Lesson 27

Lesson Outline:

Evolution of Respiratory Mechanisms – Cutaneous Exchange

- Evolution of Respiratory Mechanisms - Water Breathers
    - Origin of pharyngeal slits from corner of mouth
    - Origin of skeletal support/ origin of jaws
    - Presence of strainers
    - Origin of gills
    - Gill coverings
- Form - Water Breathers
    - Structure of Gills
        - Chondrichthyes
        - Osteichthyes
- Function – Water Breathers
    - Pumping action and path of water flow
        - Chondrichthyes
        - Osteichthyes

Objectives:

At the end of this lesson you should be able to:

- Describe the evolutionary trends seen in respiratory mechanisms in water breathers
- Describe the structure of the different types of gills found in water breathers
- Describe the pumping mechanisms used to move water over the gills in water breathers

References:

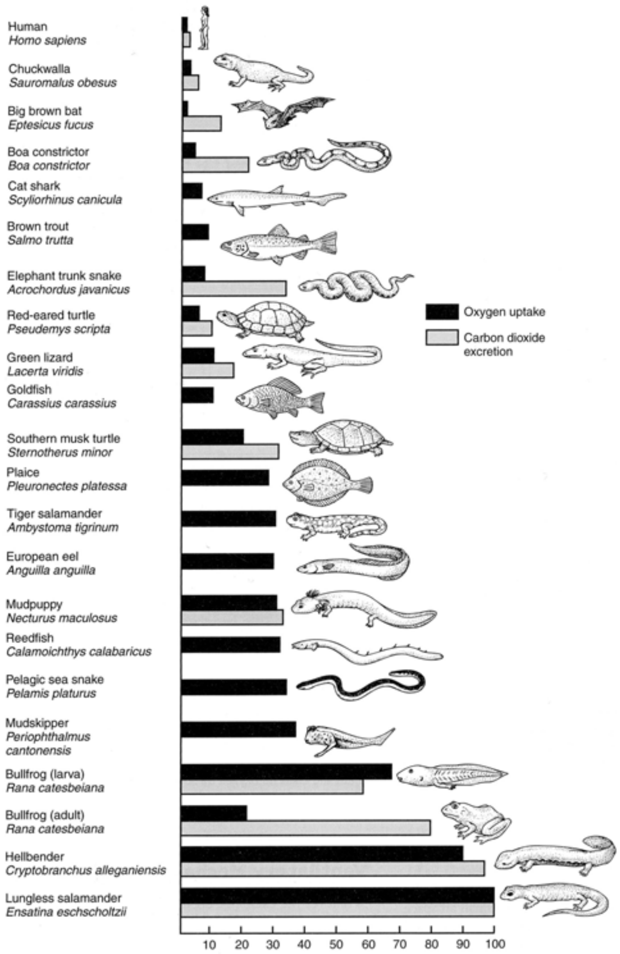
Chapter 13: pgs 292-313

Reading for Next Lesson:

Chapter 13: pgs 292-313

Function of the Respiratory System - General

Respiratory Organs
Cutaneous Exchange



Gas exchange across the skin takes place in many vertebrates in both air and water. All that is required is a good capillary supply, a thin exchange barrier and a moist outer surface. As you will remember from lectures on the integumentary system, this is often in conflict with the other functions of the integument.

Cutaneous respiration is utilized most extensively in amphibians but is not uncommon in fish and reptiles. It is not used extensively in birds or mammals, although there are instances where it can play an important role (bats loose 12% of their CO_2 this way).

For the most part, it:
- plays a larger role in smaller animals (some small salamanders are lungless).
- requires a moist skin which is thin, has a high capillary density and no thick keratinised outer layer.
- does not require a pump.
- is used more for O_2 uptake in water and CO_2 excretion in air.
- can lead to specialized adaptations to enlarge the surface area of the body.

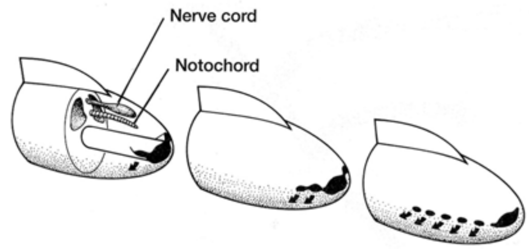
Evolution of Respiratory Mechanisms - Water Breathers

Cutaneous gas exchange probably played an important role in the earliest vertebrates, and as we have discussed, still does play a significant role in many present-day vertebrates.

Among protochordates, we then see the development of the branchial basket and the evolution of cilliary pumps for feeding. This provides a large surface area with a good blood supply that begins to assume an increasing role in respiration as well.

(branchial basket for feeding with cutaneous and branchial gas exchange.)

Origin of pharyngeal slits from corner of mouth



Remember that the pharyngeal slits are believed to have initially originated as subdivisions of the angle of the mouth that migrated back into the pharyngeal region.

Origin of skeletal support / Origin of Jaws

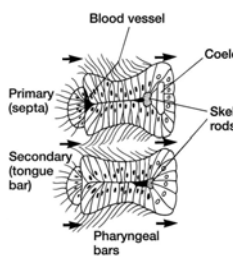
The next step was probably the evolution of muscular pumps for feeding - a muscular pump to produce a food-bearing water current. This would also lead to the branchial slits taking on even more of a role in ventilation.

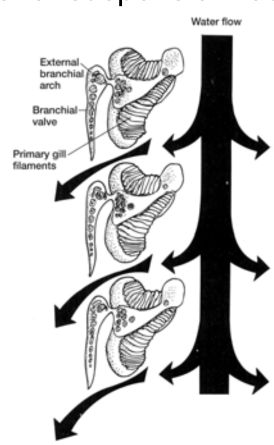
Also remember that the branchial arches develop to support the tissue between the pharyngeal slits and give them support (and the anterior two arches become the jaw).

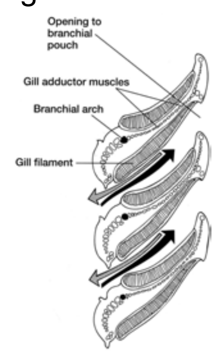
(branchial/pharyngeal slits with a muscular pump for feeding and gas exchange).

Presence of strainers

Remember that the original role of these structures was for suspension feeding and the walls of the slits were adapted accordingly.



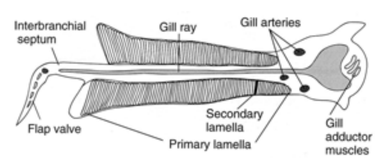


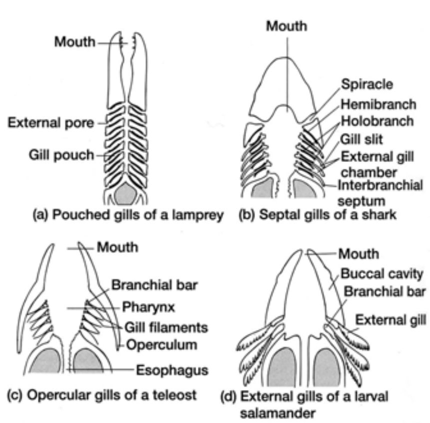


Origin of gills

With the evolution of jaws, fish were released from filter feeding and there was a transition from animals with gills for feeding and skin for respiration to animals with jaws for feeding and gills for respiration.

This would allow the evolution of larger more active animals. It would also reduce the need for cutaneous exchange and allow the evolution of dermal armour. *(muscular pump and gills for gas exchange, jaws for feeding and dermal armour).*





Gill Coverings

In lampreys, each branchial pouch opens separately to the outside.

In Chondrichthyes, individual flap valves form from individual gill septa and guard each chamber.

In most teleosts, a common operculum covers the gills.

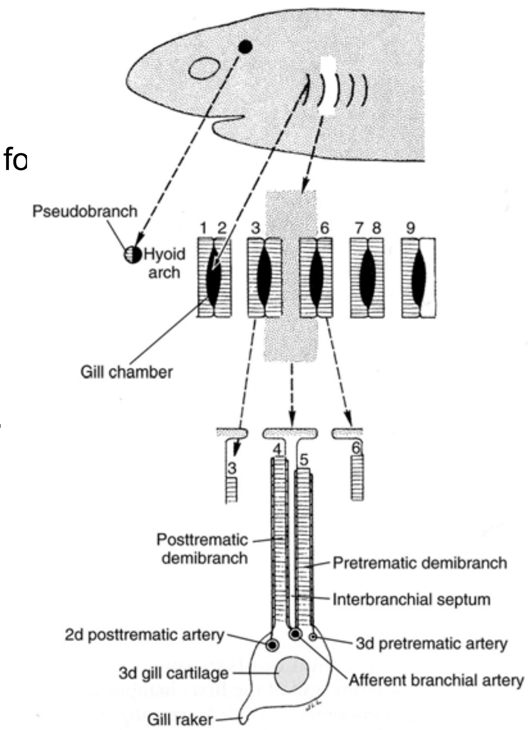
In larval salamanders as well as in larval anuran amphibians early in development, the branchial arches support external gills that project into the surrounding water.

Form - Water Breathers

Structure of gills

Chondrichthyes

We've already discussed the skeletal elements of each branchial arch (the splanchnocranium). Along the inner margins of the cartilages making up the arch are a series of small projections called gill rakers. These point forward into the cavity and form a screen across the internal gill opening that prevents fo slits and directs it posteriorly into the esophagus.



Attached to the outer lateral margins are the gill rays. These long projections support the interbranchial septum of the gills. (This is a continuous structure that runs the length of the branchial arch projecting from the arch laterally into the parabranchial chamber.

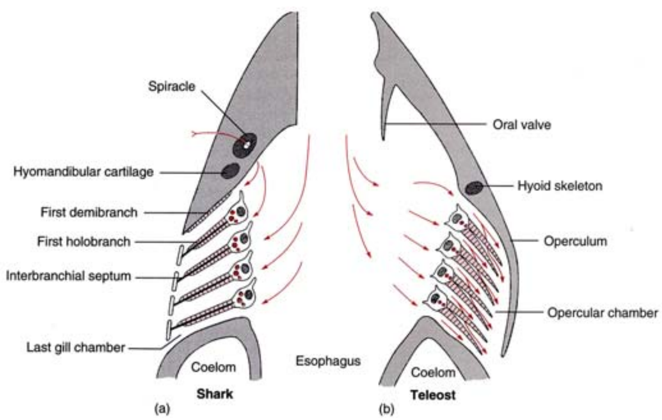
From each face of the septum, project horizontal shelves of tissue, the primary lamellae and from each face of these, project vertical ridges of tissue, the secondary lamellae. (Imagine that the interbranchial septum was the back of a bookcase, the primary lamellae were the shelves of the bookcase and the secondary lamellae were the books (both standing and hanging from the shelf).

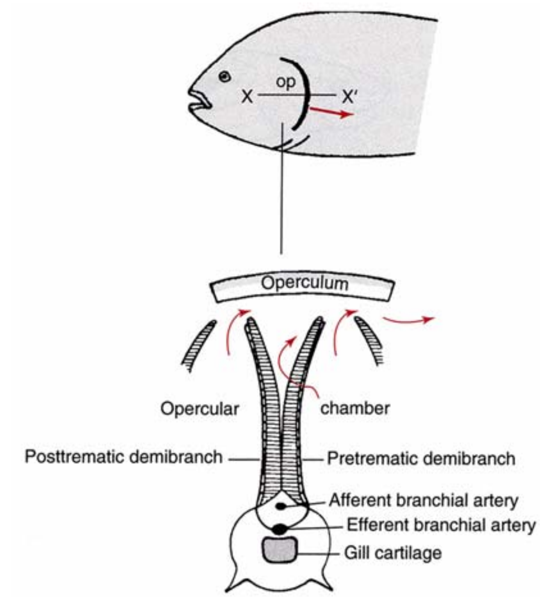
Since there are primary lamellae on both the anterior and posterior sides of the interbranchial septum, each half is referred to as a hemibranch and the complete unit is a holobranch. These names refer to the components of an arch (the pillar).

There are also terms to refer to the components of a gill slit (or branchial / parabranchial pouch). This is a respiratory unit and is composed of the posterior hemibranch of one gill arch (the pretrematic hemibranch) and the anterior hemibranch of the next gill arch (the postrematic hemibranch). These names refer to components of a gill slit (the opening).
(Note that the anterior surface of an arch forms the posterior surface of a slit).

Osteichthyes

In the teleost fishes, the gills have evolved further. Remember that in teleosts, all gills are protected by a common operculum whereas in elasmobranchs, each gill slit was protected by an interbranchial septum. Now that the interbranchial septum is no longer needed to fulfill this role, the two hemibranchs on each arch become separated and now the primary lamellae project directly from the branchial arch and the secondary lamellae still project at right angles from these. This arrangement enhances the water flow over the secondary lamellae and improves gas exchange.





Function – Water Breathers

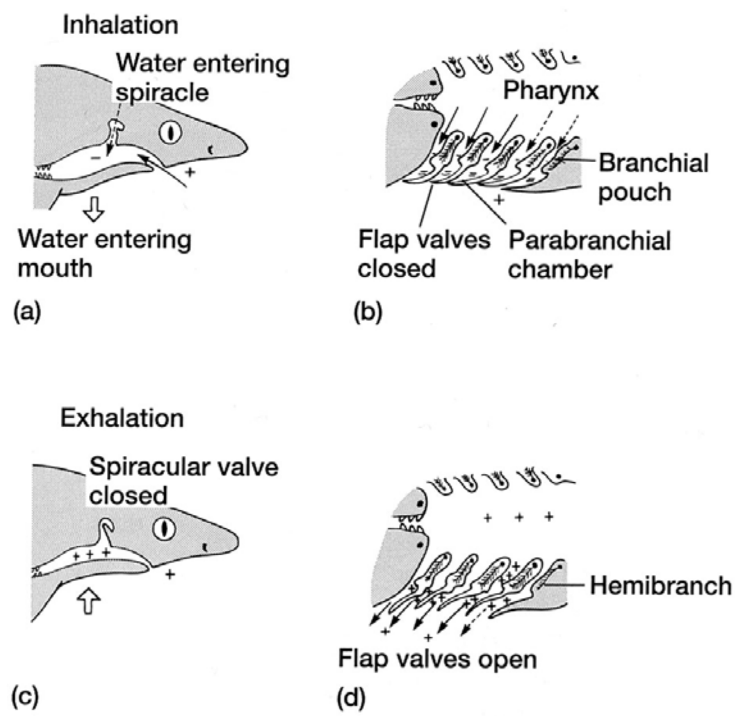
Pumping action and path of water flow

Chondrichthyes

In elasmobranches, the pump is a dual pump. The dual refers to the fact that there are really two pumps, a buccal and, in this case, a parabranchial pump. This pump works in a fashion that produces an almost continuous, unidirectional flow of water.

The pump has two phases, a suction phase and a pressure phase.

The suction phase begins when the buccal and parabranchial cavities expand creating a low pressure inside relative to outside that serves to draw water in through the mouth and spiracle. The expanding parabranchial



cavity creates a more negative pressure such that as the water enters the buccal cavity, it continues to flow over the gills and into the parabranchial cavity (water always flows from areas of high to areas of low pressure). (This negative pressure also closes the flap valves so that water does not enter through the exterior gill slits).

The pressure phase begins when the buccal and parabranchial cavities are compressed creating a high pressure relative to the outside. The mouth and spiracle close and the pressure is higher in the buccal cavity than the parabranchial cavity. This causes water to flow over the gills and out through the external gill openings.

Note that water flows over the gills from interior (buccal) to exterior (parabranchial) cavities during both phases.

Also note that the spiracle serves the same role as the mouth (from which it was derived) rather than the same role as the rest of the gill slits. In bottom dwelling sharks as well as in the rays, this takes on importance as the ventral mouth may be buried in the sand or mud as the animals lie camouflaged on the bottom while the spiracle is in an unobstructed dorsal position.

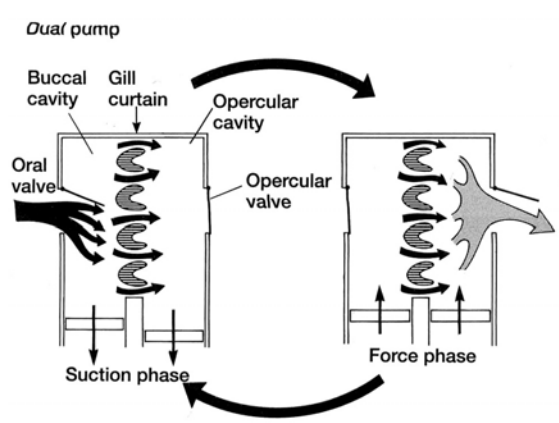
Many sharks that inhabit mid-waters use ram ventilation to replace this mechanism. With ram ventilation, the fish swim with the mouth open and allow water to flow through the buccal cavity and over the gills. In this way they achieve ventilation as a side effect of swimming and do not use their respiratory muscles at all. Some species use this to the extent that their respiratory muscles have atrophied and now they must swim to breathe.

(Some state that this eliminates the work of breathing but this is not true. While the ventilatory water flow is now a consequence of the swimming movements, swimming with the mouth open increases drag and hence the work of the locomotor muscles. Hence the work of breathing has been transferred from one muscle group to another and energy is only saved if these muscles are more efficient).

Osteichthyes

The dual pump system used by fish to ventilate their gills is virtually identical to that used by the elasmobranches and sharks and we do not need to repeat that again here other than to note the following:

- Osteichtyes do not have a spiracle.
- there are both buccal and opercular pumps involved.
- the two work in a synchronous fashion.



- each has a suction phase and a force phase.
- they produce a continuous flow of water over the gills.
- the flow of water is unidirectional - in through the mouth and/or spiracle (in those fish that have one) and out over the gills.