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Comparative animal physiological functions between species to discern physiological and evolutionary patterns

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Abstract
This truly comparative text takes a fundamental, biophysical approach toward animal physiology. Comparisons show the similarities and differences in how animals function, but stress fundamentally similar adaptations in very different animals. Abstract: The inconstant environment in which animals lives and the variation of their metabolic states determined the gas exchangers system that must be able to operate efficiently across a spectrum of conditions that range from resting to exercise and even under hypoxia. The primordial respiratory organs that evolved for water breathing were the gills, evaginated gas exchangers, whereas for terrestrial air breathing developed an invaginated gas exchangers, the lungs. Specialized organs evolved for animals that can extract oxygen from water and air, consider as a transitional breathing (or bimodal). From amphibians to mammals, it is possible to verify that the dimensions of their respiratory units are being increasingly smaller and the number per unit of lung volume increases. The evolution of the vertebrate respiratory system achieved its most efficient state in birds, with their constant volume peribronchial lungs and their highly compliant air sacs with low pressure ventilation that, enabling them to sustained flapping flight. In contrast, the mammalian bronchoalveolar lungs, with their mandatory high-pressure ventilation and great volume changes, allowed the development of adaptations that favour, for example, a highly mobile trunk for high velocity running predators or to live in a deep-sea.

Keywords: respiratory system, lung development, morphology, alveoli

Introduction

Different points of view have shaped the scientific study of the origin of life. Some of these argue that primeval life was based on simple anaerobic microorganisms able to use a wide inventory of abiotic organic materials (heterotrophic origin), whereas others invoke a more sophisticated organization, one that thrived on simple inorganic molecules (autotrophic origin) [1]. The organization and mechanisms allowing a chemical system to be materially and energetically connected with the environment, and equipped with the ability to self-construct, emerged first, and then appeared the complex chemical structures that provide the system with a temporal connection throughout successive generations. Thus, the origin of life was a process initiated within ecologically interconnected autonomous compartments that evolved into cells with hereditary and true Darwinian evolutionary capabilities [1]. Nevertheless there is a consensus that life started in an anaerobic environment in the so called "primordial broth", a mixture of organic molecules in the absence of oxygen [2]. Molecular phylogenetic studies have revealed a tripartite division of the living world into two procaryotic groups, Bacteria and Archae, and one eukaryotic group, Eucarya. To know which group is the most "primitive" would help to delineate the characters of the last common ancestors to all living beings. According to several investigators and to the procaryotic dogma, the universal ancestor was probably a thermophile because primitive Earth was hotter than today [3]. Nevertheless it is possible that the ancestor would have been a mesophile and, in this case, the root of the tree of life should be located in the eucaryal branch, with Archae and Bacteria sharing a common ancestor [3]. Almost four billion years ago, living beings that inhabited the earth were very primitive microorganisms, perhaps methanogenic bacteria, living in absolute anaerobiosis [4]. These organisms still exist in our days and are included in the Archae domain, and for this reason are central to the paleoenvironment and paleobiology studies [5]. Anaerobic fermentation was a very inefficient metabolic process of extracting energy from organic molecules and the rise of an oxygenic environment was a momentous event in the diversification of life that dramatically shifted from inefficient to sophisticated oxygen dependent oxidizing ecosystems. Subsequently, oxygen became an indispensable factor for aerobic metabolism, especially in the higher life forms. There are two widely accepted views of aerobic metabolism: first, that it was only possible after oxygen release by photosynthesis became abundant, and second, that it developed independently in diverse evolutionary lines. Analysis of the temporal distribution and geochemistry, suggest that the transition from reducing to sable oxygenic environment occurred later, between 2.3 and 1.8 billion years ago [6]. Molecular evidence shows that aerobic respiration evolved before oxygenic photosynthesis, or, in other words, cytochrome oxidase appeared before the water-splitting system. This hypothesis considers that denitrification (NO reductase) is the probable origin of aerobic respiration, that aerobic respiration arose only once the last universal ancestor was already present and that oxygenic photosynthesis developed in a single evolutionary line, the cyanobacteria, after the origin of aerobic respiration [7]. The rise of atmospheric oxygen caused by photosynthetic activity of evolving cyanobacteria must have created a remarkably strong selective pressure on organisms in both domains. Adaptations to use the new, chemically superior, electron receptor might have taken place, with similar molecular solutions creating the oxygen-reducing active sites. This would mean that the aerobic respiration has a single origin and may have evolved before the oxygen was released to the atmosphere by photosynthetic organisms and that the appearance of aerobic respiration was polyphyletic [7]. This new and more profitable method of extracting energy, aerobic respiration, should have led to a domain of aerobic organisms in the biological community, and probably even leading to the extinction of some anaerobic organisms [8, 9]. The evolution to multicellular organisms determined the appearance of more sophisticated and specialized systems for the gas exchange, in order to develop an effective system of exchange. The existence of multicellular organisms, led to rapid and progressive morphofunctional differentiation of groups of cells that became the precursors of tissues, organs and systems currently present in more complex organisms. In most cases, this cellular specialization does not imply the loss of genetic material but only changes in the genes expression [9, 10]. The promise of the recent trends in biological research is to understand the integrated function of animals and human biological systems in order to improving health of human being. The study of animal physiology is recently stimulated by the development of medical sciences as it holds many chemical and physical principles. Since the discovery of the cell structure and tissues, the science of physiology has undergone rapid development. It includes the study of vital activities in cells, tissues and organ processes such as, contractility of muscle tissue, coordination through nervous system, feeding, digestion, respiration, circulation, reproduction and hormone secretion. Virtually, every specialized field in the biological functions involves some consideration of the physiological aspect. The study of animal life is ancient, but its scientific incarnation is relatively modern. Until the comparative anatomical study on morphographs by Hunter and Cuvier, the modern areas of zoological investigations have occurred. Gradually zoology expanded behind the comparative anatomy to include the following sub-disciplines:

Zoology is the branch of biology concerned with the study animals and animal kingdom. It is also known as animal biology. The study of zoology includes the interaction of animal kingdom in their ecosystems such as Zoology is the division of biology that deals with the animal kingdom. It is the scientific study related to the entire species of the animal kingdom. classification, habits, structure, embryology, distribution, evolution, and extinct species. An ancient Greek philosopher, Aristotle, was a first person to broadly classify the living things in the 4th century BC. Firstly he divided living things into animals and plants and then continued with his further classifications. Later the words like biology, botany, and zoology came into existence.

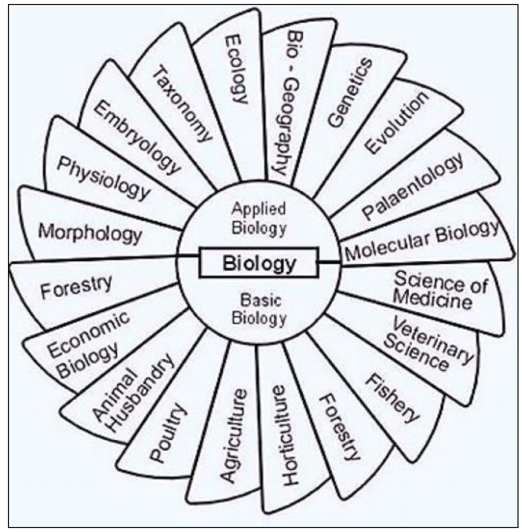

Fig 1: biology and its related branches

It is always interesting and surprising that how the different components of living organisms adjust to maintain a constant internal environment. It is the basic concern of physiology and known as homeostasis. Physiology is the subdivision of biology that deals with the various functions of living organisms. This scientific branch covers a big diversity of functions, ranging from the cellular and the interaction of organ systems which maintain for the smooth running of the highly complex biological mechanisms. The branch mainly concerned with the differences in the vital processes in different species of organisms, particularly with a view to the adaptation of the processes to the specific needs of the species, to revealing the evolutionary relationships among different species

The study of zoology includes animals physiology, their behavior, and their interaction with other species in their environment. It is a huge course that includes the distribution of every animal species on earth including extinct animals. Apart from the animal kingdom and ecosystem, zoology also explores the new areas of research. Zoography, it is also known as descriptive zoology. Comparative Zoology. Soil Zoology. Mamma logy, comparative anatomy. Herpetology. Animal physiology. Behavioral ecology. Entomology. Ornithology. Ethology studies animal behavior. Invertebrate and vertebrate zoology. Taxonomically oriented disciplines identify and classify species and study the structures and mechanisms specific to those groups.

Later, Aristotle divided animals into two classes: one with red-blood and another without such as insects and crustaceans. Then, he further classified creatures into those which were able to walk, flow and swim. The classification by Aristotle was followed till the 16th century, during the Age of enlightenment, scientists finally began to research closely. Now, zoology has become much more complex, where the living things are divided into five kingdoms, in which animal kingdom themselves divided into several smaller categories of Phylum, Class, Order, Family, Genus and, finally, Species.

These developments were synthesized in Charles Darwin's theory of evolution by natural selection. In the year 1859, Charles Robert Darwin presented the theory of organic evolution along with its observational evidence.

Respiratory Organs in Vertebrates

The steps of the evolution of terrestrial vertebrates are: change from anaerobic to aerobic life, accretion of unicells into multicellular organs, formation of a closed circulatory system, evolution of metal-based carrier pigments that improved oxygen up-take, formation of invaginated respiratory organs, physical translocation from water to land, development of a double circulation and progression from ectothermic-heterothermy to endothermic-homeothermy [14]. In vertebrates, the blood performs the task of transporting oxygen to the cells and carbon dioxide to the external environment [15]. The development of the respiratory organs of vertebrates is closely related to the primitive pharynx, since the gills of aquatic vertebrates and the lungs of terrestrial vertebrates and aquatic mammals have pharyngeal embryology origin.

In all vertebrates, at a certain stage of their development, arise bilaterally in craneo-caudal direction from the inner side of the pharynx, a series of diverticula, which evaginate towards the outer surface, forming the pharyngeal pouches. The number of pharyngeal pouches is greater in lower vertebrates, reaching fourteen in cyclostomes and only four or five in birds and mammals. The pharyngeal pouches are separated by masses of mesenchyme that have the designation of pharyngeal arches, in which is located an arterial structure, called the aortic arch, which extends from the ventral aorta to the dorsal aorta. During the ontogenesis of higher vertebrates, the pharyngeal pouches fail to open to the outside, contrarily to what happens in fish and, temporarily, in amphibians. Thus, in higher vertebrates, the pharyngeal pouches just remain during the embryonic period, where they undergo several changes, but very few or none of their initial characteristics are presented in adults. In amniotes, as in humans, only the first pair of pharyngeal pouches remains, giving origin bilaterally, the eustachian tube and middle ear.

Lungs & Associated Structures

Larynx

Tetrapods besides mammals - 2 pair of cartilages: artytenoid & cricoid Mammals - paired arytenoids + cricoid + thyroid + several other small cartilages including the epiglottis (closes glottis when swallowing) Amphibians, some lizards, & most mammals - also have vocal cords stretched across the laryngeal chamber

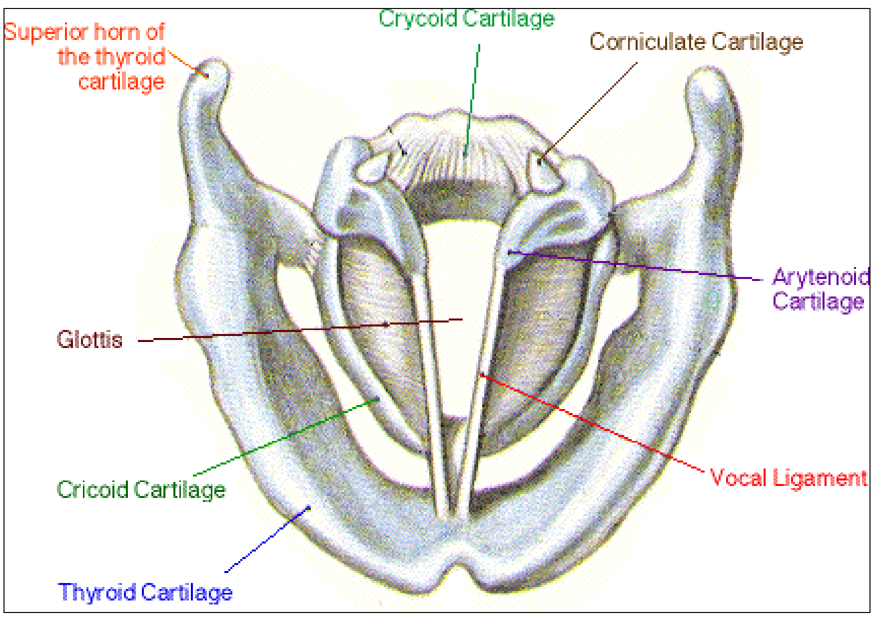

Fig 2: the laynx viewed from above

Respiration is the process of obtaining oxygen from the external environment & eliminating CO2.

External respiration - oxygen and carbon dioxide exchanged between the external environment & the body cells Internal respiration - cells use oxygen for ATP production (& produce carbon dioxide in the process)

Adaptations for external respiration: 1 - Primary organs in adult vertebrates are external & internal gills, swim bladders or lungs, skin, & the buccopharyngeal mucos. 2 - Less common respiratory devices include filamentous outgrowths of the posterior trunk & thigh (African hairy frog), lining of the cloaca, & lining of esophagus

Respiratory organs

Cutaneous respiration: espiration through the skin can take place in air, water, or both most important among amphibians (especially the family Plethodontidae)

Gills. Cartilaginous fishes

'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

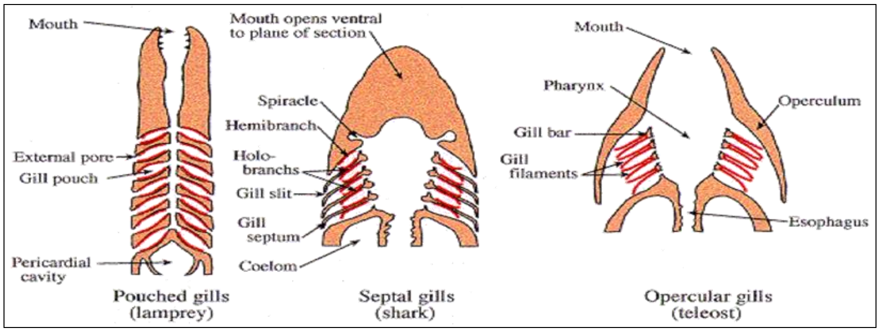

Fig 3

Bony fishes (teleosts)

- 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**

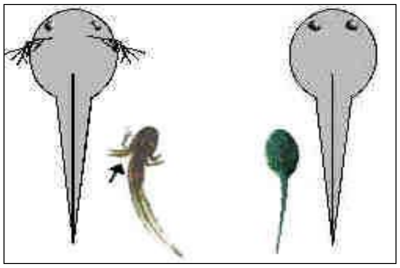

Fig 4

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).

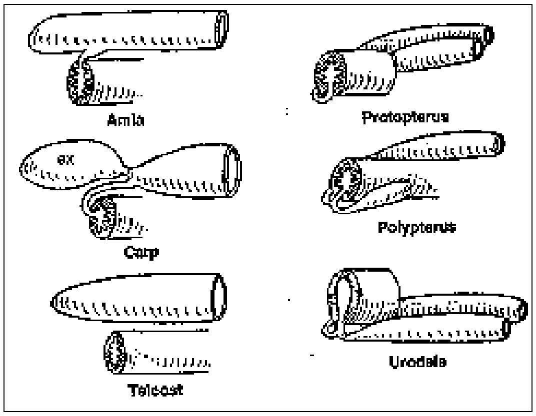

Fig 5

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

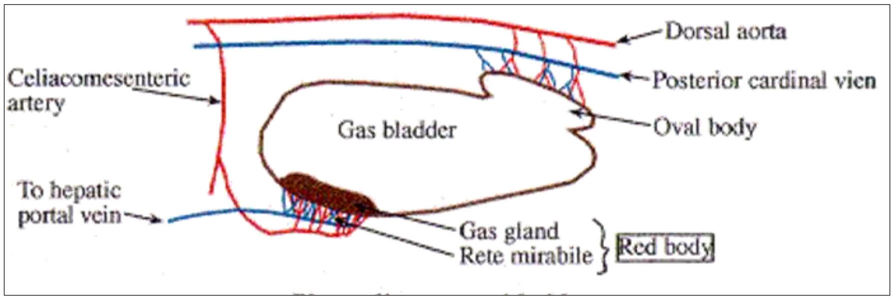

Fig 6: Physoclistous Gas Bladder

May also play important roles in

- Hearing - some freshwater teleosts (e.g., catfish, goldfish, & carp) 'hear' by way of pressure waves transmitted via the swim bladder and small bones called weberian ossicles (see diagram below)
- Sound production - muscles attached to the swim bladder contract to move air between 'sub-chambers' of the bladder. The resulting vibration creates sound in fish such as croakers, grunters, & midshipman fish.
- Respiration - the swim bladder of lungfish has number subdivisions or septa (to increase surface area) & oxygen and carbon dioxide is exchanged between the bladder & the blood

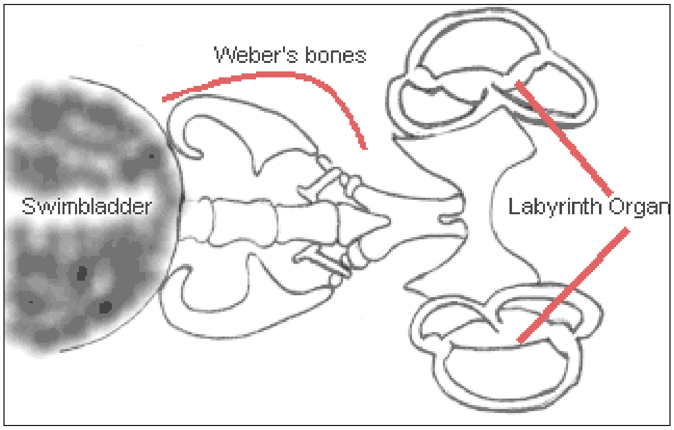

Fig 7

Conclusion and Future Prospects

Evolution and physiology have much to offer each other (36, 61, 62, 71, 72, 108, 135, 155, 214, 339, 342, 343, 388). Knowledge of physiological mechanisms can allow much deeper insight into possible reasons for evolutionary correlations and constraints than is possible for many of the traits typically studied by evolutionary biologists (e.g. morphology). A comparative perspective can even enlighten biomedical and clinical issues (460). For example, Rose and colleagues have provided clear evidence that an evolutionary perspective can (or at least should!) alter accepted views aging (179, 357-362, 384, 460). Similarly, Kluger's (242-245) studies fever and White's (456, 457) comparative perspective on acid-base balance during hypothermia have affected the way physicians view and treat human patients. "Those who see the body as a machine designed by a careless engineer are prone to therapeutic hubris. The antidote is a deep understanding of each organ's phylogeny and functions, as well as its ontogeny and structure." (460, p. 18)

We see evolutionary physiology moving forward on many fronts during the next decade. Which of the several promising areas, such as phylogenetically-based comparative studies, artificial selection studies in the laboratory, or physiological analyses of single-gene products will yield the greatest insights is difficult to predict. Perhaps the most illuminating studies will be those that apply several complementary approaches (35, 36, 39, 43, 51, 88, 155, 166, 214, 218, 302, 308, 345, 423, 432) to an ecologically and phylogenetically well-known group of species that is tractable for physiological studies. Such studies will not be easy, quick, or inexpensive, but they may yield understanding that is greater than any equivalent series of piecemeal studies done on several different species.

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