Huntington (Geo. S.)

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Comparative Anatomy and Embryology of Vertebrates as Aids in the Teaching of Human Anatomy in the Medical Course.

BY

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NEW YORK.

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THE

COMPARATIVE ANATOMY AND EMBRYOLOGY

OF

VERTEBRATES AS AIDS IN THE TEACHING OF HUMAN ANATOMY IN THE MEDICAL COURSE.[1]

By GEORGE S. HUNTINGTON, M.D.,
NEW YORK.

I FEEL some diffidence in addressing the Association on the subject of my title, for I have before me, through the courtesy of Prof. Wilder, papers and pamphlets dealing more or less definitely with the general question involved, written by Hyrtl, Waldeyer, and Turner among foreign anatomists, and by Wilder, Allen, Baker, and Minot among our own countrymen, and the list proves that the matter has received due thought and consideration at the hands of the ablest investigators and teachers of our science. If, notwithstanding, I bespeak some of your time and attention, it is not because I wish to repeat what has already been said by the eminent men quoted far better than I could hope to express it, but because the question is a many-sided one, and because I desire to emphasize certain aspects of the same in their practical bearing on anatomical instruction at our medical schools.

I may state at the outset that I do not propose to discuss the question whether comparative anatomy should be included as a separate department of study in the medical course;[2] but, as my title indicates, I wish

[1] Read before the Association of American Anatomists, Tenth Session, at Cornell University, December 30, 1897.

[2] Wilder, Burt G. Should Comparative Anatomy be Included in a Medical Course? New York Medical Journal, October, 1877.

Wilder, Burt G. The Anatomical Uses of the Cat. New York Medical Journal, Oct. 1879.

Turner, William. Address at the opening of the Anatomical Department in the new medito bring before you the employment of both comparative anatomy and embryology of vertebrates as aids in instructing medical students in human anatomy. Nor do I desire to speak of the advantages of *preliminary* work in comparative anatomy and embryology to students intending to enter the medical curriculum, beyond adding my testimony to the effect that the value of such preliminary work cannot, in my experience, be overestimated. I have occasion annually to compare the work and progress of a large number of students from all parts of the country and to note that almost without exception the men who early demonstrate their ability are those who have received practical biological training during their college course.

The questions which I wish to present for your consideration deal with the situation which confronts us, I believe, at the majority of our large centres of medical education, where students, differing necessarily widely in mental attainments, quantity as well as quality of preliminary training, meet to enter the medical curriculum, and are almost at once introduced to the study of human anatomy.

I may add that we have at Columbia during the past six years earnestly and systematically employed in our instruction in human anatomy the aids which the development and morphology of the lower vertebrates offer, so that the method upon which I can report to you has, to a limited extent, stood the practical test of experience.

The advances of the last decade in the biological sciences have changed and modified, in important and vital details, the method and scope of morphological instruction. Among the special departments in our large universities the one charged with teaching the structure of the human body to medical undergraduates should perhaps be the first to avail itself of these wider views and broadened fundamental lines. Human morphologists have long occupied a peculiar position in relation to their subject of study. For over two centuries the most minute and painstaking care has been bestowed on the investigation of man's structure, both the gross anatomy and the histology of his tissues receiving exhaustive attention. The results, embodied in almost countless volumes and pamphlets, make man to-day morphologically the best-known vertebrate.

cal building of the University of Edinburgh, October 27, 1880. Reprinted from the Lancet, November 6 and 13, 1880.

Minot, Charles Sedgwick. A Grave Defect in our Medical Education. March, 1882. Reprint.

Baker, Frank. The Rational Method of Teaching Anatomy. Read before the Biological Society of Washington, D. C., November 30, 1883. New York Medical Record, April 19, 1884.

Waldeyer, Prof. Dr. Wie soll man Anatomie lehren und lernen? Rede gehalten zur Feier des Stiftungstages der Militär-ärztlichen Bildungsanstalten am 2. August, 1884. Berlin, 1884.

Baker, Frank. What is Anatomy? A lecture delivered October 5, 1887, at the opening of the anatomical course at the Medical Department of the University of Georgetown, Washington, D. C. New York Medical Journal, October 22, 1887.

Allen, Harrison. Addresses in Anatomy: I. Comparative Anatomy as a Part of the Medical Curriculum. II. On the Teaching of Anatomy to Advanced Medical Students. Philadelphia, 1891.

This accrued knowledge is at our disposal, and is receiving constant additions, as from time to time one field after another of human anatomy is revised and studied with modern methods of investigation. I believe that our duty as teachers of this knowledge requires us to take cognizance, thoroughly and systematically, of the structural relationship of man to the remaining vertebrates; to incorporate comparative anatomy and embryology more completely in our course of instruction to medical students to a degree and in a manner which the following pages will present briefly for your consideration.

In the first place I believe that we should not lose sight of what we may term the liberal scientific education of our students, as opposed to the acquisition of purely technical professional knowledge. Even a few years ago many fundamental facts of comparative anatomy and evolution were the scientific property of a limited number of special investigators. But with the general growth of education, especially within the direct sphere of influence of our large universities, much of this knowledge has become diffused among the laity. It is almost superfluous to mention the wide educational effect of institutions like the American Museum of Natural History, the Army Medical Museum, or the National Collection.

In his relation to the community at large the physician is still *par excellence* the man of science, and I believe that as a matter of general scientific education he should possess a knowledge, founded on his university course, which will enable him to give information and express intelligent opinions on vertebrate morphology in general and in relation to the structure of man.

But, aside from this general aspect, the study of comparative forms is of the greatest possible practical benefit to the medical student. I vividly recall my own student days, and I cannot but sympathize with the feeling, more or less akin to despair, with which many students begin to apply themselves to the minute details of structure taught in human anatomy. It seems to me that it is wise to compare our system of instruction with that usually adopted in some other branches of scientific and mechanical education. It would be universally acknowledged a wrong course of procedure if a student of mechanical engineering were taught the constructive details of a modern locomotive, or of the quadruple expansion engines of an ocean steamer, before he had been offered the opportunity of examining and studying the simple piston, cylinder, or boiler; or if a course in electricity commenced with the dynamo, before taking up the magnet. And yet I believe that in many respects we err in the same direction if we place before our students the multitudinous details which the structure of a highly developed and specialized vertebrate like man offers, without availing ourselves of the advantages which the comparison with simpler and more evident forms possesses both in respect to morphology and the physiological application of structure to function.

I am aware that in the last years much progress has been made in the direction indicated, especially in the teaching of human anatomy from the developmental stand-point. My plea to-day is for the further elaboration of this method and for the systematic use of comparative anatomy in teaching the structure of the human body to medical students.

Even with the best intentions it is not always possible fully to utilize the help which embryology offers in explaining the details of complicated adult human structures. I believe firmly that lasting knowledge is only attained by bringing the student into direct contact with the object of his study. The very nature of embryological methods presents difficulties in this respect, for practical laboratory work in embryology is a *sine qua non* for successful instruction, and drawings or models, schematic or otherwise, do not replace the actual object if we seek to elucidate adult structures by developmental facts. Hence comparative anatomy steps in to fill an important gap in our available methods, enabling us to present in tangible shape the fundamental facts in the development of the higher mammalian forms, our own included, by properly selected preparations of lower types which preserve throughout life morphological conditions that are temporary and evanescent embryonic stages in the higher forms. Where possible, I believe a course of practical laboratory embryology should be offered to medical students, and my ideal of such a course would be one which puts into each student's hand preparations designed to illustrate, as they do forcibly and unequivocally, the main structural facts as permanent conditions in the adult lower vertebrates, while he is studying, microscopically, by section or reconstruction, the same conditions as temporary embryonal stages in the development of the higher forms. We tell our students that the mammalian pancreas develops as a double diverticulum of the duodenal loop, and thus explain the connection of the pancreatic ducts with this portion of the intestinal tract. I believe that this fact would impress itself far more permanently if at the same time they were able to examine a selected series of pancreatic structures and pyloric cæca, beginning, for instance, with the double diverticulum of *Lophius* and working through representative Teleost types to the pancreas of higher forms. The very fact of the morphological variations and the probably different physiological adaptations encountered in this portion of the intestinal tract in lower vertebrates, together with the variations in the arrangement of the pancreatic and biliary ducts in mammalia, render a serial study of this kind all the more valuable. Again, I know of no method which will teach the medical student in a short time more about the structure of the penis than to demonstrate to him a series of reptilian copulatory organs, where at a glance he can see the morphological principles underlying the development of the mammalian corpus spongiosum and urethra, conditions which he will invariably recall when he examines his first clinical case of hypospadias. I cannot burden you with further examples; they suggest themselves by the score; but I believe you will agree with me if I add that one demonstration of the simple carnivore or marsupial intestinal tract and peritoneum is worth tons of colored chalk and acres of blackboard in elucidating the mysteries of the "greater and lesser sac."

So much, briefly, for the connection of comparative anatomy with the practical laboratory course in embryology. If I may trespass further on your time, I should like to point out what in our experience has proved the proper place for the introduction of comparative anatomy into the general course on adult human anatomy.

I may state again, that in constructing the anatomical course at Columbia the guiding principle has been found in the conviction that the student will gain his lasting and valuable knowledge only by direct study of the cadaver. We have broken—I hope for good and all—with the didactic lecture in anatomy as commonly understood, and I may take a moment to outline our procedure, because it directly involves the question in hand. The first-year student attends no lectures in anatomy. During this year the instruction consists of practical demonstrations to small sections of the class, dealing with the anatomy of the extremities, the osteology, myology, and angiology of the head and neck, including the cervical plexus, and in direct connection with the demonstrations abundant practical work in the dissecting-room. The first-year student also attends a series of demonstrations forming what we term the "Preliminary Visceral Course," designed to afford that general information regarding the body cavities and contents which is required for the correct appreciation of the instruction offered by the Departments of Physiology and Histology.

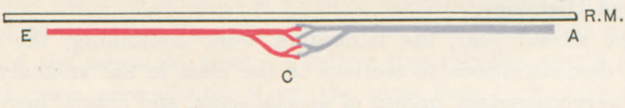
In the second year, the laboratory work continuing, the student attends demonstrations to sections of the class in the anatomy of the central nervous system, organs of special sense, and cranial nerves.

The entire second-year class attends three lectures a week on the anatomy of the body cavities and viscera. The preparations illustrating these lectures are, in the afternoons of the lecture days, demonstrated again separately to sections of the class, enabling each man carefully to inspect and study the same. In this way the opportunity is given of making the anatomical lecture what, in my opinion, it should strive to be—not an attempt to teach anatomy at long range to three hundred men at once, but an occasion for presenting a general view of the broad morphological principles which underly the construction of organs, apparatus, and systems. It is here that the significance and importance of the structural peculiarities of man can best be accentuated and illustrated in all their bearings by comparison with the morphology of the lower vertebrates. A series designed to teach the evolution of a complicated human organ, through successive stages from the simple and rudimentary form found in the lower vertebrates, or, conversely, the phylogenetic history of a human vestigial organ serially illustrated, attracts the student's attention and interest from the outset. He is offered actual facts and preparations, not dry statements or schematic drawings, and the knowledge cannot fail to be more readily acquired and more throughly assimilated. "Seeing is believing," in anatomy as elsewhere. At times, in dealing with broad general themes and subdivisions of the subject, as the genito-urinary tract, the digestive system, etc., I find it desirable to present a bird's-eye view of the structures under discussion by bringing before the students series of representative forms from all the vertebrate classes and orders before proceeding to details. Here the projection of photographs of the actual preparations by means of the lantern gives excellent satisfaction, although it does not, in my opinion, replace the personal examination of the object at close range.

I may conclude by outlining, in the case of a single organ, the scope and extent of the comparative method as we have used it profitably in practice. I have selected the lung, because a subsequent communication which I have to make to the Association on the mammalian eparterial bronchial system will enable me to present my illustration in a somewhat more complete form.

We begin our study of the respiratory system with a brief consideration of the physiological significance of the structures involved, as illustrated by the following scheme (Fig. 1).

FIG. 1.



Scheme of respiratory apparatus.

R.M. Respiratory membrane. A. Afferent vessel. E. Efferent vessel. C. Respiratory capillary net-work. O. Medium containing oxygen.

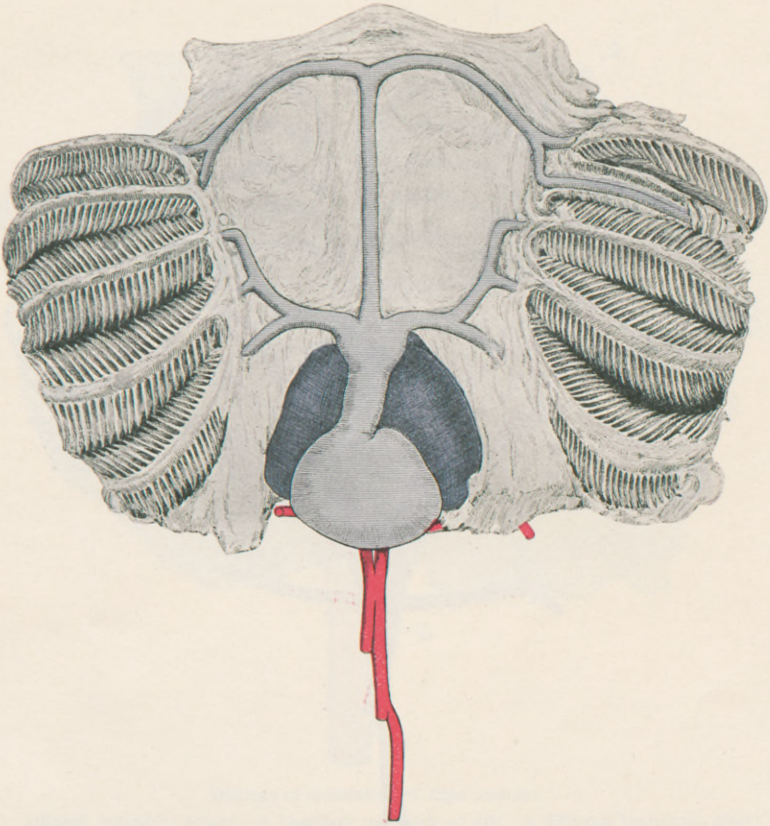
In addition to tegumentary respiration two general types of vertebrate respiration are to be recognized, depending upon the character of the oxygen-medium, whether water or air, and presenting corresponding structural modifications:

1. Medium: Water; respiratory organ: gills.
2. Medium: air; respiratory organ: lung.

We begin with respiration and the connected portion of the circulatory system in a representative fish, and select the selachian skate (*Raja* *occellata*) because it affords peculiar facilities for demonstration (Figs. 2 and 3).

The afferent arterial system proceeds from the truncus arteriosus of the single-chambered ventricle, dividing into caudal and cephalic branches, of which the former supplies three, the latter two branchial arteries to the gills (Fig. 2). These vessels carry venous blood returned

FIG. 2.



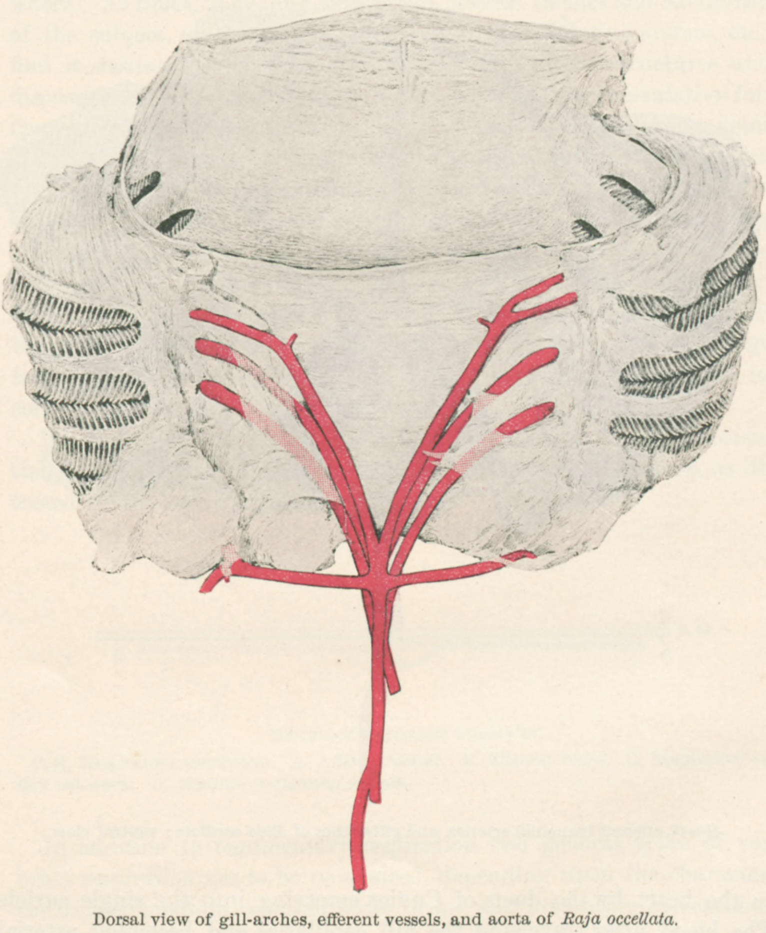
Heart, afferent branchial arteries, and gill-arches of *Raja occellata*; ventral view.

to the heart by the ducts of Cuvier emptying into the single auricle. The blood, after traversing the gill capillaries and becoming arterialized, is collected by a corresponding number of efferent branches which pass caudad and mesad on the dorsal aspect of the œsophagus, uniting to form the aorta which distributes the blood to the body, to be returned by the systemic veins to the auricle of the heart (Fig. 3).

The type here represented can be reduced to the following scheme (Fig. 4).

If now we assume that one gill on each side (the fifth) is replaced by a lung in the evolution of air-breathing vertebrates, and the corresponding arterial arch (the fifth) divided by the aortic septum from the systemic artery and converted into a pulmonary artery, the remaining four gills being no longer required, the continuity of the four cephalic arte-

FIG. 3.

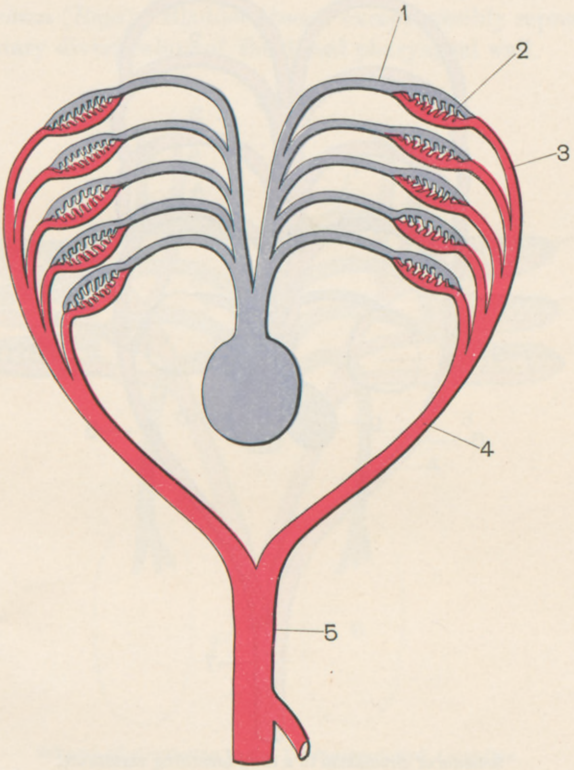


Dorsal view of gill-arches, efferent vessels, and aorta of *Raja occellata*.

rial arches will be restored. We will then have, with the divided heart and truncus arteriosus necessitated by the establishment of a pulmonary respiration, the following arrangement, which will be recognized as the fundamental type-plan in the development of the arterial system of all lung-breathing vertebrates.[1] (Fig. 5.)

That the above assumption is justified is shown by the arrangement of the circulatory system in the perennibranchial amphibia; and the lung-fishes, and the circulatory system of *Necturus* and *Menopoma*, as well as that of *Ceratodus*, are here introduced as demonstrative objects. (Schematically represented in Figs. 6, 7, and 8.)

FIG. 4.



Scheme of circulation of *Raja occellata*.

1. Afferent branchial artery. 2. Capillary net-work of gill. 3. Efferent branchial artery. 4. Aortic root. 5. Aorta.

The points which our consideration of the subject so far has developed may be summed up as follows:

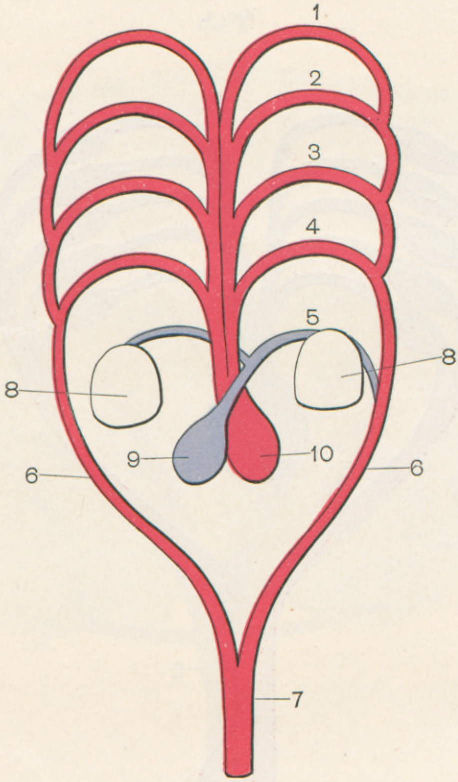
1. Unity of structural plan in all vertebrates.
2. Physiological equivalence of gill and lung.

[1] The development of the heart and arterial system has been considered in the course prior to the taking up of the respiratory system.

3. Pulmonary respiration and the necessary concomitant changes in circulation *cause* the transformation of the simple two-chambered (venous) fish heart into the four-chambered (arterio-venous) heart of the higher air-breathing vertebrates.

4. The arterial arches pass ventro-dorsad around the foregut, uniting to form the aorta on the dorsal aspect of the canal.

FIG. 5.



Scheme of circulation in a lung-breathing vertebrate.

1–5. Aortic arches. 6, 6. Aortic roots. 7. Aorta. 8, 8. Lungs. 9. Right (pulmonary) ventricle. 10. Left (systemic) ventricle.

Hence in anomalous persistence of both right and left aortic arches in man the trachea and œsophagus are included within a vascular loop. (Demonstration of correlated human aortic variations.)

We next turn to the derivation of the lung which, as above assumed, supplants the gill. Here again we begin with the type presented by the fish.

The gill-clefts of the fish correspond to the visceral clefts formed during the embryonic stages of the higher vertebrates.

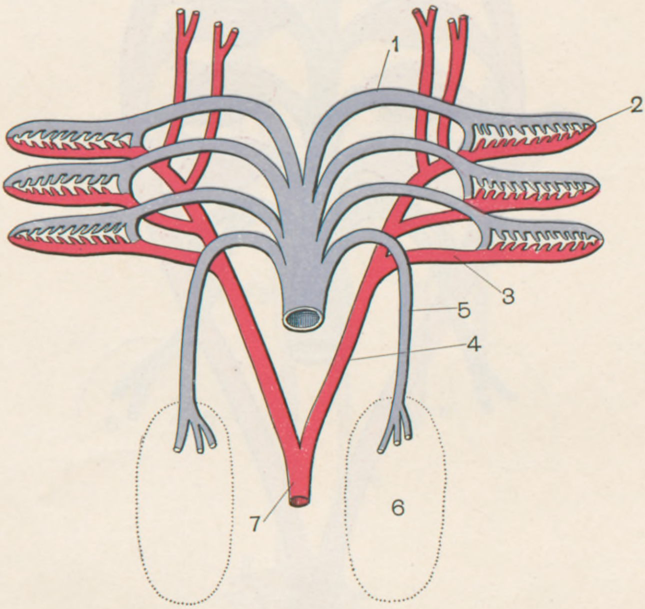
Complete clefts are formed by protrusions from the wall of the fore-gut, pouches extending laterally and finally perforating externally, establishing a passage between the pharyngeal cavern and the surface.

The number and arrangement of the clefts in the fish vary. In the embryos of the higher vertebrates there are usually four or five.

Caudad of the last gill-cleft in the fish an additional protrusion of the wall of the gut forms the "swim-" or "air-bladder," variable in development and purely hydrostatic in function. Three types of the swim-bladder are now exhibited:

1. *Selachian* (*Raja*). Bladder absent, except possibly represented by a rudimentary diverticulum of the dorsal pharyngeal wall.

FIG. 6.



Scheme of circulation in the Perennibranchial Amphibia.

1. Afferent branchial artery. 2. Capillary net-work of gill. 3. Efferent branchial artery. 4. Aortic root. 5. Pulmonary artery. 6. Lung. 7. Aorta.

2. *Ganoid* (*Acipenser*). Bladder present, connected with the lumen of the œsophagus by a hollow stalk, the *ductus pneumaticus*.

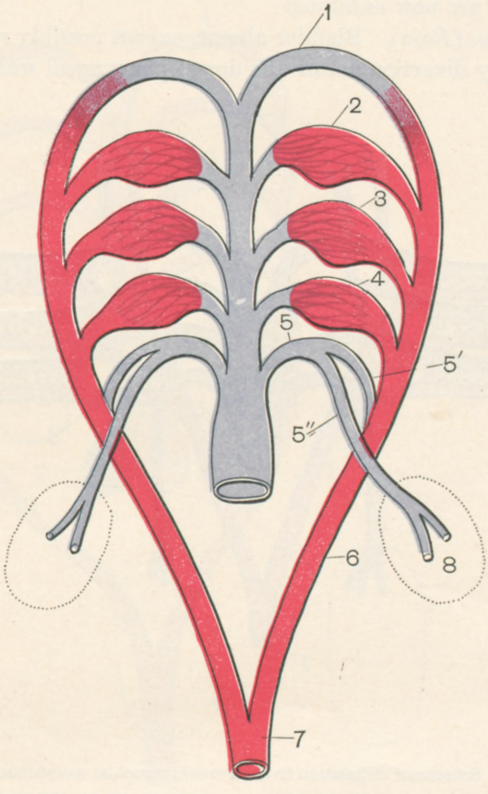
3. *Teleost* (*Gadus*). Bladder variable in its occurrence, more or less reduced. The ductus pneumaticus persists in a few forms in a rudimentary condition.

In most forms the bladder loses its original connection with the œsophagus and becomes entirely closed. The contained "air," composed of varying proportions of oxygen, nitrogen, and carbon dioxide, is derived from the blood, which in the branchial circulation absorbs air from the water and again gives it off from a "rete mirabile" placed on the internal surface of the swim-bladder.

An examination of the cod's bladder demonstrates the following points:

1. A closed sac, no communication with the œsophagus existing.

FIG. 7.



Scheme of circulation in the Dipnoi.

1. Cephalic aortal arch. 2, 3, 4. Capillary net-work of gills connected with 2d, 3d, and 4th arches. 5. Pulmonary arch. 5′. Ductus arteriosus. 5″. Pulmonary artery. 6. Aortic root. 7. Aorta. 8. Swim-bladder or lung.

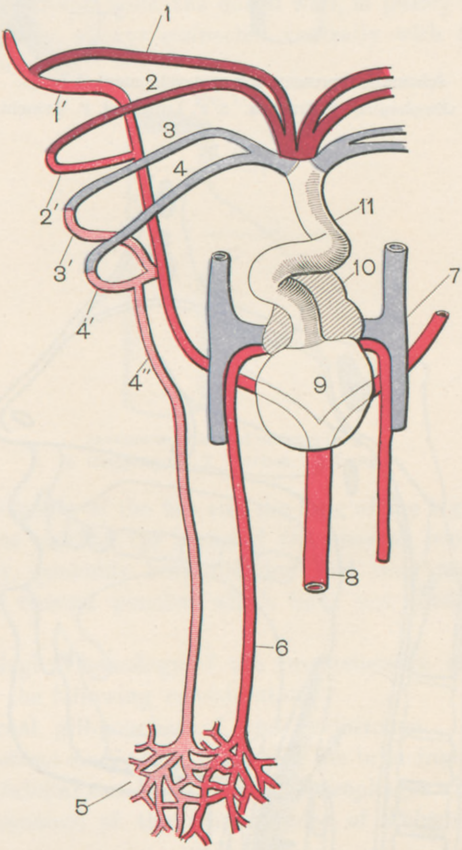
2. Lateral prolongations and blunt processes, resembling the marginal diverticula of some reptilian lungs.

3. Cephalic narrow tubular prolongations, possibly associated with the acoustic apparatus.

4. On the internal surface of the ventral wall the vascular "rete mirabile."

Turning now to the development of the lung in the higher vertebrates, we find that in them the organ first appears as a pouch protruded from the foregut and connected with its lumen by a short and wide canal, just as in the fish the swim-bladder in its original condition continues caudad the series of branchial pouch protrusions from the foregut. (Fig. 9.)

FIG. 8.

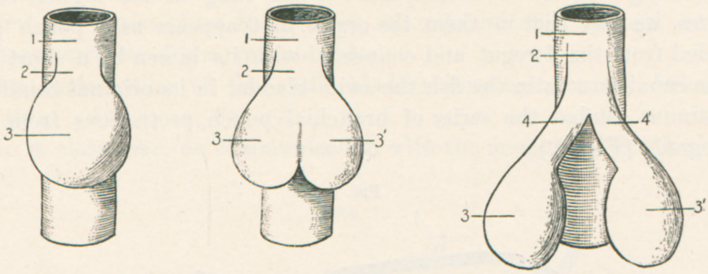


Scheme of circulation of *Ceratodus*.

1, 2, 3, 4. Aortic arches. 1′, 2′, 3′, 4′. Gill capillaries of corresponding arches. 4″. Pulmonary artery. 5. Capillary net-work of swim-bladder or lung. 6. Pulmonary vein. 7. Cardinal veins. 8. Aorta. 9. Ventricle. 10. Auricle. 11. Truncus arteriosus.

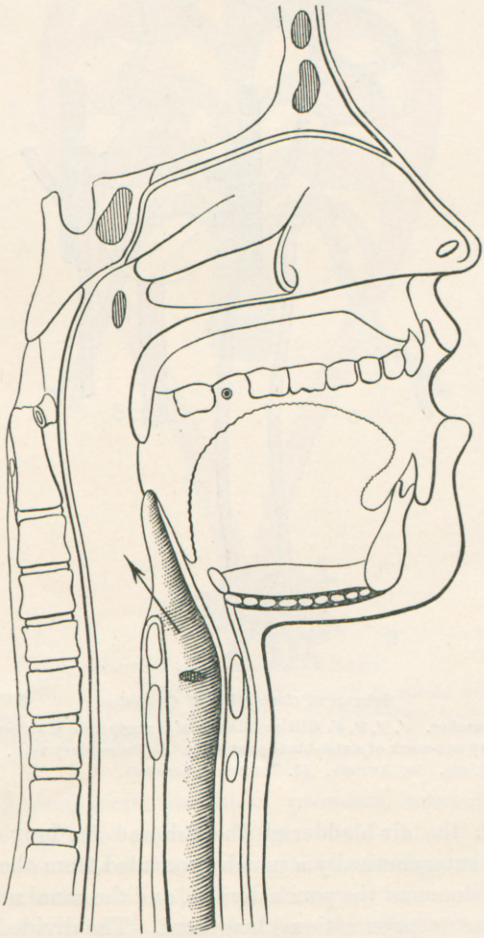
Hence, both the air-bladder of the fish and the lung of the higher vertebrates is ontogenetically a pouch protruded from the foregut. In its further development the pouch divides, and the canal uniting it to the œsophagus (ductus pneumaticus) lengthens. The divided pouch forms the bilateral lung; the duct becomes converted into the trachea and

FIG. 9.



Schematic representation of development of lungs.
1. Œsophagus. 2. Trachea. 3, 3′. Lungs. 4, 4′. Bronchi.

FIG. 10.



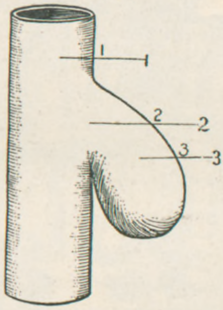
Schematic sagittal section of head and neck, showing connection of laryngeal and pharyngeal canals.

laryngeal apparatus. The connection of the latter throughout life with the cavity of the pharynx preserves the original opening leading from the foregut into the canal of the pneumatic duct. (Figs. 10 and 11.)

The main conclusions which can be based on the foregoing considerations are the following:

1. Both the air-bladder of the fish and the lung of higher vertebrates are, ontogenetically, protrusions of the wall of the foregut. The bladder, usually derived from the dorsal wall, is purely hydrostatic in function. The lung, always connected ventrally with the foregut, is respiratory in function.

FIG. 11.



Schematic profile of embryo lung.
1. Œsophagus. 2. Trachea. 3. Lung.

2. Both the bladder of the fish and the lung of the higher vertebrate embryo continue caudad the series of the visceral pouches. Hence, phylogenetically, probably both bladder and lung represent a last caudal pair of visceral pouches which have not perforated to form visceral clefts.

The morphological homology of the two structures may be further accentuated by the following considerations:

1. The internal gill-pouches of the cyclostomes. Form demonstrated: *Bdellostoma stouti* (Fig. 12), where the branchial sacs appear as dilatations of a tubular canal connecting the œsophagus with the exterior.

2. The arrangement of the swim-bladder of *Polypterus* (Fig. 13), presenting:

a. A ventral œsophageal opening.

b. A laryngeal-like aditus surrounded by a sphincter.

c. A pneumatic canal, representing the trachea.

d. A bilobed bladder, the right accompanied by the vagus nerve.

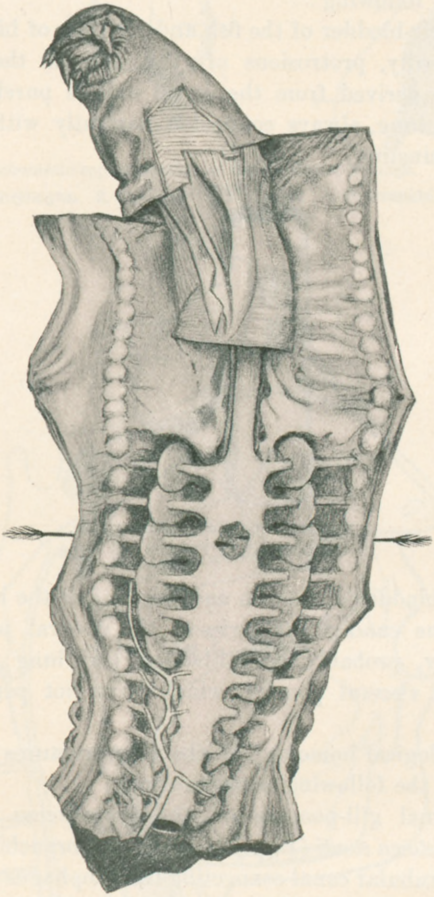
3. The structures in *Lepidosteus*, presenting:

a. A laryngeal apparatus, connected with the beginning of the pneumatic duct.

b. A vascular trabecular net-work on the internal surface of the bladder, foreshadowing the batrachian and reptilian lung.

4. The structures in the *Dipnoi*, where the swim-bladder develops directly as a lung, the pulmonary aditus presenting the same arrangement as in other forms the entrance from the œsophagus into the pneumatic duct.

FIG. 12.



Foregut, branchial pouches, and canals of *Bdellostoma stouti*.
The arrows are passed through two of the narrow external openings into the œsophagus, traversing the branchial canals and the internal gill-pouches.

Form demonstrated: *Ceratodus*.

The architecture of the lung is next considered in reference to the bronchial tree and pulmonary vascular supply. The following series is employed in demonstrating the evolutions of the compound mammalian lung from the simple air-sac.

1. *Necturus*. Type of perennibranchiate amphibian lung, consisting of simple thin-walled air-sac.

2. *Rana.* Batrachian lung. Simple sac, with air-cells.

3. *Python molurus, Agkistrodon piscivorus.* Ophidian lung, consisting of lung-sac directly continuous with trachea; air-cells and trabeculæ in cephalic portion, gradually becoming less and less marked in thin-walled distal portion. Unequal development of right and left lung.

4. *Iguana tuberculata.* Lacertilian lung; air-sac with one complete septal partition and air-cells in cephalic portion, simple in distal portion.

5. *Chelydra serpentaria.* Chelonian lung, with complete septal system, dividing lung into bronchial spaces, dorsal and ventral. Monopodic type of division of bronchial and pulmonary vascular system.

6. *Thalassochelys caretta, Loggerhead turtle.* Chelonian lung presenting direct transition to type of avian and mammalian lung; a single axial stem-bronchus and pulmonary artery, with monopodic system of division.

The details of structure of the mammalian bronchial tree and pulmonary vascular supply are demonstrated by a series of corrosion preparations, special stress having been laid upon the probable evolutionary stages leading to the asymmetrical arrangement of the right and left bronchial system common to man and most mammalia. I have a subsequent communication on this subject to place before the Association, and will consequently defer the details until the presentation of my second paper.

FIG. 13.

Swim-bladder of *Polypterus*.
1. Larynx-like opening into swim-bladder.

The detailed morphology of the human respiratory tract is next taken up from the descriptive, topographical, and medico-surgical stand-point. I may add that of the nine lectures which I usually devote to the lungs, two are utilized for the presentation of the comparative and developmental facts above outlined, the remaining seven dealing with the details of structure in man. It is quite apparent that, in order to carry out the system, much time and care must be devoted to the formation of a morphological museum for purposes of illustration. My time and space do not permit me to enter into a consideration of this important subject, the keynote to the solution of the entire problem. But I hope on some future occasion to bring before this Association our plans relating to the formation of a museum of human and comparative anatomy.

I may in conclusion add, in order that I may not give a somewhat erroneous impression, that the department of anatomy at Columbia offers laboratory work in comparative anatomy to medical students in the form of special practical courses in which every student makes his own dissections on fresh material and records his observations in notes and drawings. The number of applicants for these courses, which are optional, and the earnest and intelligent character of the work done give ample evidence of the educational value of comparative anatomy in the medical school.

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