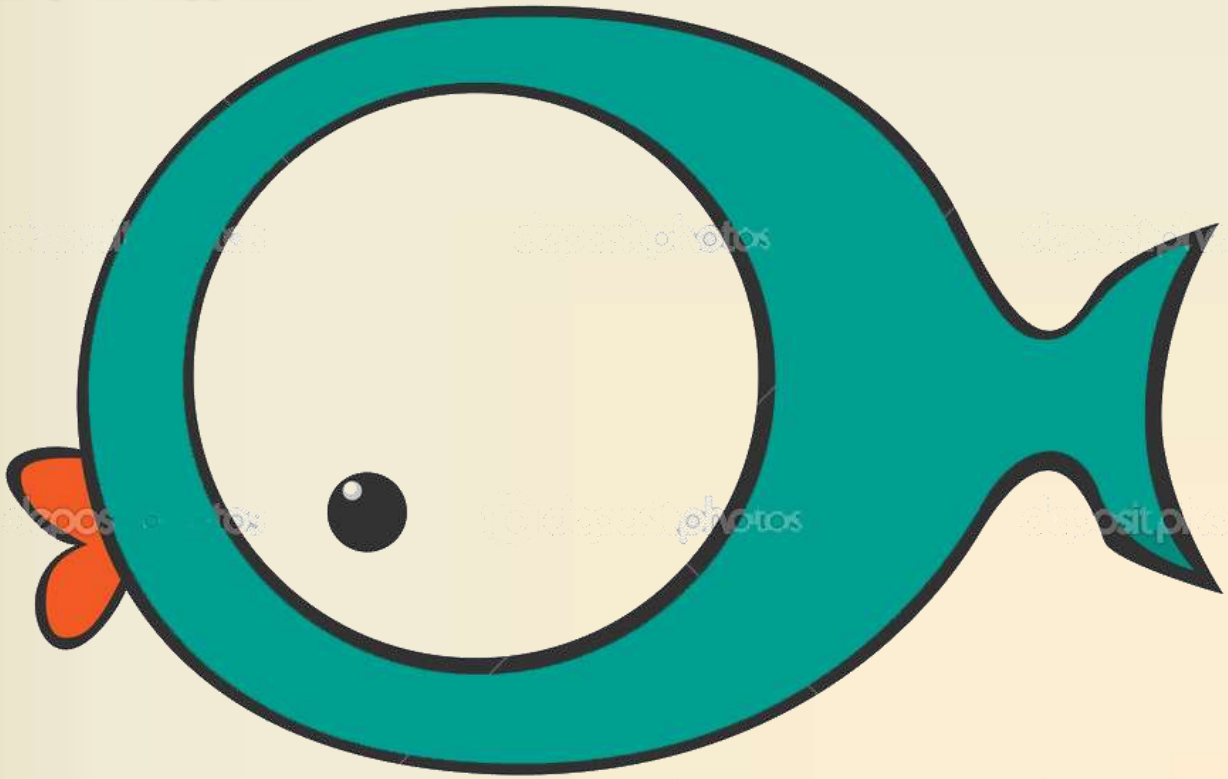
PHYSIOLOGY OF CARDIOVASCULAR SYSTEM IN FISH



The functions of cardiovascular system of a fish is to supply the tissues with oxygen and nutrients, while removing carbon dioxide and other metabolic wastes.

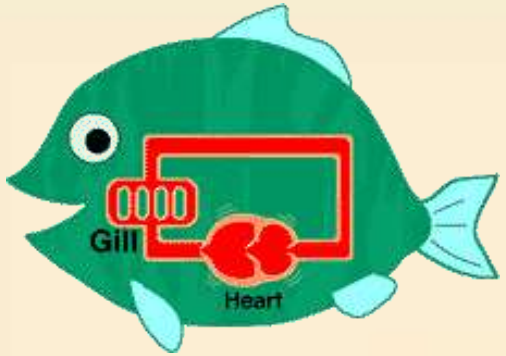
Every organ and cell in the fish's body is connected to this system.

This process of circulation is necessary for continued life of the cells, tissues, and ultimately the whole organism

CIRCULATORY SYSTEM OF FISH

As in other vertebrates the circulatory system of fish is comprised of both

- **static and dynamic components.**

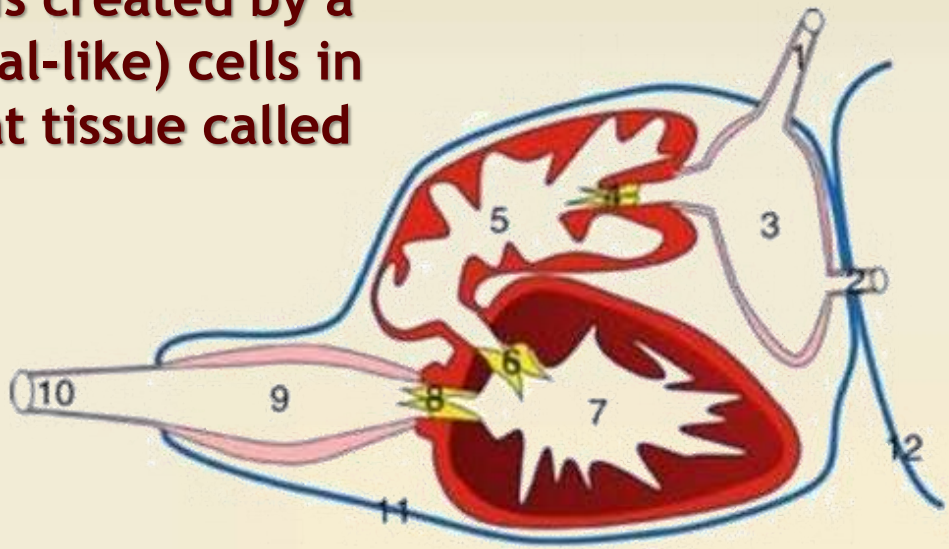


The dynamic part is the blood with all its constituent parts that flows continuously around the fish's body.

The static parts are the heart, the veins and arteries leading to and from it and the capillaries that connect them.

FISH HEART

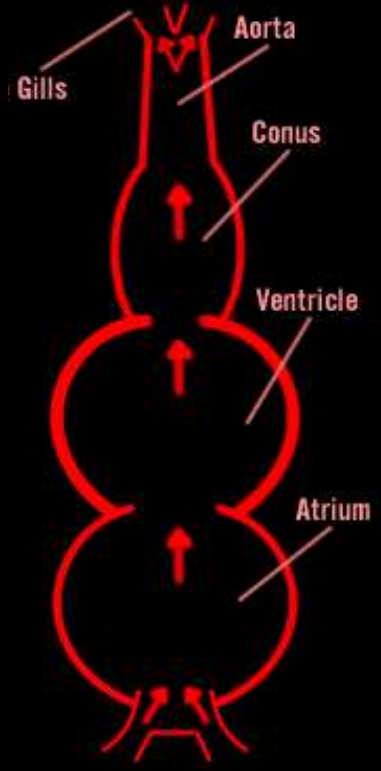
Fish do not have a very powerful heart.
It is positioned within a membranous sac, the pericardial cavity which is created by a layer of mesothelial (epithelial-like) cells in addition to connective and fat tissue called the pericardium.



1 Ductus Cuvier
2 Hepatic vein
3 Sinus venosus
4 Sino-atrial valve (ostial valve)
5 Atrium
6 Atrio-ventricular valve
7 Ventricle
8 Bulbo-ventricular valve
9 Bulbus arteriosus
10 Ventral aorta
11 Pericardium
12 Peritoneum

The heart of fish are the simplest vertebrate hearts and It's a simple, four-chambered pump :

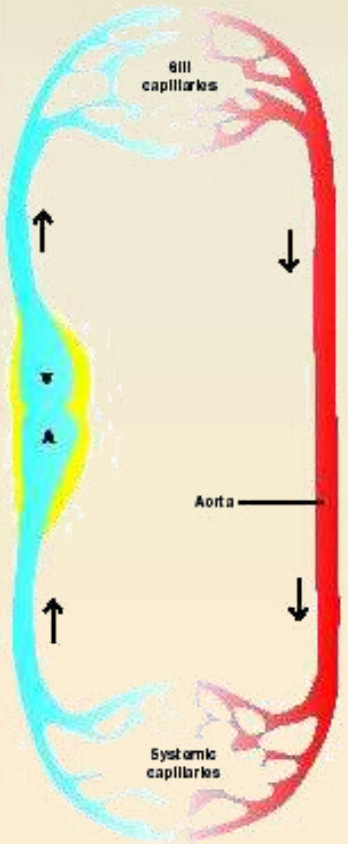
- **Sinus vensus with elastic thin wall**
- **Atrium, a thin-walled chamber of the heart that is primarily comprised of cardiac muscle tissue.**
- **Ventricle, the largest and most muscular chamber of the heart.**
- **Bulbus arteriosus**



In cartilaginous fish and bony fish other than the teleosts, the conus arteriosus and sinus venosus are contractile and may possess a number of semilunar valves.

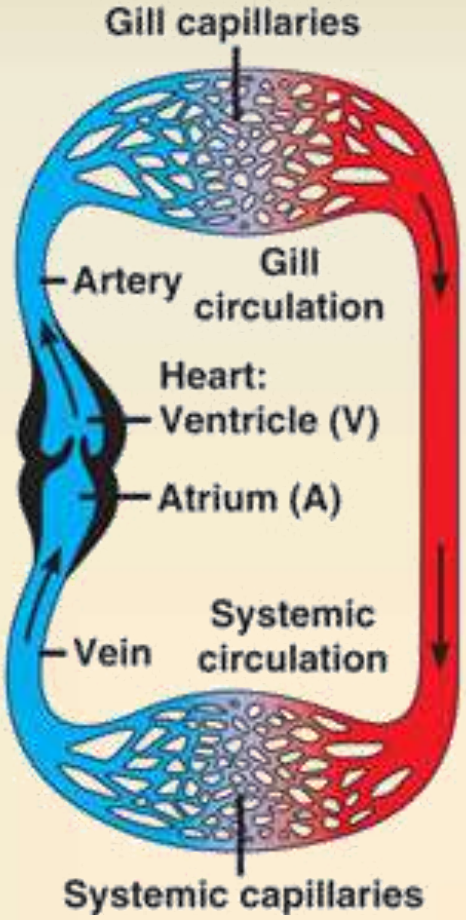
THE CIRCULATORY SYSTEM

The circulatory system of the fish consists of one main circuit, from the heart to the gills, then to the cells. The circuit is a "closed system" (it is contained in vessels and a loop).



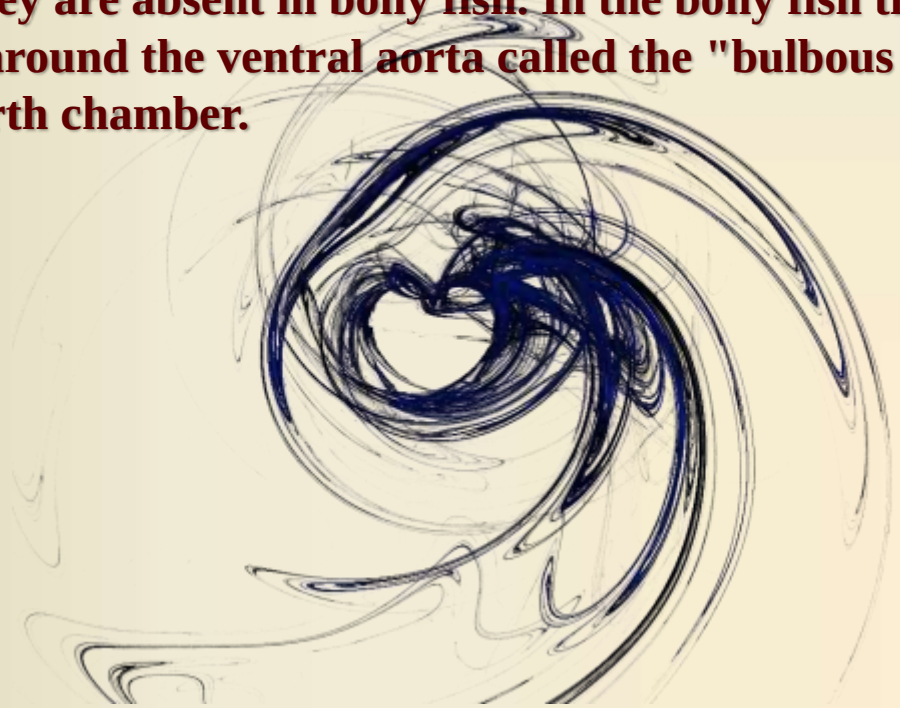
The branchial and systemic heart in fish is usually the main propulsive organ for the circulation of the blood.

- **Blood flows back to the heart via veins. Two main veins are the "Hepatic veins" (from the liver) and the ducts of "Cuviar" (the main veins from the rest of the body). These join together into one larger vein called the "Sinus venosus" .**
- **It then goes through the first valve of the heart (to keep blood from flowing backward) called the "sinuatrial valve." Blood then flows into the first chamber of the heart called the "atrium" (it is the smaller of the two chambers because it does not have to do as much work as the other chamber).**



- As the heart relaxes the blood then flows through another valve called the "atrioventricular" valve (named so because it is between the atrium and the ventricle). Blood continues into the largest chamber of the heart called the "ventricle."

- Contraction of the ventricle forces blood goes through one more valve and into the main artery called the "ventral aorta." Here is where the bony fish differs from the shark. In the shark there are more muscles and valves in this artery; they are absent in bony fish. In the bony fish there is another large muscle around the ventral aorta called the "bulbous ateriosus." Some call this a fourth chamber.



From the conus or bulbous the blood travels straight to the capillary networks of the gills where it is enriched with oxygen and the gas exchange occurs.

The oxygenated blood then passes on to the capillary networks that supply the rest of the body where exchanges with the tissues occur.

Then the blood returns to the atrium.

HAGFISH

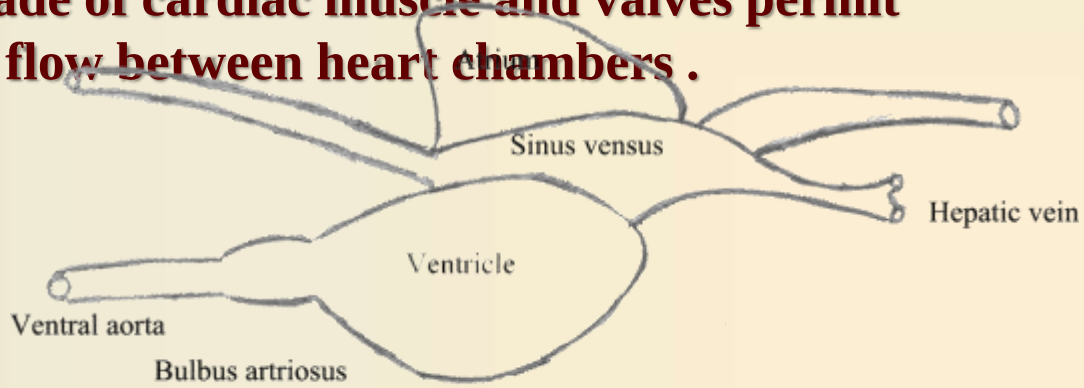
Hagfish possess a heart with 3 chambers:

the sinus venosus, a single ventricle, and a single ventricle.

They may possess a rudimentary chamber corresponding to the conus arteriosus.

The sinus venosus is the site where the contraction of the heart in initiated, which is also true of the embryonic hearts of all vertebrates .

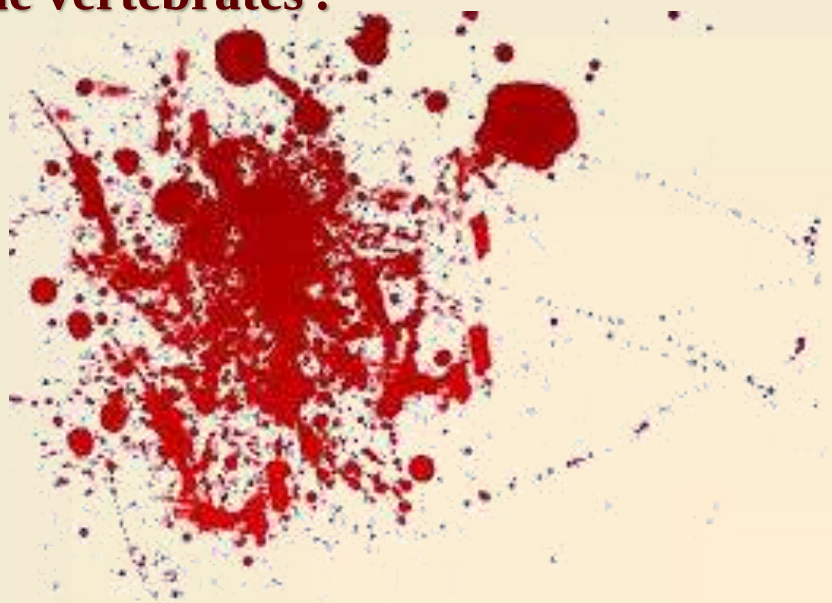
The hagfish heart is made of cardiac muscle and valves permit only one direction of flow between heart chambers .



The circulatory systems of the hagfish have both closed and open blood vessles, with a heart system that is more primitive than that of vertebrates.

This system is comprised of an extensive network of sinuses which are connected on one side by arteries and on the other by veins.

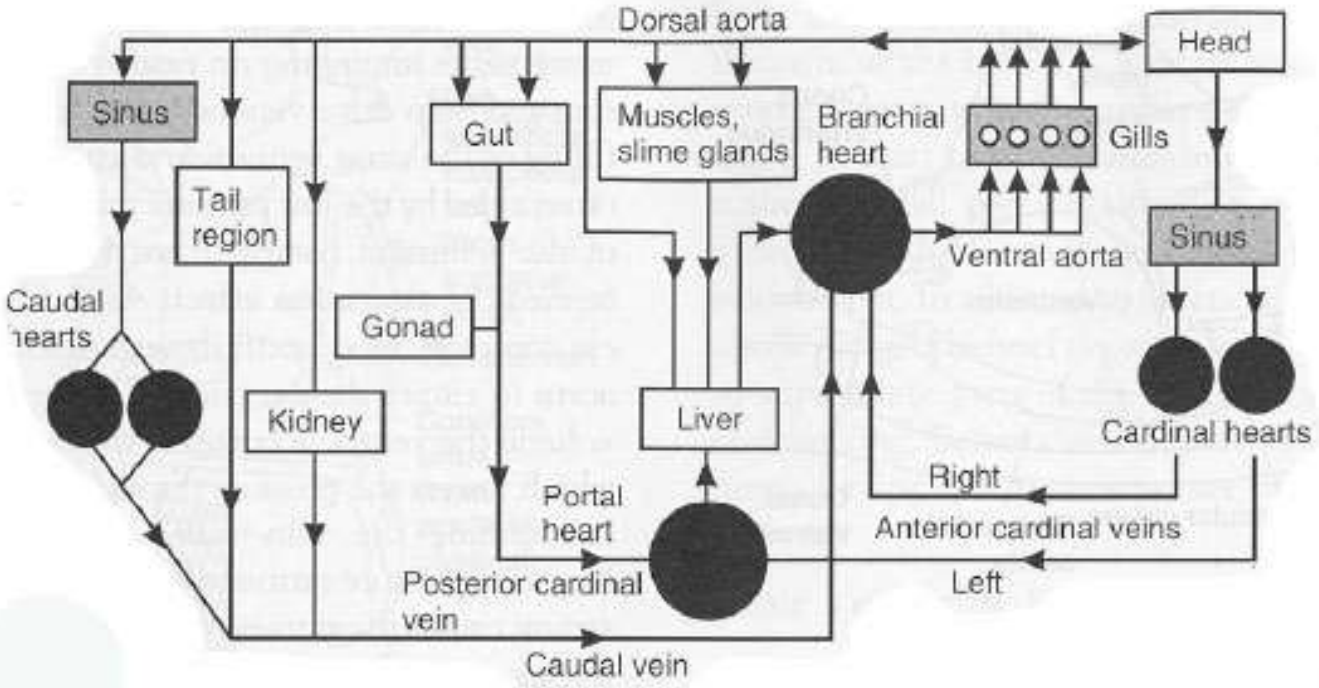
Hagfish have the greatest blood volume to body volume ratio of all the vertebrates, and > 30% of this blood resides in the sinus system. This type of partially open circulatory system also endows the hagfish with the lowest arterial blood pressure of all the vertebrates .



Instead of one heart, the hagfish has a systemic heart, plus three accessory hearts.

a) Cardinal heart helping venous return on the cardinal viens,
b) Portal heart pumping blood into the liver and
c) Caudal heart near the tail

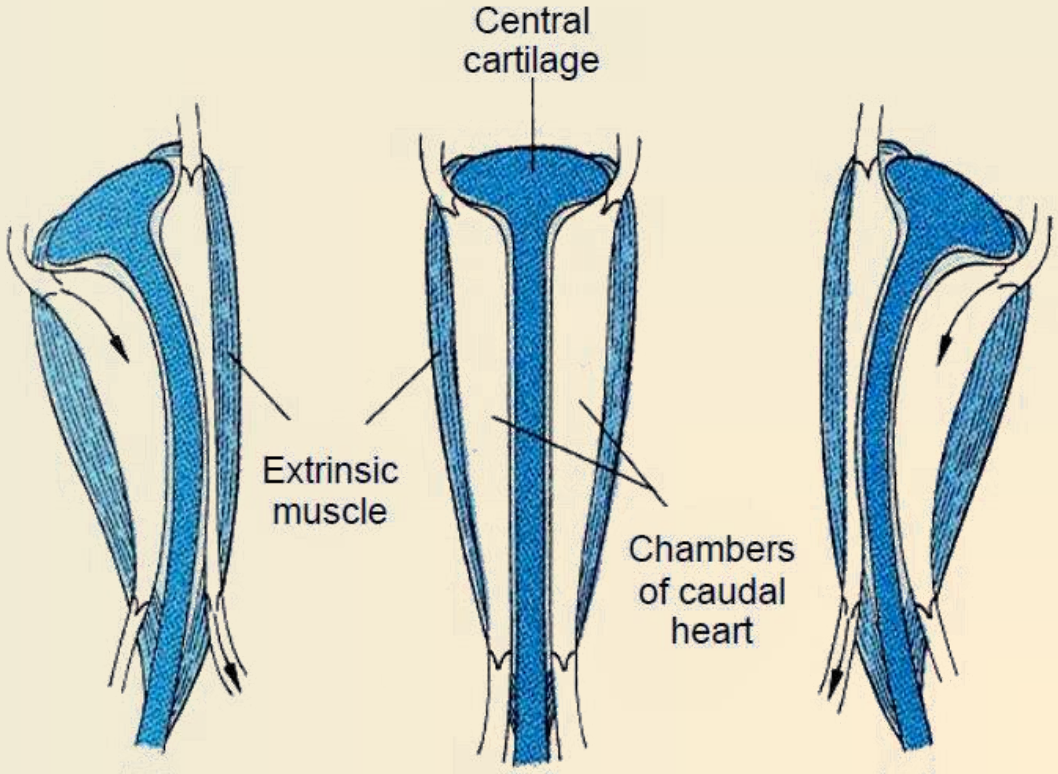
Hagfish circulation



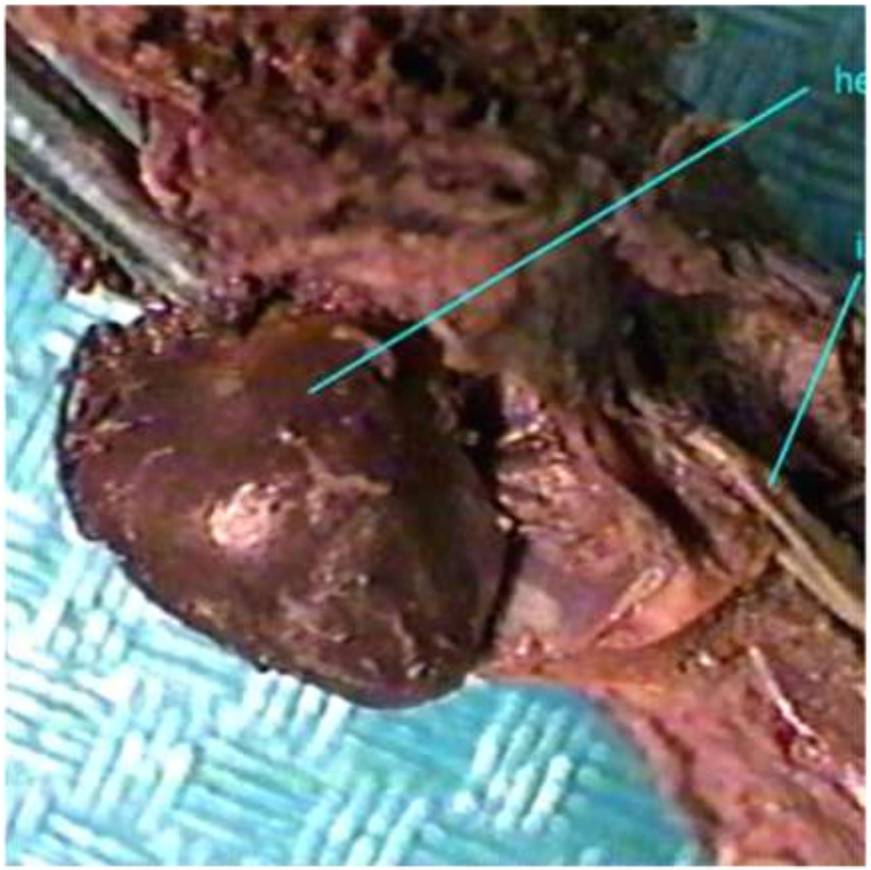
The cardinal hearts drive blood from the subcutaneous sinus (SCS), a large expandable cavity that contains the greatest amount of free blood present in the animal, into the anterior cardinal and inferior jugular veins. These channels return the blood to the portal and branchial hearts, where it is redistributed throughout the body.

The portal heart pumps portal vein blood into the liver and then the blood drains from the liver into the hepatic vein and to the bronchial heart.

The caudal heart has a completely different design. It comprises two parallel chambers around a central cartilaginous rod. The alternate contraction of two extrinsic muscles surrounding chambers bows the cartilage on one side or on the other, this alternate motion empties one chambers by contraction and simultaneously fills the other by expansion.



LAMPREY



The heart of the lamprey is a large structure, found just anterior to the liver and inside the pericardial cavity.

The heart is composed of four chambers:
a sinus venosus, atrium, ventricle
and truncus arteriosus .

the truncus arteriosus is also referred to as the conus arteriosus or the bulbis cordis.

In Lapery:

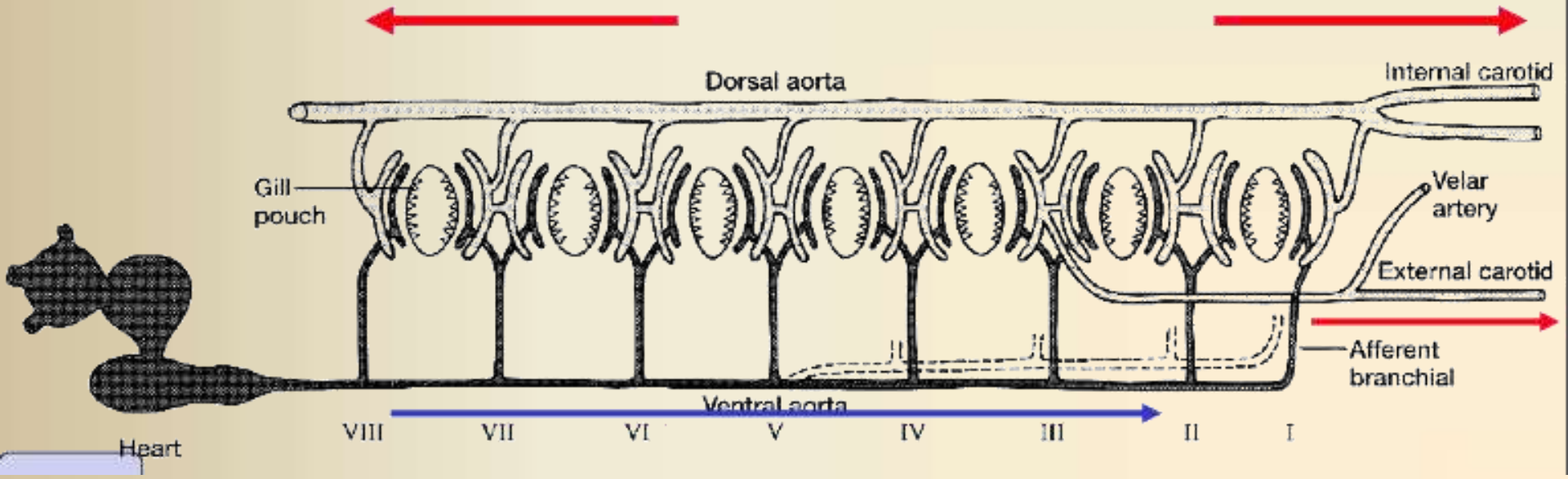
Deoxygenated blood drains from the liver into the hepatic vein and from the head via the inferior jugular vein and the paired anterior cardinal veins into the heart's thin-walled, tubular sinus venosus.

After the sinus venosus, blood passes into the heart's single atrium, and finally enters the ventricle, a muscular structure which actively pumps blood into the ventral aorta.

From the ventral aorta, blood travels to the capillaries of the gill lamellae for gas exchange.

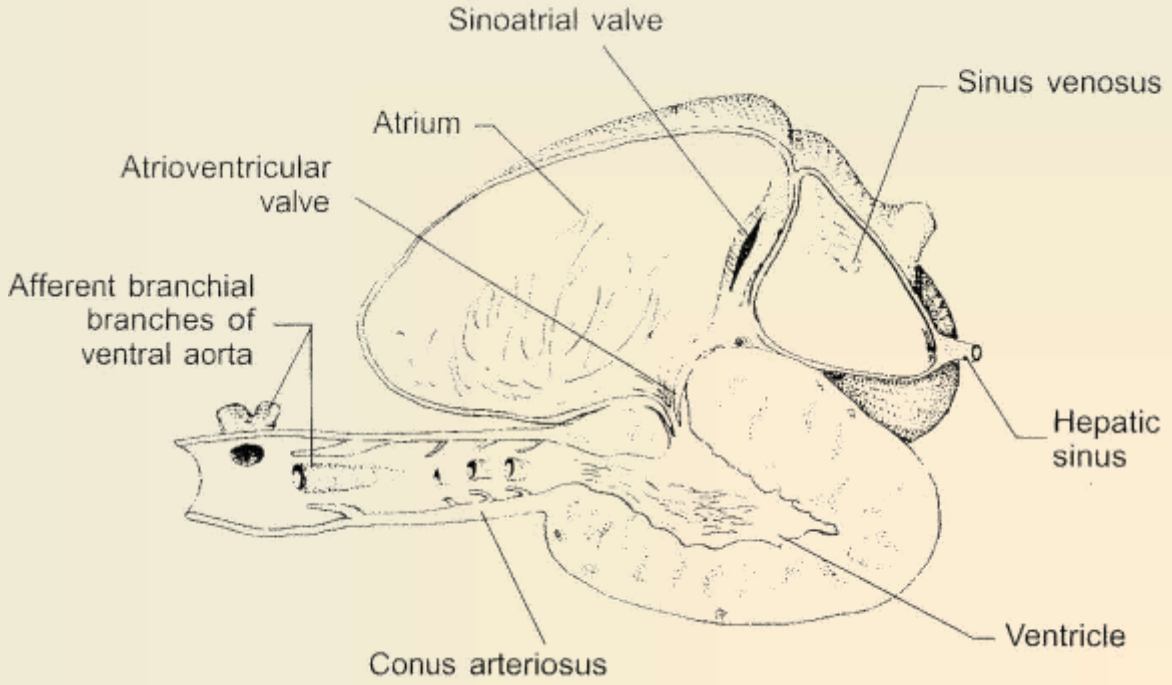
The afferent bronchial arteries branch from the ventral aorta into the gill arches, and the efferent bronchial the oxygenated blood away from the gill arches. Blood continues either to the head via the carotid arteries or caudad via the dorsal aorta for distribution to the rest of the body .

Valves prevent the backflow of blood from each of the heart's chambers.



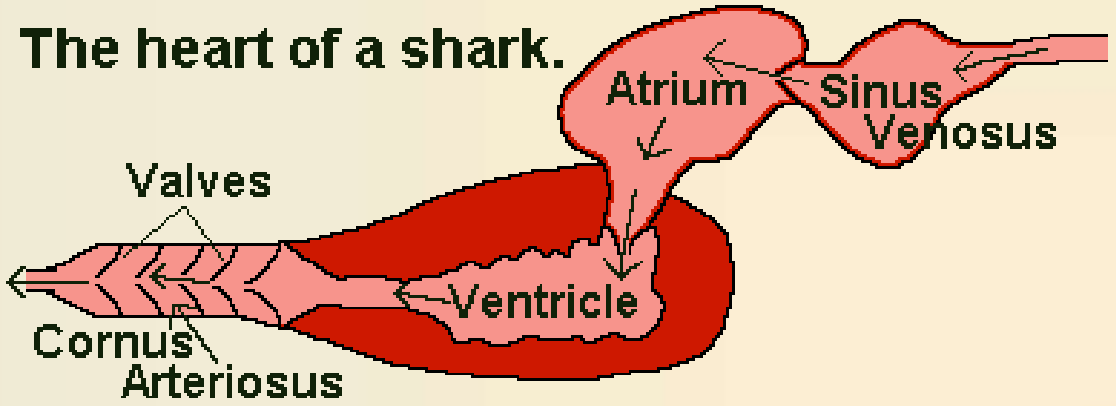
ELASMOBRANCHS

The hearts of cartilaged fish have a greater circulatory supply than observed in lampreys, complete with anastomosis between coronary vessels (as in higher vertebrates).



in Elasmobranchs the heart is ventrally located and have a four chambers:

a) **sinus venosus which collects the venous blood of the body,**
b) **thin-walled atrium,**
c) **the muscular ventricle which pumps the blood, and**
d) **the conus arteriosus which connects the heart to the ventral aorta.**



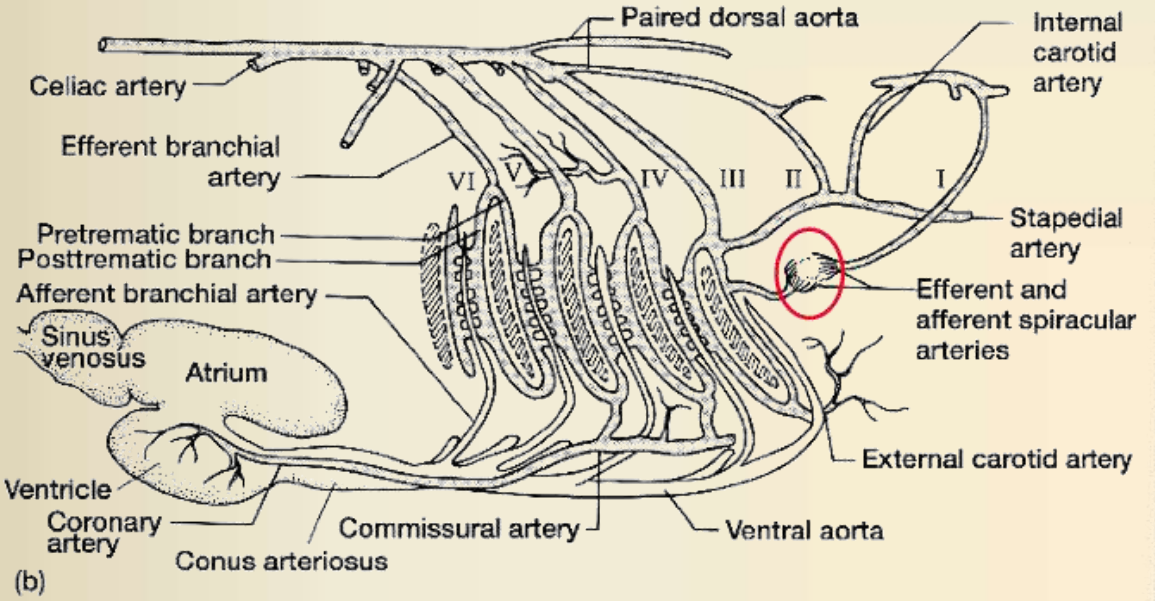
In elasmobranchs the posterior cardinal sinuses receive blood from the posterior parts of the body and drain through the common cardinal veins into the sinus venosus.
After that the blood enters the heart through the sinus venosus which drains into the atrium and then conus arteriosus.
Then the heart pumps deoxygenated blood toward the gills:

The anterior end of the conus arteriosus continues foward as the ventral aorta, the first vessel that exits the heart.

The ventral aorta divides into a series of paired afferent bronchial arteries.

These arteries are ventral to the gills & take deoxygenated blood up into the gills for gas exchange.

Oxygenated blood leaves the gills dorsally via a series of paired efferent bronchial arteries (blood "exits" the gills).
This blood is then distributed to all parts of the body.



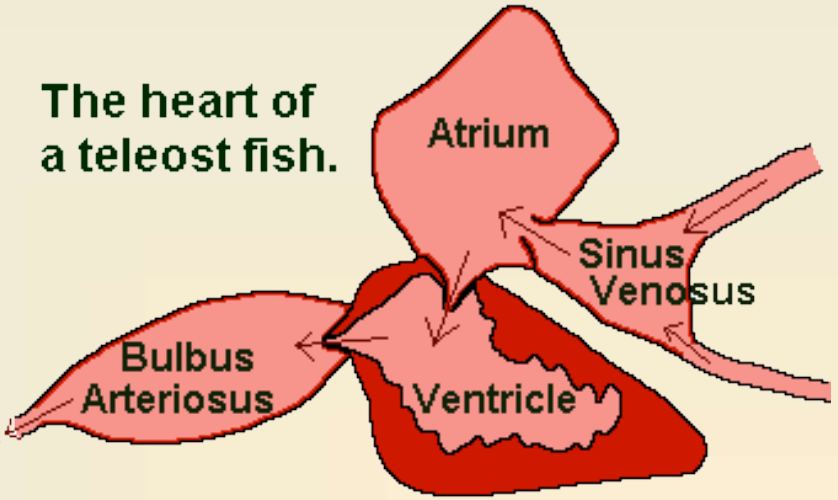
TELEOST FISH

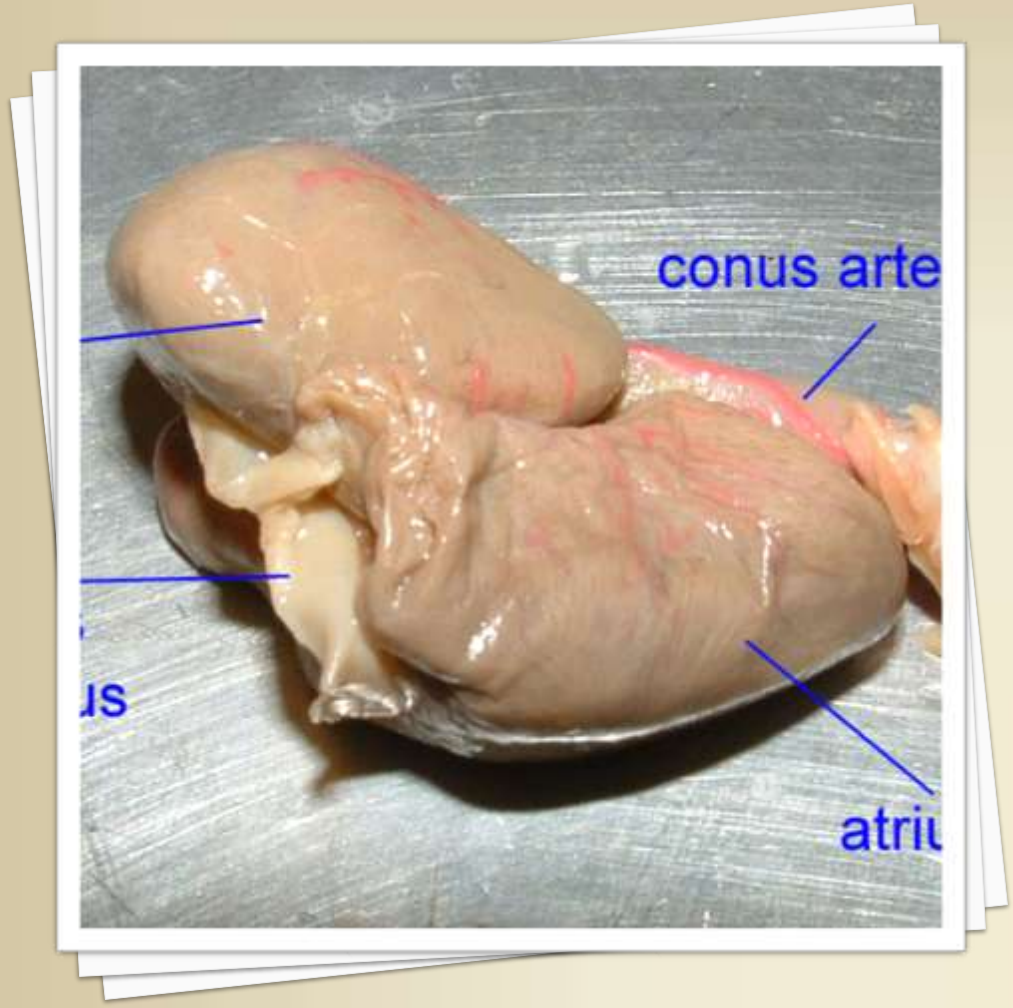
Teleost fish have a heart with 2 main chambers:

atrium and the ventricle.

The atrium has a thick and muscular walls and the ventricle is the largest and most muscular chamber of the heart.

The venous side of the heart is preceded by an enlarged chamber called the sinus venosus. The arterial side of the heart is followed by a thickened muscular cavity called the bulbus arteriosus.

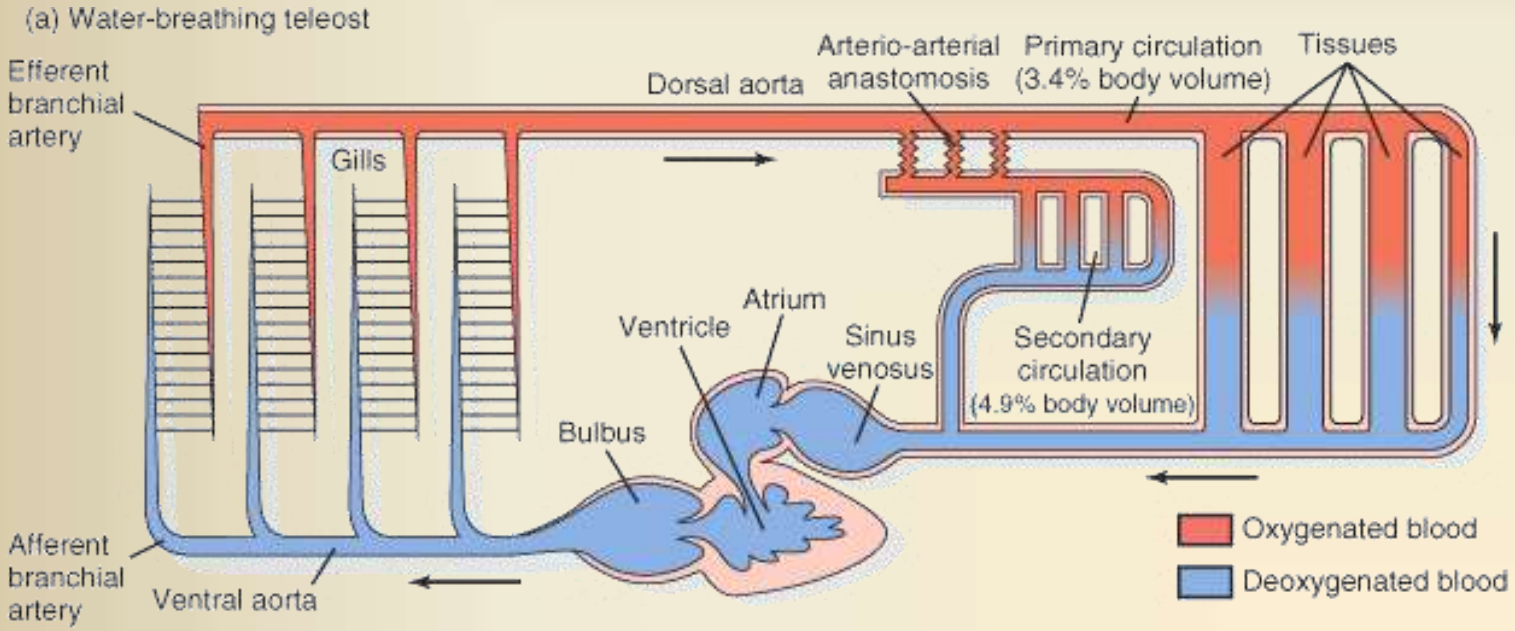




The bulbus arteriosus is a valve or series of valves that control blood flow out of the ventricle and into the ventral aorta.

In teleost;

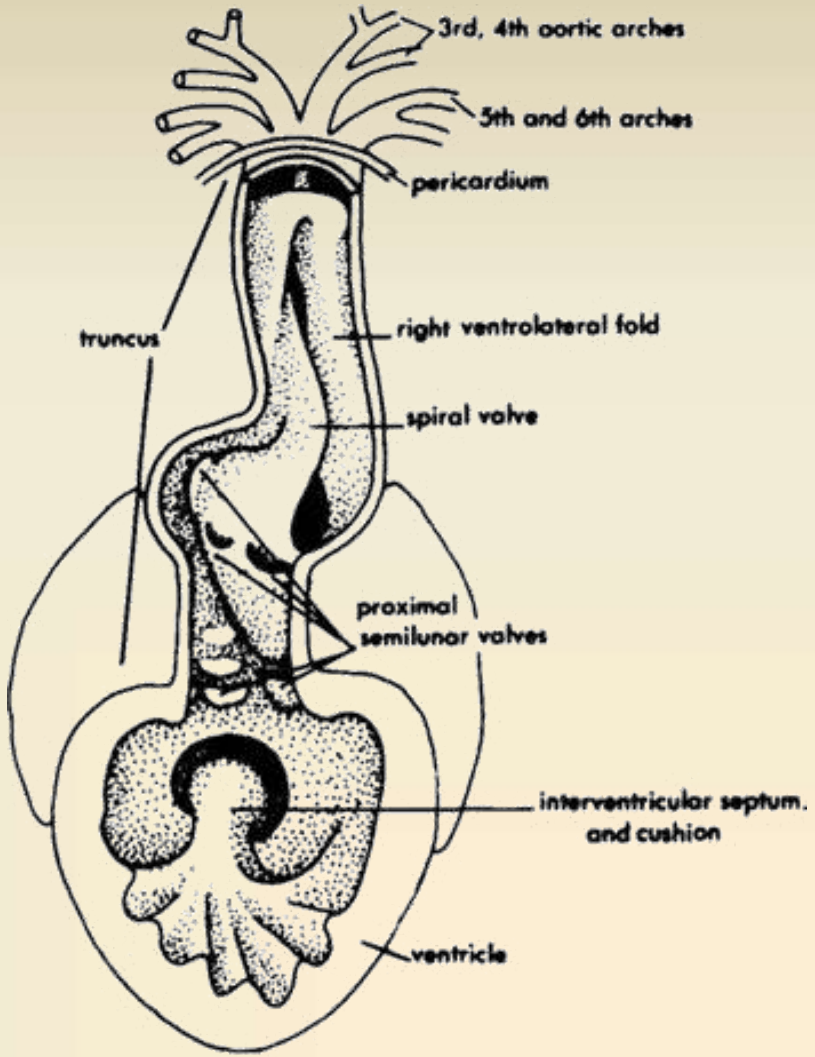
a) **The sinus venosus receives unoxygenated blood from the body, a valve at the end of the sinus venosus opens into the atrium.**
b) **Then the atrium receives unoxygenated blood and pumps it into the ventricle.**
c) **When the ventricle fills with blood it constricts and forces the blood through the bulbus arteriosus.**
d) **Blood passes through the bulbus arteriosus to the ventral aorta.**
e) **From the ventral aorta, blood flows to the gill filaments, where it is oxygenated.**


(a) Water-breathing teleost
Efferent branchial artery
Gills
Dorsal aorta
Arterio-arterial anastomosis
Primary circulation (3.4% body volume)
Tissues
Atrium
Ventricle
Sinus venosus
Secondary circulation (4.9% body volume)
Bulbus
Afferent branchial artery
Ventral aorta
Oxygenated blood
Deoxygenated blood

LUNGFISH

In lungfish the heart is surrounded by a thick, rigid pericardium, and It has a partial septum in both the atrium and ventricle and spiral folds in the bulbus that allows this to take place.

The bulbis cordis bends sharply and the wall of the ventricle (and to a lesser extent, that of the atria) has a greater amount of cardiac muscle and contains folds called trabecula.

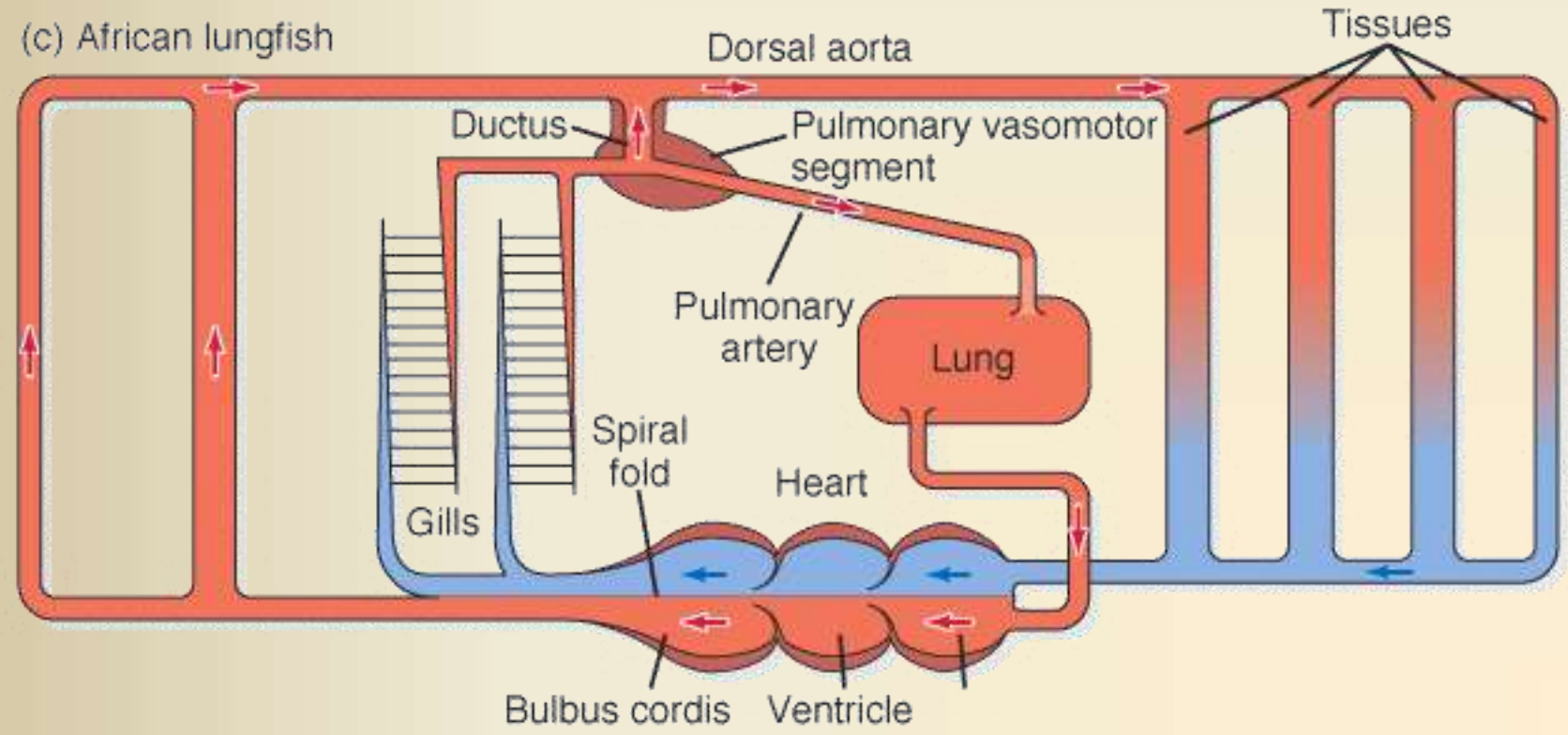


Thus in this groups oxygenated and deoxygenated blood is largely separated in the heart despite the absence of septa which completely divide the ventricles.

LUNGFISH

In lungfish, the sinus venosus empties into right atrium and the pulmonary vein empties into the left atrium.
As blood goes through the conus arteriosus, a branch carries oxygenated blood from the left side of the ventricle to the anterior gills.
A second branch of the conus carries deoxygenated blood to posterior gills and the lungs from the right side of the ventricle.
The oxygenated blood back to the heart again and then into the dorsal aorta.
This is the beginning of the double circulatory system.

However if the lung is not being used then the blood will flow from the gills through the ductus into the dorsal aorta without passing through the lung or going back to the heart.

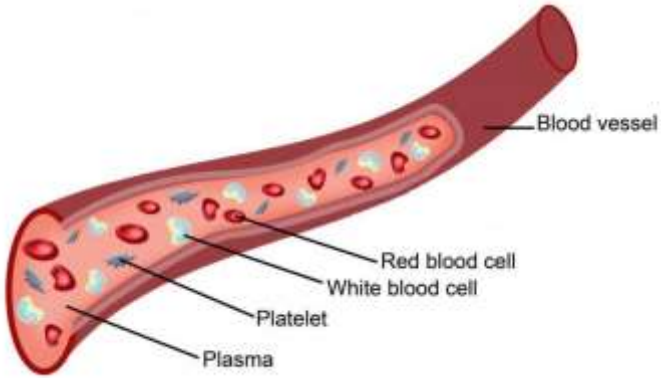


THE BLOOD

The blood is a kind of connective tissue that is consists of:

Red blood cells to transport oxygen to the cells in the fish and transport carbon dioxide away from the cells. Red blood cells are high in hemoglobin which is high in iron. The iron binds with the oxygen for transport.

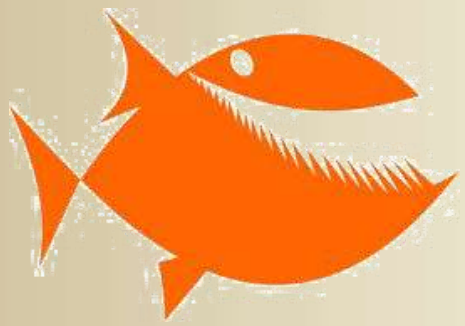
White blood cells are made up of several types and their function is to combat infection



PLASMA

Plasma is the liquid part of the blood to suspend the other components of the blood with in it, including food for the cell, hormones, and waste products from the cells to the liver and kidneys.

It is basically water with a variety of ions (Na^+, Ca^{2+}, K^+) and small organic molecules such as urea, sugars and fatty acids dissolved in it.



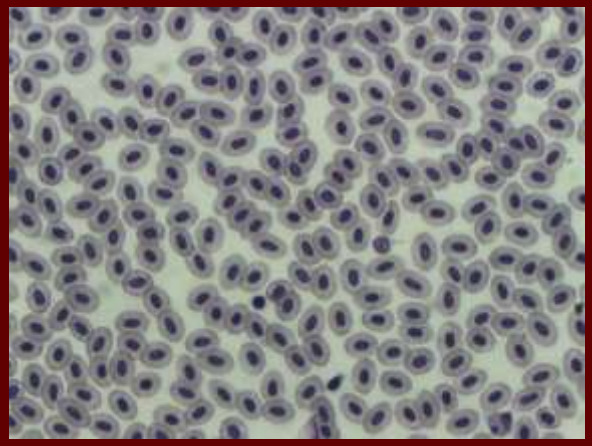
In sharks and rays blood cells are created in three different organs, the spleen, the epigonal organ which surrounds the gonads and the Leydig organ which is found in the throat near the oesophagus.

However in teleost fish blood cells are normally only produced in the spleen and the kidneys.

In lung fish Erythrocytes are formed in the spleen pulp, granulocytes in the granulocytopoietic organ of the intestine and in the capsules of kidneys, gonads, and spleen

BLOOD CELLS OF FISHES ARE CATEGORISED INTO TWO MAIN GROUPS;

•**ERYTHROCYTE (red blood cells): The term erythrocytes refers collectively to those nucleated blood cells which carry the red-pigmented.** The fish's red blood cells are elliptical. **Erythrocytes differ from leucocytes, and their primary function is in the transport of gases throughout the body.**



The blood volume of a fish consists of a plasma volume and volume of the cell within the blood, which when expressed as a percentage of the total blood volume is the hematocrit.

The blood volume of fish decrease phylogenetically.

Lamprey have a very large blood volume in excess of any other fish while the blood volume of Chondrostei, Holostei and Teleosts (both marine and freshwater species) is approximately 5-8% body weight.

Vloum	
Hagfish	17%
Lamprey	8.50%
Elasmobranch	6-8%
Tuna fish	8%
Salmon	5-7%

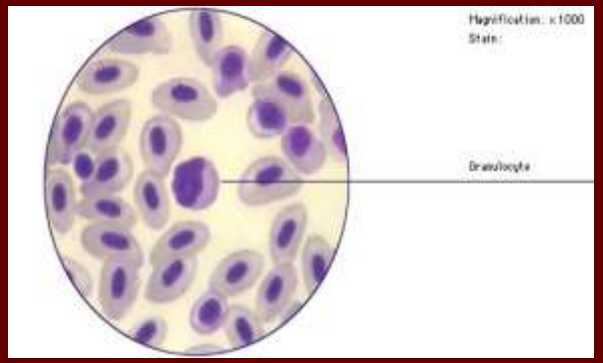
The lungfish has the largest size of RBC (35 μ) while has the least blood volume.

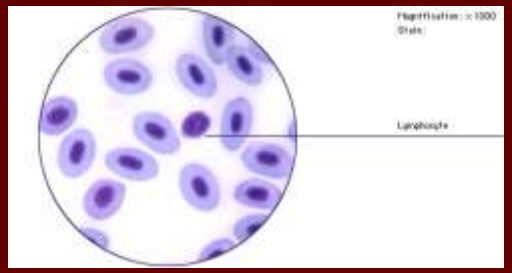
Fish	Hematocrit	Size of RBC (μ)	No of RBC
Elasmobranch	25%	20-27	>0.5 m/mm3
Teleost	20-30%	12-14	1-3 m/mm3
Lungfish		53	
lamprey		11	
hagfish			

The Icefish of the Antarctic such as *Pseudochaenichthys georgianus* have no haemoglobin in their blood and rely on gases dissolved in the plasma, this helps them become invisible, or at least harder to see. They can survive like this because;

1) they live in very cold water which has a higher content of dissolved oxygen than warm water,
2) they live fairly inactive lives so their oxygen requirements are low, and
3) their food is plentiful and easy to catch.

LEUCOCYTE (white blood cells): The term leucocytes refers collectively to those non-pigmented, nucleated blood cells whose primary function is to combat infection and in some cases to phagocytose and digest debris. They differ from erythrocytes, in that they leave the vascular system to carry out their tasks by passing through the walls of small blood vessels

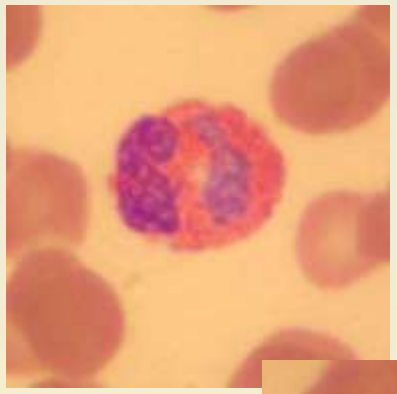


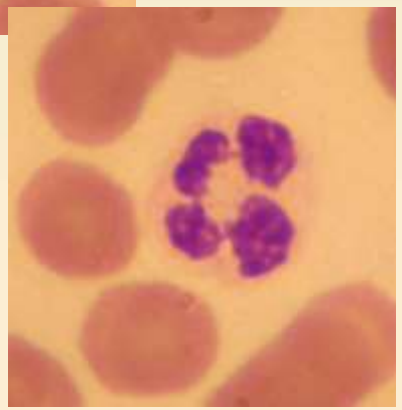


they do not contain haemoglobin. The four most important types are; Lymphocytes, Monocytes and Thrombocytes

1)Lymphocytes:- are 4.5 to 12 microns in diametre and their job is in defence is detecting and marking foreign particles, specifically they mediate antibody activity, antibodies are small molecules that find and bind to foreign materials so that Monocytes can find them.

2)Thrombocytes:- are important in blood clotting, thus they are important in conservation of resources as they prevent blood loss in case of injury.





3)Monocytes:- sometimes called Macrophages, they are important in defence, their role is to eat (phagocytize) anything they come across in the blood that might harm the fish such as bacteria, or parasite larvae.

4)Granulocytes:- are also active in defence, they specifically attack bacteria, but also seem to have a role in controlling stress.

The main functions of blood is divided into the three categories:

a) **Homeostatic functions of blood**

b) **Transport functions of blood**

c) **Immune functions of blood**

1- Homeostatic functions of Blood

Homeostasis is the maintenance (via the body's physiological mechanisms) of relatively stable conditions within the body's internal environment despite changes occurring both inside and outside the body e.g. due to eating, exercise, pregnancy, variations in external conditions, etc..

The composition of blood plasma provides the cells in the body with a suitable and stable chemical environment.

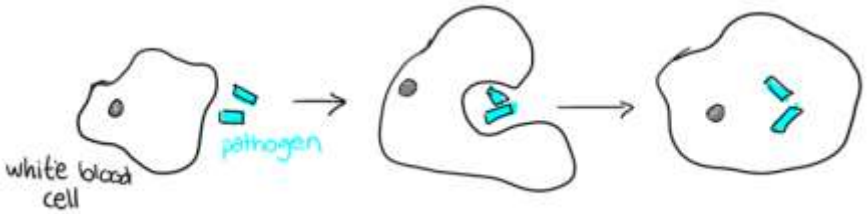
2- Transport functions of Blood

- Transports oxygen from the lungs to tissues around the body
- Transports carbon dioxide from tissues around the body to the gills and lungs (for removal from the body)
- Transports products of digestion (i.e. nutrients) from the intestine to tissues around the body.
- Transports nitrogenous waste from the liver to the kidneys
- Transports hormones from hormone producing glands to the target organs of specific hormones.
- Transports heat released by chemical processes in the body.

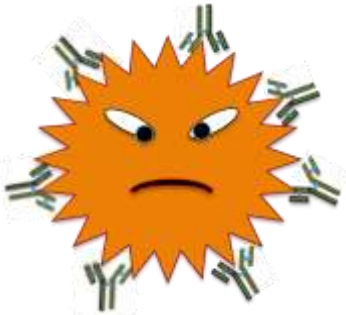
3- Immune functions of Blood

The white blood cells which are called leucocytes, perform important immune functions and are therefore described as a major part of the immune system.

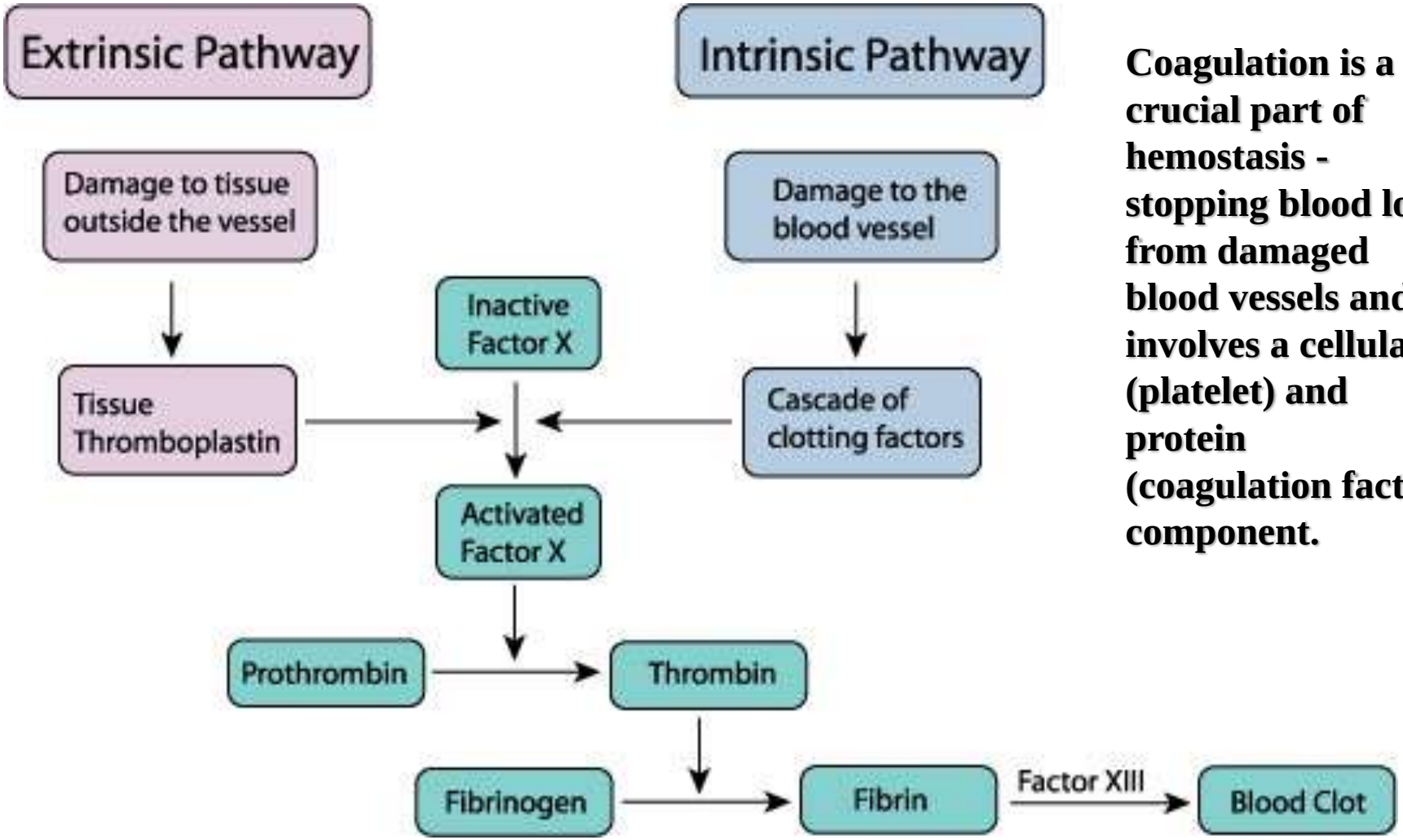
- **Blood clotting**
- **Phagocytosis**



- **Production of antibodies**

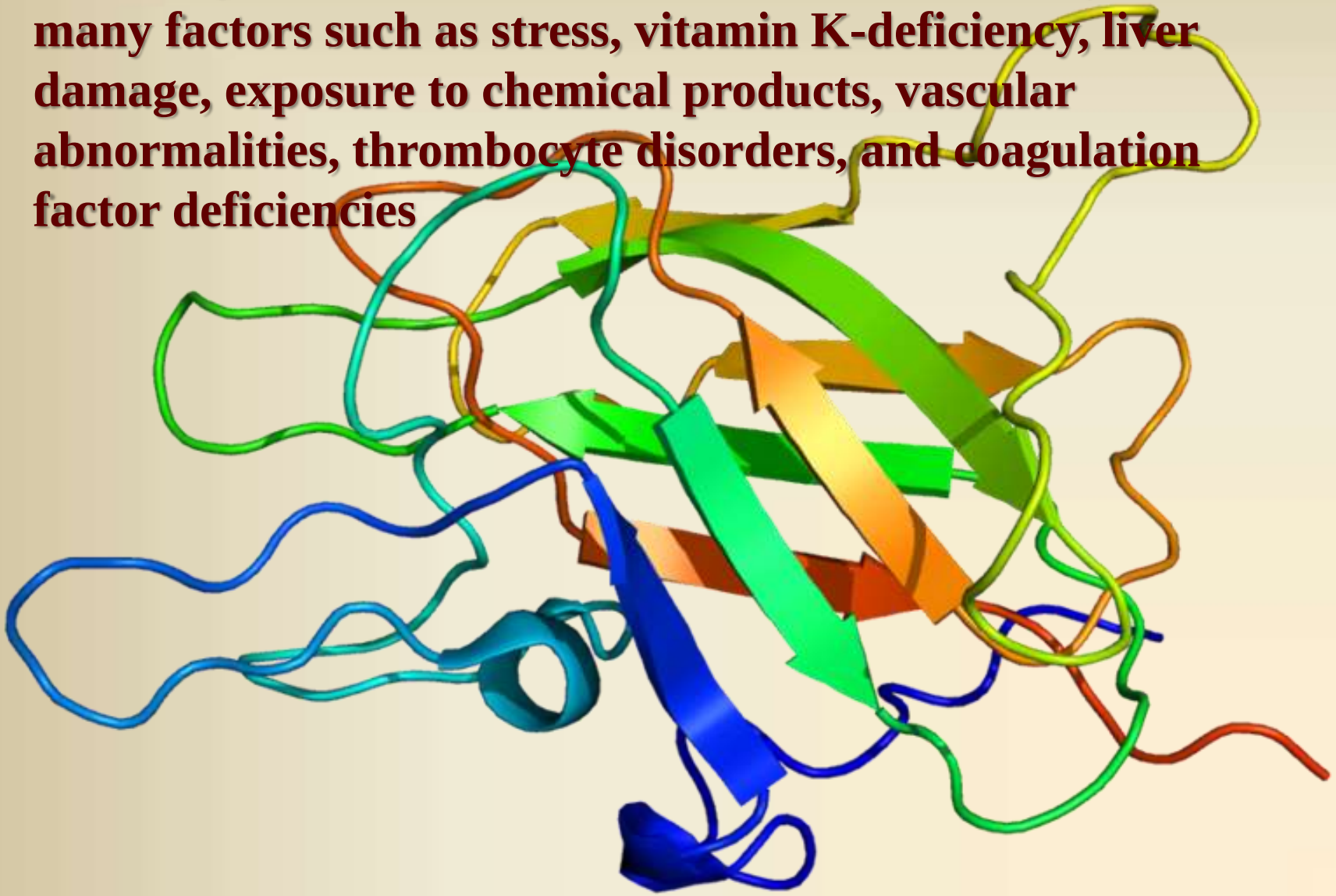


BLOOD CLOTTING



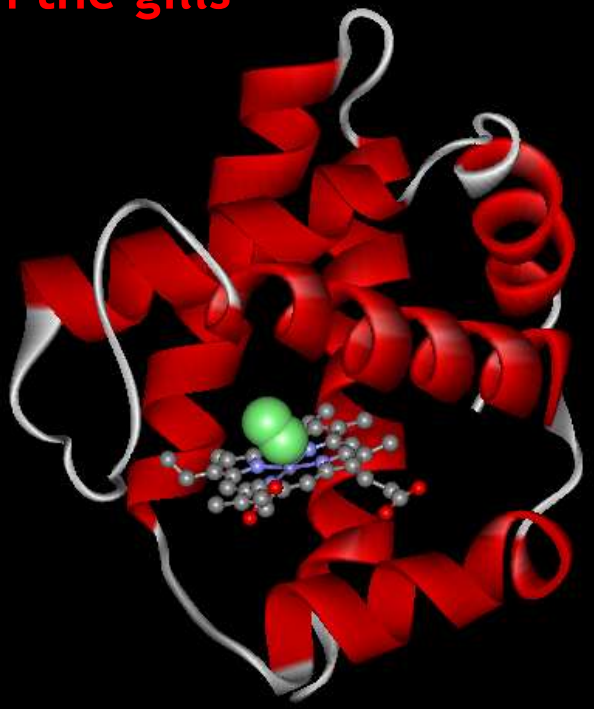
Coagulation is a crucial part of hemostasis - stopping blood loss from damaged blood vessels and it involves a cellular (platelet) and protein (coagulation factor) component.

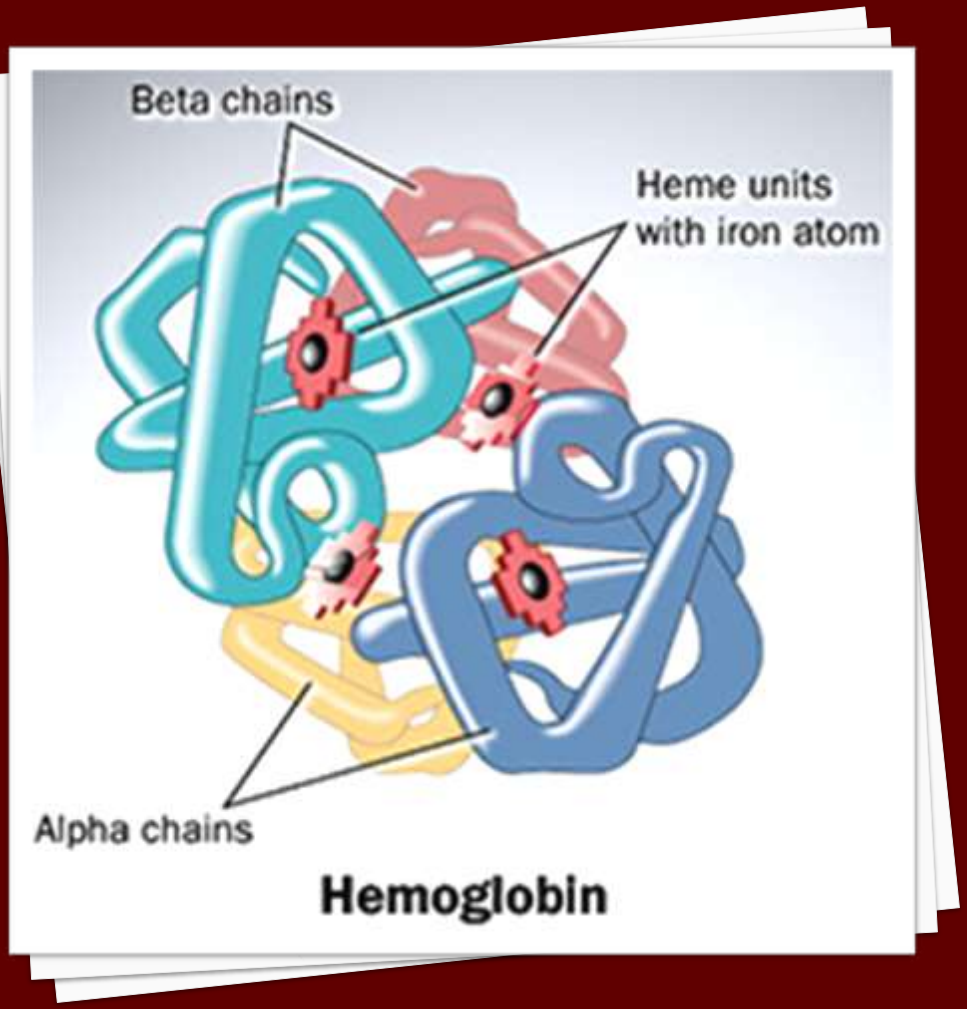
Fish coagulation mechanisms can be influenced by many factors such as stress, vitamin K-deficiency, liver damage, exposure to chemical products, vascular abnormalities, thrombocyte disorders, and coagulation factor deficiencies



HEMOGLOBIN

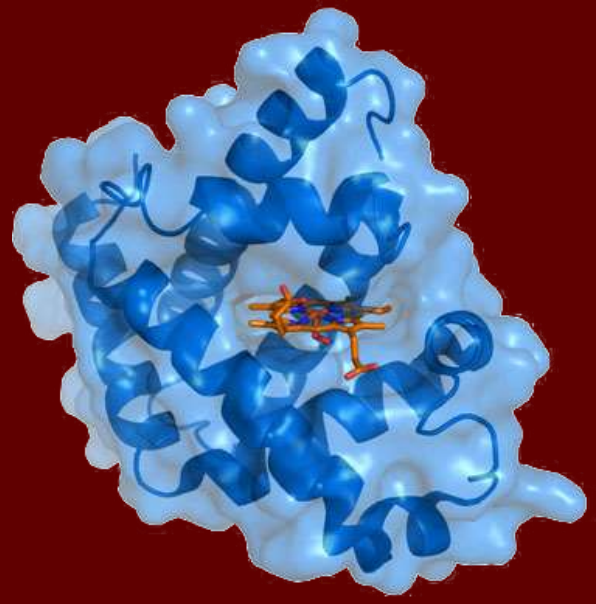
The molecule that allows the erythrocytes to do their job, and which makes them red, is called haemoglobin, or hemoglobin, and erythrocytes are full of it. Hemoglobin is the protein that transports oxygen (O_2) in the blood from the gills and lungs to the tissues of the body.





Most fishes have tetrameric haemoglobin which is built up from four different protein chains called alpha and beta chains, there are two of each in a single haemoglobina molecule. This type of haemoglobin is very similar to ours and has a molecular weight of around 65,000 daltons.

The haemoglobin of hagfish and lampreys is monomeric and called Myoglobin. It consists of a single large haem-molecule with a molecular weight of around 17,000 daltons .

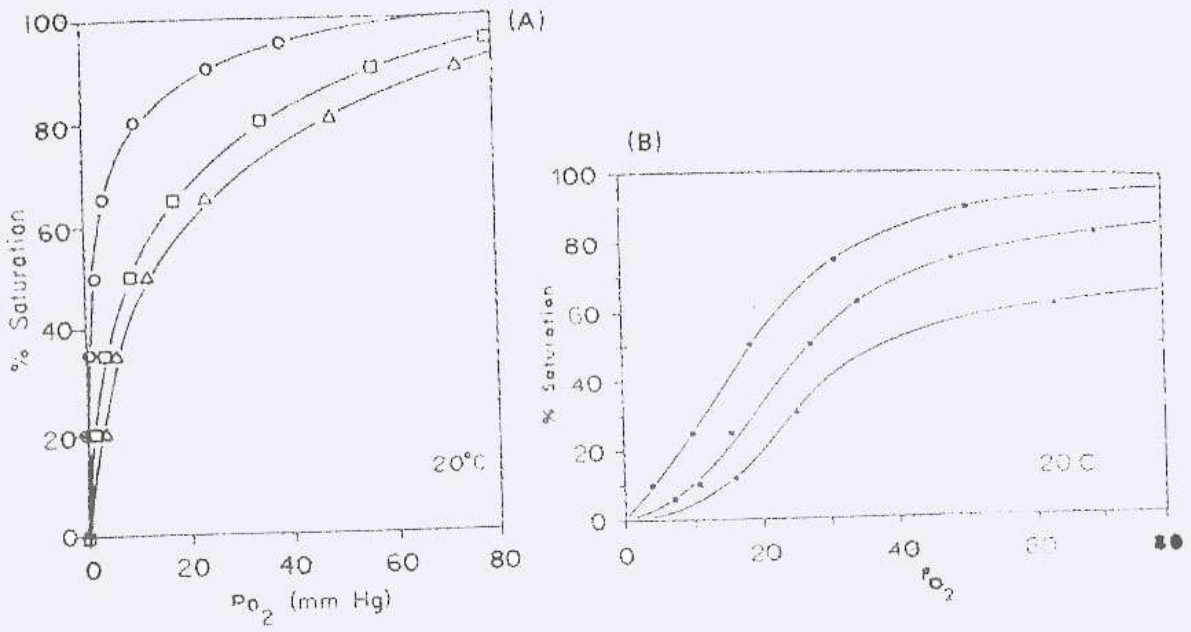


THE AFFINITY OF HEMOGLOBIN FOR OXYGEN

A convenient measure of oxygen affinity is P_{50} = partial pressure of oxygen at which one-half of the heme groups have bound oxygen.

Fish which live in a low oxygen environment (blackfish) and which lack special adaptations (lung, mouth or gut) for air breathing usually have hemoglobins with high oxygen affinities (low P50).

And the fish that live in a high PO_2 (rainbow trout) have hemohlobin with relatively low oxygen affinities.



blackfish

Rainbow trout

CARRYING CAPACITY OF OXYGEN IN BLOOD

Dissolved oxygen in plasma

Oxyhemoglobin

Icy fish	0.45-1.8%
Elasmobranch	3-6%
Teleost	8-12%
Tuna fish	20%

Factors affecting oxygen carrying capacity of blood are as follow:

Ph, Temprature, PO_2, PCO_2, Fish activity

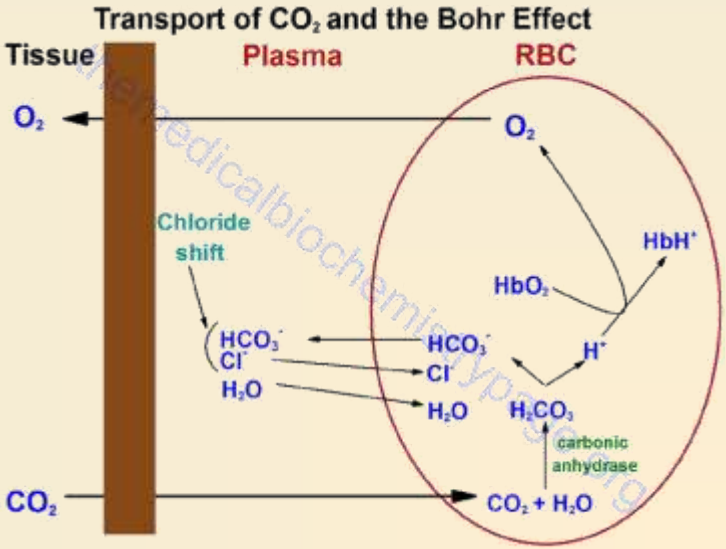
BOHR EFFECT

Bohr effect= decrease in affinity of Hb for O_2 due to decreasing pH or increasing pCO_2

↑ CO_2, ↓ pH, ↓ oxygen affinity ↑ activity of tissues ↑ unloading

- **Increase in CO_2 drives off O_2 (Bohr effect)**
- **Decrease in blood pH magnifies Bohr effect**

Within tissues (such as muscle), metabolically produced carbon dioxide (CO2) reduces blood pH and thus Hb-O2 affinity elevating blood PO2 and enhancing O2 delivery, which is collectively termed the Bohr effect.



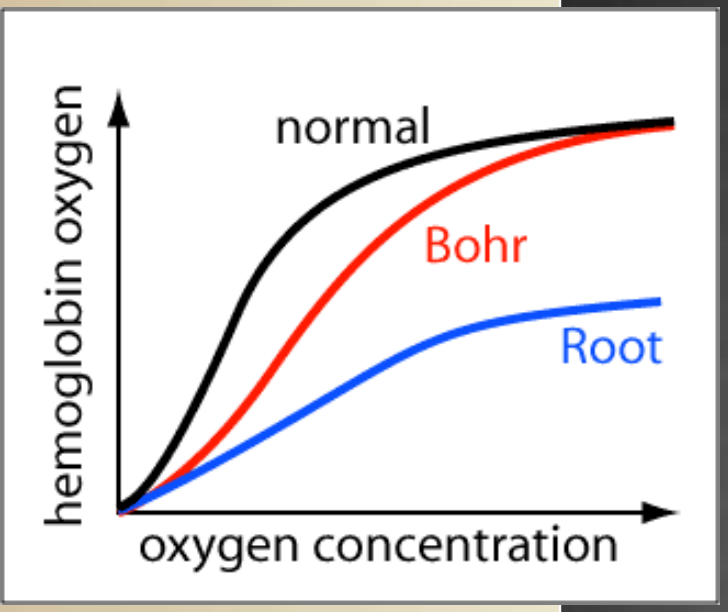
ROOT EFFECT

Root effect a reduction in blood pH reduces both Hb-O2 affinity and O2 carrying capacity due to decreasing pH or increasing pCO_2 (extreme Bohr effect)

Specific to ray-finned fishes, the Root effect has

and has a specialized roles in securing O2 delivery to the retina and swim bladder

BOHR EFFECT VS. ROOT EFFECT



Bohr shift - shape of curve;

↑ CO_2, ↓ oxygen affinity

Root effect - maximum oxygen binding;

↑CO_2, ↓ total bound oxygen

***More active species tend to have greater Bohr & Root effects**

HALDANE EFFECT

Carbon Dioxide's affinity for Deoxyhemoglobin

- **Venous blood has high affinity for CO_2**
- **Arterial (Oxyhemoglobin) has reduced affinity for CO_2**

So Hemoglobin picks up Carbon Dioxide in the tissues where:

pO_2 is low, and releases Carbon Dioxide in the gills and lungs where;

pO_2 is high

HALDANE VS BOHR EFFECT

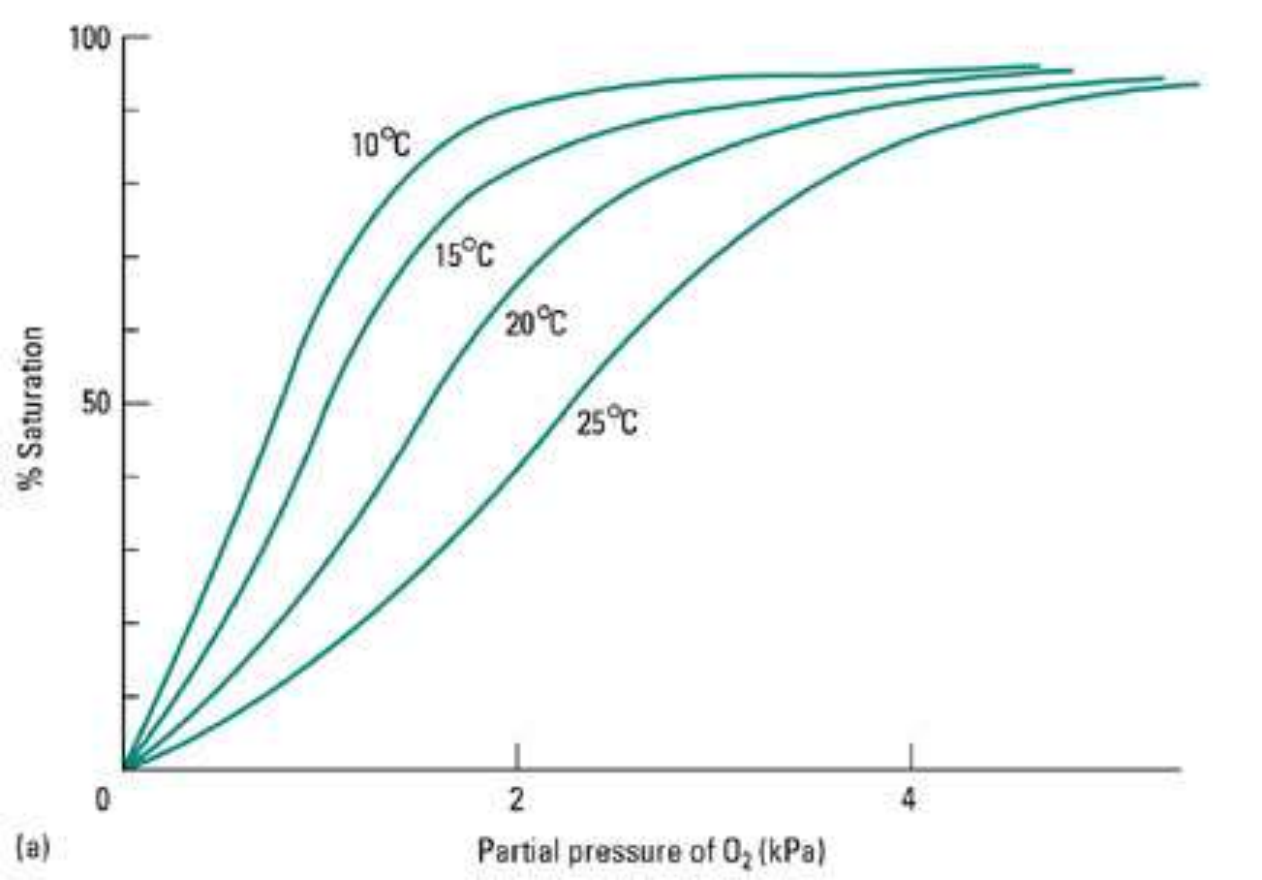
- The Haldane effect describes how **oxygen** concentrations determine hemoglobin's affinity for carbon dioxide.
  - **H** - emoglobins
  - **A** - ffinity
  - l**D**ane - Carbon **D**ioxide

- The Bohr effect, on the other hand, describes how **carbon dioxide and H+** affect hemoglobin's affinity for oxygen.
  - B
  - **O** - xygen
  - **H** - ydrogen
  - **R** – eleased in tissue

TEMPERATURE

↑ temperature, ↓ oxygen affinity

↑ activity of tissues ↑ unloading



METHB

Nitrite is toxic to fish as it diffuses from blood plasma into red cells, where it oxidezes the fe2+ in hemoglobin to the fe3+ oxidation state converting hemoglobin into methemoglobin (metHb).

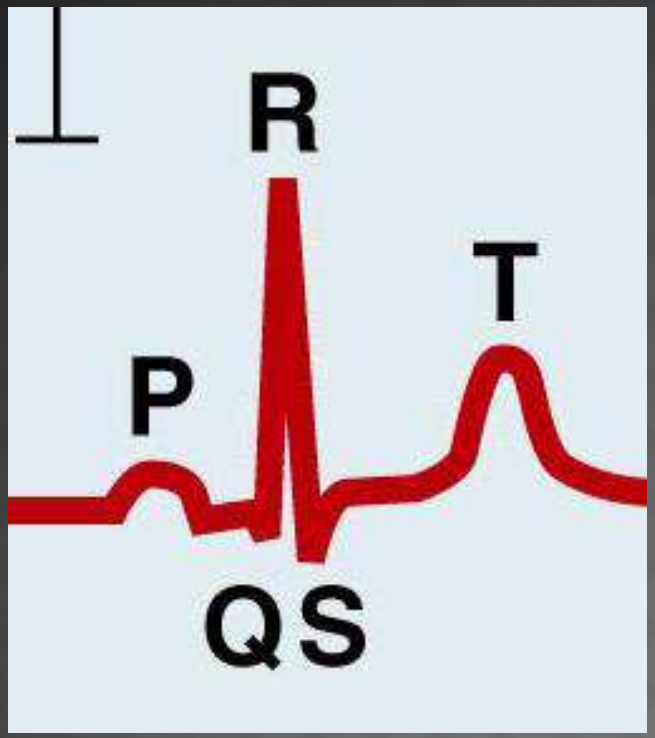
THE CARDIAC CYCLE

Cardiac Cycle: Rhythmic Pumping of Heart

2 Phases of Cardiac Cycle =

1. Systole – contraction
2. Diastole – relaxation

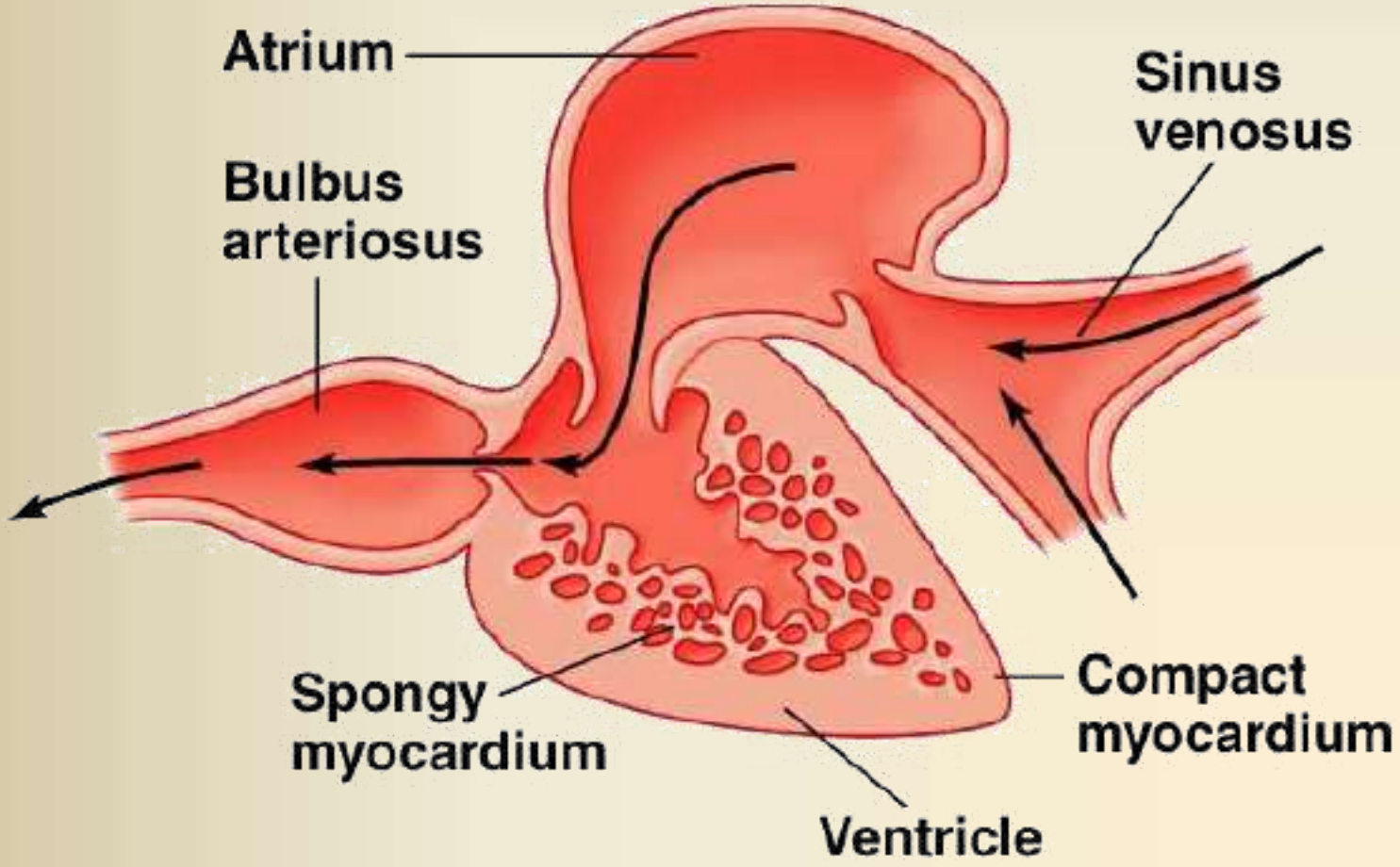
ELECTROCARDIOGRAM (EKG)= MARKERS OF ELECTRICAL ACTIVITY OF THE HEART



- P wave = atrial depolarization
- QRS complex = ventricular depolarization and atrial repolarization
- T wave = ventricular repolarization 000

IMPULSE CONDUCTION IN FISH

- Impulse codnuction via gap junctions is sufficient to provide coordinated contraction of the chambers.
- Signal travels from sinus venosus to the atrium and then to the ventricle.
- Contraction occurs in a series.


Atrium
Sinus venosus
Bulbus arteriosus
Spongy myocardium
Compact myocardium
Ventricle

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