Lesson 28

Lesson Outline:

Evolution of Respiratory Mechanisms - Air Breathers
- Form - Accessory Air Breathing Organs
  - Facultative vs Obligate
  - - Lungs

- Function - Respiratory Pumps in Air Breathers
  - Buccal Force Pump
  - Aspiration Pump
  - - Patterns of Gas Transfer in Chordates

Objectives:

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

Describe the evolutionary trends seen in respiratory mechanisms in air breathers

Describe the structure of the different types of air breathing organs found in air breathers

Describe the pumping mechanisms used to move air in and out of these structures in air breathers

Describe the different modes of gas transfer found throughout the Chordates

References:

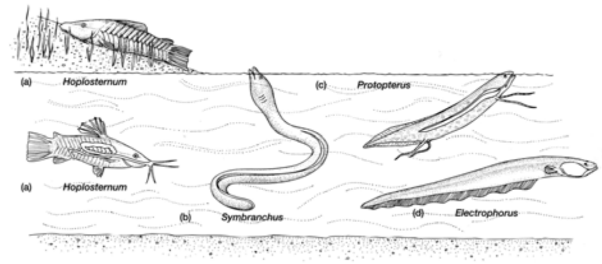
Chapter 13: pgs 292-313

Reading for Next Lesson:

Chapter 13: pgs 292-313

Evolution of Respiratory Mechanisms - Air Breathers

Air breathing organs arose before the transition from life in water to life on land. Air breathing organs have evolved multiple times within the bony fish.



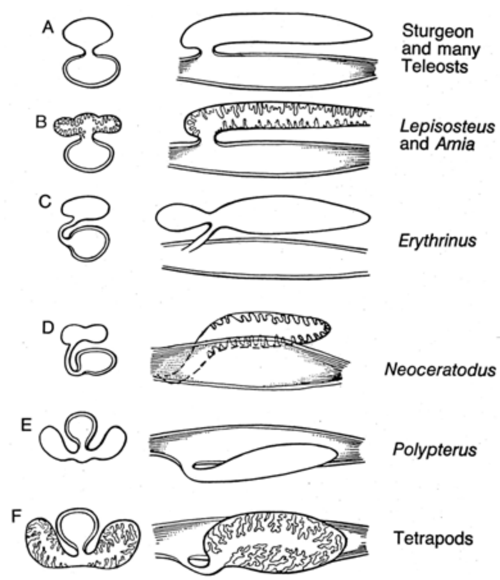
Some believe that these organs evolved in fish in fresh water susceptible to seasonal hypoxia and hypercarbia - the depletion of oxygen and build up of CO_2 due to high temperature, stagnant water and decay of organic material (or rapid plant growth where O_2 consumption exceeds O_2 production). Under these conditions, O_2 levels would get lower with depth in the water column. Fish may have first come to the surface layer where the O_2 would be the richest, to skim the surface water and this may have led to them also gulping air. This would supplement gill respiration and may have been the selective force for all of the evolutionary experiments we see in air breathing.

Others believe that these organs evolved in fish in sea water where some species began to venture onto the beach between waves to catch food (insects) or to lay eggs in temporally isolated locations

Form - Air Breathers

Accessory Air Breathing Organs

- ***reinforced gills*** -
- ***gut and digestive tract*** -
- ***buccal and pharyngeal cavity*** -
- ***buccal and pharyngeal diverticula*** -
- ***gas bladders and lungs*** - differ from lungs in two ways. They are usually dorsal to the GI tract whereas lungs are ventral. Are usually single whereas lungs are paired. Both are outpocketings from the gut and have similar nerve and muscle supply. Some feel that the lungs and swim bladders are homologous, others do not. Not sure which function came first, buoyancy or respiration.

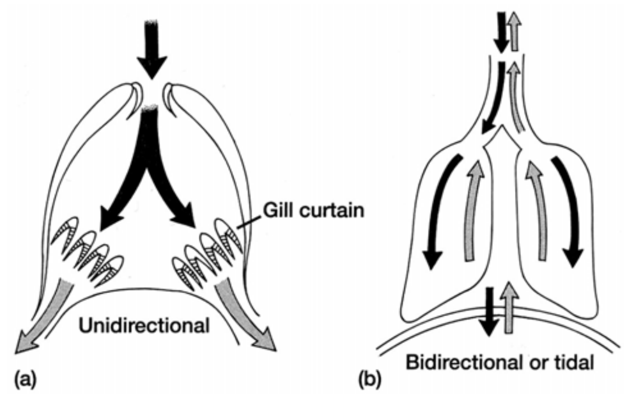


Facultative versus obligate air breathers

In many air-breathing fishes, air breathing remains facultative, that is it is a supplement to gill ventilation in times when there is insufficient oxygen uptake from water. In many species, however, things progress to the point that air breathing becomes obligatory. In most of these instances, the gills have become reduced to the point that even in well-oxygenated water, there is insufficient surface area to provide enough oxygen to take care of the metabolic requirements of the animal.

Why would the gills have become so reduced? Remember that when the fish are in hypoxic water (water with low oxygen content) and start to air breathe, blood leaving the lung or air exchange organ that subsequently passes through the gill will contain more oxygen than the surrounding water. If the gills retain good capillarity and a thin exchange barrier, oxygen will diffuse out of the blood and into the water. Under these conditions, it is an advantage to reduce and eliminate the gills.

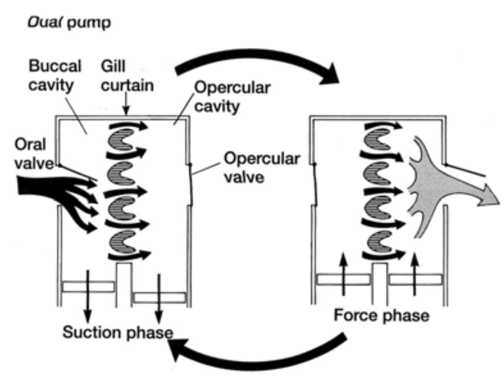
Form – Air Breathers
Structure of the Lungs



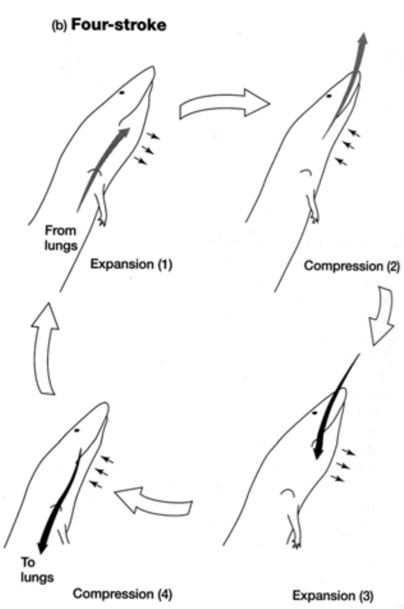
Arise as endodermal outpocketings of the gut. They are usually paired and lie within the body cavity. They are designed for breathing air and have various degrees of enlarged surface area that must be kept moist to function.

Require a pump for ventilation. Airflow is usually tidal.

Function – Air Breathers



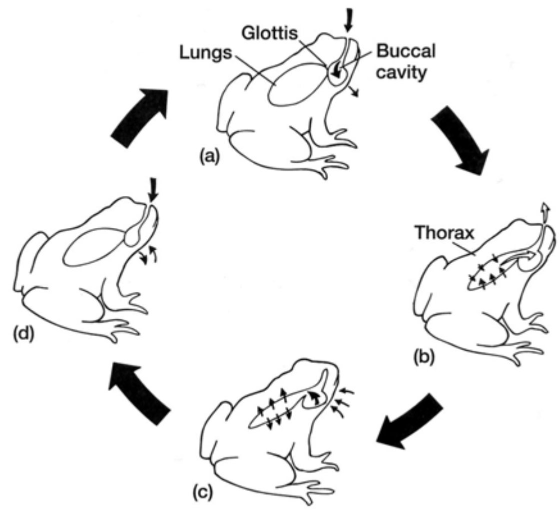
Respiratory Pumps in Air Breathers
The first air breathing mechanisms are natural extensions of the dual pump of the fish. The dual pump is modified into the buccal pump and as the gills are lost, so too is the opercular pump.



Buccal Force Pump
Most air breathing fish use a four stroke buccal pump. With the first stroke of the pump, the floor of the buccal cavity expands while the entrance to the lung relaxes and air flows from the lungs into the cavity of the mouth. The second stroke of the pump consists of elevation of the floor of the buccal cavity while the opening to the glottis constricts and gas is forced out the nares or mouth. With the third stroke, the buccal

floor drops again, expanding the cavity, only this time, fresh air is drawn in through the nares or mouth, and with the fourth stroke, the floor of the buccal cavity is elevated again while the mouth and nares close, the opening to the lungs relaxes and air is pushed into the lungs.

Amphibian larvae also use both the dual pump to move water over the gills and the buccal pump alone to ventilate their developing lungs. As adults they loose the gills and retain the buccal pump for lung ventilation. Amphibians, and some air breathing fish, however use only a two stroke buccal pump. In this case, with the first stroke of the pump the buccal floor is depressed expanding the mouth cavity. In this instance, both the opening to the lung relaxes and the mouth and nares open. Thus spent air from the lungs and fresh air from outside enter and mix together in the buccal cavity. With the second stroke of the pump, buccal compression forces the mixed buccal gas into the lungs while excess gas is expelled through the nares or mouth. In practice, there are changes in the timing of the opening of the glottis and the mouth and nares that act to minimize the amount of mixing that goes on in the buccal cavity.



Between lung breaths the animals continue to pump the buccal cavity to flush out the air and ensure that the cavity is filled with fresh air.

Aspiration Pump

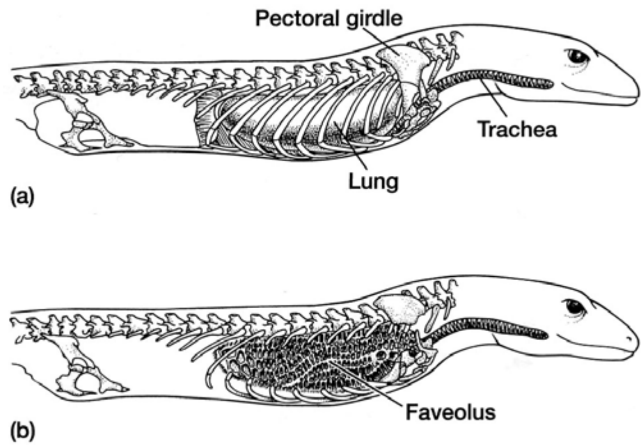
It is now proposed that the first step in the evolution of the aspiration pump was the use of active expiration to assist emptying the lungs when the glottis opened to let air out. This would speed up expiration. Once the muscles relaxed after this event, the lungs would refill due to both passive elastic recoil, and the force of air due to the buccal force pump. The intercostal muscles may have started to assist with inflation and as time went on, take over this role, freeing up the buccal cavity for other chores.

Along with lungs we see the evolution of a

- Glottis
- Secondary palate
- Pleural cavity and a diaphragm (mammals only).

While the need to get more oxygen may have been the selection force to begin air breathing, once the animals move onto land, the selection force for further development of the lungs is the need to eliminate carbon dioxide, not to take up oxygen!

With the aspiration pump, found in reptiles, birds and mammals, air is not forced into the lung but is aspirated or sucked into the lungs. The pump now includes the rib cage and intercostal muscles as well as other accessory muscles. In mammals only, this includes the diaphragm. The lungs are now "inside the pump".

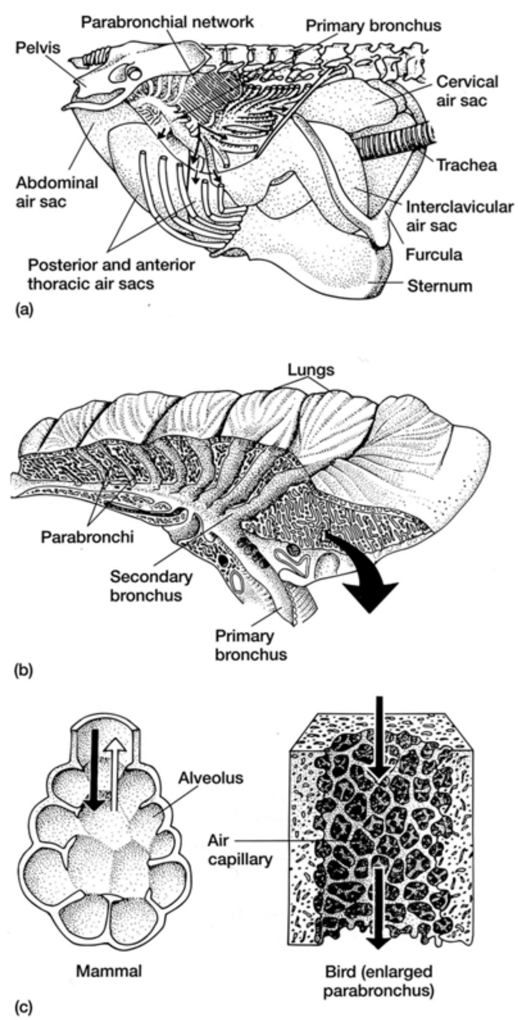


All forms of air ventilation involve the tidal movement of air in and out of the gas exchange organs. With the development of this new pumping mechanism, the buccal cavity is no longer used as a pump and feeding and breathing can be uncoupled increasing the opportunities for diversification of the breathing and feeding mechanisms.

Aspiration Pump, Tidal Ventilation but Unidirectional Flow in Birds

In birds we see, perhaps, the most efficient gas exchange organ found in air breathing vertebrates. The bird lung lies deep within the body of the animal and as such requires ventilation - but - it has been designed in such a way that, like fish, there is a unidirectional flow of air through the lung itself and a cross-current arrangement of blood capillaries with the airways that increases the efficiency of gas exchange. It is not quite as efficient as a countercurrent gas exchange system, but more efficient than the system found in mammals.

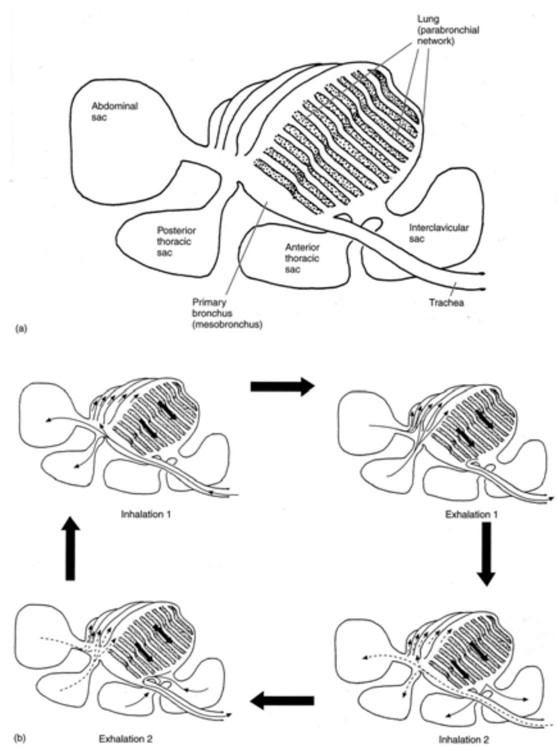
Like mammals, birds have two lungs ventilated with an aspiration pump. This is where the similarity ends.
The lungs themselves are very rigid and do not expand and compress. They also do not have alveoli but are composed of one way passages, called parabronchi, from which extend blind ending air capillaries.



Associated with the lungs are a series of air sacs. There can be as few as 5 in some species to as many as 12 in others. Most are paired but not all. The air sacs serve several functions in birds. These are the portions of the respiratory system that expand and compress to act as the aspiration pump. In general, they can be divided into the anterior and posterior air sacs.

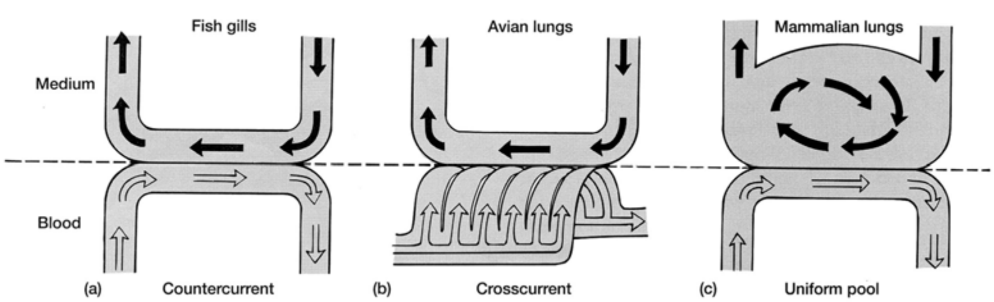
It is believed that when the chest expands due to the action of the intercostal muscles, air is drawn in through the trachea with some air entering the posterior air sacs and some entering into the caudal parts of the lungs. During exhalation, the air in the posterior air sacs now also moves into the lungs, displacing the spent air. During the next inhalation, the air in the lungs is drawn into the anterior air sacs and then with the next exhalation, this air exits the lungs via the trachea. Thus it takes two full breaths for air to pass through the entire system.

The parabronchi are the air passages that connect the posterior to the anterior air sacs. As air passes along these, it diffuses out into the air capillaries that branch from them and here; exchange takes place between the air and the blood.



Patterns of Gas Transfer in Chordates

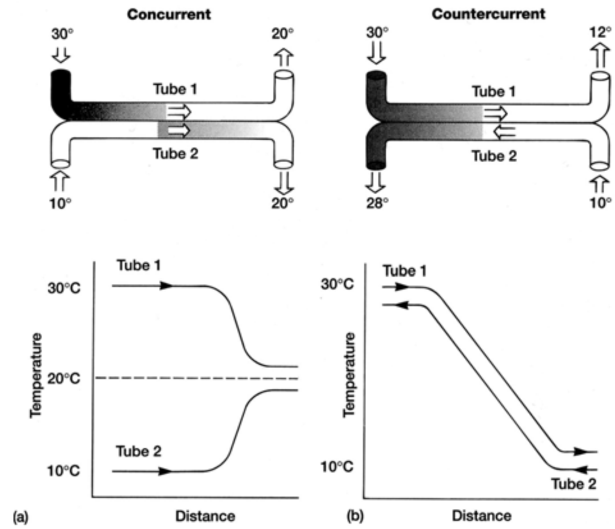
The three patterns of gas transfer encountered in vertebrate gas exchange organs are countercurrent, cross current and uniform (mixed) pool.



The most efficient is countercurrent and the least efficient is the mixed pool system. With a countercurrent system blood can fully equilibrate with "fresh" air or water.

This arrangement provides extremely efficient gas transfer. As a result, blood leaving the gills is in total equilibrium with the water; it has very high levels of O_2 and very low levels of CO_2.

With the mixed or uniform pool system, blood will equilibrate with a mixture of "fresh" and "stale" air or water. Thus, mammalian lungs are nowhere near as efficient as fish gills (think about why not and what the implications are).



The crosscurrent system is in between (but closer to a countercurrent system). Thus, bird lungs can be almost efficient as fish gills