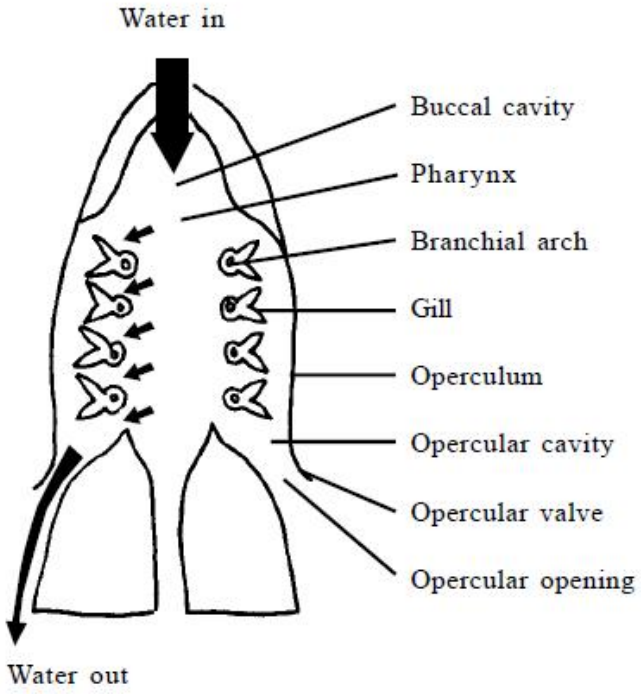
Gaseous exchange in a bony fish

Fish use water as a medium for gaseous exchange. Fish rely on specialised flaps of tissue called gills for gas exchange. Gills may be external or internal. External gills usually have a higher surface area but they are less protected.

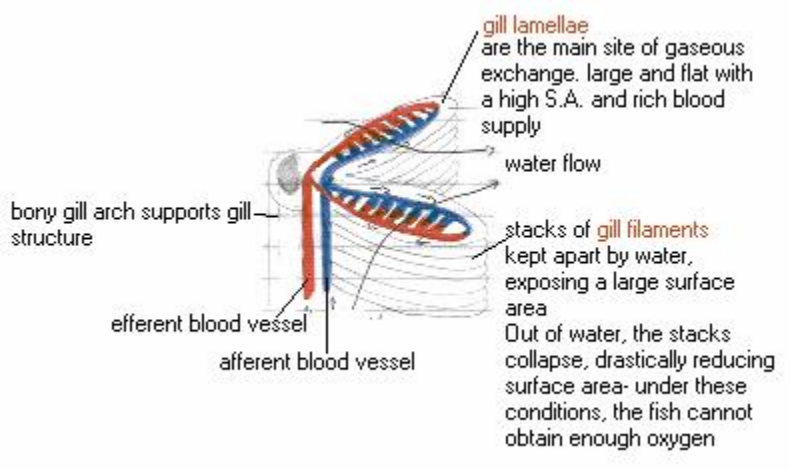
In bony fish the entire gill region is covered by a muscular flap of skin the operculum. This encloses an opercular cavity into which gills project. It protects the gills and plays a part in ventilationthe two sides of the gills are apart and poin obligue outwards from the branchial arch. The bony fish has 8 branchial arches, 4 on each side of the pharynx.

The branchial bony arches separate five pairs of gill cleft and support the lamellae. Each gill on the arches is composed of two rows of fragile gill filaments arranged in the shape of V. the filament increase on the surface area by having a rich supply of capillaries.

Horizontal section through pharynx and gills



Transverse section through the gill



The general structure of a mature gill is composed of several parts:

- Gill rakers are cartilagenous or bony parts on the pharyngeal margin of the gill and function in preventing food particles from entering the gill chambers
- Gill rays are found within the interbranchial septa and provide support for the gill
- Gill filaments are the feather-like projections of the gills across which diffusion of gases occurs
- Gill filaments also possess gill lamellae, which are small crevices through which water passes for diffusion
    - lamellae are oriented parallel to the stream of water through the gills to maximize efficiency of diffusion
    - the blood flow through the gills opposes the flow of water through the lamellae (countercurrent flow) and maximizes the efficiency of diffusion - this is important because water has about 1/30th the oxygen concentration of air

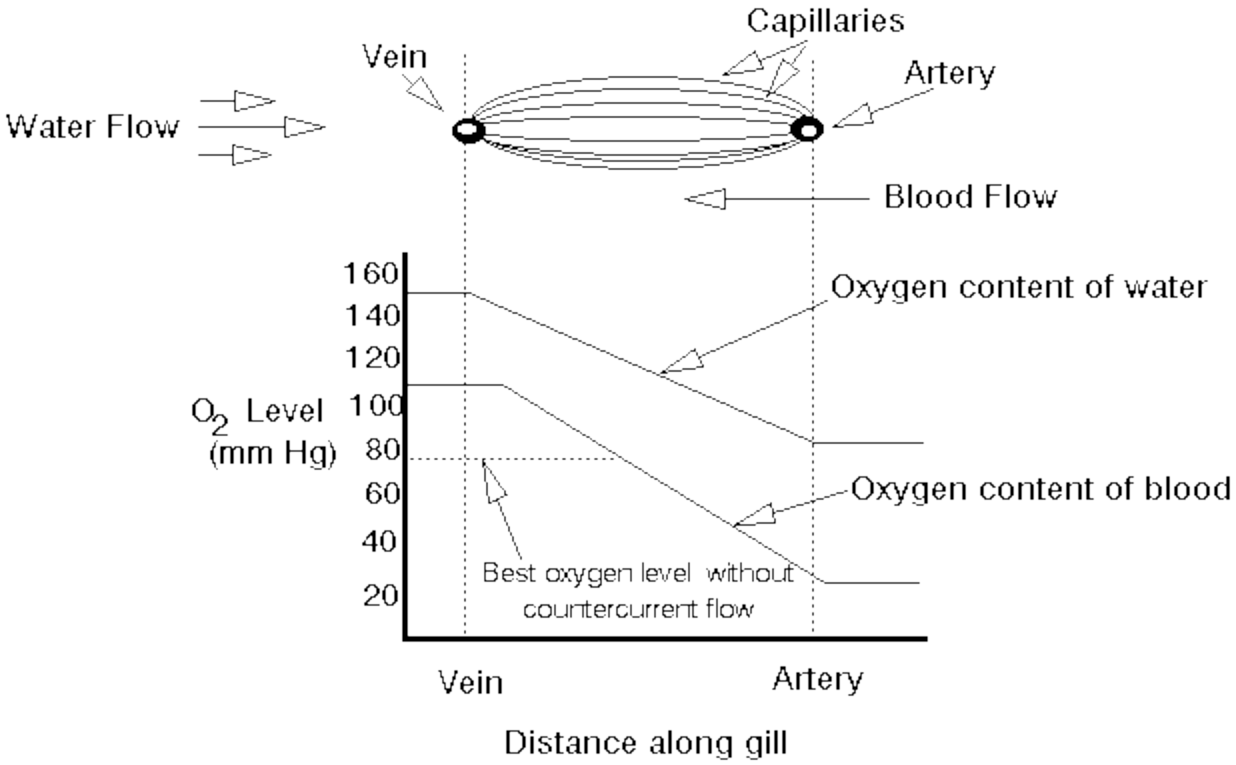
The deoxygenated blood enters the gill capillaries via the afferent branchial artery. Oxygenated blood leaves in the efferent branchial artery to join the dorsal aorta. The circulation of blood through each half gill is similar to the dog fish, but as the water pass from the pharynx into the opercular chamber, it flows between the gill plates in the direction opposite to the blood flow. The free ends of the adjacent gills touch each other to increase on the resistance to flow of water and thus the water passes between the lamellae as it flows from the pharynx to the opercular chamber and there is more time for the exchange of gases.

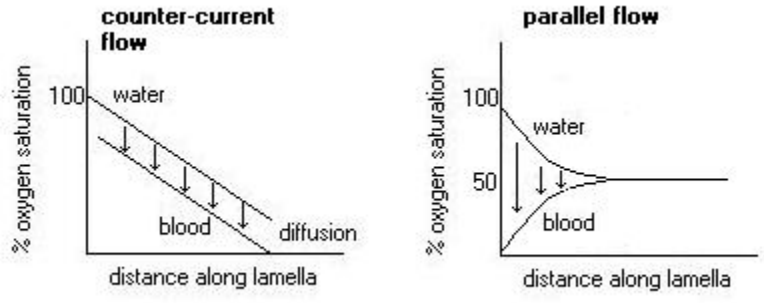
A single pair of opercular valves performs the function which in the dog fish (cartilaginous fish) is carried out by the five pairs of branchial valves.

The arrangement of gills with lamellae approximately at 90® to each other allows for a counter current exchange system for water and blood across the gill plates. This system is more efficient than that of cartilaginous fish.

Advantages of counter current flow exchange system.

In a counter current system a concentration gradient between the water and the blood is maintained along the gill. As a result higher saturation of blood with oxygen is possible and larger amount of carbon dioxide is removed.





In parallel system like in cartilaginous fish (sharks and rays) the blood in the gills travels in the same direction as the water is flowing. Therefore a steep concentration gradient between the two is only at the beginning. Diffusion takes place until the blood and water are in equilibrium, after this no net movement if oxygen into the blood or carbon dioxide of the blood occurs. As a result blood leaves the gill plate less saturated than it have been under counter current flow. This is worse if both blood and

water are flowing at the same speed. Some animals improve on the parallel system by increasing the speed of water over that of blood.

Ventilation of the gills

A ventilation mechanism operates in most fish which involves a muscular contraction which by adjusting presents in both the bucal cavity and opercular cavity cause water to move fast into the bucal cavity then through the valves of the opercular.

These muscular movement operate by changing the volume of the bucal cavity, pharynx , gill cavity and opercular cavity in that order.

As the volume of a chamber (cavity) decreases its pressure increases resulting in the squeezing of water to where the pressure is less.

These events are summarized on the graph below**…….. Check in functional approach.**

During inspiration

1. Muscular contraction exerts in the floor of the pharynx and bucal cavity resulting in bucal cavity expanding. The bucal cavity pressure decreases. Mouth valve opens leading to opening of the mouth and water with dissolved oxygen enters from the outside because of reduced pressure.

2. At the same time the operculum bulges outwards leading to the opercular cavity expanding. The opercular cavity acquires a negative pressure i.e. pressure reduces therefore opercular valve closes.

3. The expansion of the opercular cavity leads to pressure falling below that of the bucal cavity which has began to contract as a result water is sucked into the opercular cavity from buccal cavity and flows over the gills where gaseous exchange takes place.

During inspiration

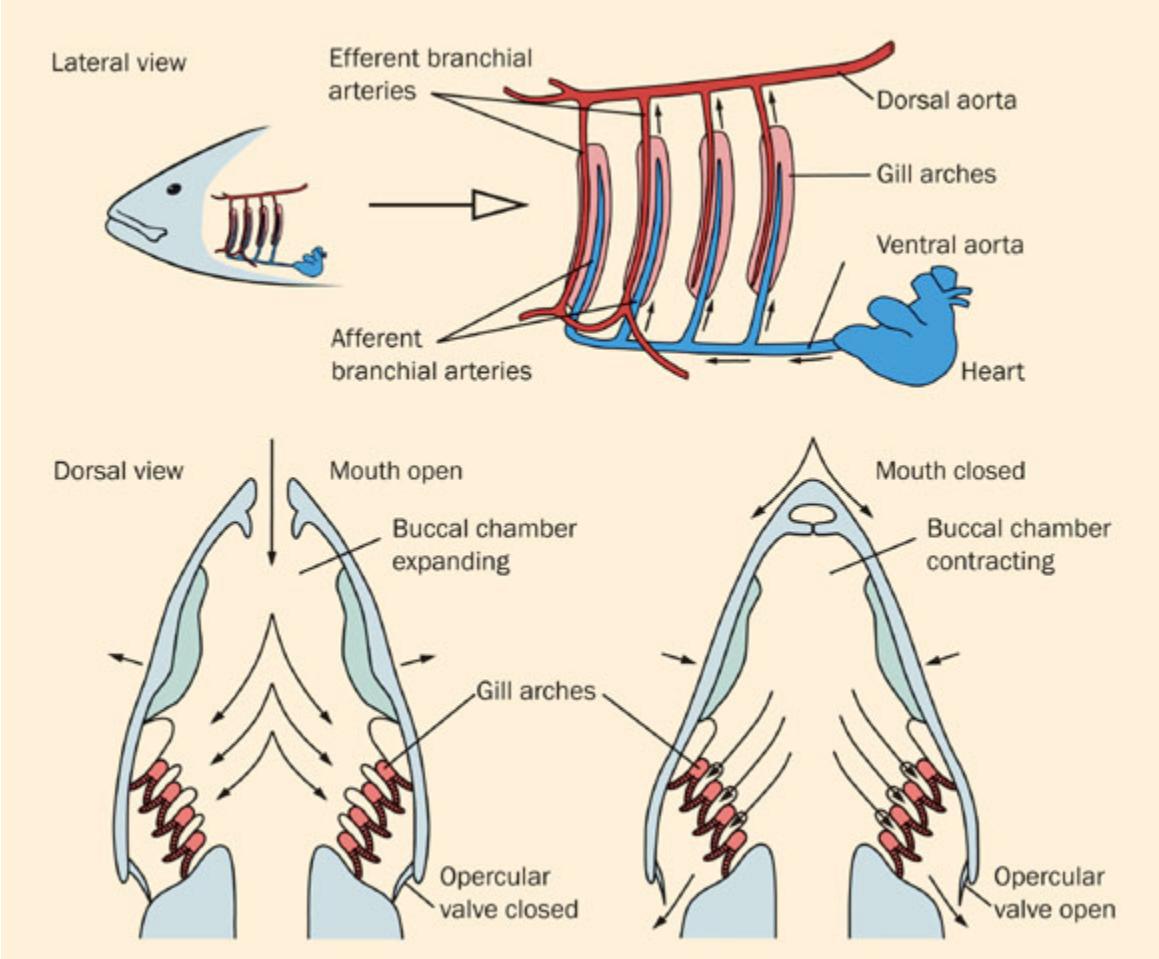
4. Muscular contraction leads to floor of pharynx raising and buccal cavity continuing to contract. The buccal cavity acquires positive pressure i.e. pressure increases, mouth valve closes and water is then forced from buccal cavity to opercular cavity.

5. There is inward movement of the operculum. The opercular cavity contracts and acquires a positive pressure, opercular valve opens and water containing carbon dioxideis expelled.

   Note that the pressure in the buccal cavity is higher than that in the opercular cavity. Also a continous stream of water is maintained over the gills throughout most of the breathing cycle by the combined action of the buccal cavity as a suction pump. Apart from the time when both the mouth and opercular valves are open, the pressure in the buccal cavity hence continous flow of water from the buccal cavity to opercular cavity.

Gaseous exchange in cartilaginous fish.

Horizontal section through the pharynx and gill



Cartilaginopus fish lack the opercular cavities but have parabranchial cavities enclosed by flap like branchial valves. The gills are supported by a series of skeletal branchial arches which are separated from one another by gill pouches through which water flows on its way over the respiratory surfaces. At the base of each gill, close to gill arch, is an afferent branchial artery which brings deoxygenated blood to the gill from the ventral aorta beneath the floor of the pharynx. The base also contains a pair of efferent branchial arteries, each derived from a loop vessel encircling the pouches on either side of the gill. An epibranchial artery conveys blood from each efferent loop to the dorsal aorta above the roof of the pharynx.

Inspiration

Water with dissolved oxygen is drawn through the open mouth and spiracles into the pharynx which is expanded as a result of contraction of hypobranchial muscles and relaxation of transverse muscles. Then it is drawn into parabranchial cavities by out ward movement branchial valves. It flows over gills in a parallel system and gaseous exchange takes place.

This takes place as blood flows through the capillaries in the gill plates. The barrier between the blood and water is only several cells thick and offer little resistance to diffusion.

During expiration water containing carbon dioxide is expelled from the gill pouches by raising the floor of the mouth cavity and pharynx. This is brought by relaxation of hypobranchial muscles, contraction of transverse muscles and mouth plus spiracles closed.

Comparison between gaseous exchange mechanism in a bony fish and cartilaginous fish

Similarities

1. The respiratory medium is water
2. Gills are the gas exchange organs and gas exchange occurs at the gill plates
3. Entry of water during inspiration is via the mouth
4. There is a ventilation mechanism ensuring continous flow of water over the gills.

Differences

Cartilaginous fish	Bony fish
Ventilation is by adjustments in the buccal cavity and pharynx	Ventilation is by adjustment in the buccal pharyngeal and opercular cavities
During inspiration water enters through the spiracles and mouth	Water enters through the mouth only
During expiration exit of water is via gill slits enclosed by the branchial valves	During expiration exit of water is via the opercular valves
They employ a parallel flow mechanism between water and blood.	They employ a counter current flow mechanism between water and blood.