Accessory Respiratory Organs in Fishes

They are divided into these groups because of the structure of their mouths and the *types* ***of skeletons they have. There are jawless fishes, cartilaginous (cart uhl AJ uh nuhs) fishes, and bony fishes. All*** *three types* ***are "cold-blooded," or ectotherms.***

Respiration:

Gas exchange in and out of a cell ($O_2 \rightarrow CO_2$)

Ventilation:

Movement of air in and out of an organism.

A ventilator is a machine used on a patient who can't breathe to physical push air in and out of their lungs.

Types of Accessory Respiratory Organs:

1. Suprabrachial Organ:

The supra-branchial organ is a specialised type of respiratory structure encountered in Clarias batrachus (Fig. 6.83A).

It has a complex structural organisation and consists of the following portions:

(a) An elaborate tree-like structure growing from the upper end of the second and fourth gill-arches of either side. This dendritic organ is composed of numerous terminal knobs, each has a core of cartilage covered by vascular membrane. Each exhibits eight folds which suggest that one such knob is formed by the coalescence of eight gill-filaments.

(b) There are a pair of highly vascularized supra- branchial chambers within which the tree-like structures are contained. The supra-branchial chambers are developed as the vascularized diverticula of the branchial chamber.

(c) The entrance of the supra-branchial chamber is guarded by 'fan'-like structures which are developed by the fusion of the adjacent gill- filaments of the dorsal side of the gill-arches.

The supra-branchial organs, like the gills, are lined by thin outer epithelial layers with inter-cellular spaces separated by the pilaster cells. The organs and the supra-branchial chambers are supplied by afferent and efferent blood vessels from the gill-arches.

The supra-branchial organs help to breathe in air. The supra-branchial chamber has inhalant and exhalant apertures. These fishes come to the surface of the water and gulp air into the supra-branchial organs. Atmospheric air from the pharyngeal cavity is taken into the supra-branchial chamber by an inhalant aperture located between the second and third gill- arches.

After gaseous exchange the air from the said chamber expels into the opercular cavity by the gill-slit lying between the third and fourth gill-arches. The fan-like structures present in the second and the third gill-arches help to intake the air while the expulsion of the air from the supra-branchial, chamber is caused by the contraction of its wall. Thus the supra-branchial chamber and its contained organs function as ‘lung’.

2. Branchial Outgrowths:

In climbing perch (Anabas testudineus) there are two spacious sac-like outgrowths from the dorsal side of the branchial chambers (Fig. 6.83B). The epithelium lining these outgrowths is highly vascular and becomes folded to increase the respiratory area.

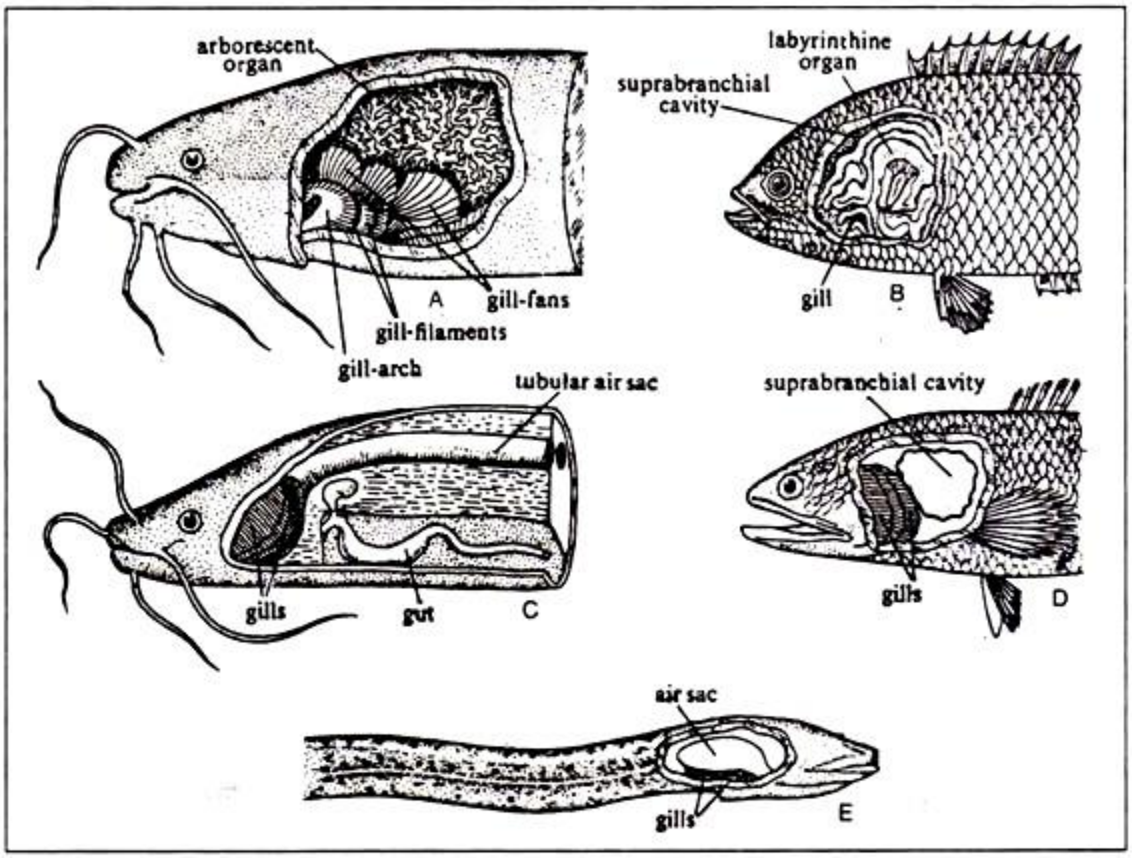

Fig. 6.83 : Accessory respiratory organs in air-breathing teleosts. A. *Clarias batrachus*. B. *Anabas testudineus*. C. *Heteropneustes fossils*. D. *Channa punctatus*. E. *Amphipnous cuchia*.

Each chamber contains a characteristic rosette-like labyrinthine organ. This organ develops from the first epibranchial bone and consists of a number of shell like concentric plates. The margins of the plates are wavy and the plates are covered with vascular gill-like epithelium.

Each branchial outgrowth communicates freely not only with the opercular cavity but also with the buccopharyngeal cavity. Air enters into the outgrowth by way of the buccopharyngeal opening and goes out through the external gill-slits. The entrance is controlled by valves.

Anabas can breathe in air by the help of these organs. These fishes have the habit of migration from one pond to the other. Their overland progression is peculiar and is assisted by the operculum and the fins. Each operculum bears sharp spines at the free edge

During travelling the opercula alternately spread out and fix to the ground by the spines and get the forward push from the pectoral fins and the tail. The proverb that the fish can climb the trees seems to be erroneous. The climbing perches are found in the branches of palm or other trees which are possibly brought there by the kites or crows while these fishes migrate over the land.

In Trichogaster fasciatus the accessory respiratory organs are similar to that of Anabas and consist of supra-branchial chamber, labyrinthine organ and respiratory membrane (Fig. 6.84).

The labyrinthine organ is simpler in construction in comparison to that of Anabas. Each organ assumes a spiral configuration with two leaf-like expansions. Each of these two expansions is composed of loose connective tissue which is covered by highly vascular epithelium.

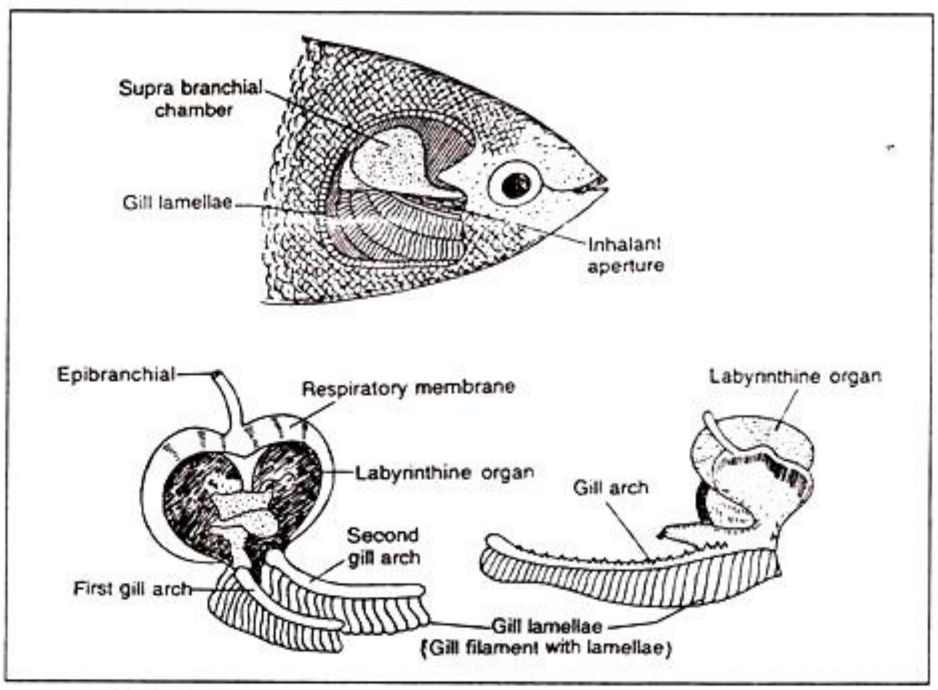

Fig. 6.84 : Gills and accessory respiratory organs of *Trichogaster fasciatus*.

3. Pharyngeal Diverticula:

In the Snake- headed fishes and Cuchia eels, the accessory respiratory organs are relatively simplified. These fishes can survive prolonged drought and their air breathing habit enables them to remain out of water for some time. In both the group of fishes, the pharynx gives a pair of sac-like diverticula for gaseous exchange.

In Channa, the accessory respiratory organs are relatively simpler and consist of a pair of air-chambers (Fig. 6.83D). These are developed from the pharynx and not from the branchial chamber as seen in others.

The air-chambers are lined by thickened epithelium which is highly vascularized. The air-chambers are simple sac-like structures and do not contain any structure. These chambers function as the lung-like reservoirs. In Channa striatus the vascular epithelium lining the chambers becomes folded to form some alveoli. The gill-filaments are greatly reduced in size.

In Cuchia (Amphipnous cuchia) the accessory respiratory organs consist of a pair of vascular sac-like diverticula from the pharynx above the gills (Fig. 6.83E). These diverticula open anteriorly into the first gill-slit. These diverticula function physiologically as the lungs.

The gills are greatly reduced and a few rudimentary gill-filaments are present on the second of the three remaining gill- arches. The third gill-arch is found to bear fleshy vascular epithelium. In Periophthalmus, a pair of very small pharyngeal diverticula is present which are lined by vascular epithelium.

4. Pneumatic Sacs:

In Heteropneustes fossil is, a pair of tubular pneumatic sacs, one on each side of the body, act as the accessory respiratory organs.

These long tubular sacs arise as the outgrowths from the branchial chamber and extend almost up to the tail between the body musculature near the vertebral column (Fig. 6.83C). In Sacco-branchus, similar tubular lung-like outgrowths of the branchial chamber extend back into the body musculature.

5. Buccopharyngeal Epithelium:

The vascular membrane of buccopharyngeal region in almost all the fishes helps in absorbing oxygen from water. But in mudskippers (Periophthalmus and Boleophthalmus) the highly vascularized buccopharyngeal epithelium helps in absorbing oxygen directly from the atmos-phere.

These tropical fishes leave water and spend most of the time skipping or ‘walking’ about through dampy areas particularly round the roots of the mangrove trees. The old idea that the mud-skippers use the vascular tail as the respiratory organ is not supported by recent Icthyologists.

6. Integument:

Eels are recorded to make considerable journey through damp vegetation. The common eel, Anguilla Anguilla can respire through the integument both in air and in water. In Amphipnous cuchia and mud- skippers, the moist skin sub-serves respiration.

Many embryos and larvae of fishes respire through the skin before the emergence of the gills. The median fin fold of many larval fishes is supplied with numerous blood vessels and helps in breathing. The highly vascular opercular fold of Sturgeon and many Catfishes serves as the accessory respiratory structure.

7. Gut epithelium:

The inner epithelium of the gut essentially helps in digestive process. But in many fishes the gut becomes modified to sub-serve respiratory function. Cobitis (giant loach of Europe) comes above the water-level and swallows a certain volume of air which passes back along the stomach and intestine. In Misgurus fossilis, a bulge just behind the stomach is produced which is lined by fine blood vessels.

The bulge acts as the reservoir of air and functions as the accessory respiratory organ. After the gaseous exchange, the gas is voided through the anus. In certain other fishes, Callichthyes, Hypostomus and Doras the highly vascular rectum acts as the respiratory organ by sucking in and giving out water through the anus alternately.

In these fishes the wall of the gut becomes modified. The wall becomes thin due to the reduction of the muscular layers.

8. Swim-Bladder acts as Lung:

Swim-bladder is essentially a hydrostatic organ but in some fishes it functions as the ‘lung’. In Amia and Lepisosteus, the wall of the swim-bladder is sacculated and resembles lung. In Polypterus the swim-bladder is more lung-like and gets a pair of pulmonary arteries arising from the last pair of epibranchial arteries.

The swim-bladder in dipnoans resembles strikingly the tetra- pod lung in structure as well as in function. In Neoceratodus, it is single, but in Protopterus and Lepidosiren it is bilobed. The inner surface of the ‘lung’ is increased by spongy alveolar structures.

In these fishes, the ‘lung’ is mainly respiratory in function during aestivation because the gills become useless during this period. Like that of Polypterus, the ‘lung’ in dipnoans gets the pulmonary arteries from the last epibranchial arteries.

In Notopterus, the swim-bladder becomes more complex and acts as a lung. Except the hydrostatic, sound production and hearing, a new function like respiration was innovated in Notopterus. In Notopterus chitala the posterior tip of swim-bladder is enlarged which is called caudal extension and the ventral part gives off several finger-like projections, the dorsal side of the gas bladder possesses a specialised striated muscle.

The anterior part extends into a projection to the ear. An artery arising from the dorsal aorta forms a network of blood capillaries that spread the entire inner surface of the abdominal and caecal parts of the swim bladder.

The blood capillaries that cover a single epithelial layer helps in the gaseous exchange between the blood and the air of the swim-bladder. This air breathing habit is considered as a secondary adaptation in these fishes.

Functions of Accessory Respiratory Organs:

The accessory respiratory organs contain a high percentage of oxygen. The fishes possessing such respiratory organs are capable of living in water where oxygen concentration is very low. Under this condition these fishes come to the surface of water to gulp in air for transmission to the accessory respiratory organs.

If these fishes are prevented from coming to the surface, they will die due to asphyxiation for want of oxygen. So the acquisition of accessory respiratory organs in fishes is an adaptive feature.

Further it has been observed that the rate of absorption of oxygen in such organs is much higher than the rate of elimination of carbon-dioxide. Hence, it is natural that the gills excrete most of the carbon-dioxide. Absorption of oxygen appears to be the primary function of the accessory respiratory organs.

Significance of Accessory Respiratory Organs:

The cause of emergence of the accessory respiratory structures in fishes in addition to the primary respiratory organ is very difficult to interpret. There are two contrasting views regarding the origin of the aerial accessory respiratory structures. First view: some fishes have the natural instinct to make short excursion to the land from the primal aquatic home.

To remain out of water, the development of certain devices to breathe in air becomes necessary. Second view holds that the fishes are forced to ascend the land when the oxygen content of water falls to a considerable extent. The fishes in that particular condition of life gulp in atmospheric air from the land and pass it into the accessory respiratory structures.

If they are prevented by mechanical barriers to come to surface, the fishes will die of suffocation. This habit of swallowing bubbles of air is observed in many bony fishes, especially living in shallow water which dries up periodically or becomes foul by the decomposition of aquatic vegetation.

As a consequence of the air-breathing habit for a considerable span of time, the fishes have developed specialised accessory respiratory organs in addition to the gills.

Most of such structures encountered in the fishes assume the shape of reservoir of air and originate either from the pharyngeal or branchial cavities. In extreme cases the reservoir may house special structure for gaseous exchange.

However, the development of such accessory respiratory organs is essentially adaptive in nature to meet the respiratory need and thus enables the fishes to tolerate oxygen depletion in water or to live on land over a varying period of time. The development of the accessory respiratory organs depends directly on the ability to remain out of the water.

- Gills (in Fishes)

- Cartilaginous fishes:
  - 5 ‘naked’ gill slits
  - Anterior & posterior walls of the 1st 4 gill chambers have a gill surface (demibranch). Posterior wall of last (5th) chamber has no demibranch.
  - Interbranchial septum lies between 2 demibranchs of a gill arch
  - Gill rakers protrude from gill cartilage & ‘guard’ entrance into gill chamber
  - 2 demibranchs + septum & associated cartilage, blood vessels, muscles, & nerves = holobranch

  - Bony fishes (teleosts): (See 'Ventilation in Teleost Fishes')

    - usually have 5 gill slits
    - operculum projects backward over gill chambers
    - interbranchial septa are very short or absent

  - Agnathans:
    - 6 - 15 pairs of gill pouches
    - pouches connected to pharynx by afferent branchial (or gill) ducts & to exterior by efferent branchial (or gill) ducts

- Larval gills:
  - External gills
    - outgrowths from the external surface of 1 or more gill arches
    - found in lungfish & amphibians
  - Filamentous extensions of internal gills
    - project through gill slits
    - occur in early stages of development of elasmobranchs
  - Internal gills - hidden behind larval operculum of late anuran tadpoles
- **Swim bladder & origin of lungs** - most vertebrates develop an outpocketing of pharynx or esophagus that becomes one or a pair of sacs (swim bladders or lungs) filled with gases derived directly or indirectly from the atmosphere. Similarities between swim bladders & lungs indicate they are the same organs.
- Vertebrates without swim bladders or lungs include cyclostomes, cartilaginous fish, and a few teleosts (e.g., flounders and other bottom-dwellers).

Swim bladders:

- may be paired or unpaired (see diagram above)
- have, during development, a pneumatic duct that usually connects to the esophagus. The duct remains open (physostomous) in bowfins and lungfish, but closes off (physoclistous) in most teleosts.

- serve primarily as a hydrostatic organ (regulating a fish's specific gravity)
- gain gas by way of a 'red body' (or red gland); gas is resorbed via the oval body on posterior part of bladder
- **Fish gills** are organs that allow fish to breathe underwater. Most fish exchange gases like oxygen and carbon dioxide using gills that are protected under gill covers on both sides of the pharynx (throat). Gills are tissues that are like short threads, protein structures called filaments. These filaments have many functions including the transfer of ions and water, as well as the exchange of oxygen, carbon dioxide, acids and ammonia.[1][2] Each filament contains a capillary network that provides a large surface area for exchanging oxygen and carbon dioxide.
- Fish exchange gases by pulling oxygen-rich water through their mouths and pumping it over their gills. In some fish, capillary blood flows in the opposite direction to the water, causing counter-current exchange. The gills push the oxygen-poor water out through openings in the sides of the pharynx. Some fish, like sharks and lampreys, possess multiple gill openings. However, bony fish have a single gill opening on each side. This opening is hidden beneath a protective bony cover called the operculum.
- Juvenile bichirs have external gills, a very primitive feature that they share with larval amphibians.
- Previously, the evolution of gills was thought to have occurred through two diverging lines: gills formed from the endoderm, as seen in jawless fish species, or those form by the ectoderm, as seen in jawed fish. However, recent studies on gill formation of the little skate (*Leucoraja erinacea*) has shown potential evidence supporting the claim that gills from all current fish species have in fact evolved from a common ancestor.[3]

Breathing with gills

Air breathing fish can be divided into *obligate* air breathers and *facultative* air breathers. Obligate air breathers, such as the African lungfish, are obligated to breathe air periodically or they suffocate. Facultative air breathers, such as the catfish *Hypostomus plecostomus*, only breathe air if they need to and can otherwise rely on their gills for oxygen. Most air breathing fish are facultative air breathers that avoid the energetic cost of rising to the surface and the fitness cost of exposure to surface predators.[4]

All basal vertebrates breathe with gills. The gills are carried right behind the head, bordering the posterior margins of a series of openings from the esophagus to the exterior. Each gill is supported by a cartilagenous or bony gill arch.[5] The gills of vertebrates typically develop in the walls of the pharynx, along a series of gill slits opening to the exterior. Most species employ a counter-current exchange system to enhance the diffusion of substances in and out of the gill, with blood and water flowing in opposite directions to each other.

The gills are composed of comb-like filaments, the gill lamellae, which help increase their surface area for oxygen exchange.[6] When a fish breathes, it draws in a mouthful of water at regular intervals. Then it draws the sides of its throat together, forcing the water through the gill openings, so that it passes over the gills to the outside. The bony fish have three pairs of arches, cartilaginous fish have five to seven pairs, while the primitive jawless fish have seven. The vertebrate ancestor no doubt had more arches, as some of their chordate relatives have more than 50 pairs of gills.[7]

Gills usually consist of thin filaments of tissue, branches, or slender tufted processes that have a highly folded surface to increase surface area. The high surface area is crucial to the gas exchange of aquatic organisms as water contains only a small fraction of the dissolved oxygen that air does. A cubic meter of air contains about 250 grams of oxygen at STP. The concentration of oxygen in water is lower than air and it diffuses more slowly. In a litre of freshwater the oxygen content is 8 cm^3 per litre compared to 210 in the same volume of air.[8] Water is 777 times more dense than air and is 100 times more viscous.[8] Oxygen has a diffusion rate in air 10,000 times greater than in water.[8] The use of sac-like lungs to remove oxygen from water would not be efficient enough to sustain life.[8] Rather than using lungs "Gaseous exchange takes place across the surface of highly vascularised gills over which a one-way current of water is kept flowing by a specialised pumping mechanism. The density of the water prevents the gills from collapsing and lying on top of each other, which is what happens when a fish is taken out of water."[8]

Higher vertebrates do not develop gills, the gill arches form during fetal development, and lay the basis of essential structures such as jaws, the thyroid gland, the larynx, the *columella* (corresponding to the stapes in mammals) and in mammals the malleus and incus.[7] Fish gill slits may be the evolutionary ancestors of the tonsils, thymus gland, and Eustachian tubes, as well as many other structures derived from the embryonic branchial pouches

Bony fish

In bony fish, the gills lie in a branchial chamber covered by a bony operculum (*branchia* is an Ancient Greek word for gills). The great majority of bony fish species have five pairs of gills, although a few have lost some over the course of evolution. The operculum can be important in adjusting the pressure of water inside of the pharynx to allow proper ventilation of the gills, so that bony fish do not have to rely on ram ventilation (and hence near constant motion) to breathe. Valves inside the mouth keep the water from escaping.

Cartilaginous fish

Sharks and rays typically have five pairs of gill slits that open directly to the outside of the body, though some more primitive sharks have six or seven pairs. Adjacent slits are separated by a cartilaginous gill arch from which projects a long sheet-like septum, partly supported by a further piece of cartilage called the gill ray. The individual lamellae of the gills lie on either side of the septum. The base of the arch may also support gill rakers, small projecting elements that help to filter food from the water.[7]

A smaller opening, the spiracle, lies in the back of the first gill slit. This bears a small pseudobranch that resembles a gill in structure, but only receives blood already oxygenated by the true gills.[7] The spiracle is thought to be homologous to the ear opening in higher vertebrates.[11]

Most sharks rely on ram ventilation, forcing water into the mouth and over the gills by rapidly swimming forward. In slow-moving or bottom dwelling species, especially among skates and rays, the spiracle may be enlarged, and the fish breathes by sucking water through this opening, instead of through the mouth.[7]

Chimaeras differ from other cartilagenous fish, having lost both the spiracle and the fifth gill slit. The remaining slits are covered by an operculum, developed from the septum of the gill arch in front of the first gill.[7]

The shared trait of breathing via gills in bony fish and cartilaginous fish is a famous example of symplesiomorphy. Bony fish are more closely related to terrestrial vertebrates, which evolved out of a clade of bony fishes that breathe through their skin or lungs, than they are to the sharks, rays, and the other cartilaginous fish. Their kind of gill respiration is shared by the "fishes" because it was present in their common ancestor and lost in the other living vertebrates. But based on this shared trait, we cannot infer that bony fish are more closely related to sharks and rays than they are to terrestrial vertebrates.[

Lampreys and hagfish

Lampreys and hagfish do not have gill slits as such. Instead, the gills are contained in spherical pouches, with a circular opening to the outside. Like the gill slits of higher fish, each pouch contains two gills. In some cases, the openings may be fused together, effectively forming an operculum. Lampreys have seven pairs of pouches, while hagfishes may have six to fourteen, depending on the species. In the hagfish, the pouches connect with the pharynx internally. In adult lampreys, a separate respiratory tube develops beneath the pharynx proper, separating food and water from respiration by closing a valve at its anterior end.[7]

Breathing without gills

Although most fish respire primarily using gills, some fishes can at least partially respire using mechanisms that do not require gills. In some species cutaneous respiration accounts for 5 to 40 percent of the total respiration, depending on temperature. Cutaneous respiration is more important in species that breathe air, such as mudskippers and reedfish, and in such species can account for nearly half the total respiration.[13]

Fish from multiple groups can live out of the water for extended time periods. Amphibious fish such as the mudskipper can live and move about on land for up to several days, or live in stagnant or otherwise oxygen depleted water. Many such fish can breathe air via a variety of mechanisms. The skin of anguillid eels may absorb oxygen directly. The buccal cavity of the electric eel may breathe air. Catfish of the families Loricariidae, Callichthyidae, and Scoloplacidae absorb air through their digestive tracts.[4] Lungfish, with the exception of the Australian lungfish, and bichirs have paired lungs similar to those of tetrapods and must surface to gulp fresh air through the mouth and pass spent air out through the gills. Gar and bowfin have a vascularized swim bladder that functions in the same way. Loaches, trahiras, and many catfish breathe by passing air through the gut. Mudskippers breathe by absorbing oxygen across the skin (similar to frogs). A number of fish have evolved so-called accessory breathing organs that extract oxygen from the air. Labyrinth fish (such as gouramis and bettas) have a labyrinth organ above the gills that performs this function. A few other fish have structures resembling labyrinth organs in form and function, most notably snakeheads, pikeheads, and the Clariidae catfish family.

Breathing air is primarily of use to fish that inhabit shallow, seasonally variable waters where the water's oxygen concentration may seasonally decline. Fish dependent solely on dissolved oxygen, such as perch and cichlids, quickly suffocate, while air-breathers survive for much longer, in some cases in water that is little more than wet mud. At the most extreme, some air-breathing fish are able to survive in damp burrows for weeks without water, entering a state of aestivation (summertime hibernation) until water returns.

Parasites on gill

Fish gills are the preferred habitat of many ectoparasites (parasites attached to the gill but living out of it); the most commons are monogeneans and certain groups of parasitic copepods, which can be extremely numerous.[14] Other ectoparasites found on gills are leeches and, in seawater, larvae of gnathiid isopods.[15] Endoparasites (parasites living inside the gills) include encysted adult didymozoid trematodes,[16] a few trichosomoidid nematodes of the genus *Huffmanela*, including *Huffmanela ossicola* which lives within the gill bone,[17] and the encysted parasitic turbellarian *Paravortex*.[18] Various protists and Myxosporea are also parasitic on gills, where they form cysts.

Gills mediate the gas exchange in **fish**. These organs, located on the sides of the head, are made up of gill filaments, feathery structures that provide a large surface for gas exchange. The filaments are arranged in rows in the gill arches, and each filament has lamellae, discs that contain capillaries. Blood enters and leaves the gills through these small blood vessels. Although gills are restricted to a small section of the body, the immense respiratory surface created by the gill filaments provides the whole **animal** with an efficient gas exchange. The surrounding water keeps the gills wet.

A flap, the operculum, covers and protects the gills of **bony fish**. Water containing dissolved oxygen enters the fish's mouth, and the animal moves its jaws and operculum in such a way as to pump the incoming water through the gills. As water passes over the gill filaments, blood inside the capillaries picks up the dissolved oxygen. Since the blood in the capillaries flows in a direction opposite to the flow of water around the gill filaments, there is a good opportunity for absorption. The circulatory system then transports the oxygen to all body tissues and picks up carbon dioxide, which is removed from the body through the gills. After the water flows through the gills, it exits the body behind the fish's operculum.