Respiratory System & Gas Bladder

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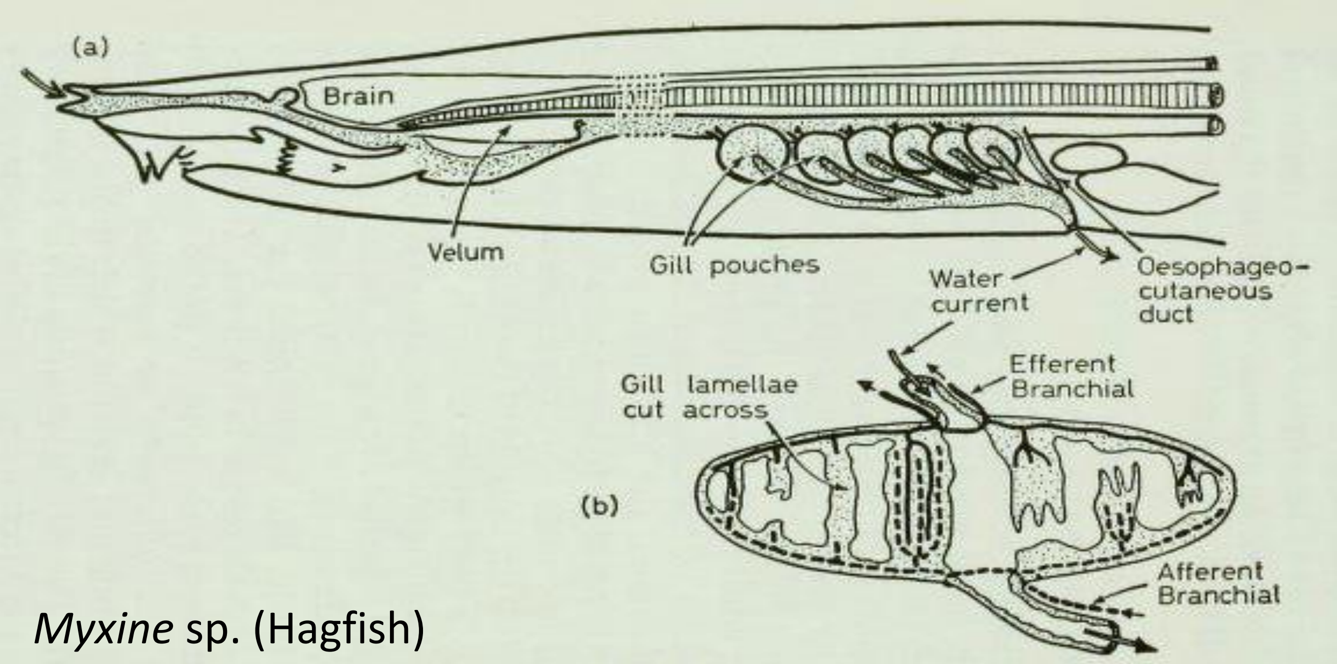
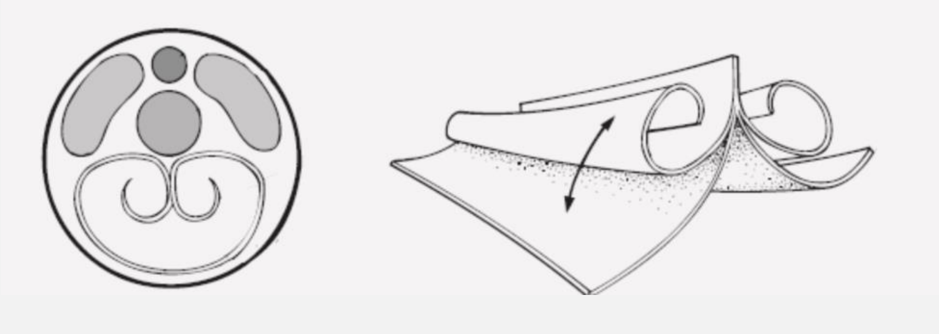
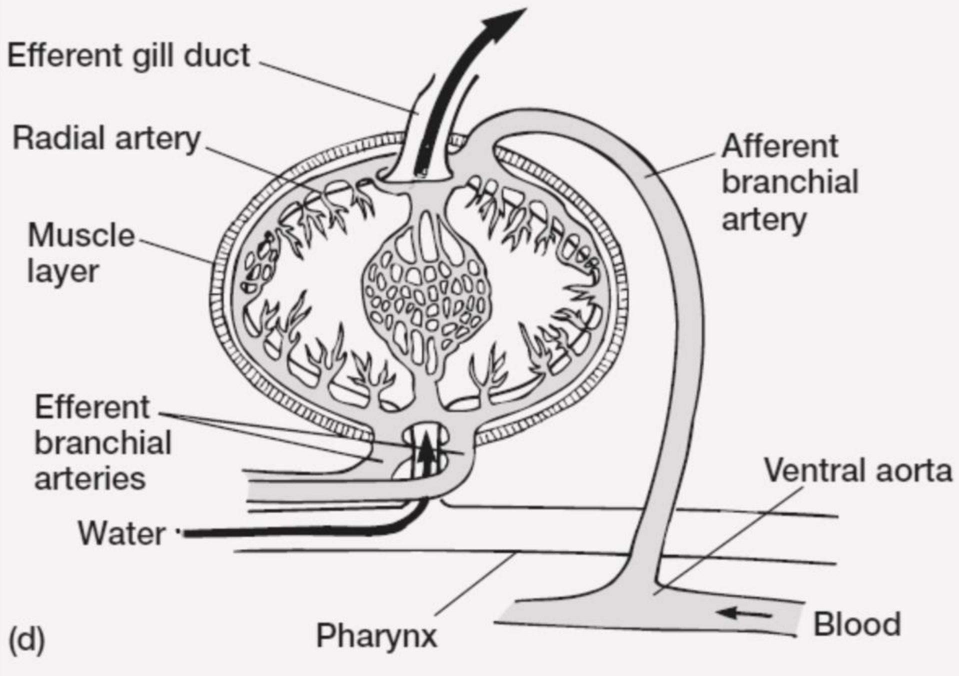
Ventilation of Internal Gills: Agnathous

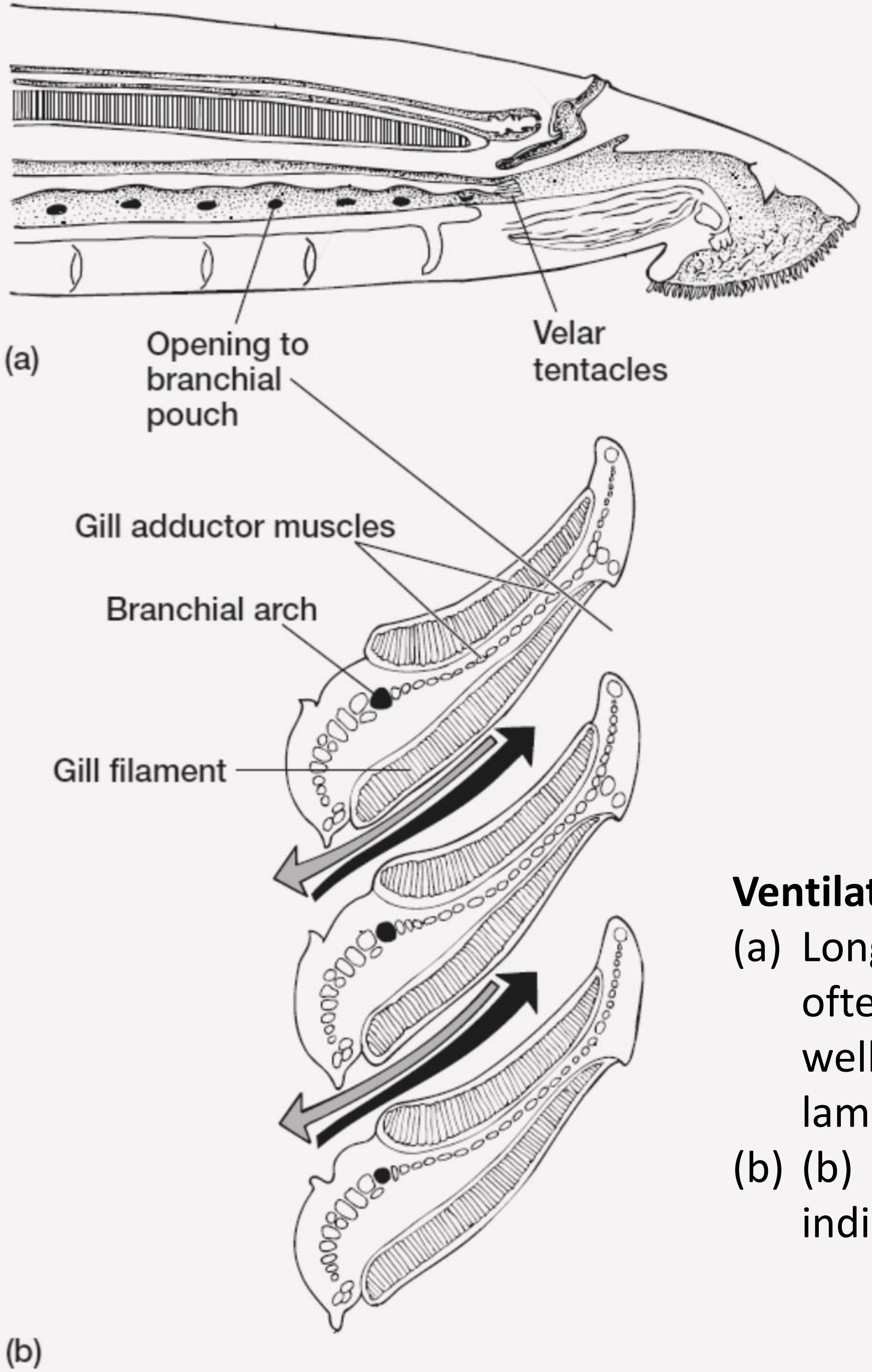
- In lampreys and hagfishes the respiratory mechanisms are completely different based on their ecological niche

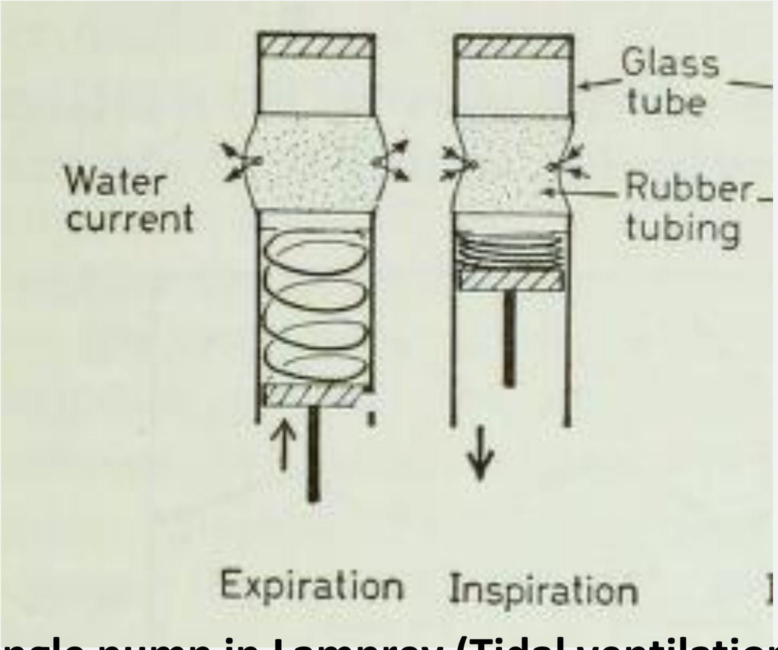


Myxine. (a) Longitudinal section to show the position of the velar chamber and the direction of the respiratory current when the animal is not attached to its prey. The distance between the velar chamber and the gill exits has been shortened as indicated by the dotted lines. (b) Pouched gill to show the direction of water flow opposite to that of the blood. Sphincters are present on the gill ducts at three points, (1) shortly after leaving the oesophagus, (2) before entering the gill pouch, (3) immediately after leaving the pouch. (Based on Cole, F. J. : *Trans. R. S. Edinb.* Vol. 49, 1913.)









Single pump in Lamprey (Tidal ventilation)

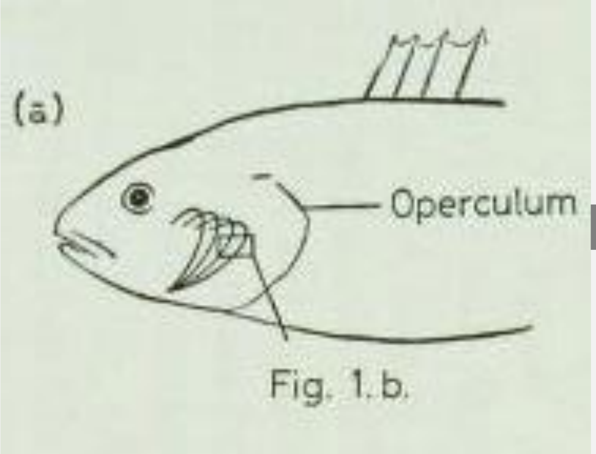
Ventilation in the adult lamprey:

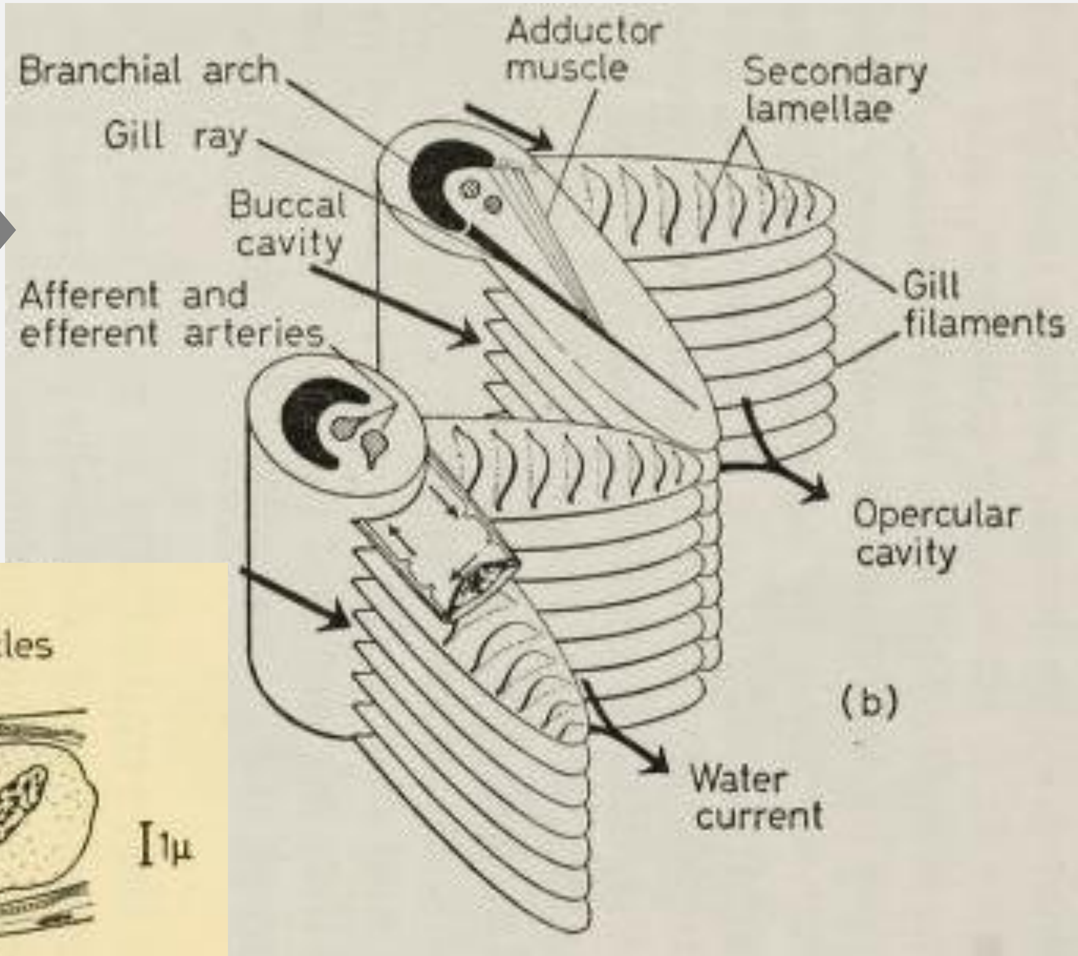
(a) Longitudinal section. Because the adult lamprey's mouth often is attached to prey, water must alternatively enter as well as exit via pharyngeal slits. Thus, gill ventilation in the lamprey, **unlike most fishes, is tidal.**

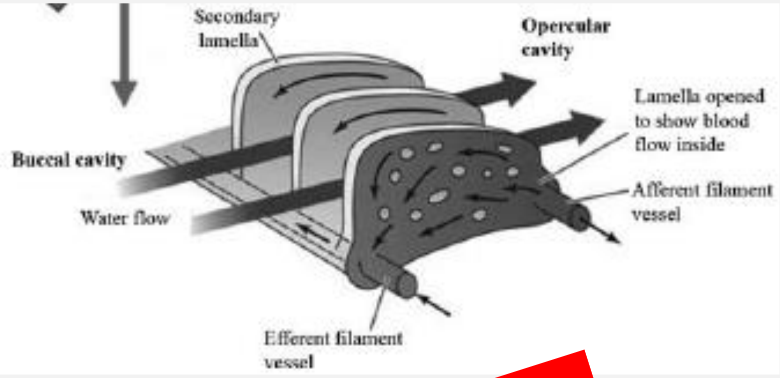
(b) (b) Frontal section of three gill arches. Double arrows indicate tidal flow of water: black, inflow; gray, outflow.

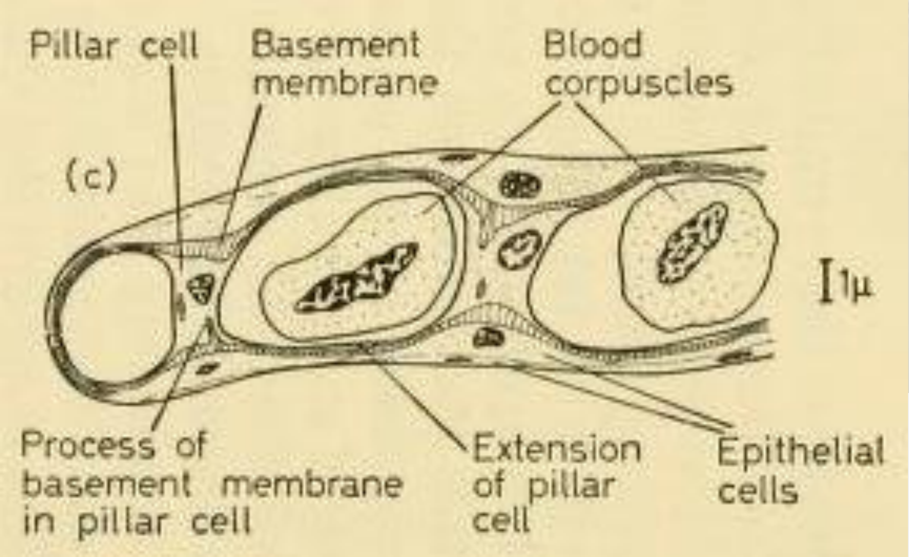
(After Vertyebrates, Kardong, 6ed)

Ventilation of Internal Gills: Bony Fishes



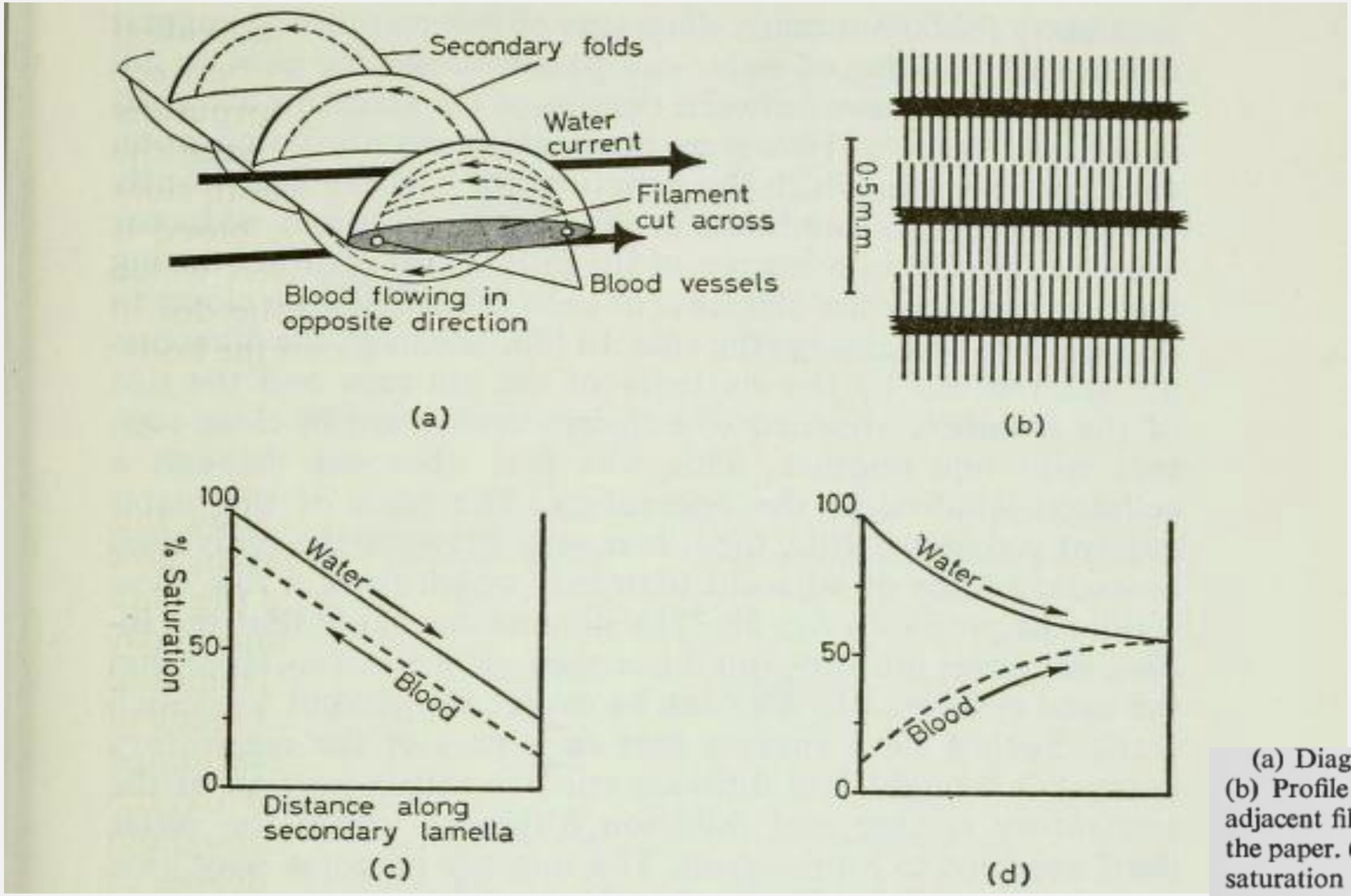






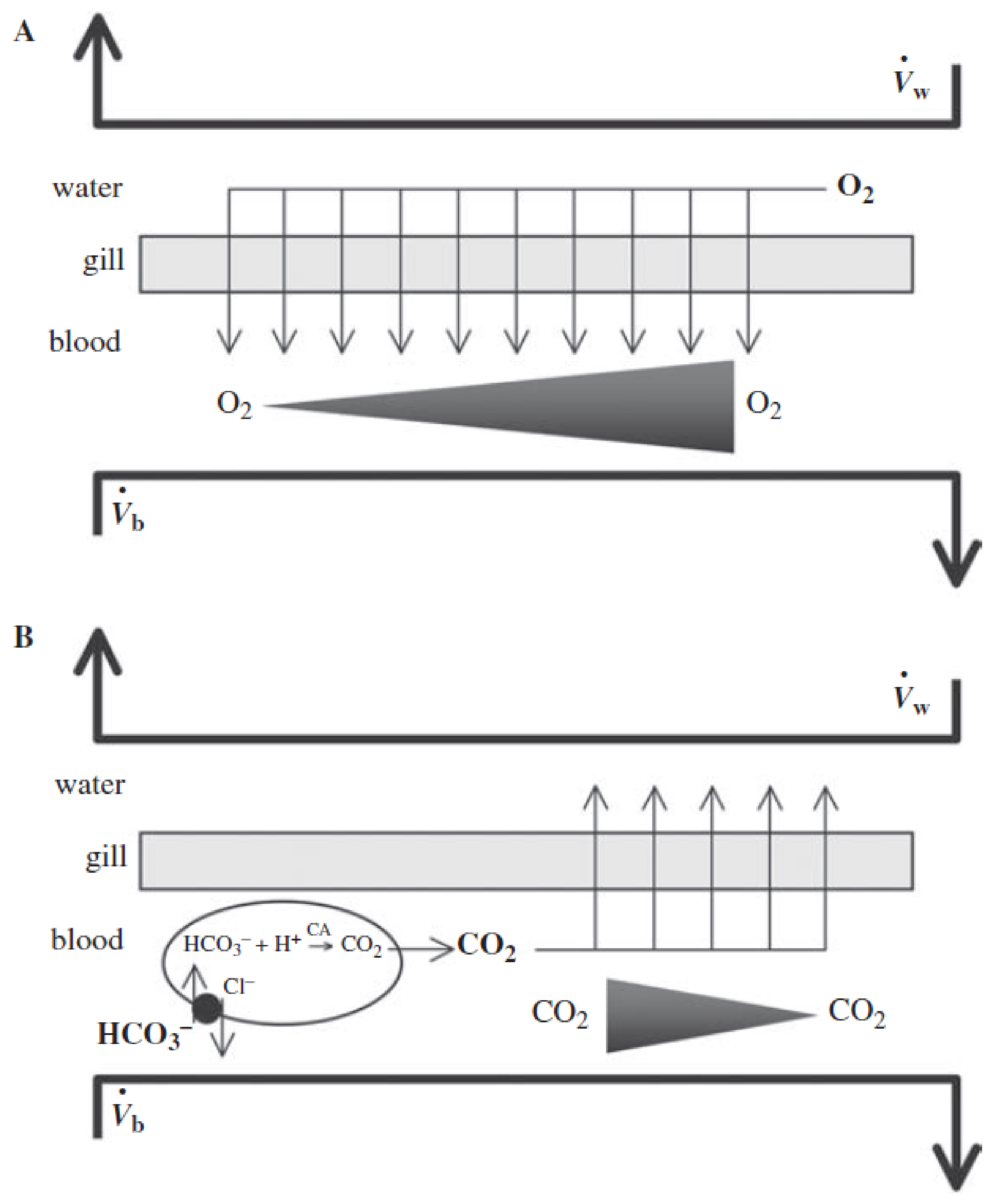
The gills of teleost fishes. (a) View from left side to show the position of four gill arches beneath the operculum. (b) Filaments and associated structures attached to two neighbouring branchial arches. (c) Section through a secondary lamella, based upon electron micrographs. (a and b modified after Bijtel, J. H.: *Arch. nécrl. Zool*, Vol. 8, 1949).

(After Comparative Physiology of Vertebrate Respiration, Huges, 1965



(a) Diagram to illustrate the counter-flow across a gill filament. (b) Profile of the sieve provided by secondary lamellae of three adjacent filaments. The water passes at right angles to the plane of the paper. (c) and (d) Theoretical graphs of the change in percentage saturation of the water and blood with oxygen during their passage across a secondary lamella. It is assumed that both fluids move at the same speed and have equal O_2 capacities. The flow is *counter* in (c) but *parallel* in (d). (a and b after Hughes, 1961.)

(c) Counter-current; (d) concurrent



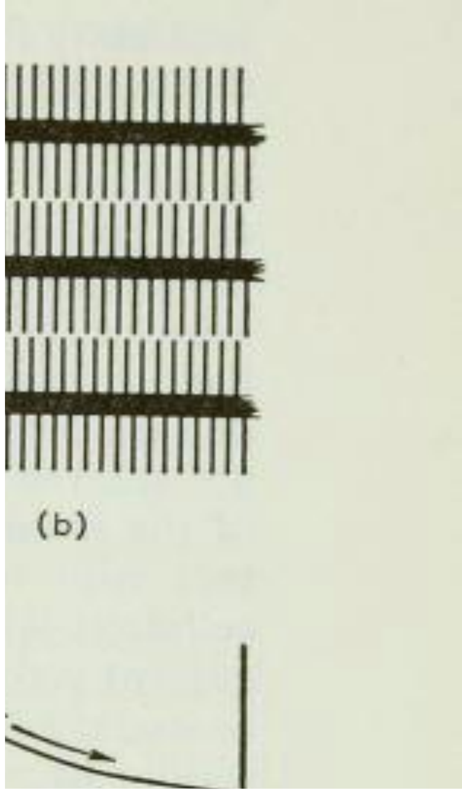
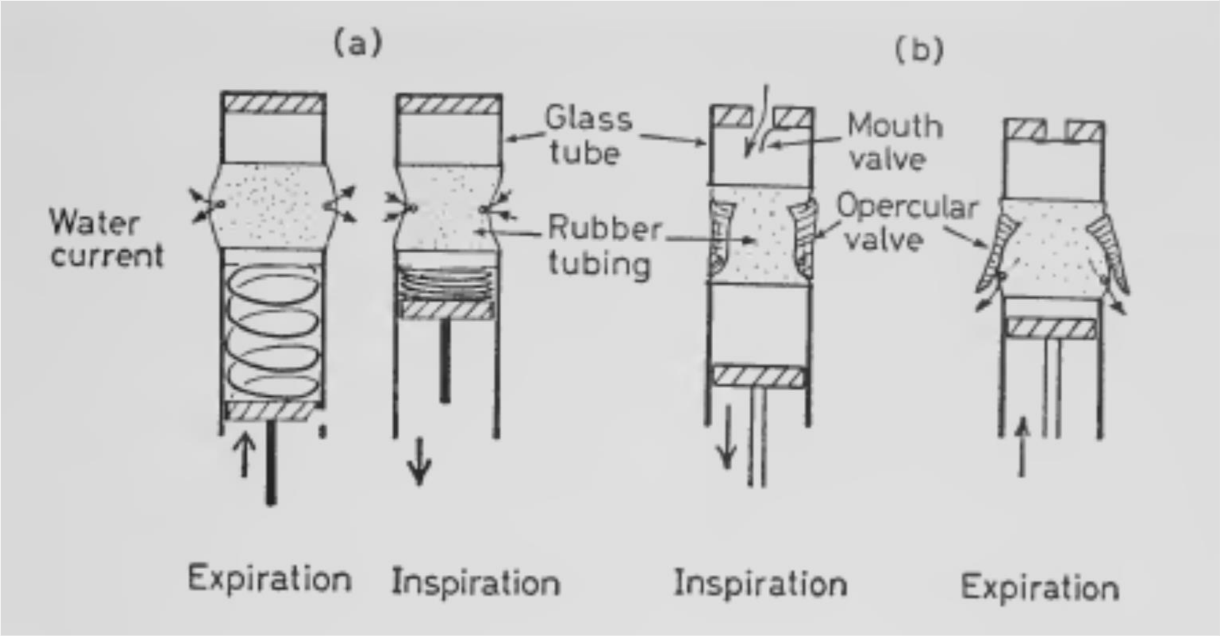


Fig. 3.3 Schematic models of O_2 (A) and CO_2 (B) transfer across the gills of typical teleost fish. In theory, any area of the gill that is both ventilated and perfused is available for O_2 diffusion, and O_2 transfer is limited primarily by perfusion. For CO_2 transfer, the conversion of plasma HCO_3 to molecular CO_2 is limited by the slow rate of entry of HCO_3 ions into the red blood cell. Thus, the surface area available for CO_2 diffusion out of the blood is limited (i.e. the functional surface area for CO_2 diffusion is less than the total surface area). Because of these chemical equilibrium limitations, branchial CO_2 transfer in teleost fish behaves as a diffusion limited system. CA, carbonic anhydrase; $\dot{V}_b$, blood flow; $\dot{V}_w$, water flow.

(After Respiratory Physiology of Vertebrates, Nilsson, 2010



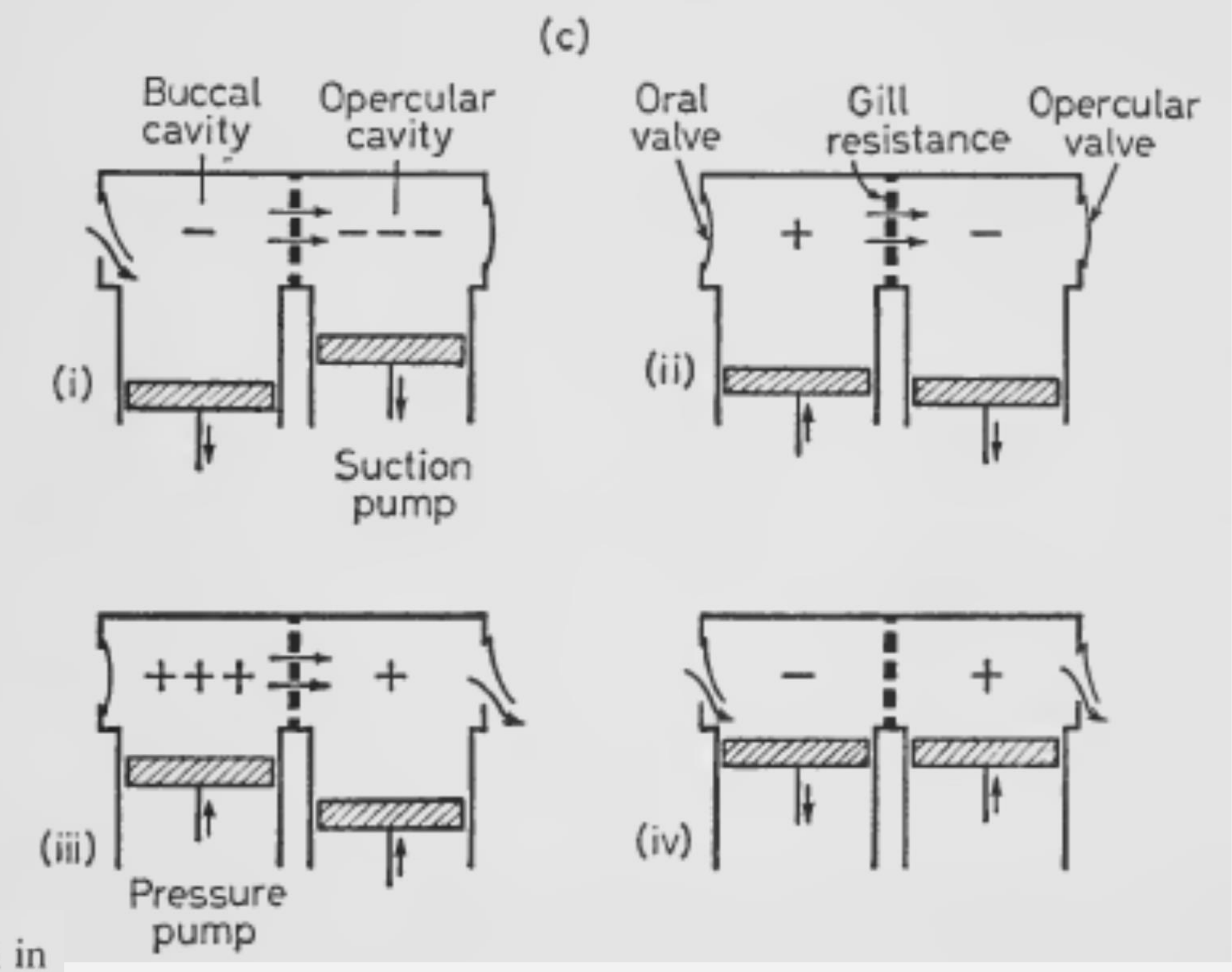
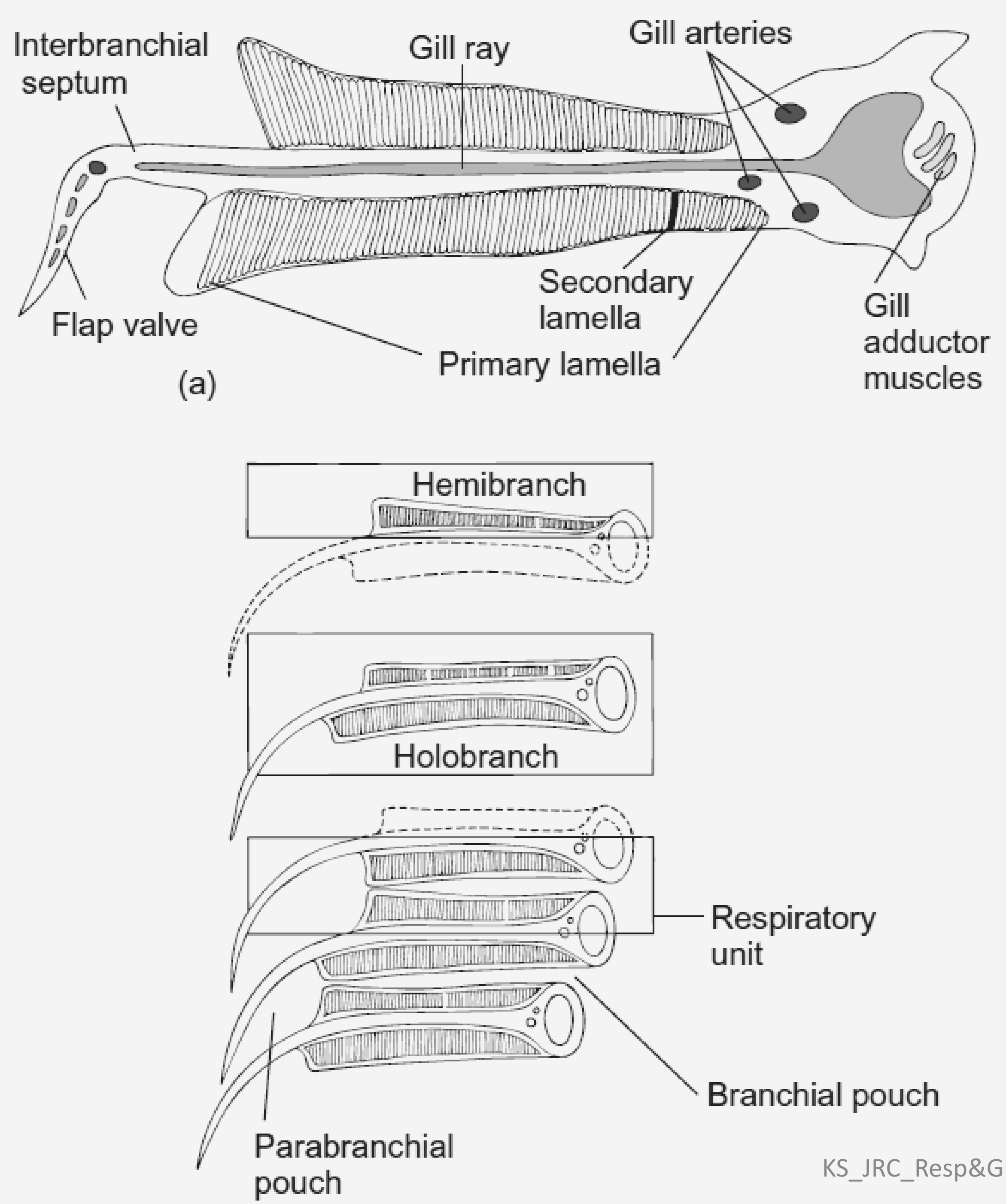


Diagram of models to illustrate the mechanisms of ventilation in fishes. (a) Lamprey when attached to its prey, inspiration being due to the elastic recoil (spring) of the branchial skeleton. (b) Mechanism in teleost fishes if a single pump. (c) The double pumping mechanism which operates in bony and cartilaginous fishes. Water passes across the gills in three phases. In phase 4 there may be some reversal in the flow but this is a very brief part of the cycle. (c after Hughes, 1961.)

The operation of a double-pumping mechanism and the consequent continuous flow across the gills make the terms inspiration and expiration not entirely suitable.

These are applicable to tidal ventilation but for fish a subdivision of each respiratory cycle into four parts is preferable

Ventilation of Internal Gills: Cartilaginous fishes



Shark gill

(a) The interbranchial septum has banks of lamellae supported by gill rays and a medial branchial arch

(b) Structural units include a hemibranch and a holobranch as well as a functional respiratory unit

(After Vertyebrates, Kardong, 6ed)

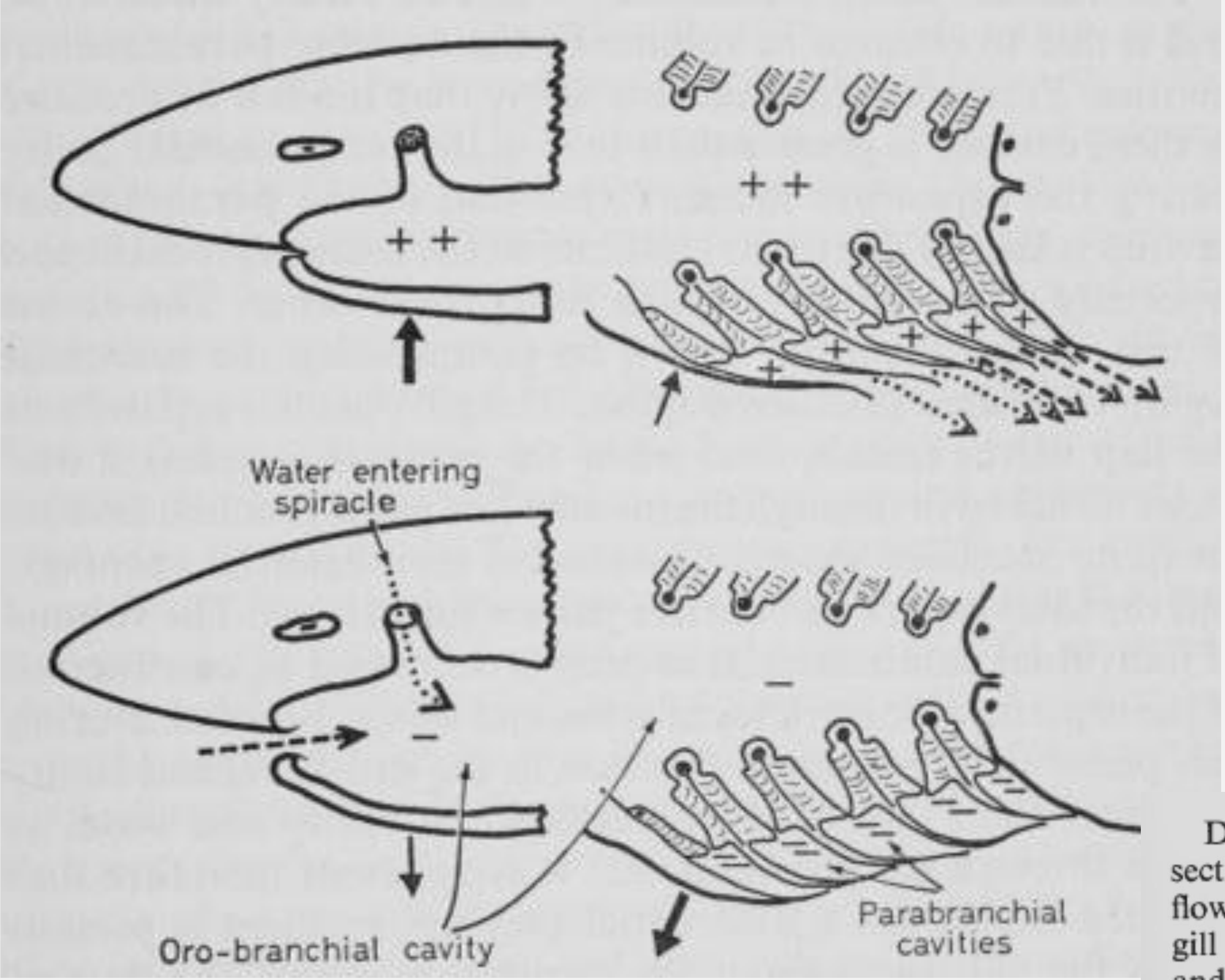
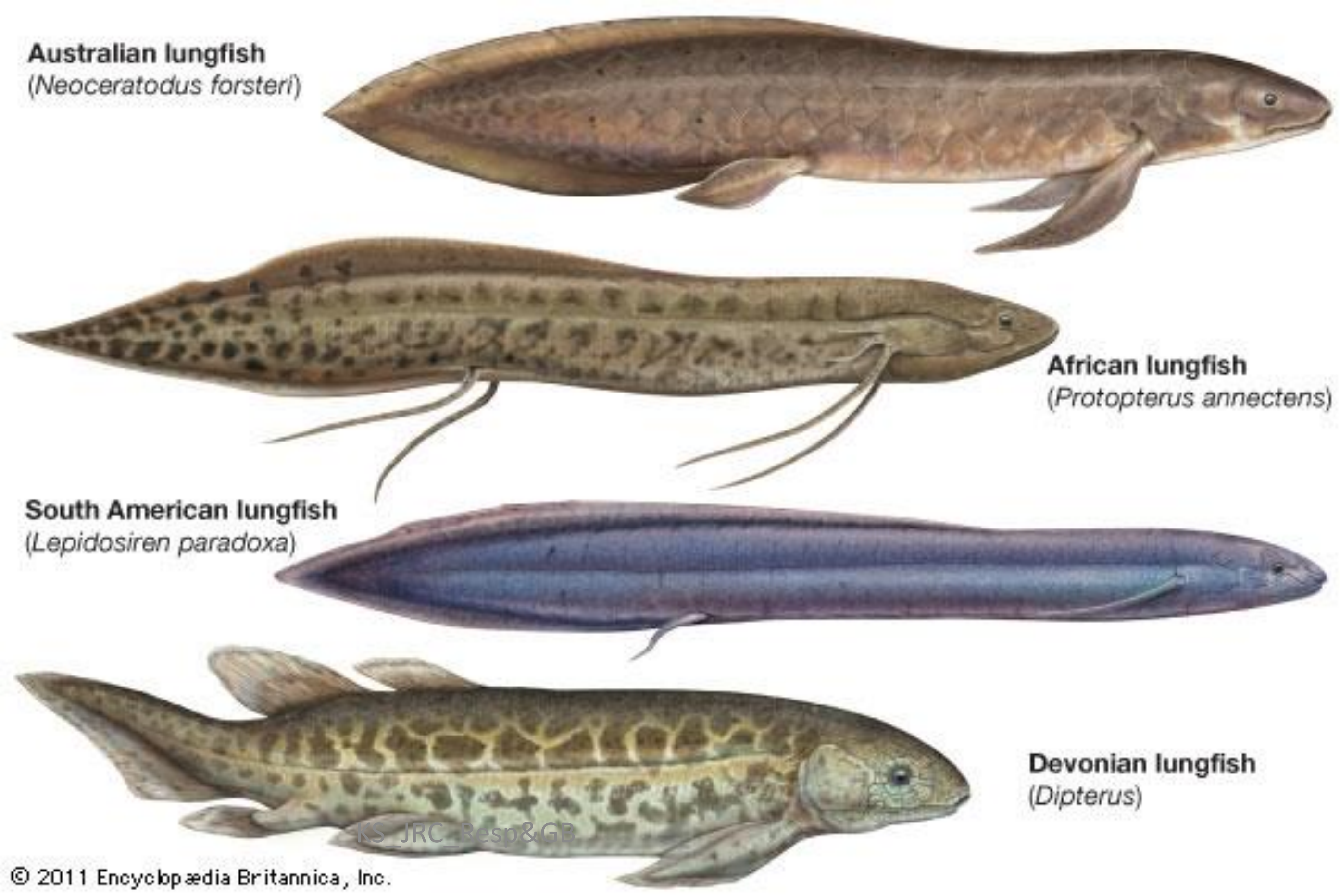
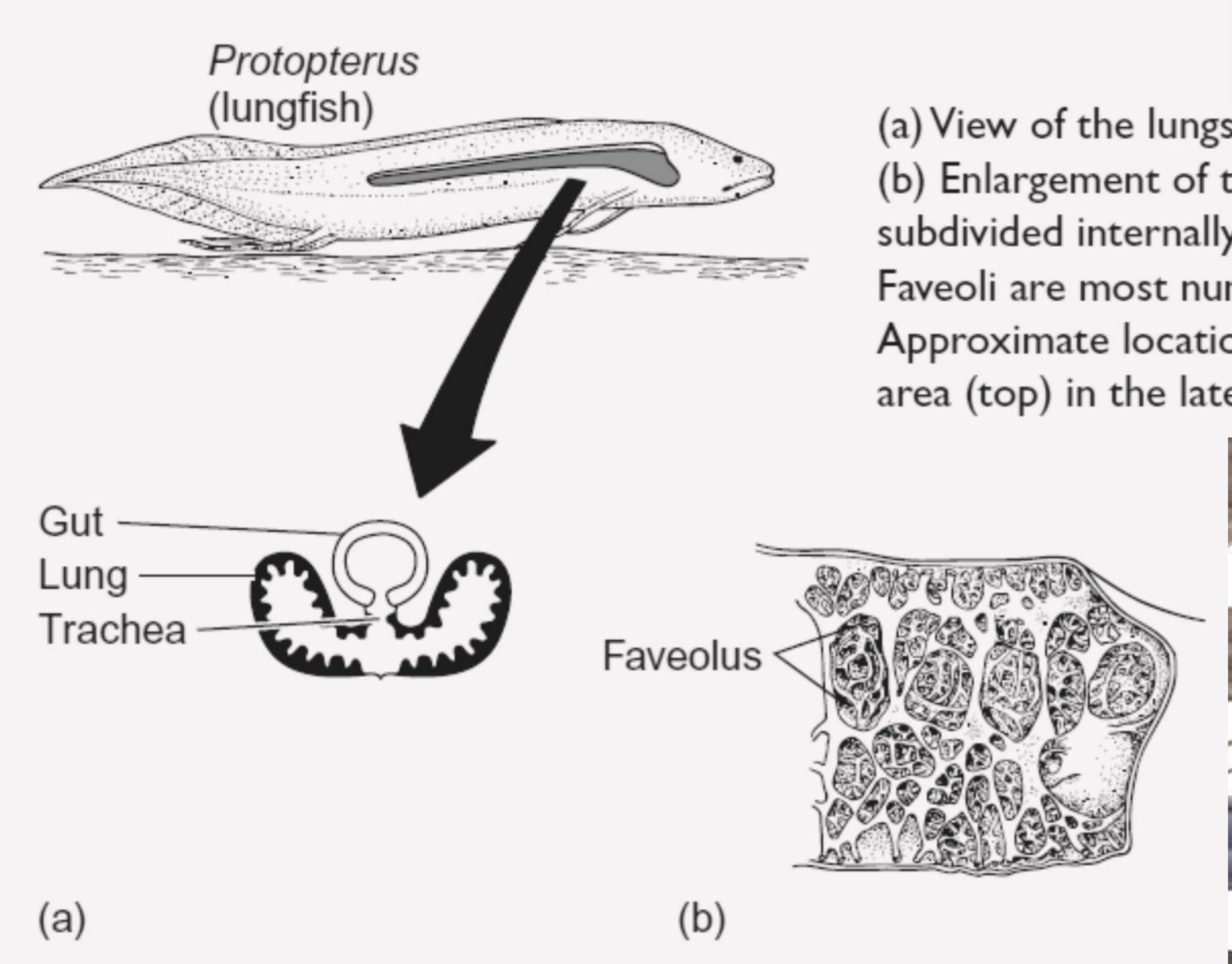


Diagram of a dogfish in side view (anteriorly) and horizontal section (posteriorly) to show the path of the respiratory current. The flow is unilateral. The horizontal sections pass through the external gill slits and illustrate the changes in volume of the parabranchial and oro-branchial cavities. Pressures in these cavities are indicated with respect to zero pressure outside the fish. Full line arrows show the movements of the mouth and branchial regions, with their thickness indicating the relative strength of contraction.

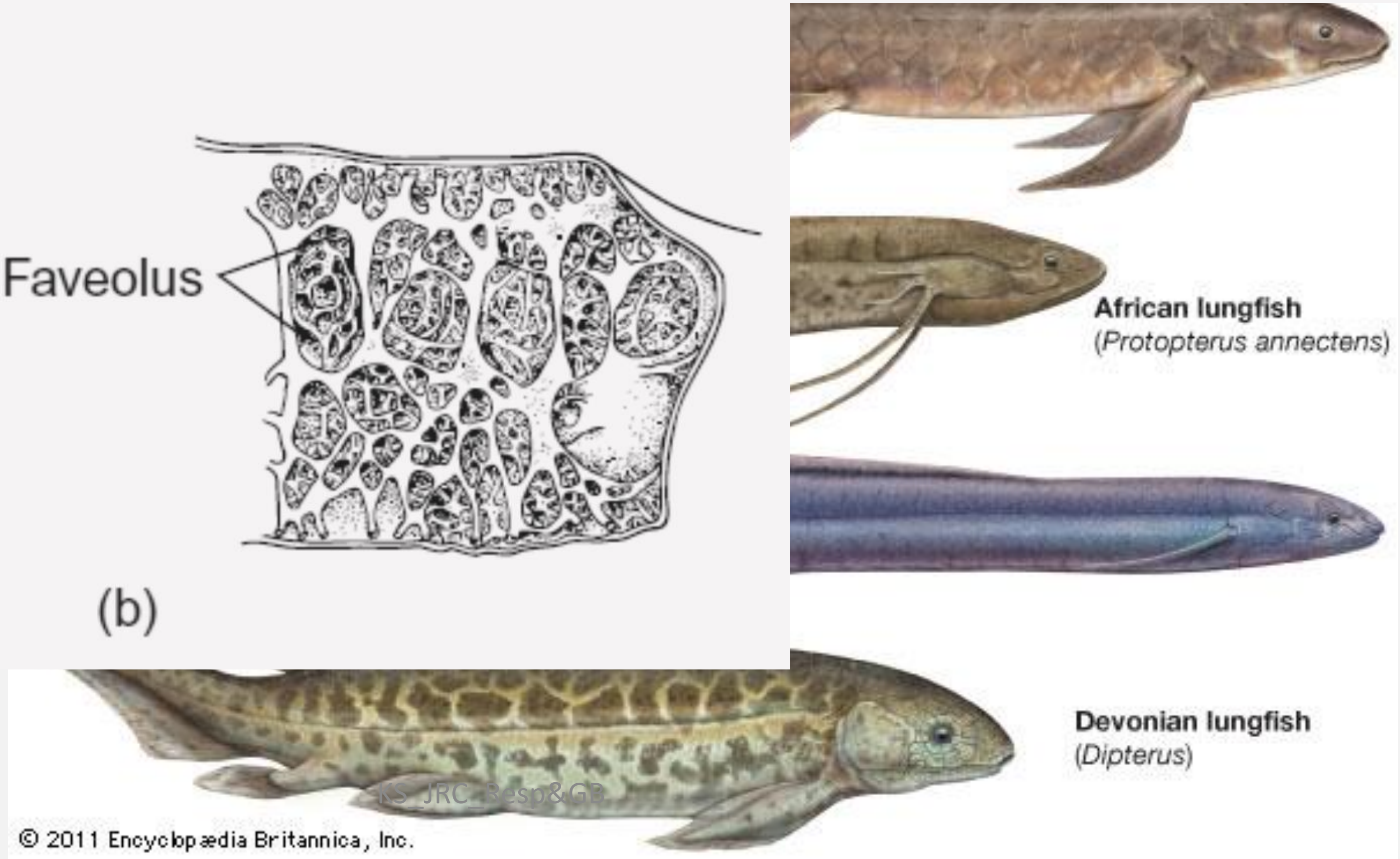
Arial Respiration in Lung Fishes

- Lungfishes arose in the Devonian period
- They are **closely related to** the group of fishes **(Crossopterygii)** which gave rise to the first land vertebrates
- In **common with crossopterygian fishes** they **possess internal nostrils** which can be seen in the three living genera of lungfishes
- These are found in the three southern continents and are **Neoceratodus (Australia), Protopterus (Africa), and Lepidosiren (South America)**





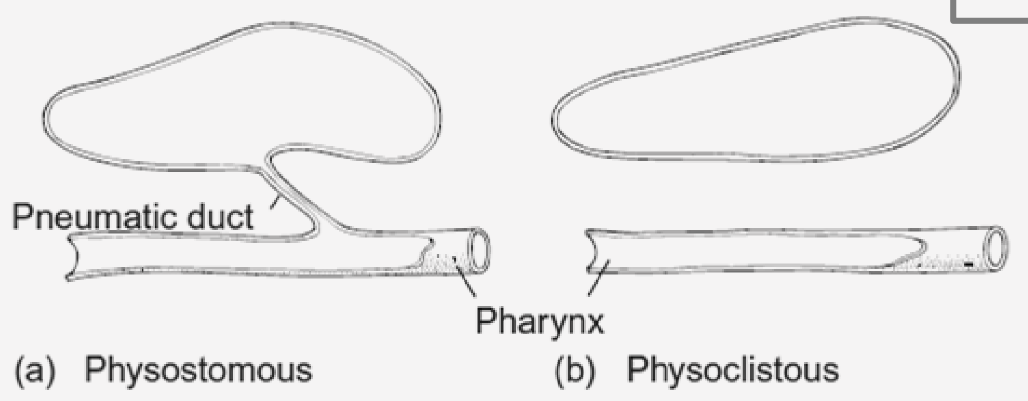
(a) View of the lungs from the right side and in cross section.
(b) Enlargement of the internal wall of the lung. The lung is subdivided internally, forming small compartments, or faveoli. Faveoli are most numerous in the anterior part of the lung. Approximate location of the lungs is indicated by the darkened area (top) in the lateral view of the fish's body.



- Only ***Neoceratodus* is able to survive** if it is not allowed to come to the surface and only this **genus has well-developed gill filaments**
- The branchial arches of *Lepidosiren* pass through the gill arches with few capillaries and the blood does not come into close contact with water
- In *Neoceratodus* the branchial arches break up into fine capillaries in the gills. It normally breathes under water with the mouth slightly open and a current produced by slow movements of the two opercula
- This Australian lungfish rarely comes to the surface, but the other two genera regularly (e.g. every 15-30 minutes in *Protopterus*) come to the surface and gulp air through the mouth In fact only
- ***Protopterus* makes a mud cocoon** although ***Lepidosiren* is also able to aestivate**, but ***Neoceratodus* cannot survive out of water for long periods**
- *Protopterus* may survive as long as 3-5 years in such a state
- Within the cocoon the O_2 consumption falls by 50% during the first week and finally after several months to only 10% of its initial level
- Awakening from this remarkable state of dormancy is readily induced by the threat of asphyxiation.

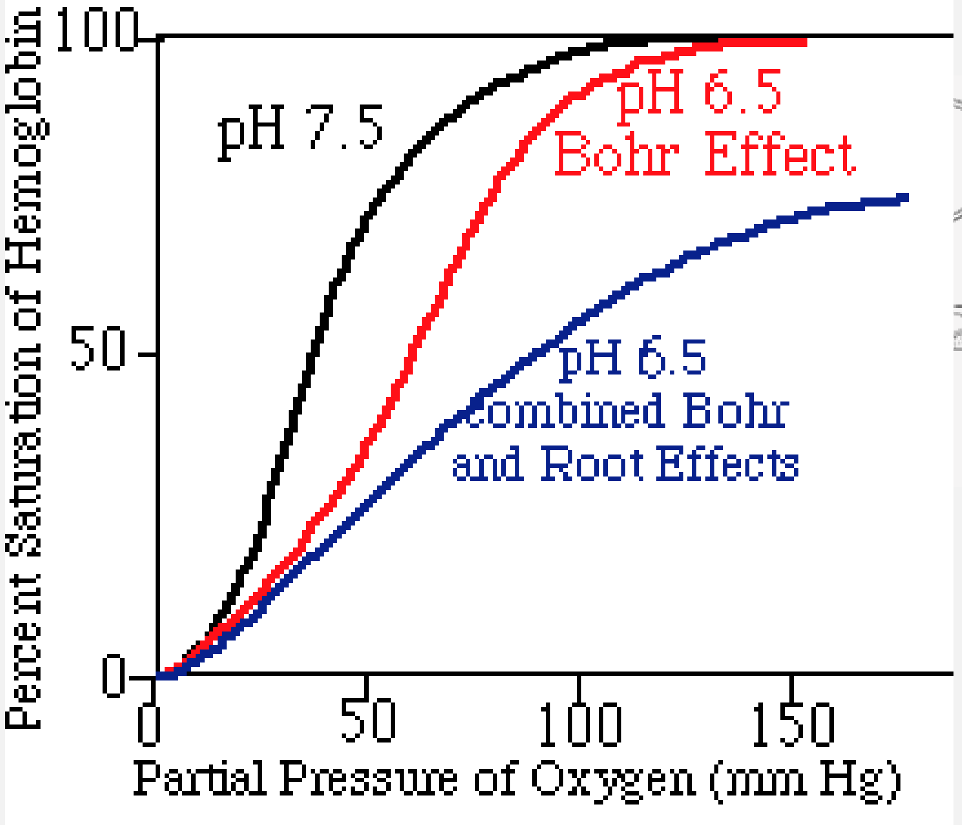
Swim Bladder and the Origin of Lungs

Swim Bladder

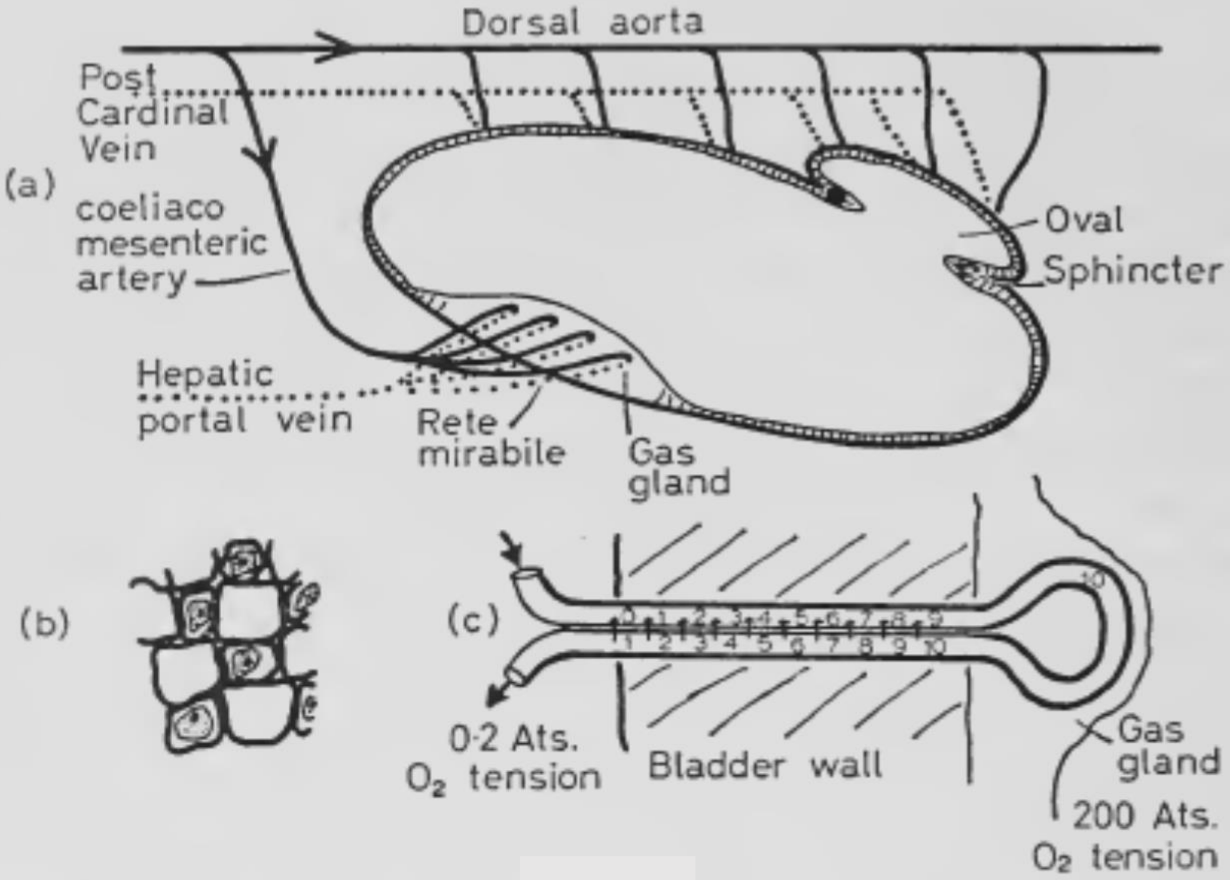


Structure

- Two layers, tunica externa and tunica interna, are usually distinguished
- The outer layer is often highly extensible and consists of a trellis of elastic fibers
- The tunica interna has no elastic fibres but contains collagen and smooth muscle
- In most swimbladders, two distinct vascularized regions are recognized, one of which is ventral and called **the gas gland**. Dorsally and posteriorly is found the **oval**, so called because of its shape when viewed from inside the bladder



- ✓ **Root Effect** is the phenomenon where an **increased proton** or carbon dioxide concentration (lower pH) **lowers hemoglobin's affinity and carrying capacity for oxygen**
- ✓ The Root effect is to be distinguished from the Bohr effect where only the affinity to oxygen is reduced.



Diagrams to show the structure of a physoclistous swimbladder. (a) General organisation and blood supply. (b) Transverse section through the rete mirabile to show the close relationship between afferent and efferent capillaries. (c) Diagram illustrating the role of the hair-pin counter-current in maintaining the very large difference in O_2 tension between the contents of the bladder and the blood supply in a deep-sea fish. The arrows indicate the diffusion of oxygen across the rete. (b and c after Scholander, 1958.)

Evolution of Lung

For clarity, lung and gas bladder differences are detailed before discussing their evolutionary relationship. Vertebrate lungs share most of the following characteristics:

i. Embryonic origin as a small outpocketing from the ventral wall of the alimentary canal that persists and gives rise to ventrally positioned (i.e., closer to the ventral body wall) and paired organs
ii. The presence of a valvular glottis in the floor of the alimentary tract that guards the entrance to the lung
iii. The presence of a pulmonary circulation (i.e., afferent and efferent vessels leading more or less directly from the heart to the lungs and returning, Chapter 4).

Gas bladders by contrast:

i. Have an embryonic origin from the side or dorsal aspect of the alimentary canal, occur higher in the body (for vertical stability in water), and are not paired (although the bilobed structure of some reflects a primitively paired state)
ii. Do not always have a glottis and may or may not retain an open pneumatic duct (i.e., physostomous versus physoclistous, Chapter 2)
iii. In most cases, receive blood in parallel with the systemic circulation and thus lack a specialized circulatory loop functionally equivalent to a pulmonary circulation (Chapter 4).

Class OSTEICHTHYES

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Subclass: Sarcopterygii (fleshy fins)

n–Recent

Lycoptera, *Mormyrus*, elephant snout fish, *Pantodon*, butterfly fish

Superorder 4: Clupeomorpha. Cretaceous–Recent
Clupea, herring

Superorder 5: Ostariophysi (ossicle fishes). Eocene–Recent
Cyprinus, carp: *Tinca*, tench; *Silurus*, catfish;
Gobio, gudgeon; *Phoxinus*, minnow

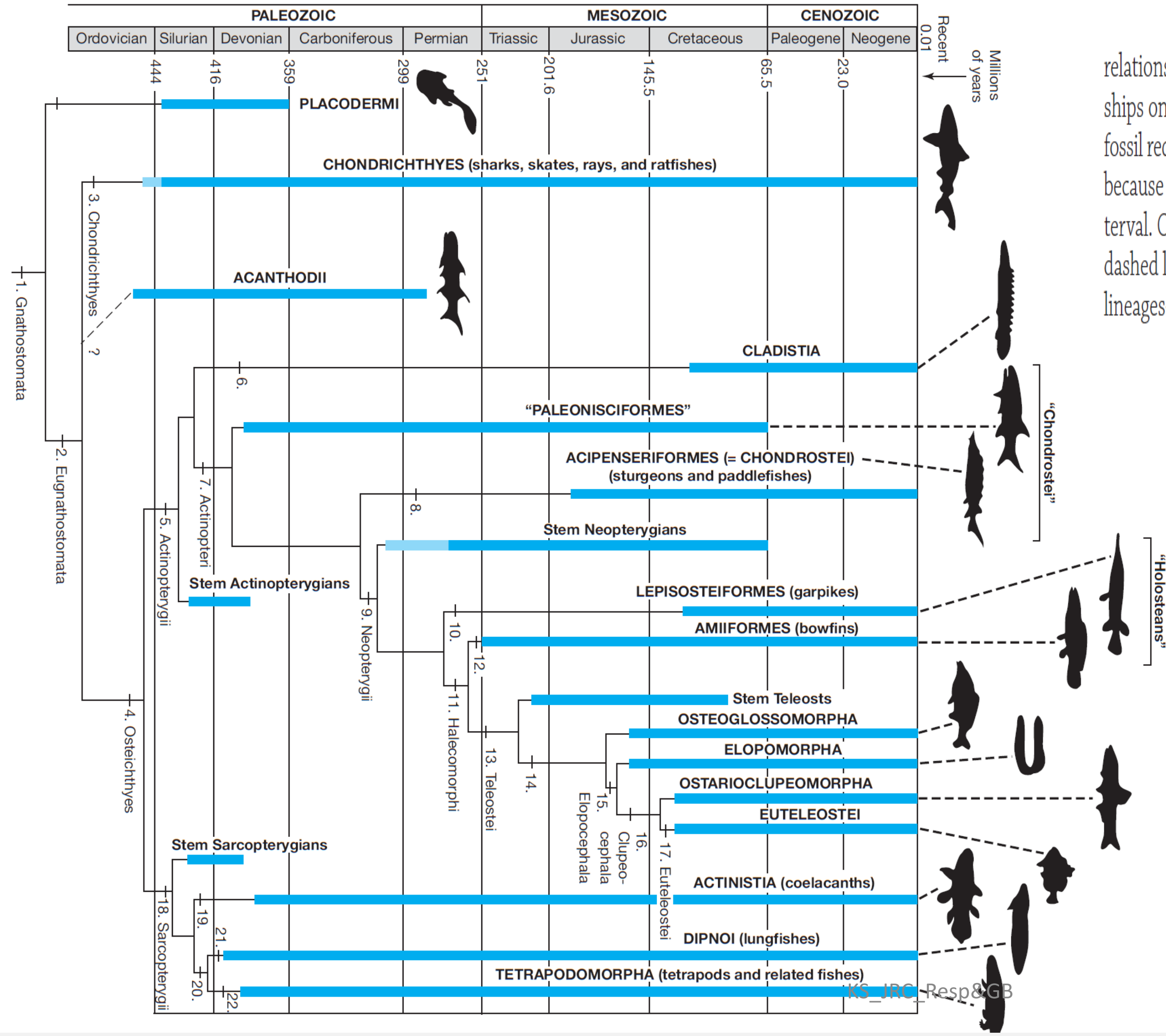
Superorder 6: Protacanthopterygii (early spine fin fishes). Upper Cretaceous–R
Salmo, trout; *Esox*, pike; *Astronesthes*, deep-sea snaggletooth; *Myctophus*, la

Superorder 7: Paracanthopterygii (nearly spiny fin fish). Eocene–Recent
Lophius, anglerfish; *Photocorynus*, deep-sea anglerfish; *Lepadogaster*, suckerfi

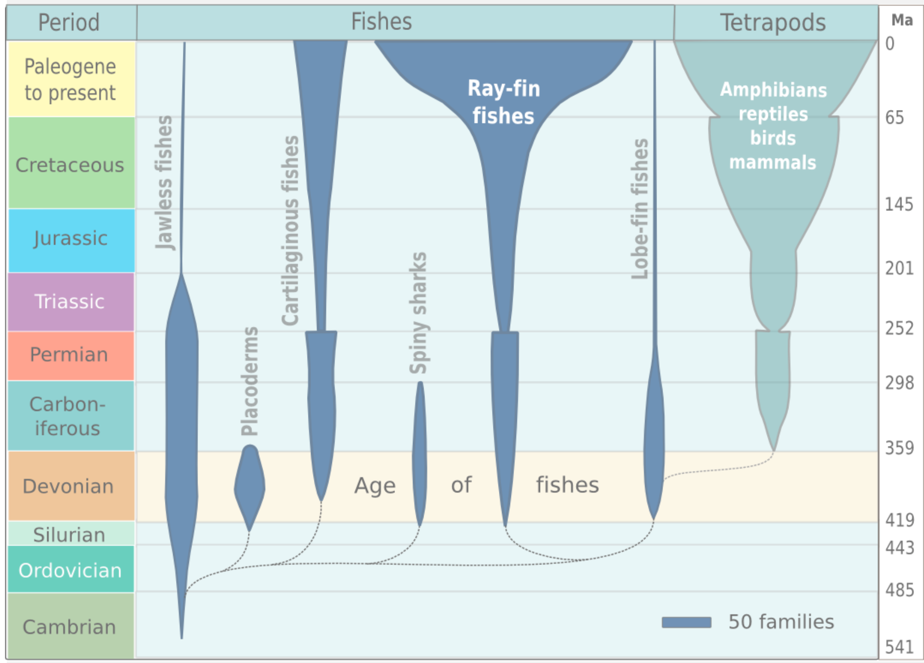
Superorder 8: Atherinomorpha (smelt fishes). Upper Cretaceous–Recent
Exocoetus, flying fish; *Belone*, garfish

Superorder 9: Acanthopterygii (spiny fin fishes). Upper Cretaceous–Recent
**Hoplopteryx; Gasterosteus*, stickleback; *Syngnathus*, pipefish; *Hippocampus*,
Dory; *Perca*, perch; *Labrus*, wrasse; *Uranoscopus*, star gazer; *Blennius*, blenny; *Pleuronectes*, plaice
Solea, sole; *Exocoetus*, flying fish; *Belone*, garfish

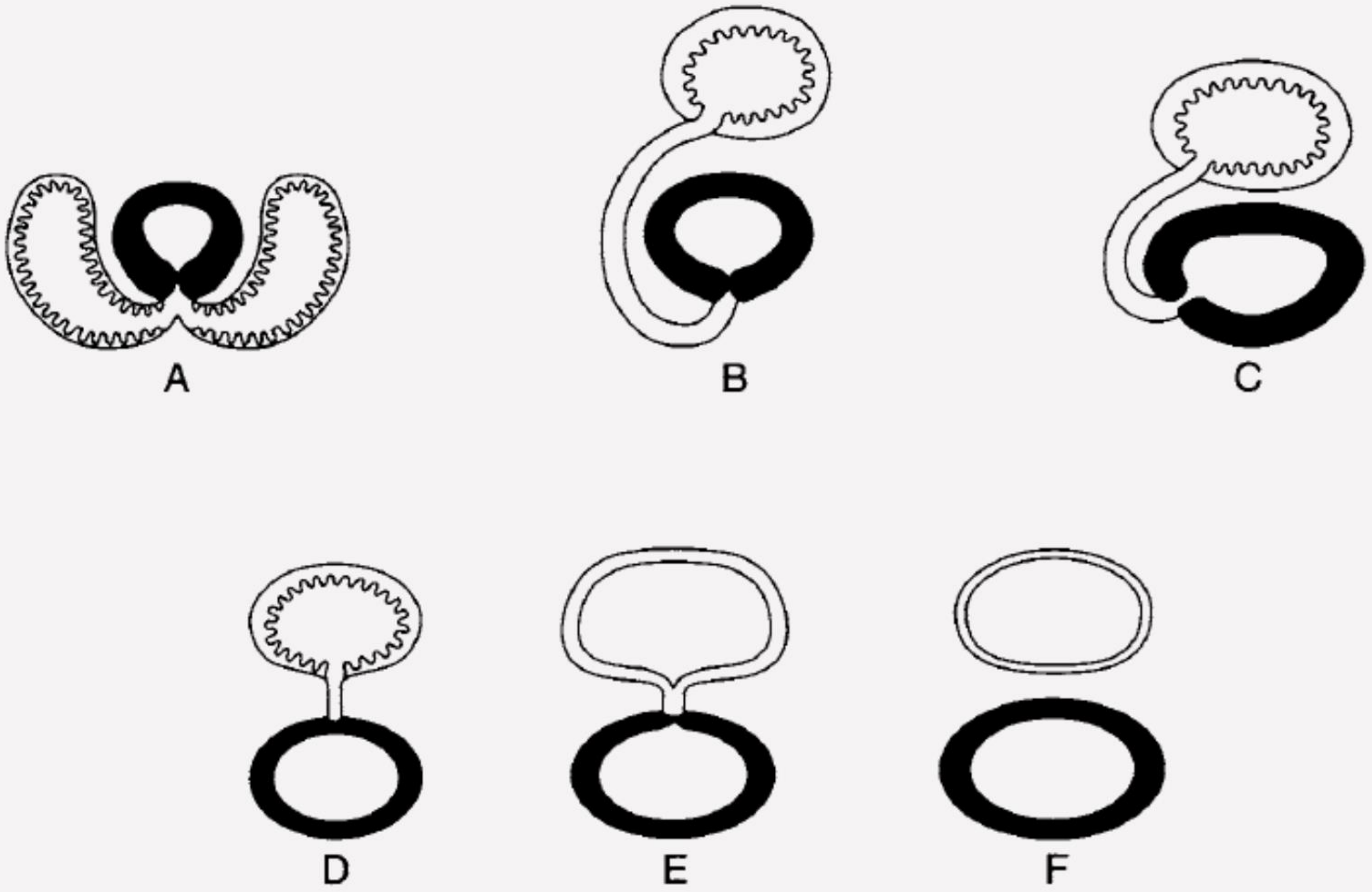
Classification of (bony) fishes as per Young, 3rd ed



Phylogenetic relationships of bony fishes. This diagram depicts the probable relationships among the major groups of basal gnathostomes. The black lines show interrelationships only; they do not indicate times of divergence or the unrecorded presence of taxa in the fossil record. Lightly shaded bars indicate ranges of time when the taxon is believed to be present, because it is known from earlier times, but is not recorded in the fossil record during this interval. Only the best-corroborated relationships are shown, and uncertainties are indicated by dashed lines. The numbers at the branch points indicate derived characters that distinguish the lineages—see the Appendix for a list of these characters.

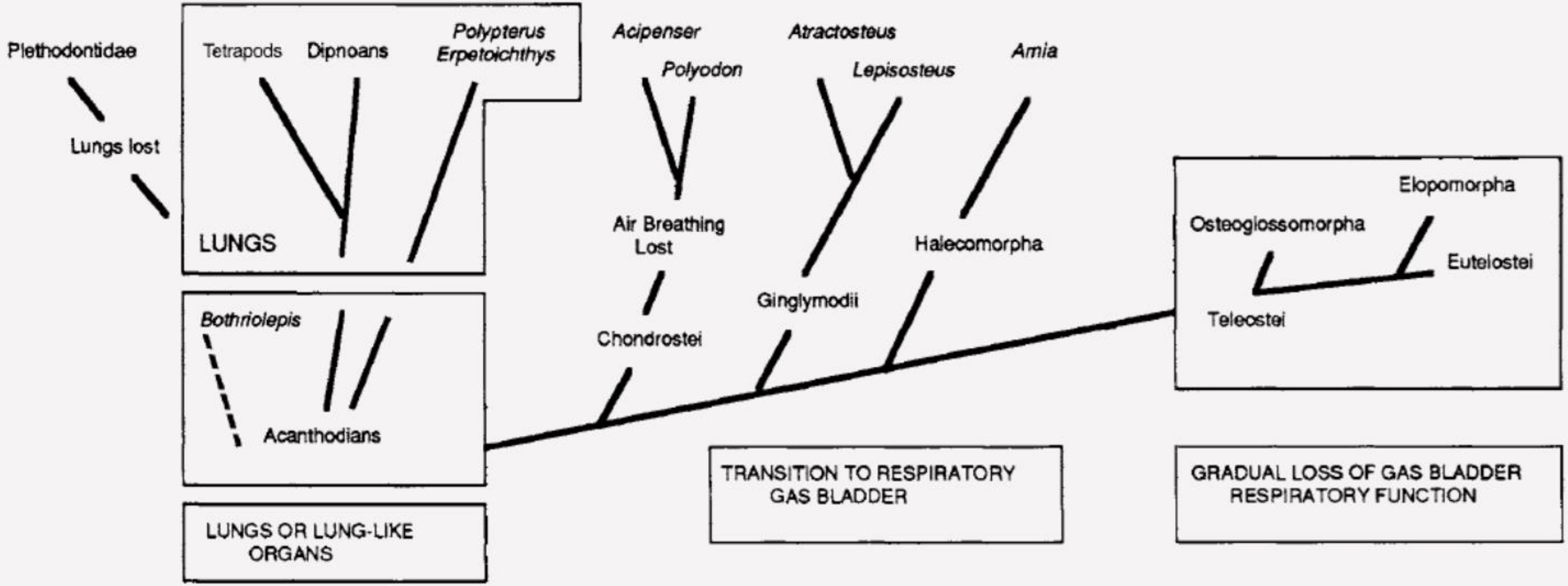


Lung to Gas bladder Transition (Sagemehl Hypothesis)



Possible intermediate morphological stages in the evolutionary transition from a ventral lung (A) to a dorsal, non-respiratory gas bladder. Alimentary canal in each stage represented by thick black wall; respiratory surface by convoluted line. **A,** Ventral lungs. **B,** Dorsal lung with a ventral glottis and elongated pneumatic duct. **C,** Gut rotation. **D,** Dorsal pneumatic duct. **E,** Configuration as in D but with loss of respiratory function. **F,** Physoclistous gas bladder.

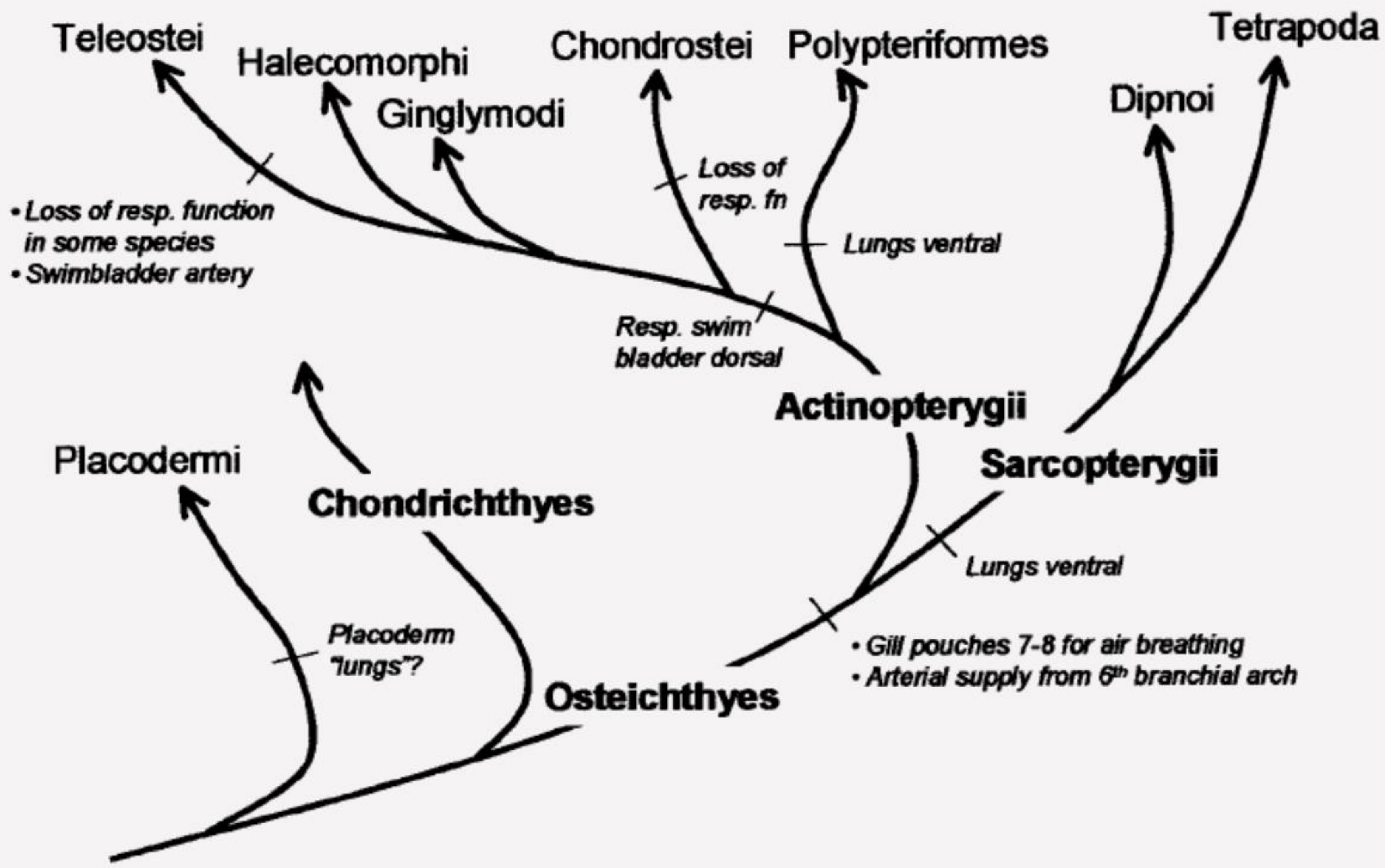
Evolution of Lung



Probable phylogeny of vertebrate air breathing showing the origin and evolution of the lung and other ABOs among early fishes, the evolutionary development of the lung in tetrapods and various fishes, the gradual transition among fishes, from lung to gas bladder, and the loss of air breathing and lungs or lung-like structures from diverse groups.

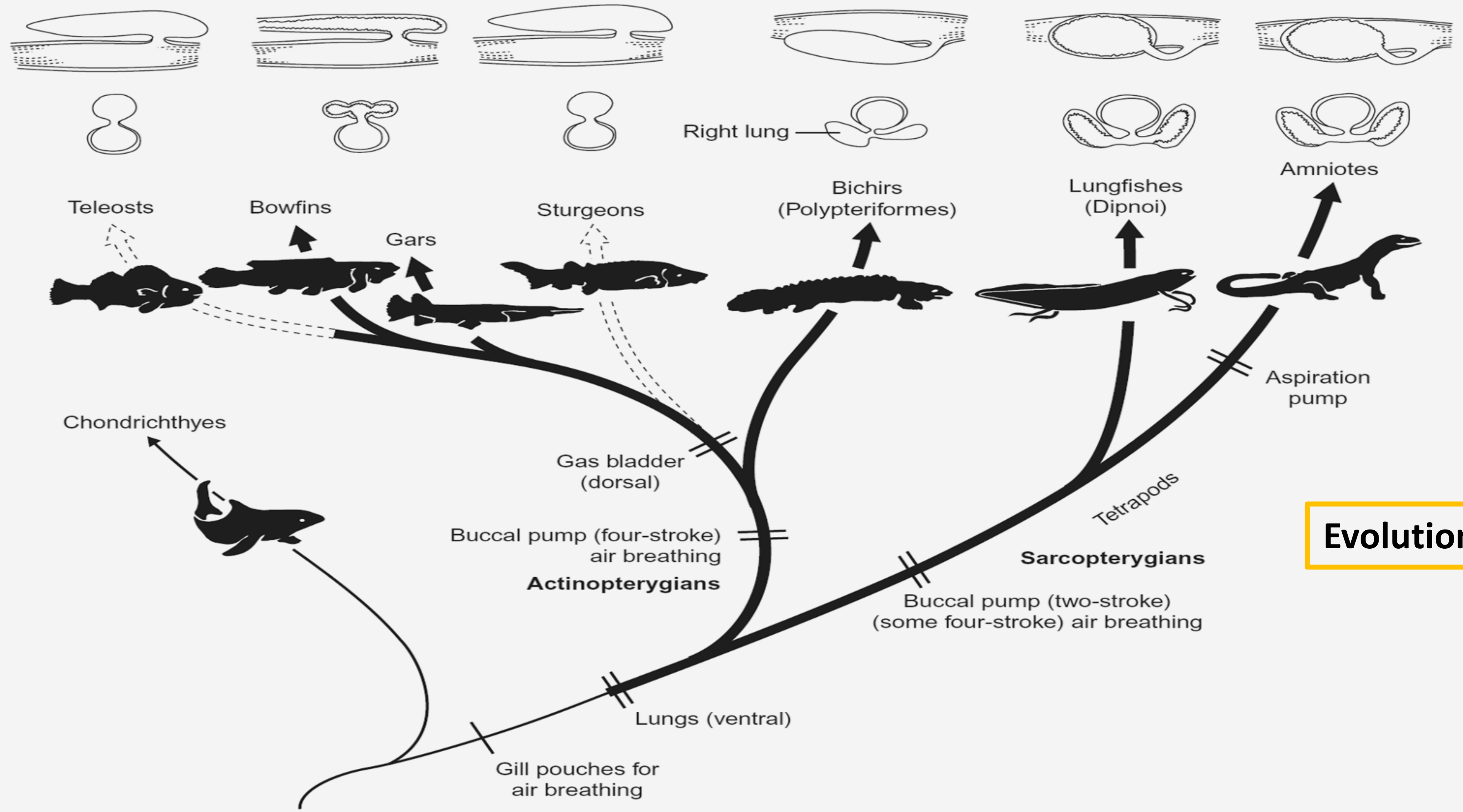
Graham et al. (19)

Phylogeny of Lung



Schematic diagram of the evolutionary sequence of air-breathing organs among the fishes. The ontogenetic origin (i.e., ventral or dorsal) and the evolution of lungs, swim bladders, and their blood supply and the loss of respiratory function are indicated in italics. *Resp.* = respiratory; *fn* = function. Figure modified from Perry et al. (2001).

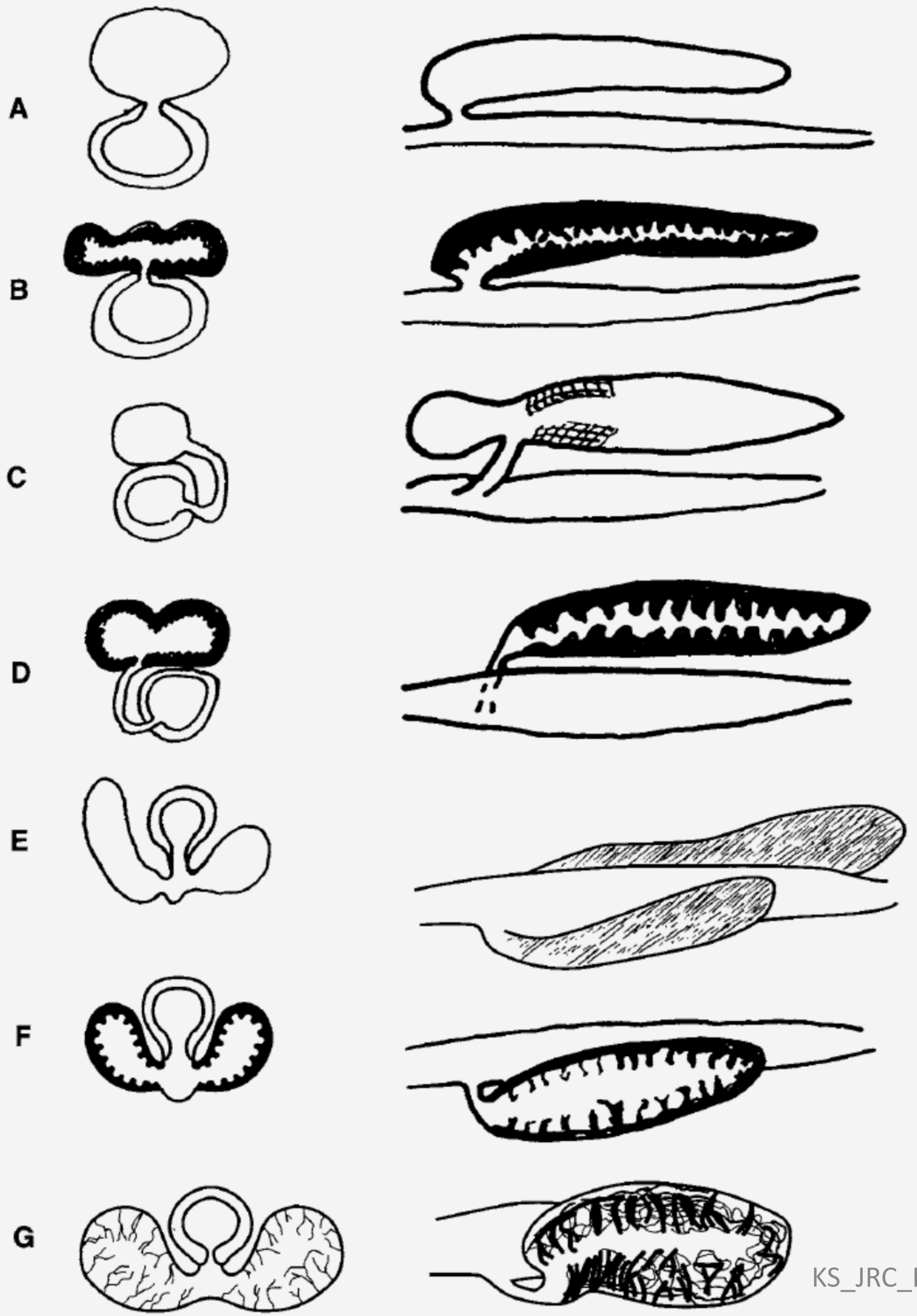
Daniels et al. (2004)



Evolution of Gas Bladders

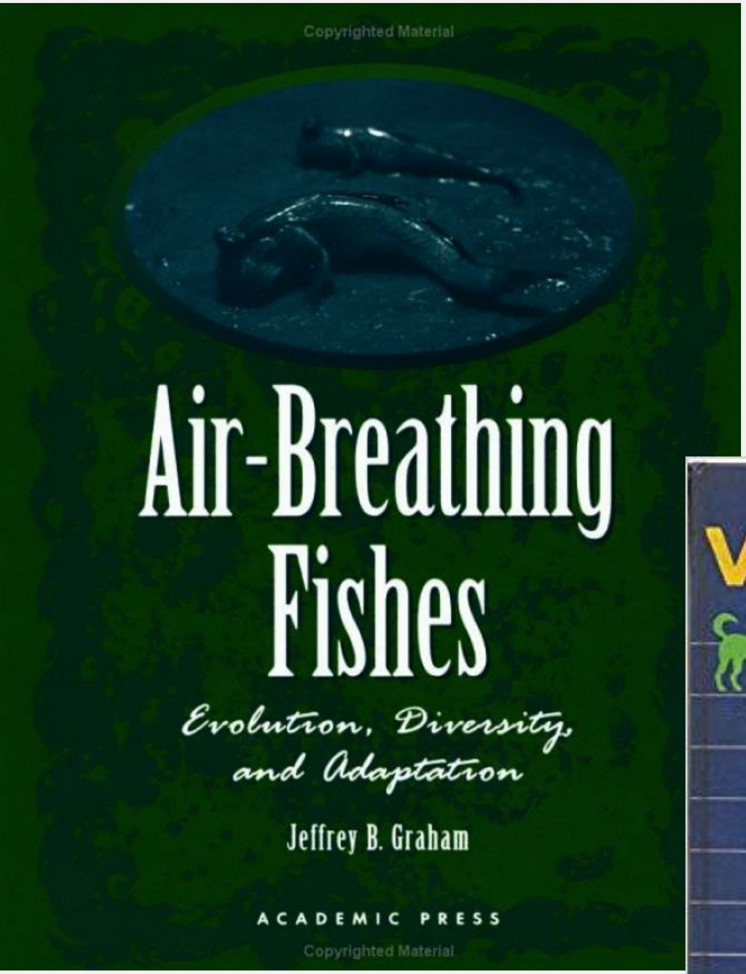
Evolution of gas bladders: Lungs, ventral in position, evolved in the common ancestor to actinopterygians and sarcopterygians. Swim bladders in actinopterygians may have evolved independently, or they may have been modified from earlier lungs. Some gas bladders are respiratory in function. Above the dendrogram outlining the evolutionary rise of each group, there are sagittal (top) and cross-sectional (bottom) views of the lung and its connection to the digestive tract. In Polypteriformes (Polypterus), paired lungs open through a common muscular glottis into the right floor of the pharynx. The left lung is reduced, the right one long, but the epithelial lining of both is smooth. Swim bladders of sturgeons originate from the stomach and those of primitive teleosts from the esophagus, suggesting that these nonrespiratory gas bladders may be of independent origin in these two groups. Dashed arrows indicate points where the respiratory function of the gas bladder is lost

Progressive Spatial Evolutionary Changes of Lung/Gas Bladder in Respect to Gut



Modified version of Bashford Dean's (1895) original figure showing the evolutionary progression of the relative position between the gut and lung or gas bladder in fishes and tetrapods. Cross sections depict relationships as seen from head-end of the body. Morphological conditions are: **A**, Physotomous, non-air-breathing: Sturgeon and many teleosts. **B**, *Lepisosteus* and *Amia*. **C**, *Erythrinus* (note origin of pneumatic duct from the left side of gut). **D**, *Neoceratodus* (note that the pneumatic duct originates ventrally but ascends on the right side of the gut, Dean had originally illustrated this on the left side). **E**, *Polypterus* and *Erpetoichthys* (note that Dean did not illustrate furrows or smaller size of the left lung). **F**, *Lepidosiren* and *Protopterus*. **G**, Tetrapods.

References



AMER. ZOOL., 28:739–759 (1988)

Form and Function of Lungs: The Evolution of Air Breathing Mechanisms[1]

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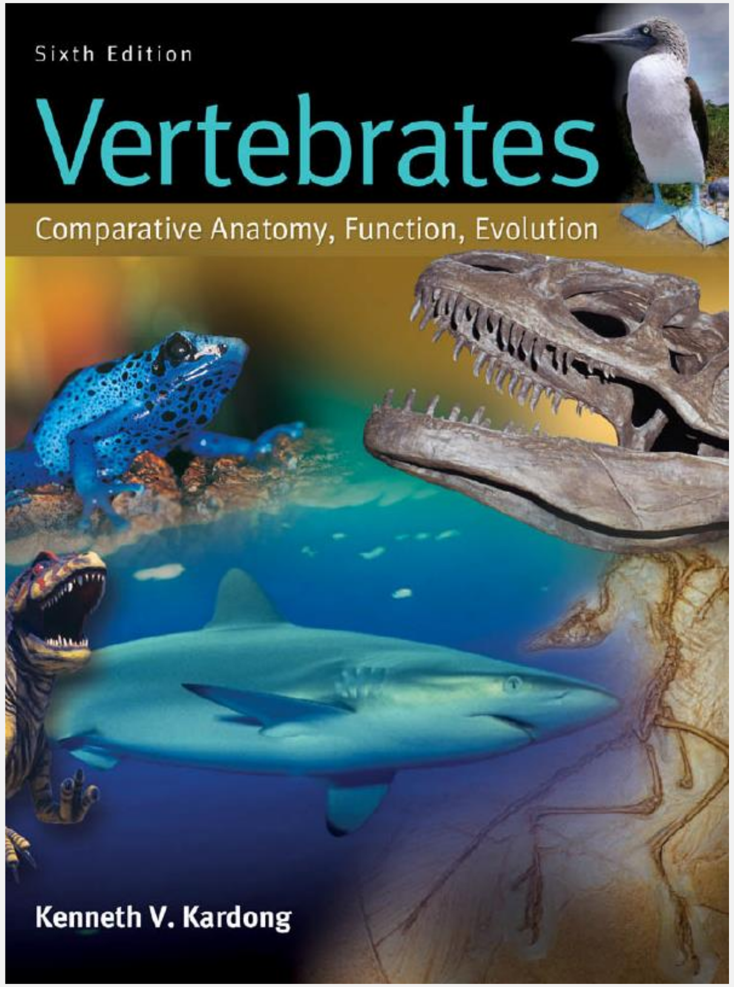
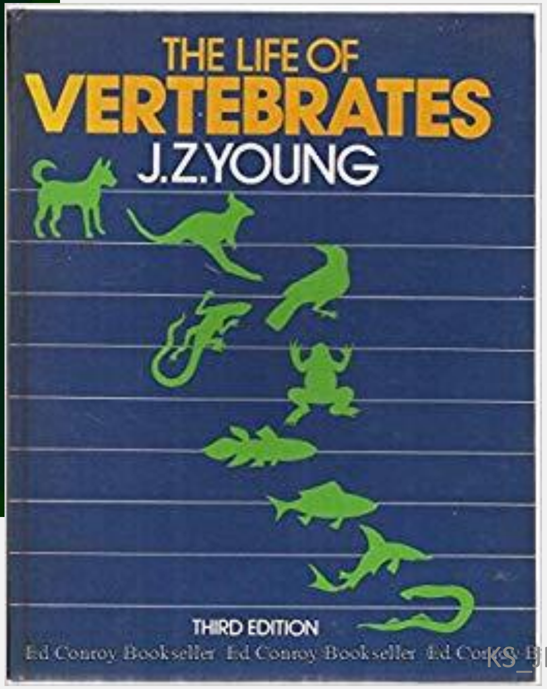
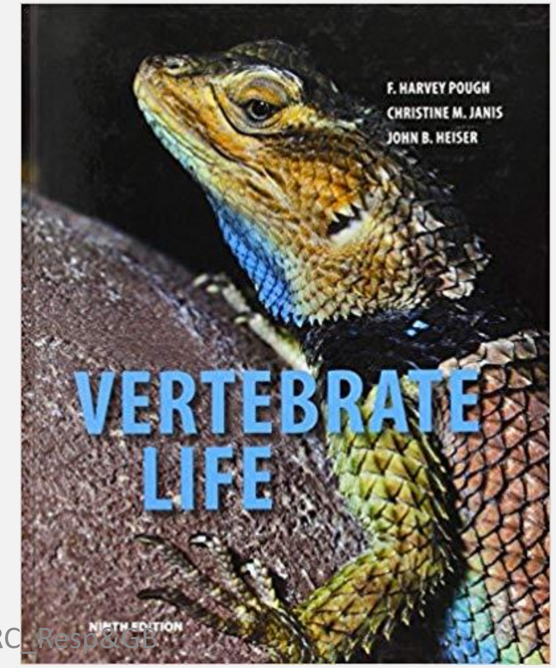
SYNOPSIS. Structural evolution of the vertebrate lung illustrates the principle that the emergence of seemingly new structures such as the mammalian lung is due to intensification of one of the functions of the original piscine lung. The configuration of the mechanical support of the lung in which elastic and collagen fibers form a continuous framework is well matched with the functional demands. The design of the mammalian gas exchange cells is an ingenious solution to meet the functional demands of optimizing maintenance pathways from nucleus to the cytoplasm while simultaneously providing minimal barrier thickness. Surfactant is found in the most primitive lungs providing a protective continuous film of fluid over the delicate epithelium. As the lung became profusely partitioned, surfactant became a functionally new surface-tension reduction device to prevent the collapse of the super-thin foam-like respiratory surface. Experimental analyses have established that in lower vertebrates lungs are ventilated with a buccal pulse pump, which is driven by identical sets of muscles acting in identical patterns in fishes and frogs. In the aquatic habitats suction is the dominant mode of feeding generating buccal pressure changes far exceeding those recorded during air ventilation. From the perspective of air ventilation the buccal pulse pump is overdesigned. However in terrestrial habitats vertebrates must operate with higher metabolic demands and the lung became subdivided into long narrow airways and progressively smaller air spaces, rendering the pulse pump







That's all Folks!