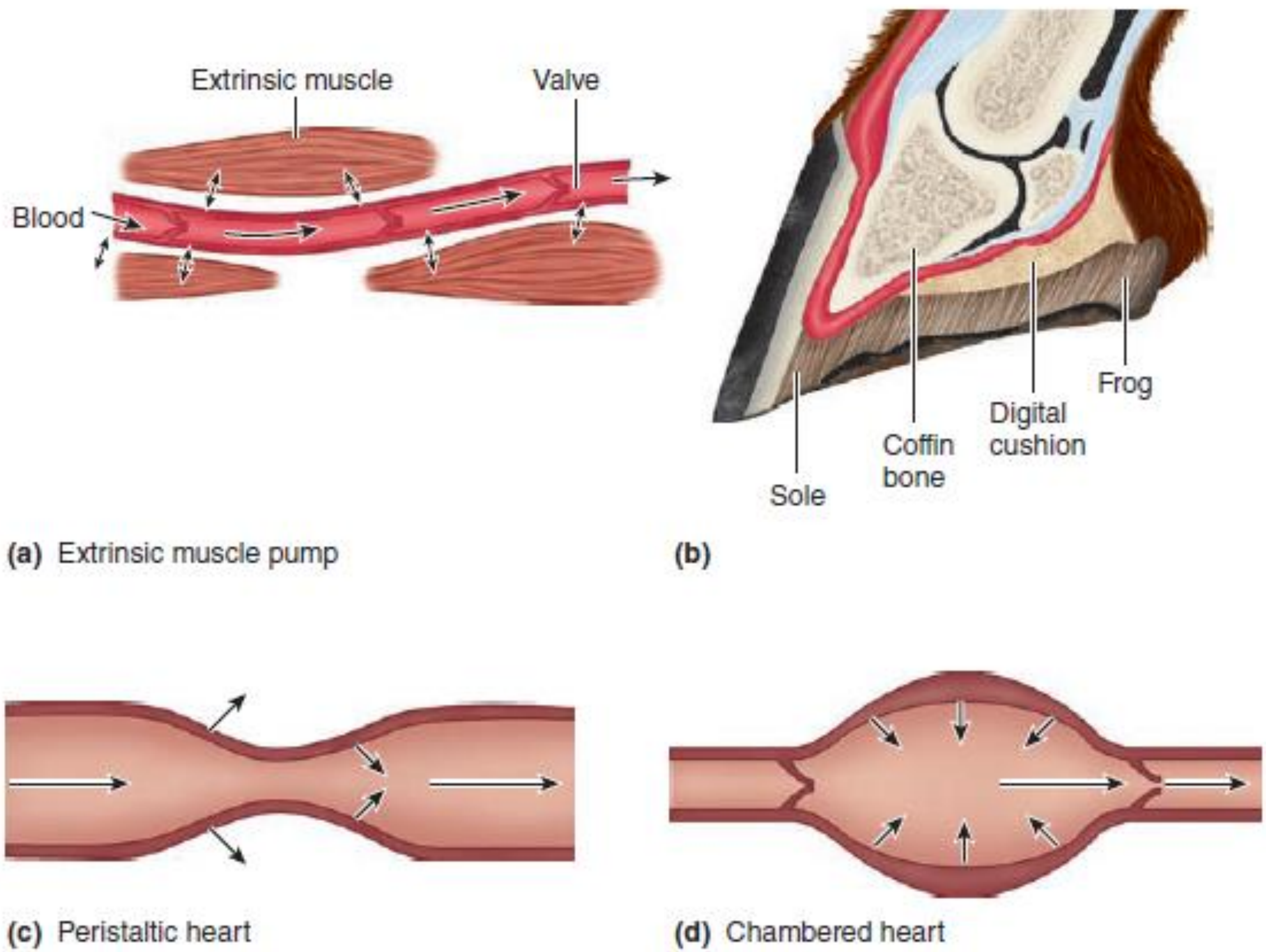
Example: Draculin, a glycoprotein isolated from vampire bat (Desmodus rotundus) saliva, is a natural anticoagulant which inhibits specific activated coagulation factors.

Thromb Haemost 1995; 73(01): 094-100, DOI: 10.1055/s-0038-1653731

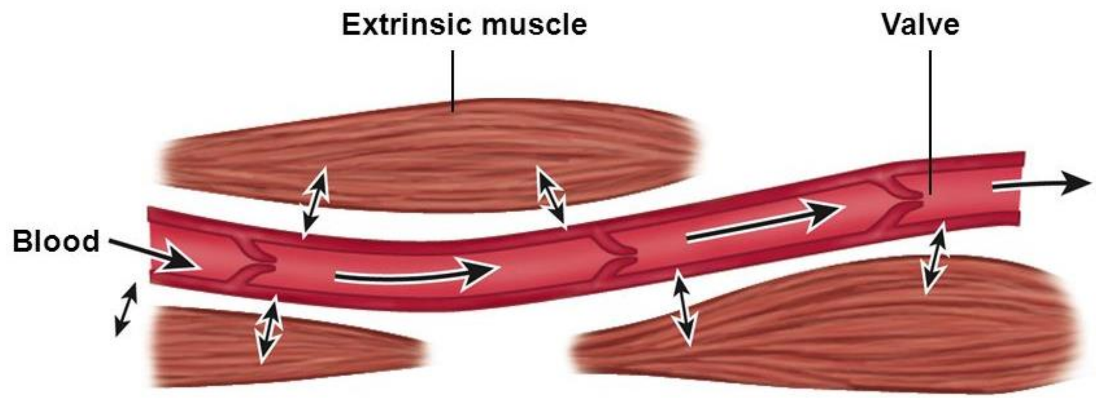
Circulatory pumps



Types of pumps in the animals, evolution



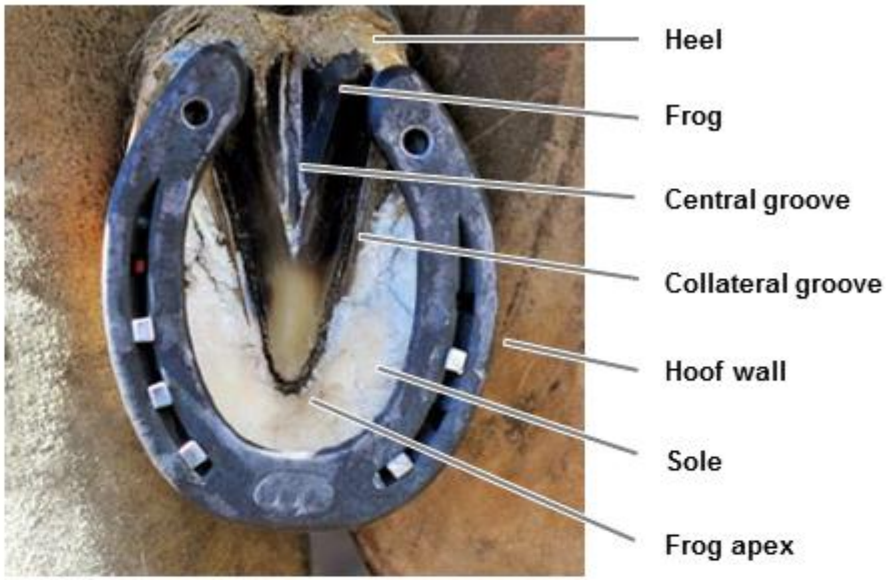
External muscle pump

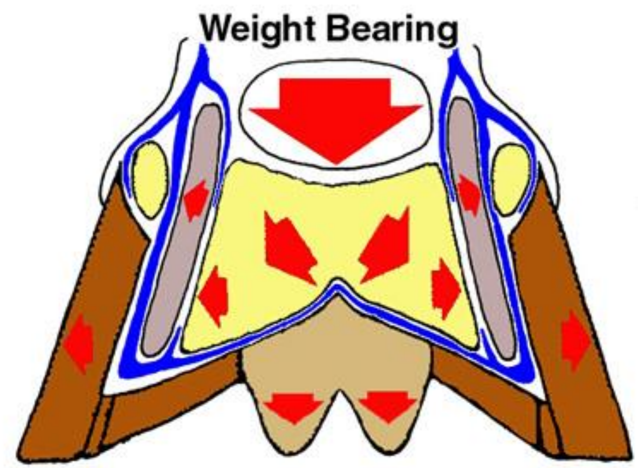


(a) Extrinsic muscle pump

External muscle pump expands and compresses a blood vessel (black arrows) and forces blood to flow along the vessel (colored arrows); valves maintain a unidirectional flow, e.g., nematode, scaphopod mollusk, and some leeches with no heart to propel blood flow, and the skeletal muscle pump of vertebrates.

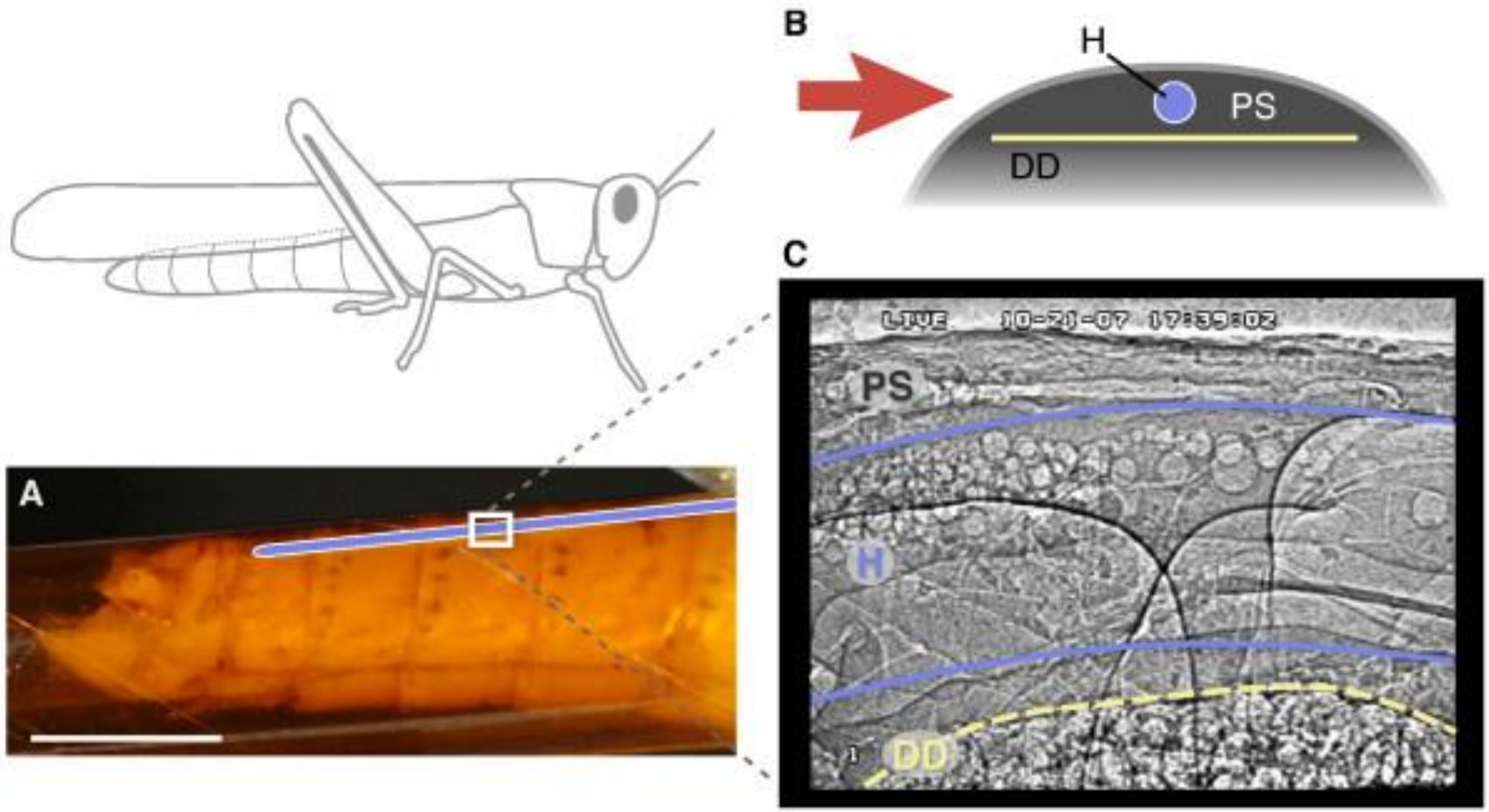
The cartilaginous "frog"





Blood is pumped from the heart through arteries to the hoof and is assisted in its return through a "pumping mechanism" in the hoof. This mechanism is necessary due to the position of the hoof in relation to the heart. There are no muscles in the lower leg or hoof to aid in the return of venous blood to the heart. Thus, the hoof has to pump venous blood back to the heart.

Peristaltic heart



Peristaltic tubular heart forces blood along a vessel (which may have valves to ensure one-way flow) by peristaltic contractions, e.g., insect heart.

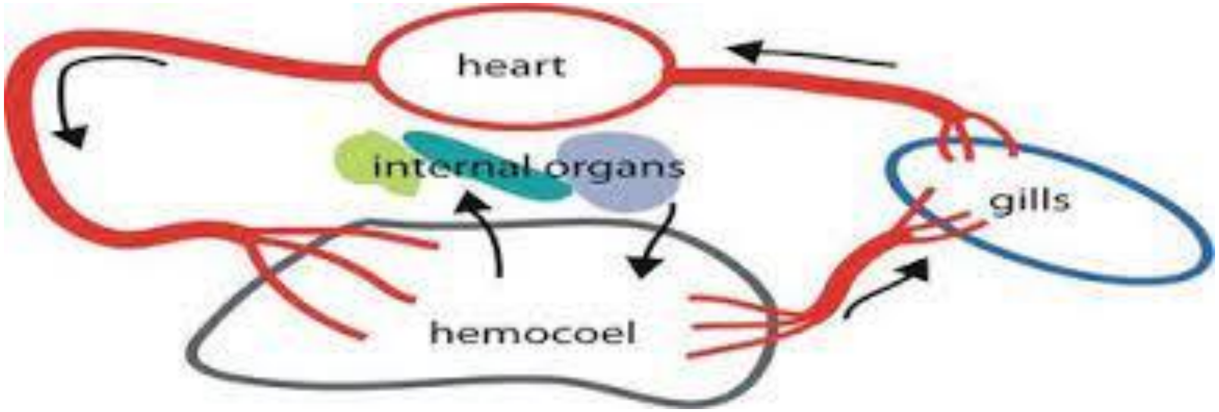
DID YOU KNOW?

Paul Yancey

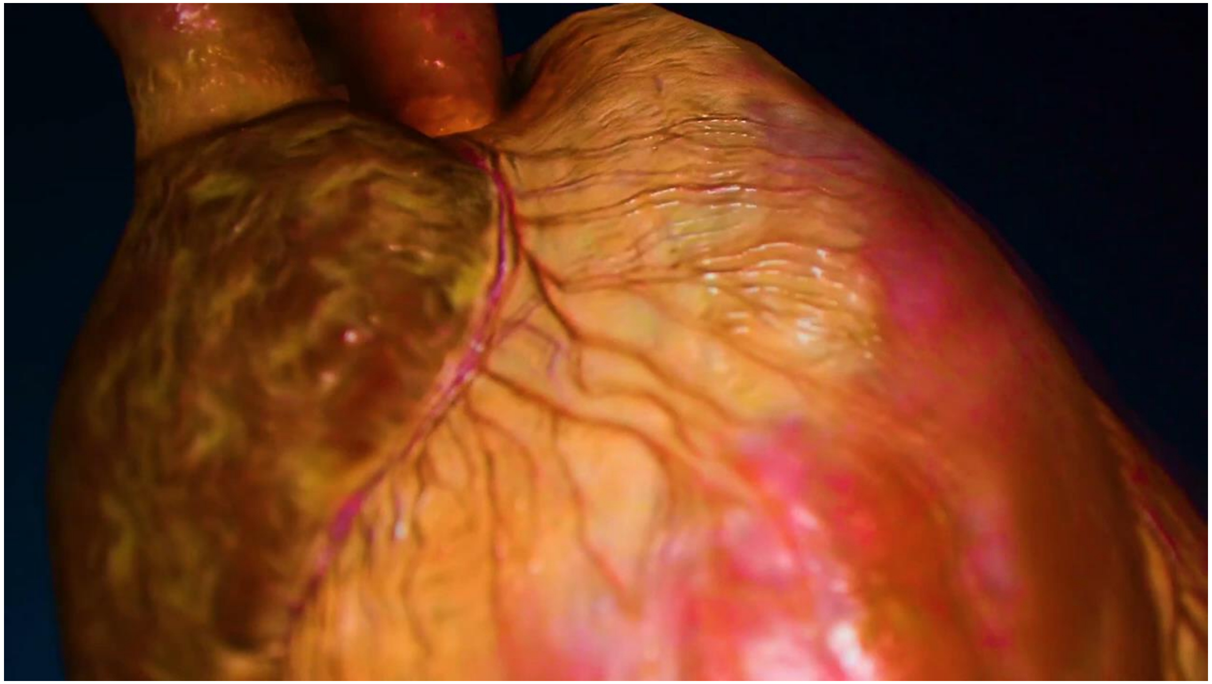
A grasshopper has a heart with an open circulatory system, but its main heart stops pumping when the animal is moving. This is because movements of the body wall and limbs are sufficient to pump the blood during locomotion.

Chambered heart

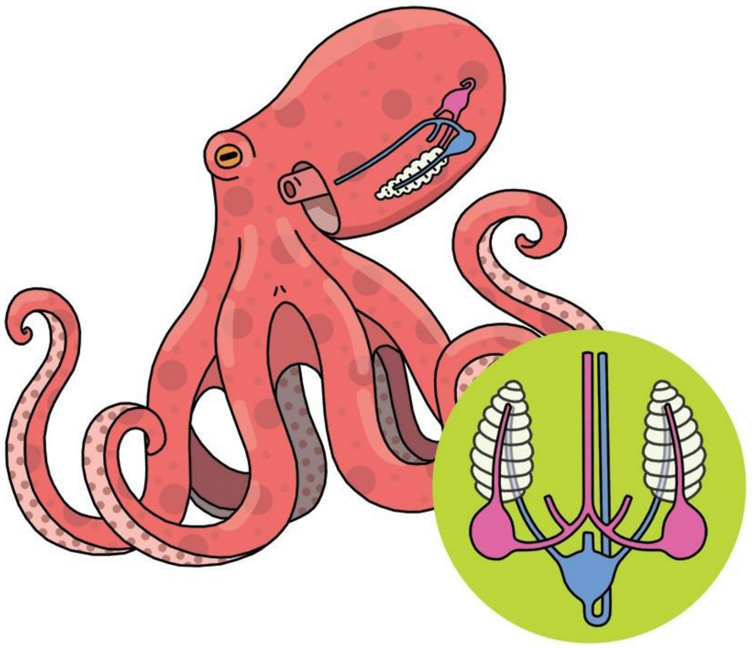
Chambered hearts with valves and relatively thick muscular walls are less commonly found in invertebrates but do occur in some mollusks, especially cephalopods (octopus and squid).



Do octopuses come from outer space?

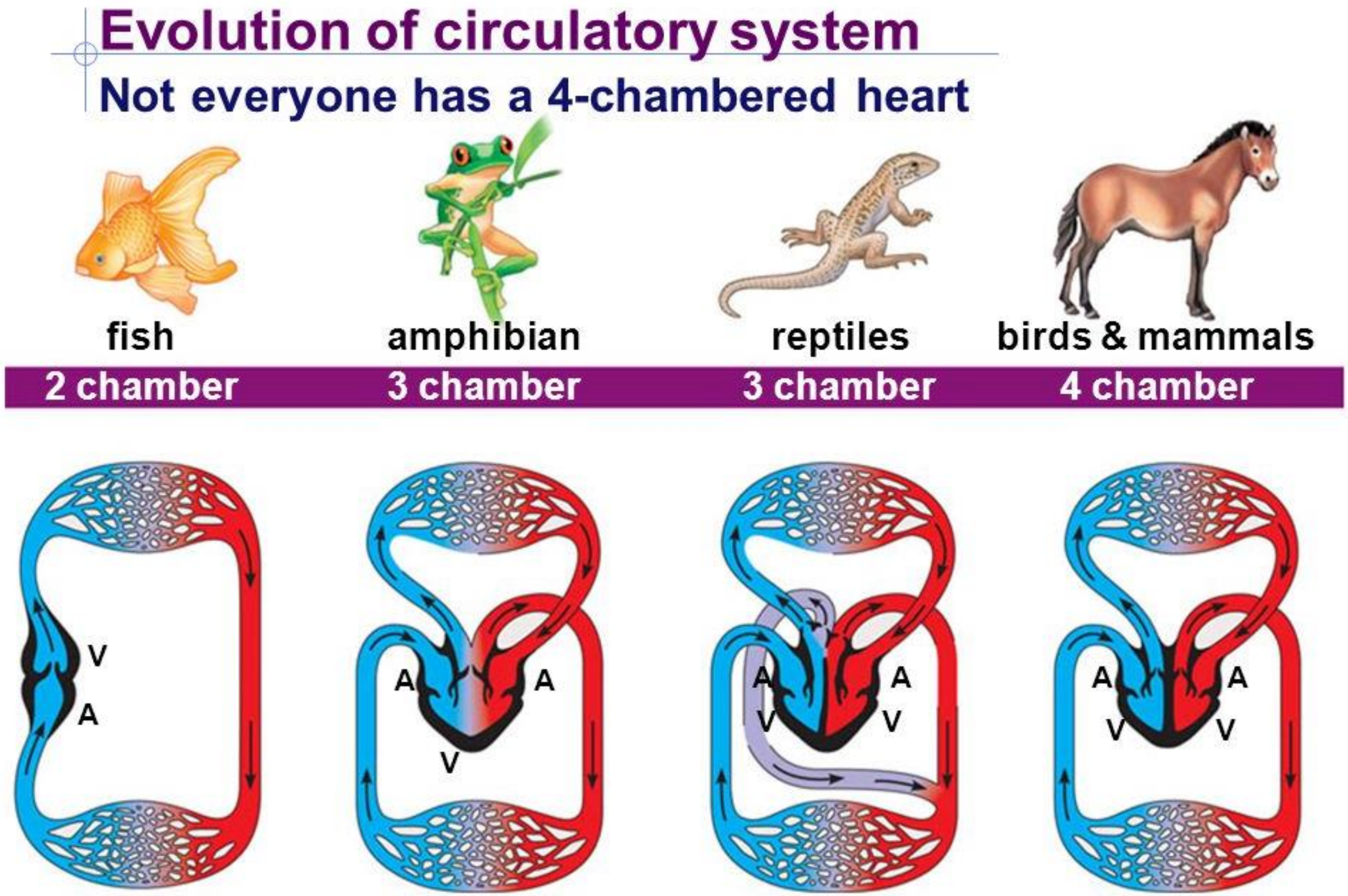


https://www.youtube.com/watch?v=BIQFblffD9w



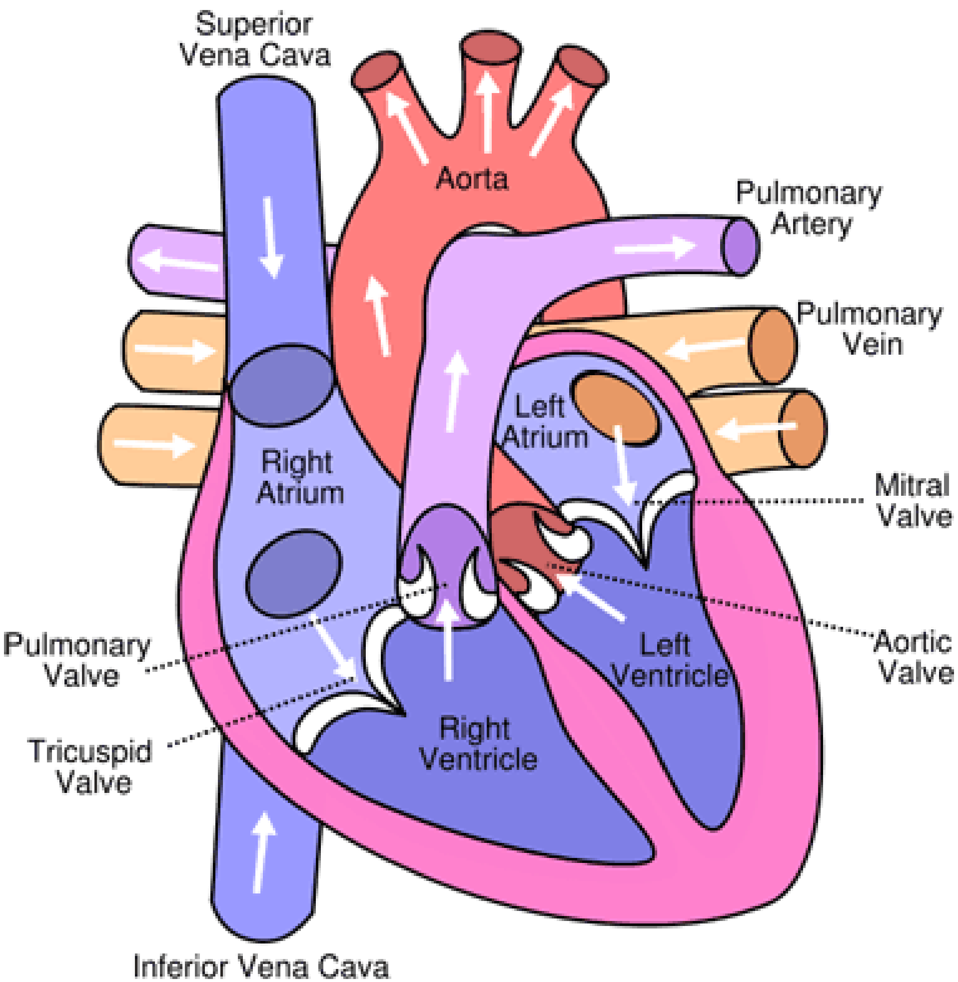
- ✓ An octopus's three hearts have slightly different roles. One heart circulates blood around the body, while the other two pump it past the gills, to pick up oxygen.
- ✓ The blue blood is because the protein, haemocyanin, which carries oxygen around the octopus's body, contains copper rather than iron like we have in our own haemoglobin.
- ✓ The copper-based protein is more efficient at transporting oxygen molecules in cold and low-oxygen conditions, so is ideal for life in the ocean.
- ✓ If the blood (called haemolymph in invertebrates) becomes deoxygenated - when the animal dies, for example - it loses its blue colour and turns clear instead.

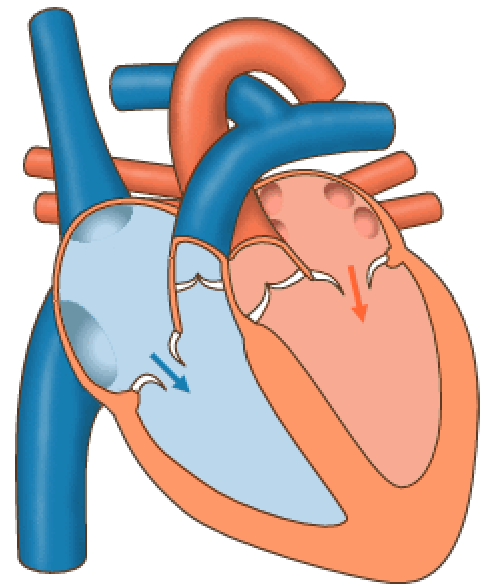
There are significant differences in the structure of the heart and the circulation of blood between the different vertebrate groups due to adaptation during evolution and associated differences in anatomy.



The Mammalian Heart: *A Closer Look*

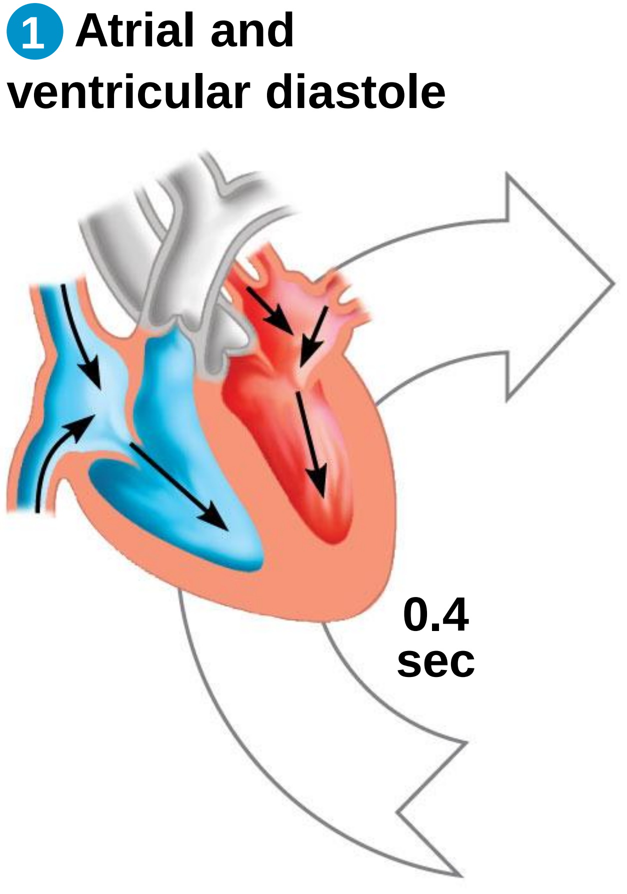
- A closer look at the mammalian heart provides a better understanding of double circulation

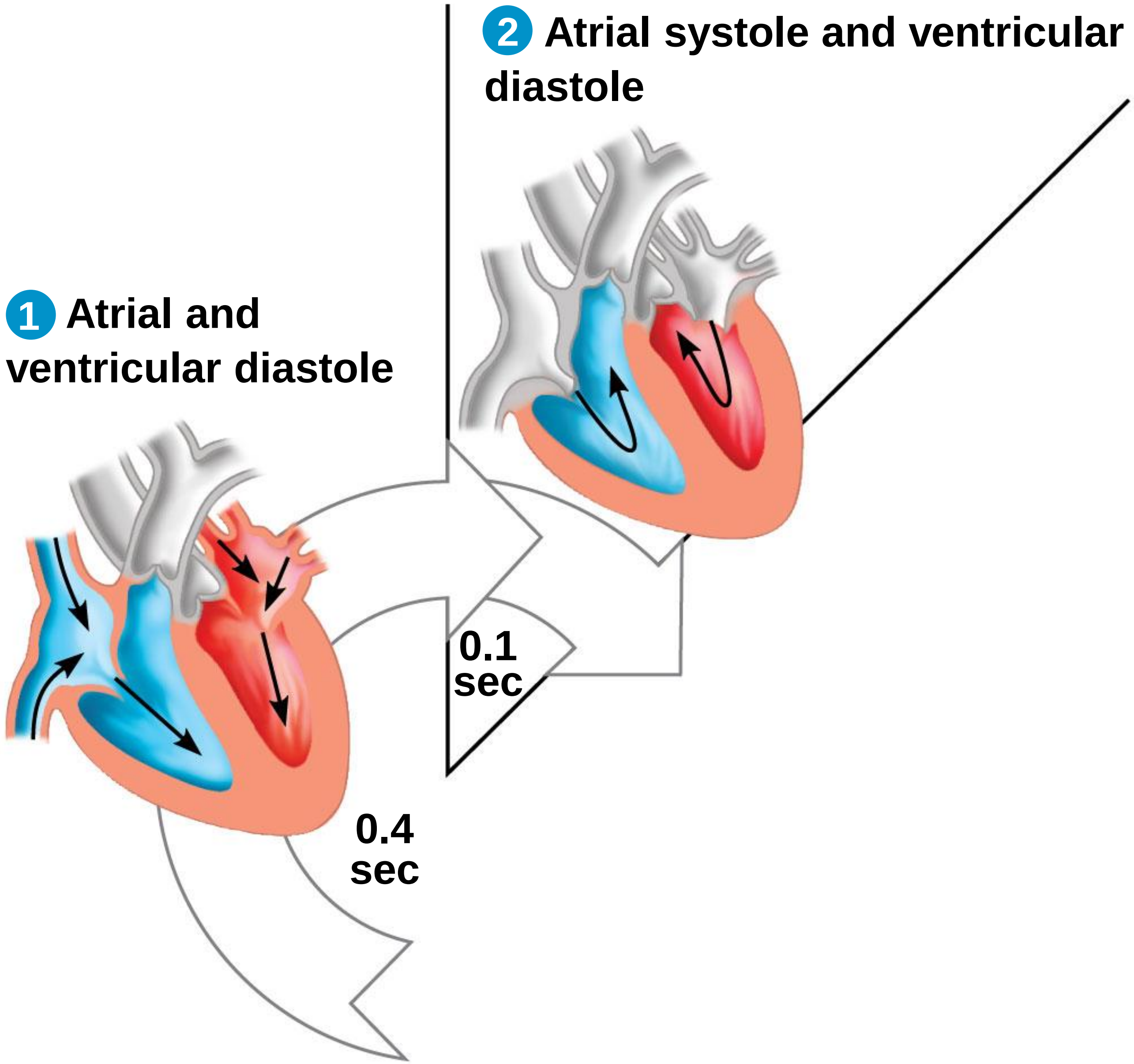




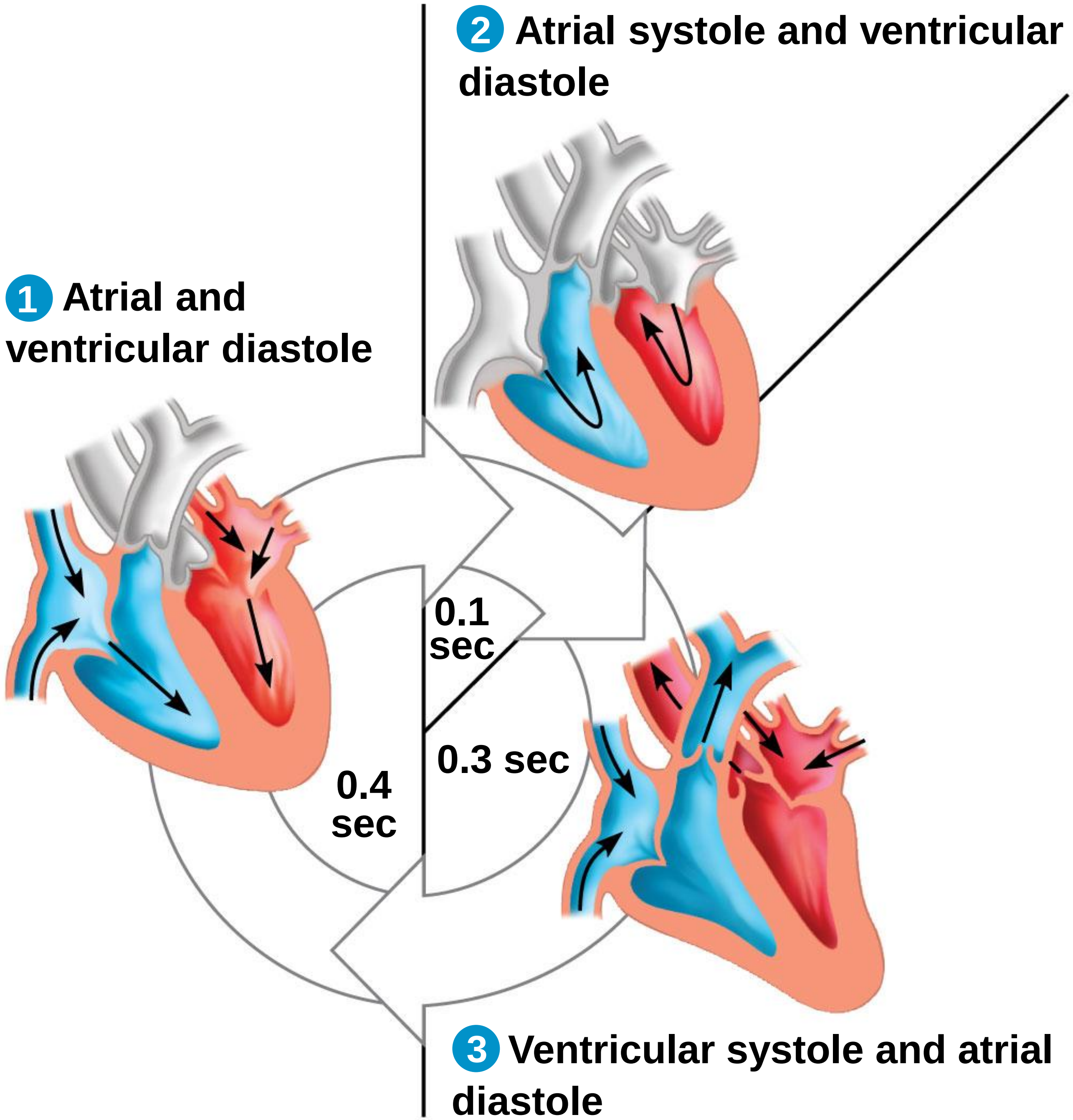
cardiac cycle

- The heart contracts and relaxes in a rhythmic cycle called the **cardiac cycle**
- The contraction, or pumping, phase is called **systole**
- The relaxation, or filling, phase is called **diastole**

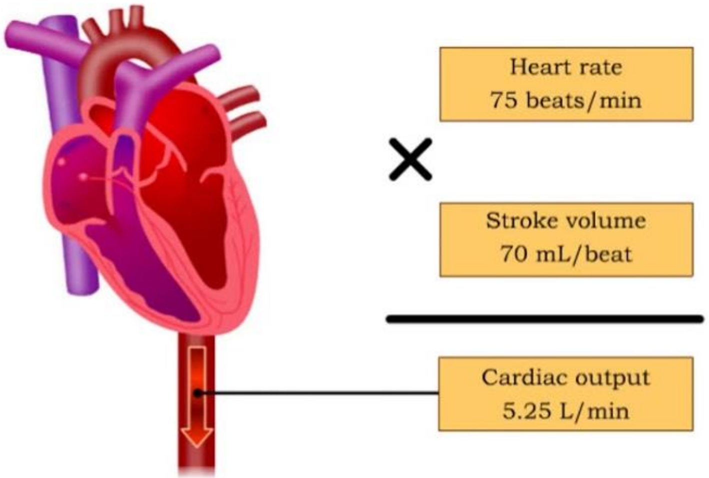




2 Atrial systole and ventricular diastole
1 Atrial and ventricular diastole
0.1 sec
0.4 sec



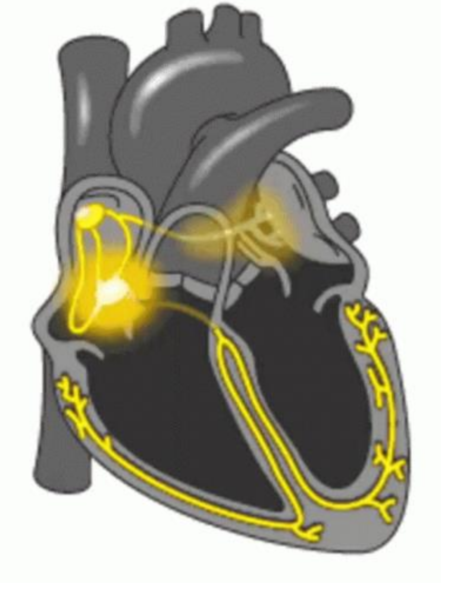
1 Atrial and ventricular diastole
2 Atrial systole and ventricular diastole
0.1 sec
0.3 sec
0.4 sec
3 Ventricular systole and atrial diastole

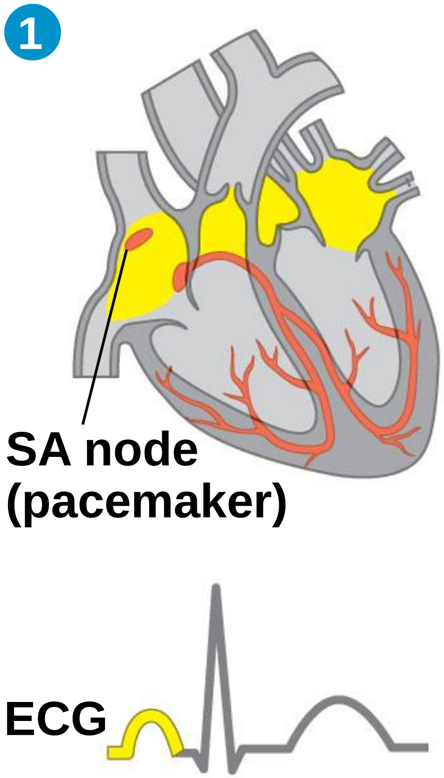


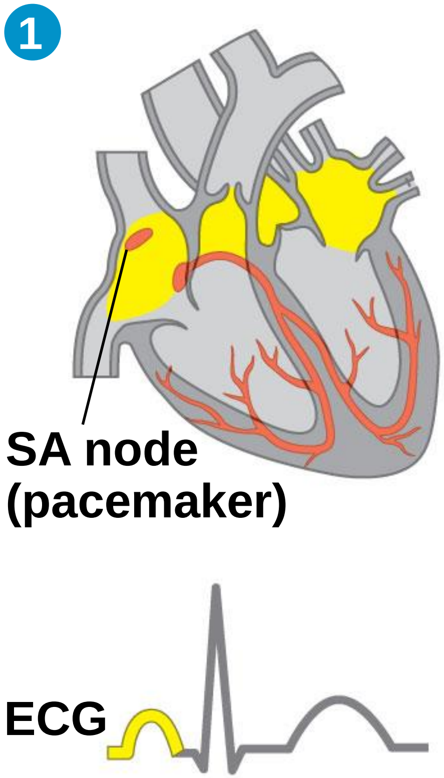
1. The **heart rate**, also called the pulse, is the number of beats per minute
2. The **stroke volume** is the amount of blood pumped in a single contraction
3. The **cardiac output** is the volume of blood pumped into the systemic circulation per minute and depends on both the heart rate and stroke volume

Maintaining the Heart’s Rhythmic Beat

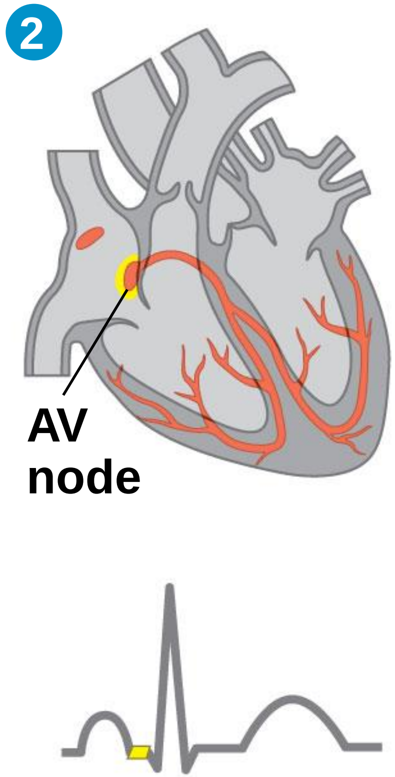
- Some cardiac muscle cells are self-excitable, meaning they contract without any signal from the nervous system
- The **sinoatrial (SA) node**, or pacemaker, sets the rate and timing at which cardiac muscle cells contract
- The electrical impulses in the heart produce electrical currents that flow through the body and can be measured on the skin using electrodes. This information can be observed as an electrocardiogram (ECG)



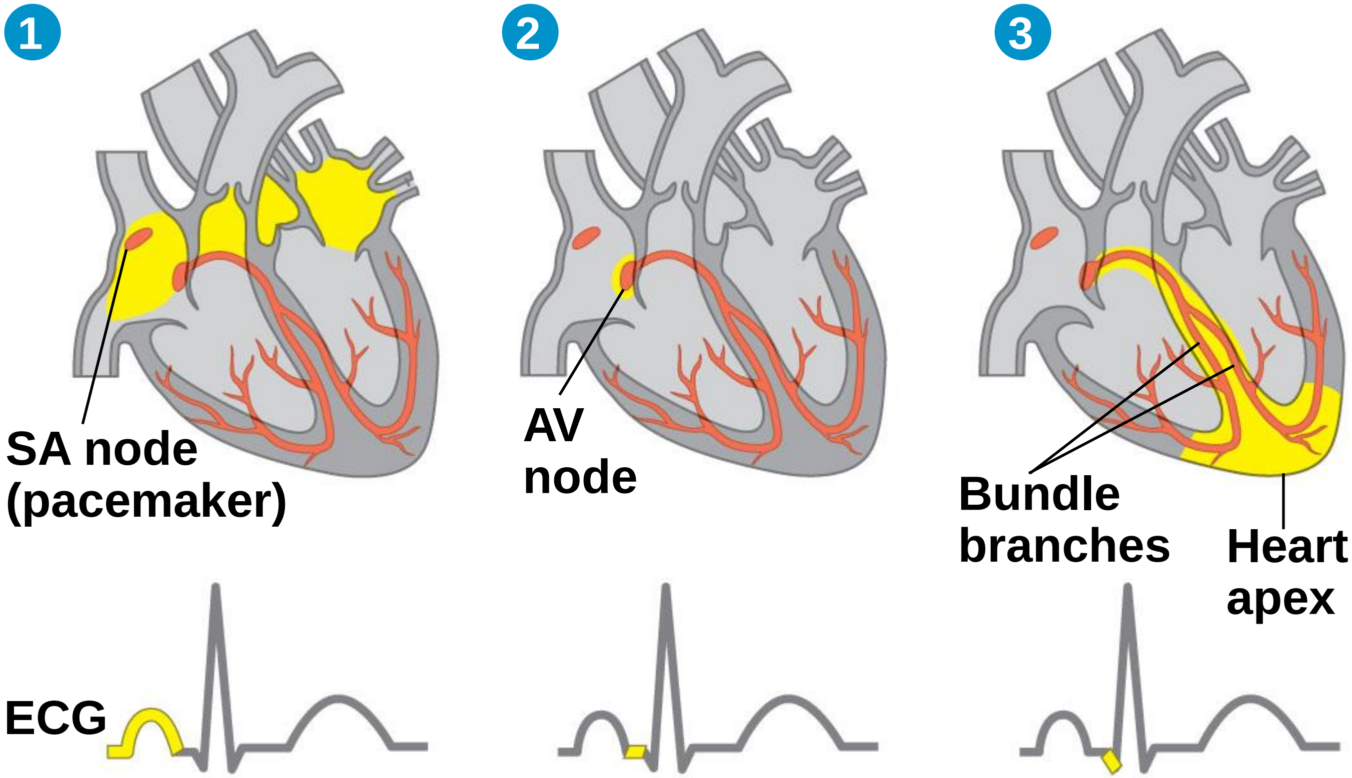

1
SA node
(pacemaker)
ECG

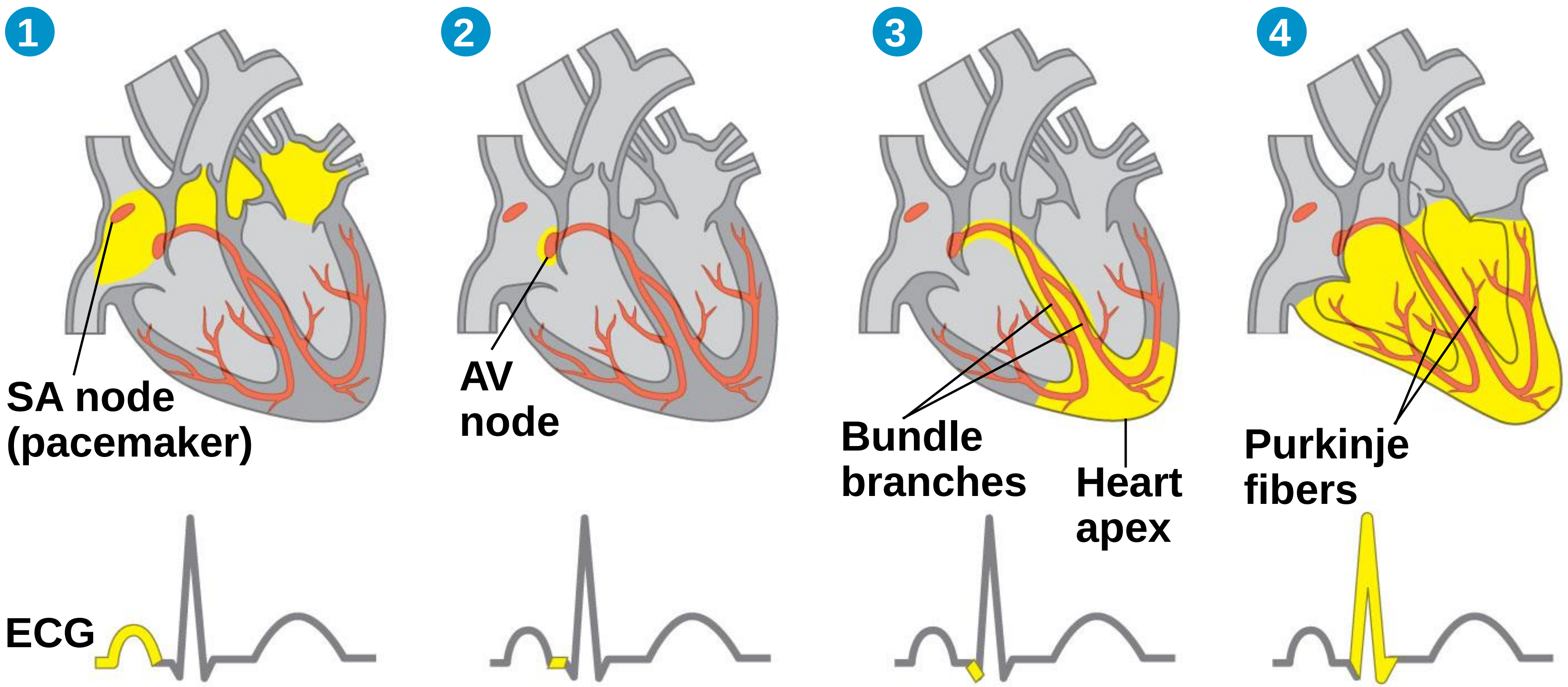


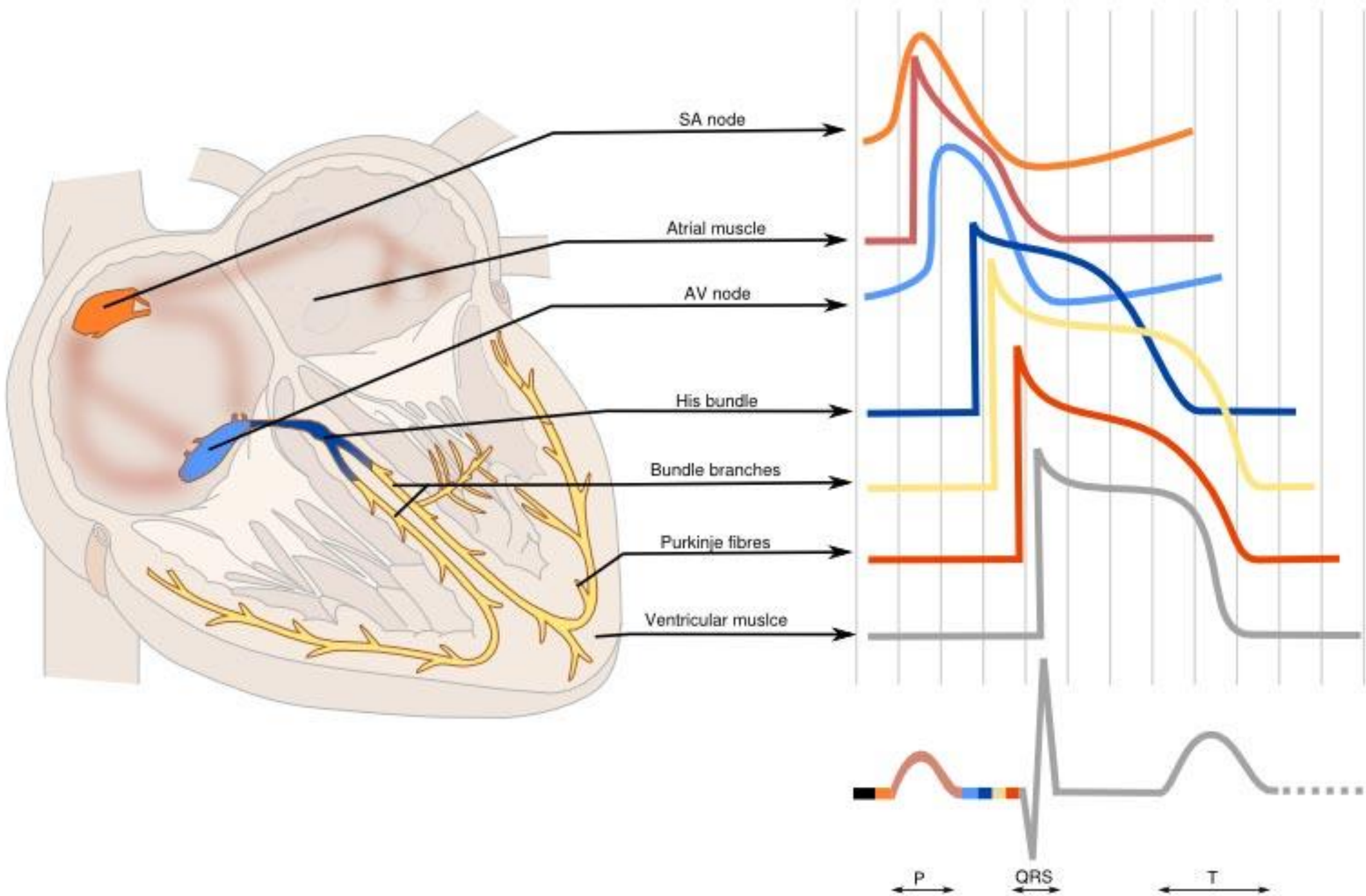
1
SA node
(pacemaker)
ECG



2
AV
node

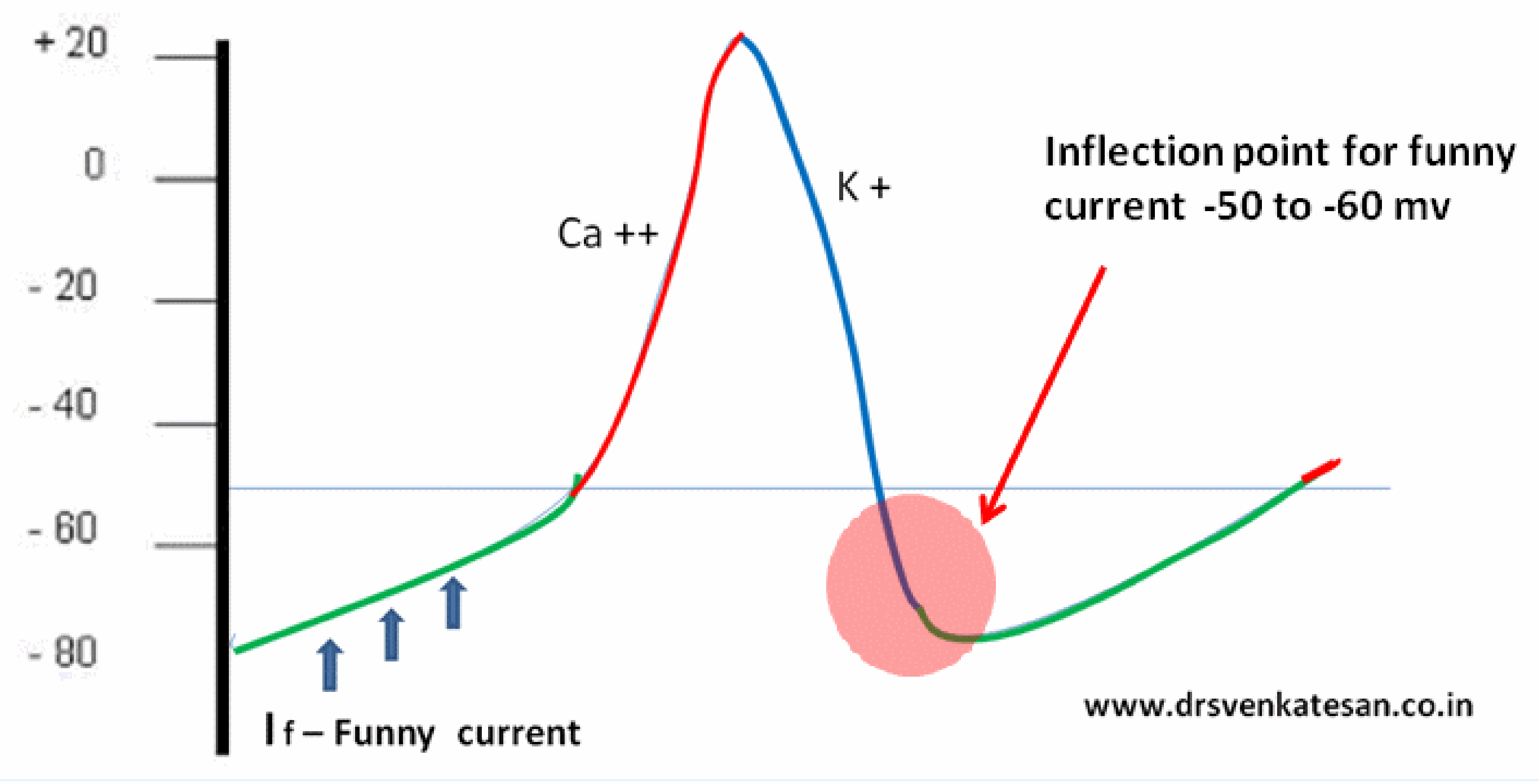

1
2
3
SA node (pacemaker)
AV node
Bundle branches
Heart apex
ECG

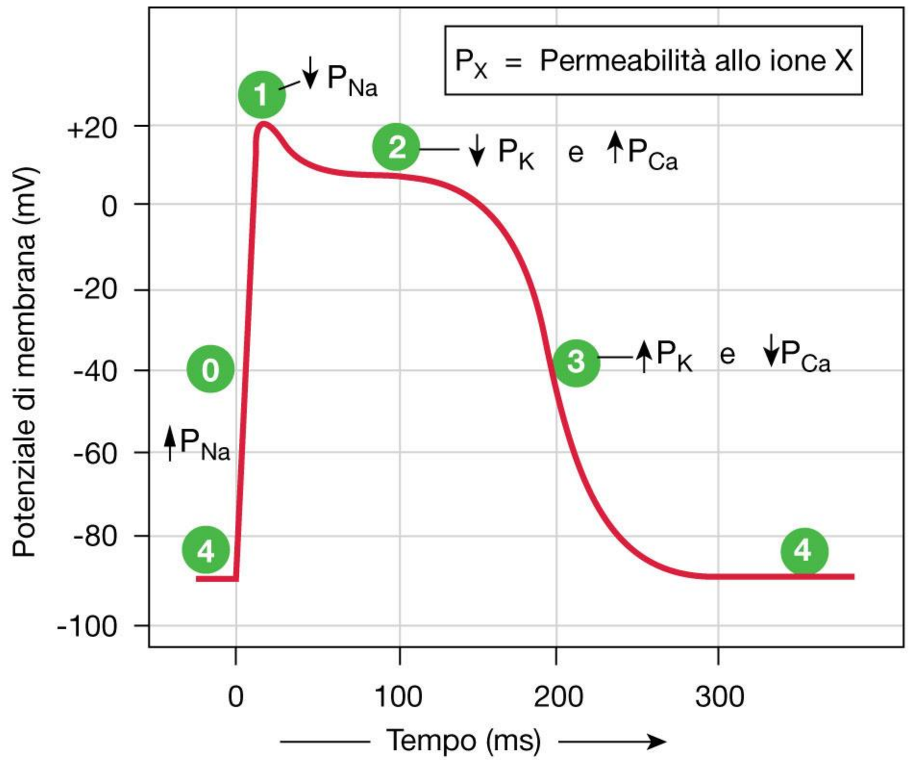

1
2
3
4
SA node
(pacemaker)
AV
node
Bundle
branches
Heart
apex
Purkinje
fibers
ECG



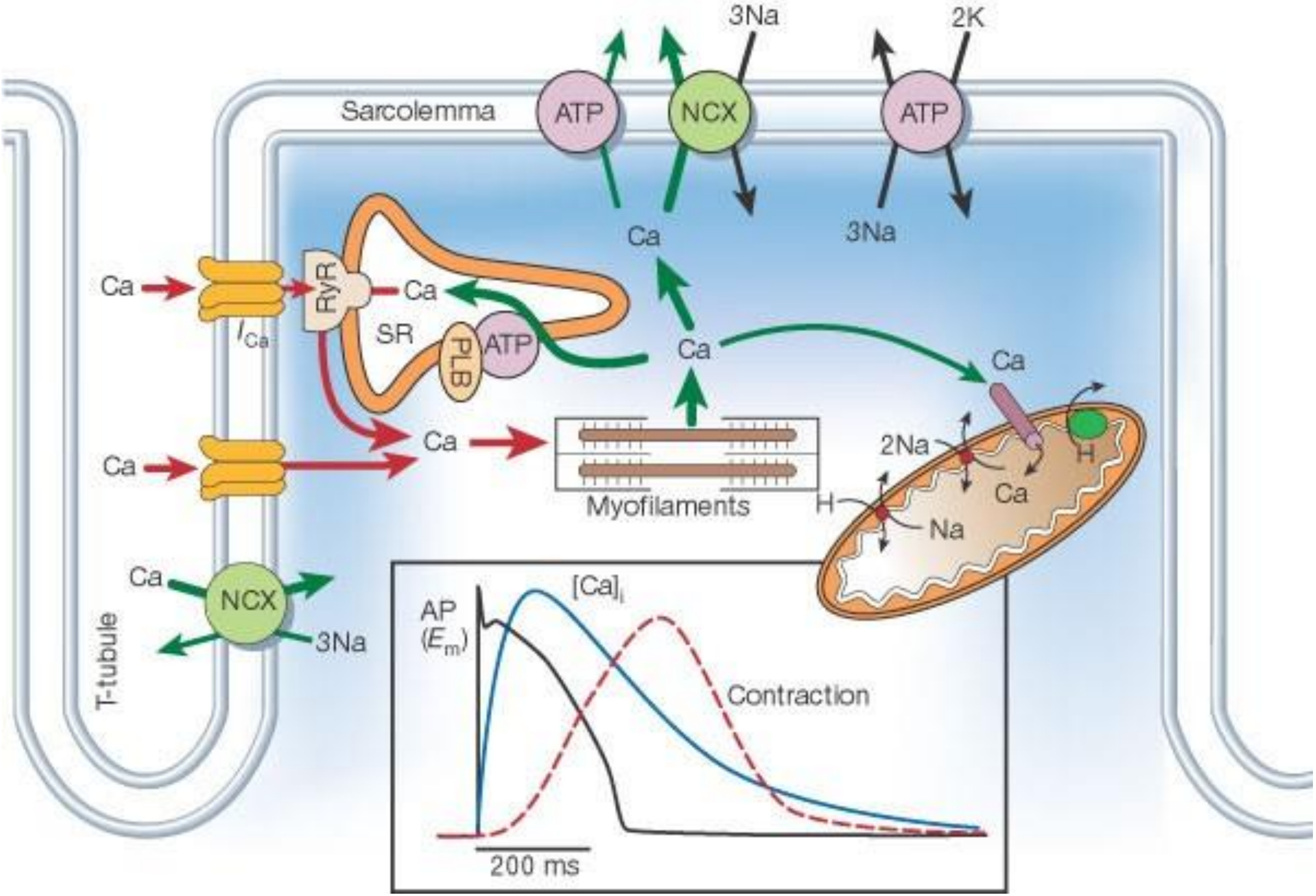
SA node
Atrial muscle
AV node
His bundle
Bundle branches
Purkinje fibres
Ventricular muslce
P
QRS
T

Components of *pacemaker* potential

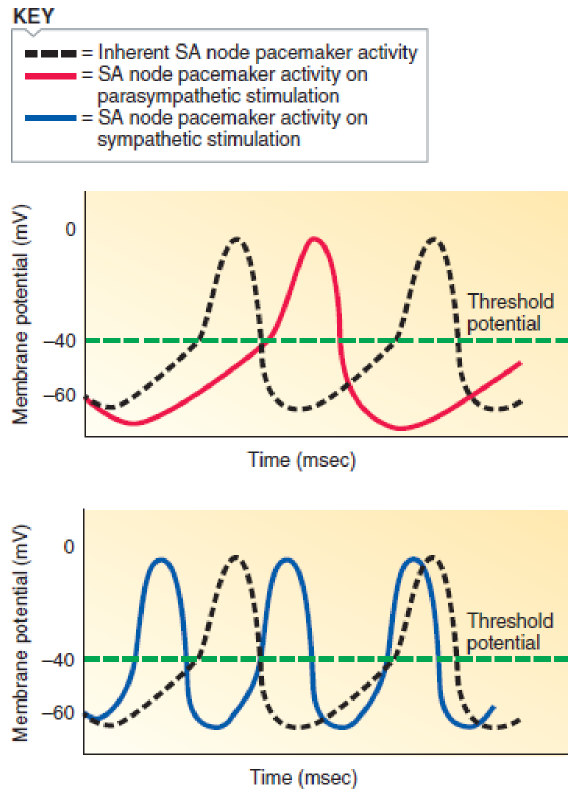




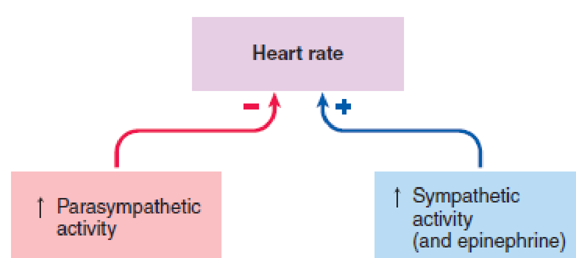
Fase	Canali di membrana
0	Canali del Na^+ si aprono
1	Canali del Na^+ si chiudono
2	Canali del Ca^{2+} si aprono; canali rapidi del K^+ si chiudono
3	Canali del Ca^{2+} si chiudono; canali lenti del K^+ si aprono
4	Potenziale di riposo


3Na
2K
Sarcolemma
ATP
NCX
ATP
3Na
Ca
Ca
RyR
Ca
SR
PLB
ATP
Ca
Ca
I_{Ca}
Ca
Ca
Ca
Myofilaments
2Na
H
Ca
H
Na
Ca
NCX
3Na
T-tubule
AP
(E_m)
$[Ca]_i$
Contraction
200 ms

- The pacemaker is regulated by two portions of the nervous system: the sympathetic and parasympathetic divisions
- The sympathetic division speeds up the pacemaker
- The parasympathetic division slows down the pacemaker
- The pacemaker is also regulated by hormones and temperature

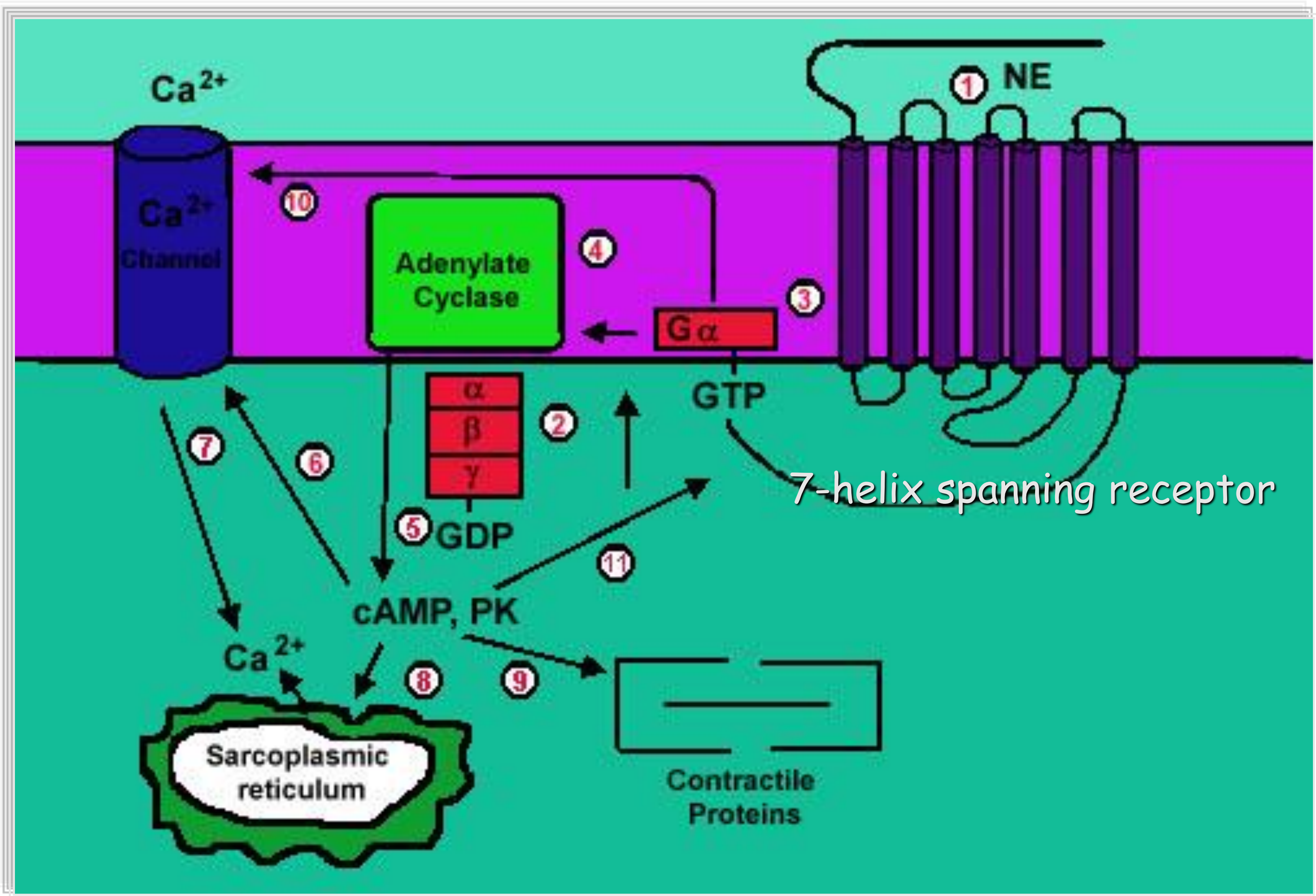


(a) Autonomic influence on SA node potential

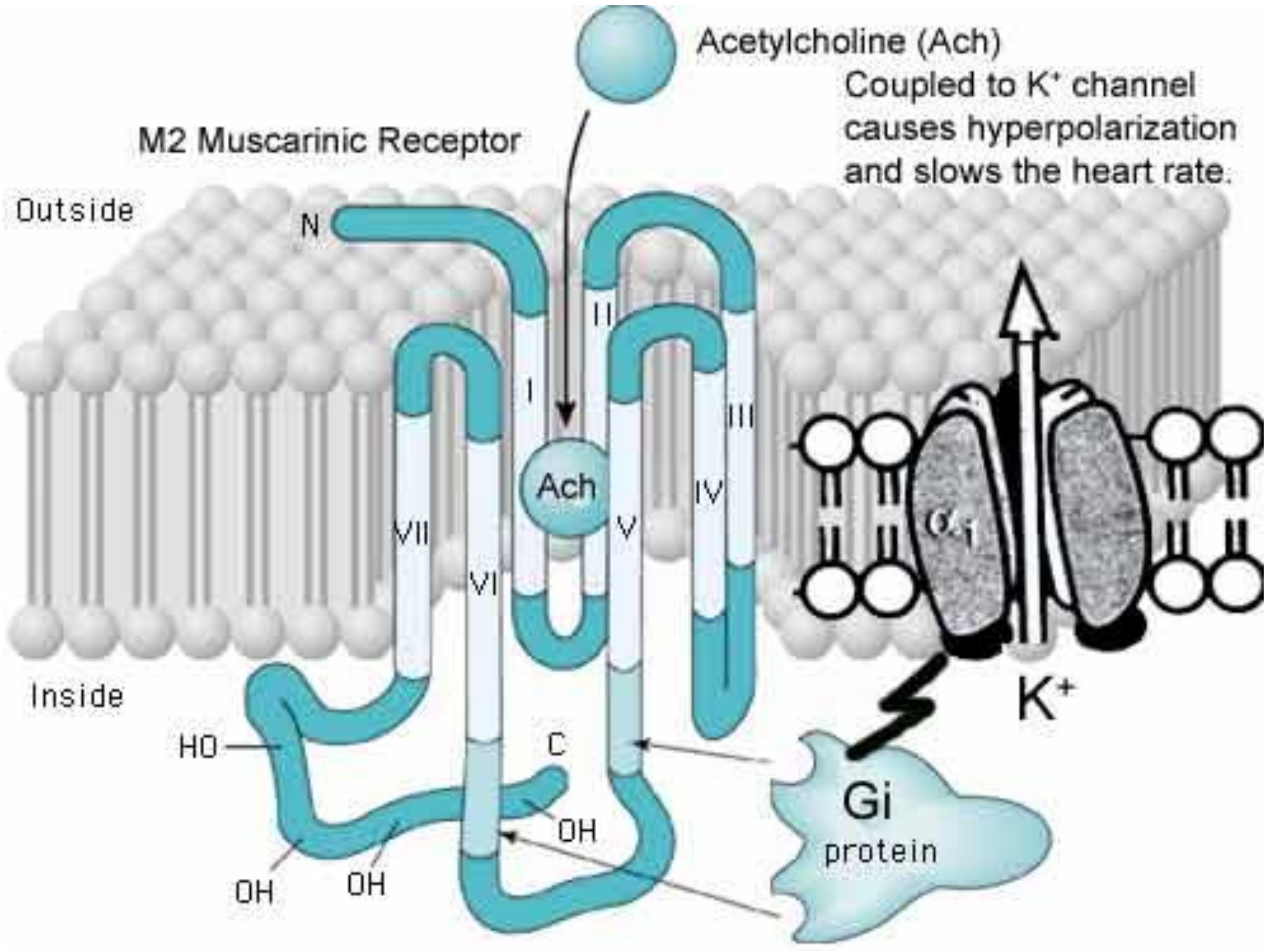


(b) Control of heart rate by autonomic nervous system

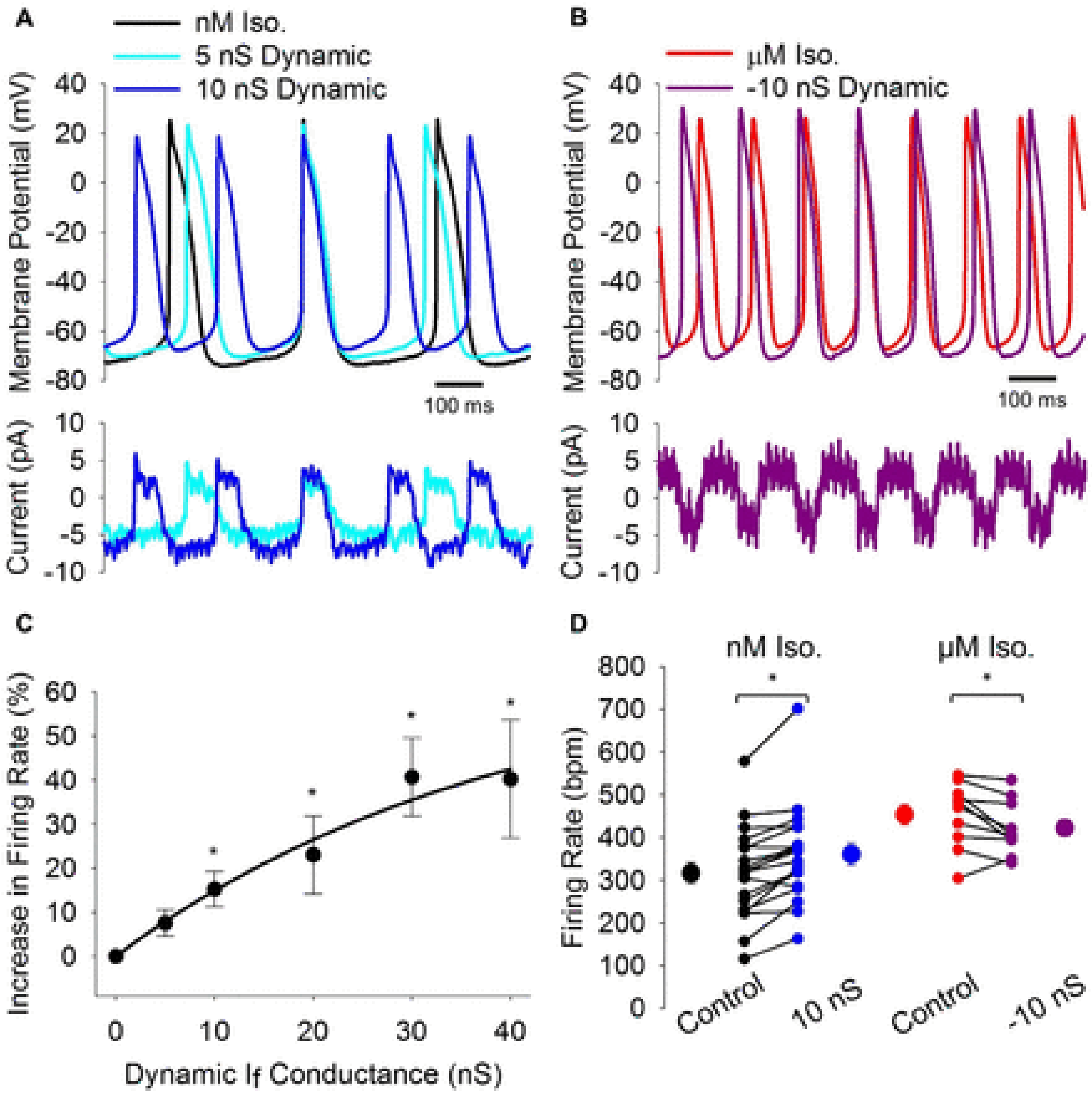
The sympathetic system



The parasympathetic system



I_f in «fight or flight» response



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