VIVEKANANDA COLLEGE

THAKURPUKUR

KOLKATA-700063

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TOPIC: RESPIRATORY ORGAN IN FISH (GILLS)

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NAME OF THE TEACHER: RANU CHAKRAVARTY

NAME OF THE DEPARTMENT: DEPARTMENT OF ZOOLOGY.

RESPIRATORY ORGAN IN FISH: STRUCTURE OF GILLS

The process of obtaining oxygen from the environment and eliminating carbon dioxide is termed as external respiration. It is accomplished via respiratory membranes that are part of some organ. Organs that are essential for external respiration constitute, collectively called respiratory system.

These respiratory membranes are highly vascular, epithelium must be thin, the surface should be moist to facilitate diffusion of gases through the semipermeable membrane, and it must be in contact with the environment or the environment must be brought into the contact with the respiratory surface.

RESPIRATORY ORGANS

In most vertebrates the organs of external respiration are thin-walled structures well supplied with blood vessels. Such structures bring blood into close association with the external medium so that the exchange of gases takes place across relatively small distances. There are three major types of respiratory structures in the vertebrates: gills, integumentary exchange areas, and lungs. The gills are totally external in a few forms (as in *Necturus*, a neotenic salamander), but in most they are composed of filamentous leaflets protected by bony plates (as in fish). Some fishes and numerous amphibians also use the body integument, or skin, as a gas-exchange structure. Both gills and lungs are formed from outpouchings of the gut wall during embryogenesis.

Major modifications in the design of respiratory organs have occurred during animal evolution to optimize the diffusion of important gases. The rate of passive diffusion between an organism and its environment depends on several factors.

- One is surface area: The greater the available surface area, the greater is the opportunity for molecules to move across an epithelial surface
- Another factor is distance: The greater the distance, the longer it will take for molecules to reach their destinations.
- A third factor is the resistance to diffusion by the tissue barrier itself.
- The difference in partial pressures across the exchange surface.

GILLS IN FISH

Internal gills in fishes are associated with pharyngeal slits and pouches. Often they are covered and protected laterally by soft skinfolds, such as the interbranchial septum in chondrichthyan fishes, or by a firm operculum, as in many osteichthyan fishes. Ventilation usually involves the muscular pump of the buccal cavity actively driving water across the internal gills.

SEPTAL GILLS IN CHONDRICHTHYES

Numbers: Most elasmobranchs -sharks, skates and rays are pentanchid having 5 pairs of gill pouches containing gills.

Location: Five gill pouches are present in a series on either side in the lateral wall of pharynx, behind the hyoid arch. A pair of functional spiracles located dorsally immediately in front of the hyomandibular cartilages.

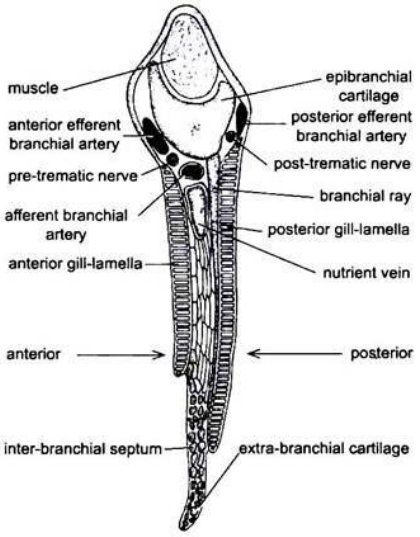


Fig.14.26. *Scoliodon.* A horizontal section through a holobranch parallel to the branchial lamellae.

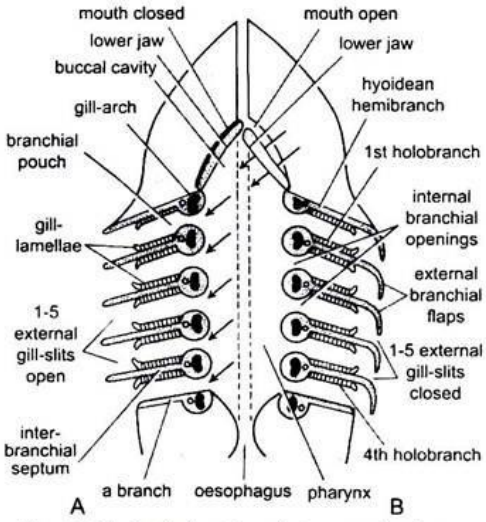


Fig. 14.27. *Scoliodon.* Respiratory mechanism. A–Expiration; B–Inspiration.

Structure:

- Each gill-pouch is compressed antero-posteriorly. It opens into pharynx by a large **internal branchial aperture** and to outside by a narrow **vertical external branchial aperture** or gill-slit.
- Two adjacent gill-pouches are completely separated from each other by a vertical fibro-muscular partition, the inter-branchial or gill septum.
- The inner or pharyngeal border of each gill septum is supported by a cartilaginous visceral arch or gill arch with its slender branchial rays that radiate from the gill cartilage.
- The septum is covered by an epithelium and contains blood vessels, nerves, etc. The mucous membranes of a septum is raised into numerous horizontal leaf-like folds, called **Primary gill lamellae or gill filaments.** The primary lamellae are composed of standing rows of secondary lamellae. These constitute the gill proper and are richly supplied with blood-capillaries.
- Each septum bears two sets of gill-lamellae, one on its anterior face and the other on its posterior face. Each set makes a half gill **called demibranch or hemibranch**, while both the sets attached to a gill arch and its gill septum constitute a complete gill **called holobranch**. The posterior or the post-trematic demibranch of a septum has longer lamellae than those of the anterior or pre-trematic demibranch. A gill pouch thus contains two demibranchs belonging to two adjacent gills. This constitutes the **Respiratory unit**.
- Stubby **gill rackers** projecting from the pharyngeal border of each gill arch guard the slit like entrances from the pharyngeal lumen into the gill chambers, protecting the gills from mechanical injury.
- In *Scoliodon*, the hyoid arch bears only a demibranch on its posterior face, the first four branchial arches bear holobranchs, while the fifth branchial arch is a branch or without any gill.
- In elasmobranch fishes, the interbranchial septa extend well beyond their gill lamellae to form flaps which protect the gills as well as external gill slits. Such gills are called lamelliform and are regarded more primitive than those of bony fishes.

[In *Scoliodon* in front of hyoid arch or the first internal gill slit, on either lateral side of pharynx, is present an oval pit of spiracle. It has no gill lamellae and 'no external opening and is regarded a vestigial gill pouch. But in most others elasmobranch fishes, it contains minute gill lamellae, consisting of avascular rete/network develops in its anterior wall forming a false gill or pseudo-branch and opens to the exterior by an external aperture just behind the eye]

Mechanism of respiration:

During respiration, water taken into the pharynx via spiracle and mouth. Most of the water entering via the spiracles in sharks flows into the first two gill pouches, whereas that entering via the mouth enters the last three pouches.

1. Inspiration: A series of branchiometric muscles, constrict the external gill slits and expand the buccopharyngeal chamber and enlarging its cavity. As the external gill slits are tightly closed, a vacuum is created and the water is sucked through the spiracle and the open mouth.
2. Then the mouth closes, the gill chambers are expanded by the action of the levator and hypobranchial muscles, and he gill chambers fill with water.
3. Expiartion: At the same time the constrictor and inter-branchial muscles contract raising the floor of pharynx and reducing its volume. As a result, water is forced into gill pouches, over the gill lamellae, and out through the open external gill slits.

In the interval between expiration and the next inspiration, both mouth and the gill slits remain open.

Opercular gills in bony fishes

The operculum of the bony fishes provides a protective cover over the branchial arches and the gill they support.

Number: Teleosts have 4 pairs of filiform gills supported by the first 4 pairs of gill arches.

Location: Four gills are present on either side of pharynx in a common gill chamber.

Structure:

- Each gill chamber is covered externally by a bony flap, the operculum, that commences at the hyoidarch and extends caudad, covering the gill chambers on either side.
- A branchiostegal membrane is attached to the posterior margin of operculum. The chamber opens to outside by a large crescentic branchial or gill aperture behind the operculum and in front of the pectoral fin.
- Each gill consists of two rows (hemibranchs) of slender gill filaments called the primary gill filaments. The filaments are attached to an extremely reduced interbranchial septum so that their distal ends hang freely in the gill chamber. This type of gill is called **filiform or pectinate.** Thus there are 8 hemibranchs or 4 holobranchs only attached to first 4 branchial arches, and 5 gill slits on cither side beneath an operculum.
- The inner or pharyngeal border of each gill arch has teeth-like processes, **the gill rakers**, which do not permit food particles to enter the gill chamber.

- Each gill filament bears several minute transverse plates or lamellae covered with thin epithelium and containing minute capillaries between afferent and efferent branchial arteries.

MECHANISM OF RESPIRATION

Breathing movements occur in two steps , the gill chambers working as suction pumps.

1. Inspiration: during inspiration the opercula and the branchiostegal membrane press against the body keeping the two external branchial apertures tightly closed. The gill arches bulge laterally enlarging the internal capacity of the bucco-pharyngeal cavity which works as a suction pump. As a result the oral valves open and water flows in through the opened mouth to fill the bucco-pharyngeal cavity.
2. Expiration: Now the oral valves close shutting the mouth , the gill arches contract and the opercula and the branchiostegal membrane lift, opening the external branchial apertures. Consequently, the water under pressure is forced to pass over the gill filaments and out through the external branchial apertures. An oral valve at the anterior end of the oro-pharynx immediately behind the mouth prevents escape of water by mouth. Thus a suction pump or a pressure pump, operating rhythmically, keep the gills bathed in oxygenated water.

PHYSIOLOGICAL SIGNIFICANCE OF THE GILL

- Position of gill arches beneath the operculum on the left side of fish. The operculum has been lifted to show the arch.

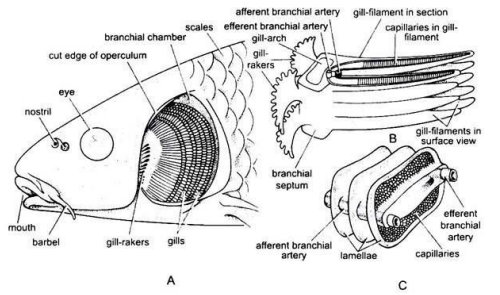


Fig. 15.10. Gills of a bony fish. A – Operculum cut away showing gills in the left gill-chamber; B – Part of gill showing gill-rakers and filaments; C–Three lamellae of gill-filament showing blood supply.

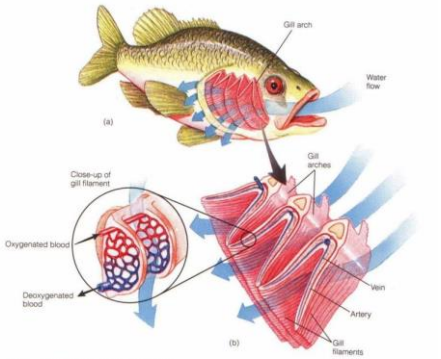


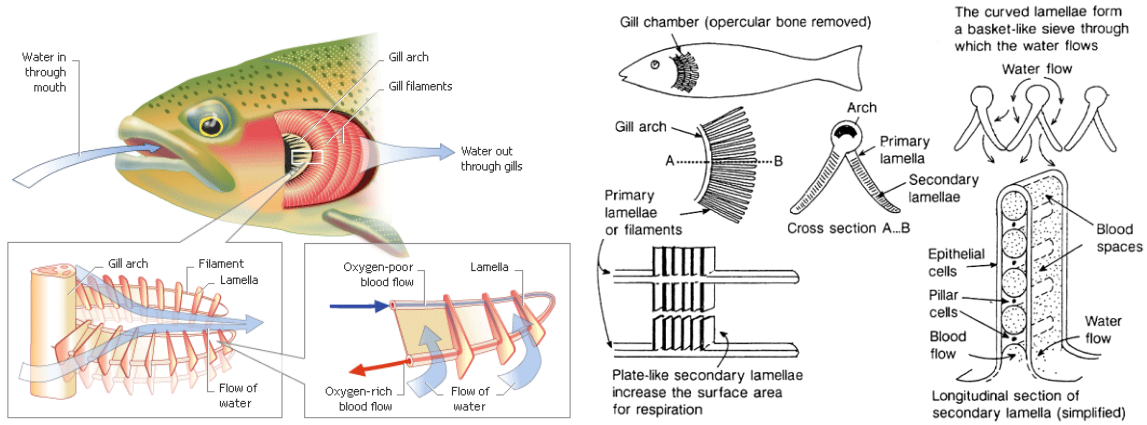
Figure 13.1 The Gills of a Fish

- Part of two adjoining gill arches with their filaments. The tips meet to form a sieve like arrangement for flow of water. The water moves through the mouth over the branched gills. Solid arrows show the flow of water.

- Part of a single filament showing the flat lamellae the flow of water is opposite to the direction in which the blood moves.

Oxygen passes from the water into the blood at the gills. Removal of carbon dioxide also occurs, as the blood containing high concentrations of the waste gas goes to the gills, and the carbon dioxide diffuses out into the water down a diffusion gradient (external water has lower

concentrations of carbon dioxide than levels in the blood, so this sets up a diffusion gradient.

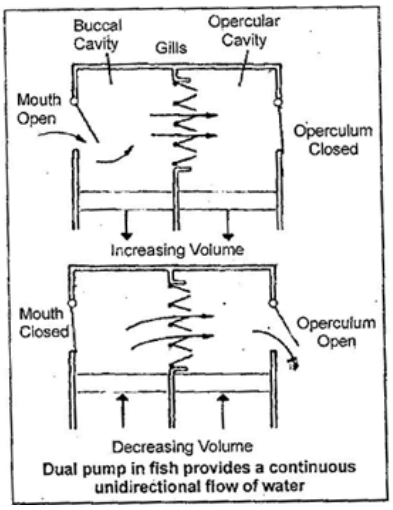


Each gill is composed of many filaments that are each covered in many lamellae. The lamellae contain blood capillaries, which have blood flowing in the opposite direction to the water. The blood flows through the lamellae in the opposite direction to the water.

This is a counter current flow. It ensures the maximum exchange possible occurs. Fish ventilate their gills to maintain the gas concentration gradient. They continuously pump their jaws and opercula to draw water in through the mouth and then force it over the gills and out through the opercular valve behind the gills.
This one-way ventilation is necessary because water is denser and more viscous than air, so it cannot be contained in delicate sac-like lungs found in air-breathing animals. In the gill lamellae the blood flows towards the front of the fish while the water flows towards the back. This counter current system increases the concentration gradient and increases the efficiency of gas exchange. About 80% of the dissolved oxygen is extracted from the water.
By using the pumping action of mouth and opercular cover, the aquatic animals move water over the gills. Water is drawn into the mouth, passes over the gills and flows out through the opercular clefts, valves guard the entrance to the buccal cavity and opercular clefts and gives a unidirectional flow of water. The volume of the buccal cavity can be changed by lowering of the jaw and the floor of the mouth.
The volume of the opercular cavity can also be changed by the movements of opercular flaps that swing out to enlarge the cavity and swing in to reduce it. The breathing cycle is important for maintaining the pressure differential across the gills. For the continuous flow of water, the pressure in the opercular cavity is always slightly lower than the pressure in the buccal cavity.

Teleost fish use a buccal-opercular pump to ventilate the gills. However, if a fish swims forward with its mouth open, water will flow across the gills without active pumping by the muscles surrounding the buccal and opercular cavities.

This strategy is called ram ventilation, and is used by many active fish species. Ram ventilation is efficient because the fish does not need to use the muscles around its buccal and opercular cavities to move water through the gills. However, the fish needs to be swimming, which is energetically costly, and its body position with the mouth open may increase drag on the fish and increase the cost of locomotion. Many fishes like shark breathe by pumping at low speed and change to ram ventilation at high speed.



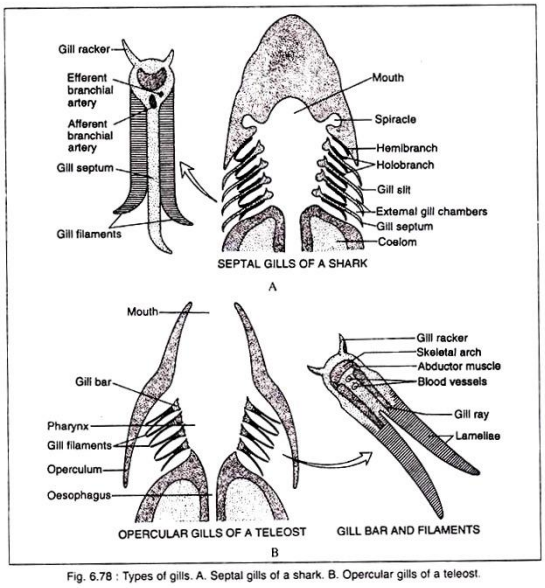


Fig. 6.78 : Types of gills. A. Septal gills of a shark. B. Opercular gills of a teleost.