CHAPTER XXI

COMPARATIVE ANATOMY

Introduction. In the three preceding chapters we have studied (*a*) the cell; (*b*) we reviewed briefly the development of the animal from the fertilized egg-cell stage, and (*c*) we distinguished the principal tissues of which the organs are composed.

We have learned that there are three great groups of physiological processes: (1) those more intimately associated with metabolism; (2) those of adjustment and (3) reproduction. All these functions are performed by the simple one-celled Protozoa as well as by the highly specialized Mammal. In our studies of animals, we found as we proceeded that special organs were found in the higher forms for the carrying on of particular functions. With the increase in number of cells, elaborate specialization of organs is necessary to enable every cell to function properly, and proper functioning of every cell involves basic and functional metabolism. Great elaboration of organs of adjustment makes possible a greater feeding range; greater protection against enemies; greater freedom from the restrictive effects of changing environmental conditions — in short, greater control of nature.

A single-celled animal, such as the Amoeba, needs food. It seeks its food, devours it, and within the province of its single-celled body occur not only the processes of metabolism but also those of adjustment and reproduction. In the case of the dog, however, an elaborate set of organs must function before each and every cell in its body can even receive food for basal and functional metabolism.

We will now study the comparative anatomy of animals in order to gain a broader conception of morphology. Because of limited space, we will confine this study chiefly to a study of the comparative anatomy of Vertebrates although references will be made to lower forms. Furthermore, the organs involved in the function of reproduction will be omitted, since a special chapter on this subject will include a general review of the *organs* and *methods* of reproduction in *all* animals together with a few considerations that are not limited to the field of comparative anatomy.

It will be found that the generalizations now presented constitute an important body of evidence in support of the theory of organic evolution.

As stated above, in this chapter we shall consider the comparative anatomy of the organs of metabolism and adjustment. Properly speaking, metabolism is a name applied to those chemical processes taking place *within the cell* whereby it performs its special work and also maintains life activity, *i.e.*, functional and basic metabolism. But the organs of digestion, respiration, circulation and excretion, for example, are closely associated with making cellular metabolism possible. On this account we have taken the liberty of calling such structures *organs* of metabolism. Moreover, the organs of adjustment are also concerned, though more remotely, with making possible the basic and functional metabolism of cells. It should also be remembered that both are concerned primarily with the life of the individual that possesses them, and basic to its reproductive functions.

I. Comparative Anatomy of Organs Primarily Related to Metabolism

A. Organs of Digestion. (*a*) *Lower Animals.* Neither Protozoa nor Sponges have definite organs of digestion. In Coelenterates there is a blind sac with one opening serving as a mouth and anus. In Hydra this sac is somewhat tubular in form and is composed of endoderm cells. Endoderm appears early in the development of higher animals and forms the lining of the digestive tract in all of them. It also forms glands whose secretions are concerned in digestion. In the Flatworms the digestive tract is still a blind sac of endoderm, but the sac is not a simple tube. It has many diverticula and extends to all parts of the body. In the Roundworms there is a straight intestinal tract with mouth and anus. In Annelids the digestive tract shows indications of specialization. The Earthworm has a pharynx, oesophagus, crop, gizzard, and intestine ending in an anus. The crop and gizzard may be considered a sort of stomach. In Arthropods the arrangement is somewhat similar, that is, mouth, oesophagus, stomach, and intestine, though the tube shows various special structures in different groups of this phylum. Studied from the viewpoint of the kind of food eaten, these special structures are seen to be adaptively modified.

(*b*) *Vertebrates.* A striking similarity of plan is seen in the digestive tract of Vertebrata although the general plan shows ample adaptive modifications (Fig. 324). Associated with the mouth are (*a*) teeth, and (*b*) from Amphibians upward, also *salivary glands* and (*c*) the *tongue*, which is *glandular* and *sensory.* In *Dipnoi* and forms above, the nasal sacs open into the mouth.

Behind the mouth is the *pharynx.* On the side walls of this in fishes are *gill clefts.* The *Eustachian tubes* of higher Vertebrates are the modified *spiracular clefts* of Elasmobranchs. The gill clefts functional in Fishes and Amphibians are present only in the embryos of Reptiles, Birds and Mammals for a short time. The skeletal supports of the gills of Fishes and Amphibia are modified for different uses in higher forms. The *thyroid* and *thymus glands* are associated with the pharynx, arising from it in the embryo but later losing their original connection. Associated with the pharynx is the *swim bladder* of fishes, which usually originates dorsally; and in land Vertebrates, the *lungs*, which originate ventrally. These outgrowths of the digestive tracts are not concerned with digestion. The pharynx leads into the *oesophagus.* This simply carries the food down to the *stomach.* The stomach is an enlargement of the digestive tube where food compounds undergo a partial simplification or digestion. On the whole it is saccular in form. Two portions are recognized — the *cardiac* or oesophageal end, and the *pyloric* or intestinal end.

Different types of glands are present in great numbers in the wall of the stomach. The special modifications of the stomach in birds and ruminant mammals are recalled here. Animals could do without a stomach if they were given the form of food the stomach prepares. Close behind the stomach of most Vertebrates are found two glands connected with the first part of the intestine next to the stomach. These are the *liver* and the *pancreas.* They have to do with the digestion of food within the intestinal tract or chemical changes elsewhere. The intestine is divided into two portions: a longer *small intestine* of small diameter and a shorter *large intestine* of large diameter. Most digestion occurs in the *small intestine.* Its internal surface is increased by various folds or outgrowths and its wall contains multitudes of glands concerned

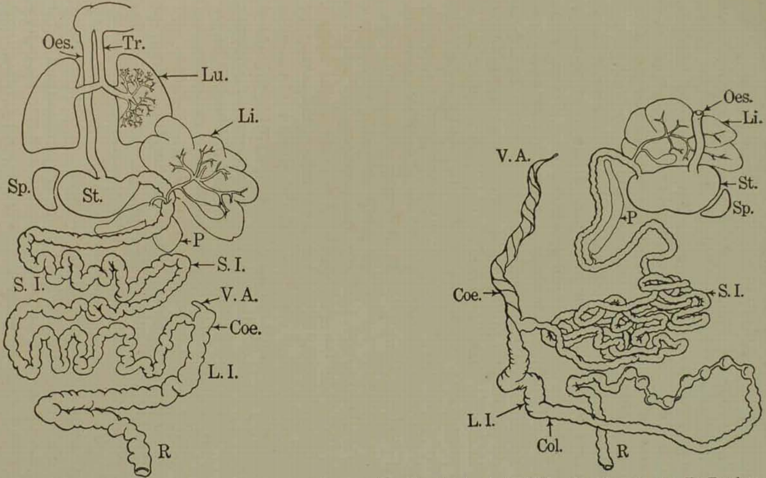


FIG. 324. — At left, diagram of digestive tract of dog; at right, digestive tract of rabbit. Oes. Oesophagus; Tr. Trachea; Lu. Lung; Li. Liver; Sp. Spleen; St. Stomach; P. Pancreas; S. I. Small intestine; V. A. Vermiform appendix; L. I. Large intestine; Col. Colon; Coe. Coecum; R. Rectum.

with digestion. In the *large intestine* the unabsorbed material is prepared for expulsion or defecation. At the junction of the small intestine and large intestine of Mammals there is a pouch, the *coecum.* This is very long and tubular and important from an absorptive point of view in herbivorous forms like the rabbit. Extending from the end of this, there is a diverticulum called the *vermiform appendix.* It is very short and rudimentary in Carnivora. Infection developing in this appendage often leads to fatal cases of blood poisoning. The length of the digestive tract is related to the kind of food eaten. Herbivores have a tube about twenty-five times the length of the body, while that of Carnivores is only about five times the length of the body. However, an exception is the sea-lion's intestine, which is of great length. The hind gut ends in the *cloaca.* Into this the ureters and gonaducts open in most Vertebrates except the higher Mammals. In Amphibia, the *cloacal bladder* grows out ventrally from it. In the higher Vertebrates this is represented in the embryo by a foetal structure called the *allantois* (Fig. 311), concerned with embryonic respiration and nutrition. The *bladder* of Reptiles, Birds and Mammals develops from the base of the allantois. In the higher Mammals, the cloaca becomes divided into a faecal portion, associated only with the digestive tract, and a urino-genital sinus, the terminal portion of the urino-genital systems.

From a simple straight tube in lower forms, the digestive tract has become a long, coiled, exceedingly complex structure with many special regions concerned in doing more effectively, extensively and completely the various jobs concerned in digestion. Its chief work is to convert food into a form in which it may be used by the body cells and to separate the useful from the useless portion.

B. Organs of Respiration. Protozoa, Porifera, Flatworms, Roundworms and some Annelids have no special organs of respiration. The surface of the body is readily permeable to the gases concerned in respiration. *Gills* appear in Annelids and Mollusks. The Crustacea have gills, and these organs are present also in fishes and in some Amphibia through life, although in other Amphibia restricted to the larval stage. A gill is an organ provided with a capillary system covered with a thin membrane and surrounded by water. Oxygen dissolved in the water can easily permeate the membrane of the gill and enter the blood of the capillary, and similarly CO_2 can easily pass from the blood through the wall of the capillary and gill membrane into the water. Gills may be leaf-like or like a tuft of hairs or slender processes. In the aquatic dragon-fly nymph, the hind gut is filled with plate-like gills. In certain Fish, Insects and Worms, the hind gut may be filled with fresh water from time to time and so serve as a respiratory organ. The cloacal bladder of the frog is thought to serve in this way at times.

Outside air is delivered directly to the various tissue cells through a complicated system of tubes called *tracheae* in the case of insects.

In Reptiles, Birds and Mammals, gill clefts are formed in the embryo, and paired lungs are later formed from the ventral side of the embryonic gut. In Dipnoi, the dorsal air sac is supplied with pulmonary blood vessels and serves as a sort of lung. Developing as sacs associated with the digestive tract (*pharynx*) and inside the body cavity, the lungs are protected. The respiratory surfaces continue to be moist in all forms. Lungs are relatively simple sacs in Amphibia (Fig. 325). The inside walls are honey-combed with little chambers or *alveoli*, whereby the total respiratory surface is somewhat greater than the total external surface of the lung. In the Reptile the lung is relatively larger and more complex. There is a great increase in the number of air sacs or alveoli, and in the interior of the lung of the turtle there is an open passageway. In the Bird and Mammal the lungs consist chiefly of branching bronchial tubes terminating in multitudes of microscopic air sacs, whose membranous walls contain pulmonary capillaries. Thus a much greater extension of respiratory surface is packed into a small compass. In man, the total respiratory surface of the lung is a number of times the surface area of the body. In the frog, it is only a small part of this. However, the frog's skin also serves as a respiratory organ. The air chambers connected with the lungs of birds serve as aids to the mechanics of respiration.

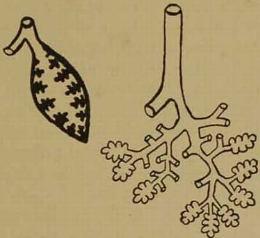


FIG. 325. — At left, diagram of lung of frog with relatively small respiratory surface; at right, part of mammal lung with relatively great respiratory surface.

The appearance of lungs in the higher Vertebrates involves a rearrangement of blood vessels, muscles, nerves and skeleton. Some of these parts are especially concerned in inspiration and expiration. The change from aquatic to terrestrial mode of life has involved active pumping or suction of air into the lungs of these forms.

C. Organs of Circulation. No special system for the conveyance of oxygen foods and wastes is needed in Protozoa, Porifera, Coelenterates, Flatworms or Roundworms. When a body cavity appears and organs develop in it and the mass of cells increases, the needs of the organs and tissues are not adequately taken care of by the old-fashioned method of transfer from cell to cell or from one cell mass to a tissue space and thence to another cell mass. This primitive method is still prevalent in the passive plant world. The term gastrovascular cavity, used in connection with Coelenterates and Flatworms, refers to the fact that the digestive tract serves the two functions of digestion and circulation. In the earthworm, the peristalsis of the body and intestine *aid* in circulating the blood. The coelomic cavity is filled with coelomic fluid which contains food material absorbed from the intestine. There are perforations in the septa. Peristalsis therefore drives the coelomic fluid back and forth and brings the body wall and internal organs into contact with digested food. The open funnels of the nephridia are immersed in this coelomic fluid. Possibly the primary function of earthworm blood is respiratory. Insects have an open or lacunar blood system. The heart is tubular and lies dorsal to the intestine. Short arterial trunks from the heart carry the blood forward into *sinuses* or spaces. Here it " circulates " about the tissues and then returns to the heart through lateral slits.

On the other hand, in Vertebrates (Fig. 326) there is a *closed blood system*. The blood, containing oxygen, food and wastes, flows in special tubes, forming one continuous interconnected system. The blood is continually leaving the heart through arteries into a system of very fine tubes, called capillaries within the tissues and returning through veins to the heart. It is open to the extent that oxygen and food solutions can pass from capillary to tissue space and waste products in the reverse direction. In Mollusks and Arthropods are found all grades between the open-system type and the closed system. In insects with tracheae, the vascular system is not concerned with delivery of air to tissues and the system is open.

The heart, arteries, veins and capillaries are structurally similar in part. Essentially tubes, they vary according to the needs. The heart is primarily a pump with valves and hence is muscular and elastic. Arteries must withstand considerable pressure and hence are thick-walled, tough, elastic and muscular. Capillaries are thin, fine, membranous-walled tubes. Veins are provided with valves so that the blood as it progresses toward the heart cannot return toward the capillaries. The membrane forming the wall of the capillaries also forms the lining of the heart, arteries and veins.

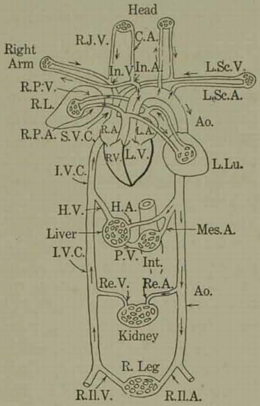


FIG. 326. — Diagram of circulation of mammal. R. A. Right auricle; R. V. Right ventricle; R. P. A. Right pulmonary artery; R. P. V. Right pulmonary vein; L. A. Left auricle; L. V. Left ventricle; Ao. Aorta; L. Sc. A. Left subclavian artery; L. Sc. V. Left subclavian vein; In. A. Innominate artery; C. A. Carotid artery; R. J. V. Right jugular vein; In. V. Innominate vein; R. L. Right lung; Mes. A. Mesenteric artery; H. A. Hepatic artery; P. V. Portal Vein; Int. Intestine; H. V. Hepatic Vein; Re. A. Renal artery; Re. V. Renal vein; R. Il. A. Right iliac artery; R. Il. V. Right iliac vein; I. V. C. Inferior vena cava; S. V. C. Superior vena cava.

The heart of lower forms is a tube. In the embryo of Vertebrates it is at first tubular, then grows into the form of the letter "S" reversed. In Fishes (Fig. 327 — 1) it is divided into two portions. The anterior dorsal loop of the "S" widens out into a thin, saccular auricle while the posterior ventral loop of the "S" becomes the thick muscular ventricle. A valve develops between the auricle and ventricle. Venous blood from the body fills the auricle. This contracts, filling the relaxed and empty ventricle. When filled, the ventricle contracts, closing the valve to the auricle, forcibly driving the blood forward through the arterial system, aided by the muscular contractions of the arteries. The fish heart contains exclusively venous blood. In larval Amphibians *the heart is similar to that of Fishes.*

But in lunged forms, like the frog (Fig. 327 — 2) the transition from gills to lungs has brought a change in the heart, for now body or venous blood and blood from the lungs is returned to different chambers of the heart. The single auricle has become divided into two, a right and a left auricle. From the body the right auricle receives the venous blood, which is poor in oxygen and rich in carbon dioxide. From the lung the left auricle receives blood which is rich in oxygen but poor in carbon dioxide. *Both* these auricles open into *one ventricle* and the complete separation of the non-aerated blood and aerated blood is not possible. In other words, Amphibia have not completely adapted themselves to land or air breathing.

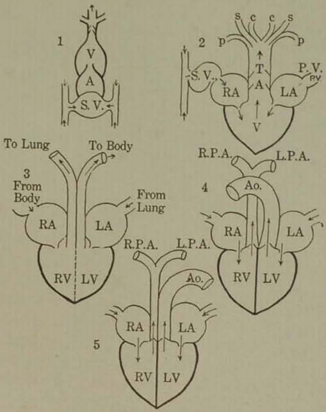


Fig. 327. — Comparative anatomy of vertebrate heart. 1. Fish; 2. Amphibian; 3. Reptile; 4. Bird; 5. Mammal. S. V. Sinus Venosus; A. Auricle; V. Ventricle; R. A. Right Auricle; R. V. Right ventricle; L. A. Left auricle; L. V. Left ventricle; R. P. A. Right pulmonary artery; Ao. Aorta; T. A. Truncus arteriosus; c-s-p, carotid, systemic and pulmonary arteries of frog. P. V. Pulmonary vein.

Reptiles are somewhat like Amphibia (Fig. 327 — 3). There are two completely separated auricles, but the single ventricle shows some advance. It contains a sort of partition, perforated and open, it is true, but dividing it, in a way, into right and left ventricular portions. It serves fairly well to regulate the currents of blood, so that non-aerated (venous) blood is directed from the right side of the ventricle to the lungs and the aerated blood from the left side of the ventricle to the body. However, strangely enough, the partition is *complete* in the *Crocodilia*, where there are *two* completely separated auricles and *two* ventricles. This is also the condition in Birds (Fig. 327 — 4) and Mammals (Fig. 327 — 5). So the heart in its evolution changes from a *tube* to a *four-chambered* organ. With the appearance of the right and left auricles and right and left ventricles, the heart has been divided into a right half and a left half. The *right heart* is associated with non-aerated blood pouring in from the body generally, and being sent to the lungs; while the *left heart* is associated with this blood returning aerated from the lungs and sending it out all over the body. The fact that so important an organ as the heart is modified in its relation to respiration indicates the importance of respiration in vertebrate life.

In describing the vascular system of the dogfish (Fig. 328 *A*) and fishes in general it was stated that from the ventricle the blood was pumped forward into a vessel on the median ventral floor of the mouth. From this vessel branches pass to the gills. These are called the *afferent* branchial arteries since they carry blood to the capillaries of the gills. From these capillaries blood flows dorsally through *efferent* branchial arteries to the dorsal aorta, which has many branches for distributing the blood to various organs of the body. These sets of branchial arteries on both sides of the pharynx, extending from the ventral blood vessel to the dorsal (aorta) vessel, are known as the aortic arches. There are typically six pairs of these arches, but of special interest are four pairs which are here numbered 3, 4, 5 and 6 — number 3 being most anterior. The arrangement appears to be entirely different in Birds and Mammals. Studies in comparative anatomy, however, show a *progressive change* from what is found in the dogfish to that of the higher animals.

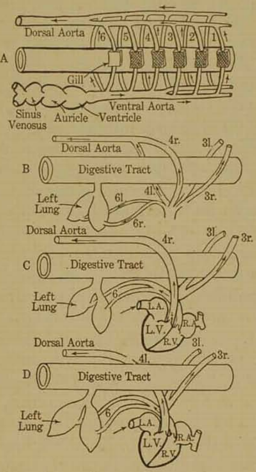


FIG. 328. — Comparative anatomy of aortic arches of Vertebrates.

The arrangement in frog tadpoles is quite like that of the fish. But when metamorphosis occurs and the fish-like tadpole becomes an air-breathing frog, the following changes occur (Fig. 328 *B*). As the gills disappear, the afferent and the efferent branches unite. Remnants of the first two unite with the third branchial artery on each side, which loses its connection with the dorsal aorta and passes forward into the head, being known as the *carotid artery.* The fourth pair remains conservative, that is, each passes up around the intestine and the *two unite* to *form the dorsal aorta.* These are known as the *systemic arteries.* The fifth pair degenerates. The sixth pair bud off a branch on each, which grows *out to the lung.* The connection with the dorsal aorta degenerates, so that the sixth branchial arch is converted into the *pulmonary arteries.* The above changes illustrate change of function in which structures formerly used for one purpose are modified for other uses, due to a different mode of life. Many instances of such modifications of organs can be found both in animals and plants. The general condition of the aortic arches of reptiles is much the same as that just described for Amphibia. But it is very interesting to know that the embryo reptile first possesses rudimentary arches similar to that of fish, though of course there are no gills. A modification is found in Birds and Mammals. The main arteries from the heart are much the same as in Amphibians and Reptiles with some important differences. In Birds (Fig. 328 *C*) the carotid arteries have shifted and originate from an aortic arch. This same branch also supplies branches to the breast and wings. In the frog, arteries similar to the last arose from the systemic. In Birds, only the right branch of the systemic pair of the frog remains. It is very large and is known as the arch of the aorta. It arises from the left ventricle. There is no sign of the fifth. The sixth or pulmonary pair originate from the right ventricle.

The condition in Mammals is similar to that in Birds, with this curious difference (Fig. 328 *D*). The great aorta as it originates from the left ventricle is the *left* branch of the systemic pair of the Amphibia and Reptiles instead of the *right* as in Birds. In Birds, the great aorta turns from the heart over to the right side of the body. In Mammals it curves over to the left and then around to the backbone. In the embryos of these forms (Birds and Mammals) the early history of the vessels from the heart is fish-like, then amphibian-like, and then bird- or mammal-like. Even more remarkable is another observation. It was stated that in metamorphosis of the frog the sixth aortic arch buds off the pulmonary. For some time this artery, however, continues a connection with the dorsal aorta, but this connection later degenerates as the gill degenerates. Curiously enough this same procedure is gone through in the embryonic development of the pulmonary artery of higher forms, such as Mammals. In the vast majority of cases, the connection between this sixth arch and the dorsal aorta, although open at birth, soon closes and degenerates. But in *some* cases it fails to do so and persists on one side in the adult condition after birth. This queer anomaly of great theoretical interest is known in *human* anatomy as the "*Ductus Botalli*," and it occurs, though very rarely, in human beings, indicating the anatomical relationship of man to the lower animals.

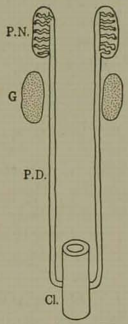


Fig. 329. — Diagram of vertebrate pronephros. PN. Pronephros; G. Gonad; P. D. Pronephric duct; Cl. Cloaca.

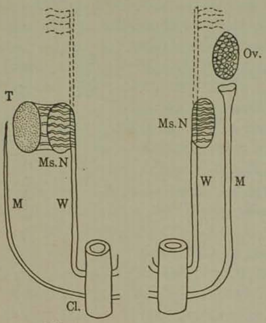
D. Excretory Organs. Protozoa, Porifera, and Coelenterates have no special excretory systems. Excreta are probably discharged from the free surfaces of the cells. In the flatworm there is a complicated system of tubes joining longitudinal canals which discharge wastes to the outside. Each branch tube ends internally in a flame cell, already described.

In the earthworm (Annelid) there are pairs of serially repeated nephridia. In Amphioxus a somewhat similar condition is found.

In early vertebrate embryos there appears a *Pronephros* or front kidney (Fig. 329). This consists of a series of segmentally arranged nephridial tubules each opening into the body cavity at their inner ends. The outer ends, however, do not open separately to the outside of the body as in the earthworm, but are connected to a *conducting tubule* or *segmental* or *pronephric duct* which connects posteriorly with the cloaca. In Cyclostomes, the pronephros remains throughout life, although somewhat degenerated. In some Fishes and Amphibia it is found in early stages.

Later in the embryos of Fishes and Amphibia, a second set of nephridial tubules develops toward the posterior end of the animal.

As this group of tubules develops, the first group (Pronephros) degenerates. The second kidney is called the *Mesonephros* (Fig. 330). In Elasmobranchs and some Amphibia the pronephric duct develops lengthwise into two. One of these remains as the ureter and the mesonephric tubules discharge into it. The other duct becomes the oviduct in the female. Each of the oviducts is funnel-shaped at the anterior end but opens into the cloaca at the posterior end. The new kidney is also called the *Wolffian body,* and the ureter tube is called the *Wolffian duct,* while the oviduct tube is called the *Müllerian duct.*[1] A curious condition prevails in male animals that possess a mesonephros, in that *the Müllerian duct often persists as a blind rudimentary tube.* From the testes, fine tubes, called the *vasa efferentia,* grow out connecting the testis with the *Wolffian duct,* which also *serves in the male as a sperm duct, during the breeding season.* During the remainder of the year, it is only a ureter. The mesonephros or Wolffian body is the functional kidney of Fishes and Amphibia. The adult kidney is not merely a few segmentally repeated nephridial tubules. It is a compact organ consisting of a very great many tubules, all joining larger branch ducts which in turn empty into the ureter.



Male Female

FIG. 330. — Mesonephros and related structures. Ms. N. Mesonephros; T. Testis; M. Müllerian duct; W. Wolffian duct; Ov. Ovary.

In Reptile, Bird and Mammal embryos, the pronephros first forms, then as it degenerates the mesonephros develops. Then a new third kidney forms, namely, the *Metanephros* (Fig. 331). It is posterior to the mesonephros. Moreover, it develops a new functional discharging tube, the ureter. In the meantime, the mesonephros gradually disappears. The metanephros remains as the functional adult kidney of Reptiles, Birds and Mammals.

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[1] In many Vertebrates the Müllerian duct develops from tissues near the Wolffian duct.

The Müllerian duct of the mesonephric system persists, however, as the functional oviduct of females. The vasa efferentia of the testis pass into the Wolffian duct, which now performs the *exclusive duty* of a *sperm duct* or *vas deferens*. In early embryonic tubules of the pro- and mesonephros the outer ends open by ciliated funnels into the body cavity, as in the earthworm. This end is the nephridial mouth or *nephrostome*. In the mesonephros, a small cup-shaped cavity develops near the nephrostome. This becomes filled with capillaries, and is known as a *Malpighian body*. Indications of nephrostomes are still present in the frog's kidney. They appear on the surface as pits. But they do not form in the metanephros. In this kidney the tubules are supplied entirely by the blood and terminate in Malpighian bodies (Fig. 343).

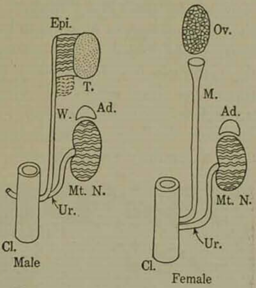


FIG. 331. — Metanephros and related structures. Mt. N. Metanephros; Ur. Ureter; Ad. Adrenal; Epi. Epididymis; T. Testis; Ov. Ovary; W. Wolffian duct; M. Müllerian duct; Cl. Cloaca.

II. Comparative Anatomy of Organs of Adjustment

Notwithstanding the fact that the organism is a complete whole whose parts are interdependent, the foregoing systems of organs are more immediately concerned in keeping the cells supplied with metabolic material and in removing wastes. Life is one continual process of adjustment to varying environmental conditions. Moreover, food and security from possible enemies must be obtained. Certain systems of organs seem to be concerned with this part of life. They are the *sensory*, *nervous* and *muscular* systems. Locomotion in higher forms like Vertebrates is often rapid, sustained, covering large distances and consuming much energy. In these cases muscles are associated with skeletons. Moreover, the surface of the body is covered with skin that protects internal organs. In discussing organs of adjustment skin and skeleton should be included.

A. Skin or External Covering. In some Protozoa, the external superficial protoplasm is more dense than that inside and from it may extend cilia or flagella. In Coelenterates, the ectoderm is covered with a non-cellular thin coat — the cuticle. In flatworms there is a somewhat similar but firm cuticle and in some parasitic roundworms it is somewhat thickened and hard. In Annelids it is thin, as in the active earthworm. The shell of Mollusca and the chitinous exoskeleton of the Arthropoda are recalled. In Vertebrates skin is a special, complicated tissue composed of two main layers: (*a*) *epidermis*, formed of several layers of cells most of which are dead and "horny," called the stratum corneum, derived from a deeper living germinating layer, the *stratum germinativum*. The epidermis contains no blood vessels or nerves. Below the epidermis is the (*b*) *dermis* or lower skin, which is a special connective tissue with blood vessels and nerves. The epidermis is nourished by these. From the *epidermis* are derived some types of scales and feathers, hairs, nails, claws, and mammary, sweat and oil glands. From the *dermis* is derived the scales of most fishes, bony plates of crocodilia, and of such Mammals as the armadillo and some of the bones of the skull. The skin contains important sense organs of touch, pain and temperature. It develops also sweat, oil and mammary glands.

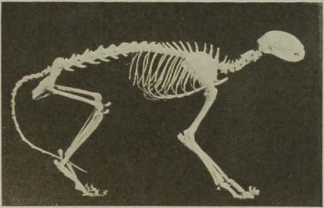


FIG. 332. — Skeleton of cat. Axial skeleton — skull and spinal column. Appendicular skeleton—Shoulder girdle and fore limb; pelvic girdle and hind limb.

B. Skeleton. A supporting framework of a sort occurs in radiolarian Protozoa and the Vertebrates, although many intervening forms lack it. In Arthropods there is a horny or chitinous outside skeleton, somewhat analogous to the armor of old-time knights. To the inner surface of these parts are attached muscles which connect adjoining parts. In Vertebrates there is an endoskeleton of cartilage in lower forms; and of cartilage and bone in such intermediate forms as Amphibia, but almost entirely of bone in Birds and Mammals.

The skeleton of the Vertebrate consists of an *axial* and an *appendicular* part (Fig. 332). The first (Fig. 333) consists of the skull and vertebral column. The appendicular part consists of the front limbs and pectoral girdle, and the hind limbs and pelvic girdle.

The mammalian skull (Fig. 333) consists of the *cranium* and *face.* The cranium incloses the brain, while the face forms the nostrils, mouth, jaws, etc. Some of the bones of the cranium frequently found are frontals, parietals, occipital, temporals, ethmoid and sphenoid. The face is formed by the nasals, lachrymals, malars, palatines, maxillaries, pre-maxillaries and vomers. The lower jaw is the dentary or mandibular. There is considerable variation in the bones of the skull, but the similarities are as notable as the differences.

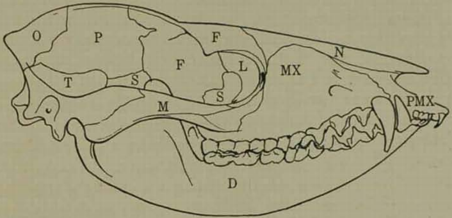
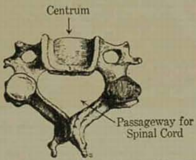
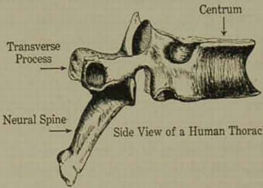


Fig. 333. — Side view skull of opossum. Cranial bones shown are F. Frontal; S. Sphenoid; P. Parietal; O. Occipital; T. Temporal. Facial bones shown are M. Malar; L. Lachrymal; MX. Maxillary; PMX. Premaxillary; N. Nasal. Lower jaw is (D) Dentary or Mandibular.



Face View of a Human Cervical Vertebra



Side View of a Human Thoracic Vertebra

Fig. 334. — Human vertebrae.

The vertebral column, the backbone of the Vertebrate, is composed of vertebrae. A vertebra (Fig. 334) possesses a supporting centrum, the neural arch inclosing the spinal cord, the neural spine to which some muscles of the back are attached and transverse processes to which ribs may be attached. Five kinds of vertebrae are found in Mammals, all modifications of a generalized type, namely, 1. *cervical,* forming the neck; 2. *thoracic,* which always have ribs in the mammals; 3. *lumbar;* 4. *sacral,* to which the pelvic girdle is joined and 5. *caudal,* or tail vertebrae. Vertebrate ribs may be lacking or there may be many. They are present, wherever needed, to support the walls of the trunk.

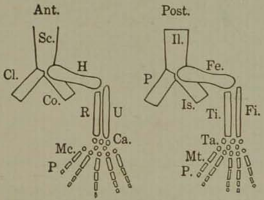


Fig. 335. — Structure of appendicular skeleton of (land) Vertebrates. Anterior — Sc. Scapula; Cl. Clavicle; Co. coracoid; H. Humerus; R. Radius; U. Ulna; Ca. Carpals; Mc. Metacarpals; P. Phalanges. Posterior — Il. Ileum; P. Pubis; Is. Ischium; Fe. Femur; Ti. Tibia; Fi. Fibula; Ta. Tarsals; Mt. Metatarsals; P. Phalanges.

There is also a fundamental similarity between the anterior and posterior appendages (Fig. 335). In the first place both pectoral and pelvic girdles consist of three parts — a *dorsal element,* the *scapula* in the pectoral girdle and the *ileum* in the pelvic girdle. The scapula is joined indirectly by ligaments and muscles to the axial skeleton, while the ilium is firmly united directly to sacral vertebrae. Each girdle has two processes extending ventrally. In the pectoral girdle, the *procoracoid,* and in the pelvic, the *pubis,* extend down and forward, while in the pectoral, the *coracoid,* and in the pelvic, the *ischium,* extend down and backwards. The procoracoid is represented by cartilage and it is replaced in higher forms by a bony clavicle. There are many departures from this underlying simple type plan and variation in structure appears to be related to variations in function.

The forelimb consists of a *humerus* joined to the pectoral girdle, where its three parts meet; next of a *radius* and *ulna* forming the forearm, then of eight *carpal* or wrist bones, of five *metacarpal* or hand bones, and five fingers or *digits,* each composed of several phalanges. The hind limb consists of a *femur* or thigh joined to the pelvic girdle, where its three bones meet; then the *tibia* and *fibula* or leg; the eight *tarsal* or ankle bones; five *metatarsals* or foot bones, and five toes each composed of phalanges. In forms above Fishes, this appendage plan prevails, although there are all sorts of modifications of it since the appendages function in a great variety of ways.

C. Muscles. The skull protects the brain, and the backbone and ribs protect visceral organs. But more than this, the backbone is a rigid axis to which levers are attached. These levers are moved by skeletal muscles in limbed forms for use in locomotion. In the tubular earthworm's body wall and likewise in its intestine there are longitudinal and circular muscles. The contraction of the body wall and of the intestine is peristaltic, which has already been explained. It is the common movement of intestines, oviducts, ureters and arteries of Vertebrates.

The Amphioxus body wall possesses a series of segmentally repeated muscle masses or *myotomes*. These are seen also in Fishes and in lower Amphibia and in the embryos of higher forms. They are more primitive in forms without limbs. Their successive contraction on one side and relaxation on the other moves the body sidewise as in the movements of the tail in swimming. Skeletal muscles of the adult develop from portions of the embryonic myotomes. When limbs are introduced, the segmentally arranged embryonic portions in the neighborhood of the limbs grow out to the girdle and limb bones and form the special muscles of those organs. With the increasing modifications in the limbs and with changes in their use, the modifications in the muscles become more complex. The fore and hind limbs of Necturus are small and quite similar, and the muscles of each are similar. In the frog, there are short, weak, front limbs and large, strong, hind limbs. The muscle outfit of each is extremely different. The muscle system of the front limb and hind limb of a bird are very different. One does not find any close similarity between the musculature of the front limbs of a dog, horse, bat or chimpanzee. Muscles are plastic structures, far more plastic than bone, and to the comparative anatomist even bone is not regarded as unchangeable. In spite of the extreme modifications of muscles in different types, the trained myologist is satisfied as to a simple general underlying plan. Skeletal muscles usually have a contractile portion called the *belly* and two ends terminating in inelastic *tendons* attached to bones. The muscle has a proximal end, attached to some part toward the central axis. This is the *origin* of the muscle. The outer distal end is the *insertion*. The *origin* is usually fastened to a support, and the muscle lifts a lever to which it is *inserted*.

D. Nervous System. First indications of special fibers which conduct impulses have been noted in certain Protozoa, such as Euplotes. Definite nerve cells are found in Coelenterates. Neurons and nerves are present in all higher forms. Annelids show a centralized nervous system with ventral nerve cord, segmental ganglia, dorsal brain and peripheral nerves. Arthropods with their condensed bodies show a concentration of this same general plan in the large cerebral and thoracic ganglia. Both have a ventral nerve cord and an anterior nerve ring about the anterior end of the intestine. The nervous system reaches its highest development in the Vertebrates, where it is organized into (*a*) *central nervous system* of brain and spinal cord, (*b*) *peripheral system* of cranial and spinal nerves and (*c*) *sympathetic system*. In the study of the Vertebrates a general increase in the size and the importance of the cerebral hemispheres (Fig. 336) is seen as we pass from Elasmobranchs to Mammals, culminating in the human brain, where it is relatively enormous and richly fissured and convoluted, thus making the *cortex* (or rind) of greater area than the cranial space it occupies. The olfactory lobes and optic lobes decrease relatively in size and importance, while the increase in the cerebellum is secondary only to that of the cerebrum. Between the cerebral hemispheres and optic lobes is the between-brain or *diencephalon*. Projecting from this on the ventral side toward the roof of the

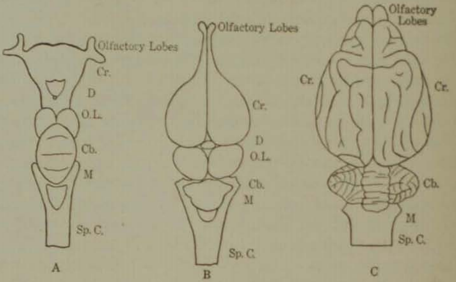


FIG. 336. — Dorsal view of brain of A.— Dogfish; B. — Alligator; C. — Dog (after Ziegler models); Cr. Cerebrum; D. Diencephalon; O. L. Optic lobes; Cb. Cerebellum; M. Medulla; Sp. C. Spinal cord.

mouth is an outgrowth. Here is attached an important ductless gland, the *pituitary*. Also from the dorsal surface a stalk-like structure extends upward, known as the *pineal gland*. In all Vertebrates, the five parts of the brain are plainly discernible. The cranial nerves of all are similar in location, structure and function, and this is true of the spinal cord and spinal nerves. Analysis of the nervous system shows that it is composed of complex cells of varying shapes called neurons. Proper connections and organizations of these make possible the carrying out of adjustments. Operations of internal body organs are carried out with the help of the sympathetic system. The part played by hormones is discussed on page 434. Some nerves contain only afferent fibers. Examples are the following *cranial nerves:* first or olfactory, second or optic and eighth or auditory. The third, fourth and sixth *cranial nerves* are purely *motor* since they carry only motor impulses to the muscles of the eye. The fifth, seventh, ninth and tenth *cranial nerves* resemble spinal nerves in that they contain both sensory and motor fibers. Sir Charles Bell in 1824 first proved the existence of sensory and motor pathways in nerves. He remarked that "they do not in any case interfere with or partake of each other's influence."

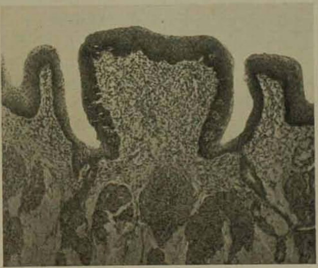


FIG. 337 *A*. — Photomicrograph of section of a vallate papilla of tongue. Sensory cells of taste are located in special organs (taste buds) on side walls of the papilla. (Photo by Cooper.)

E. Sense Organs. Sense organs, developed from ectoderm, are cellular structures whose function is to receive stimuli from the external medium.

References to the sensory organs of lower groups have been made. The earthworm does not have well-recognized special sense organs of touch, smell, or sight and yet is sensitive to all these types of stimuli. Probably insects react to ranges of stimuli beyond our knowledge. Arthropods and Mollusks have well-developed sense organs. The sense organ of smell of

Mammals consists of cells located in membranes in the nose. These cells are connected by nerves to the brain. There are only nasal sacs in Fishes, while in higher forms they open by passageways into the pharynx and take on a double function, assisting also in respiration. The skin contains many sensory organs of touch, pressure, temperature and pain. Sensory organs occur in muscles and are stimulated when the muscle changes its form, thus giving an idea of muscular movement. Special cells in the taste buds of the tongue are stimulated by certain substances in food and drink (Fig. 337 *A*).

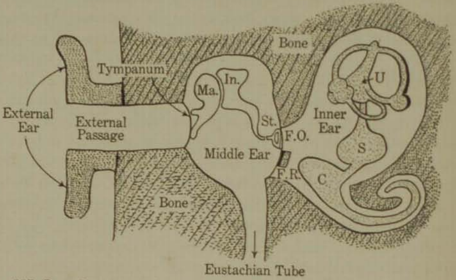


FIG. 337 *B*. — Structure of mammalian ear. Ma. Malleus; In. Incus; St. Stapes; F. O. Fenestra ovalis; F. R. Fenestra rotunda; U. Utriculus; S. Sacculus; C. Cochlea.

The ear develops as a pit in the ectoderm. Ears like this are found in Invertebrates. In the Vertebrates this pit becomes detached from the surface and forms the internal ear surrounded by a bone of the skull (Fig. 337 *B*). Inside of the skeletal surroundings it occurs as a membranous sac filled with liquid and becomes very complicated. It forms two sacs known as the *sacculus* and *utriculus*. From the sacculus develops, in higher forms, the spirally tapering cochlea containing sensory cells stimulated indirectly by sound waves outside the body. The sensory cells of the cochlea are connected by certain fibers of the eighth cranial nerve to the brain. From the utriculus there develops the semicircular canals. One of these is horizontal, the other two are vertical and at about a right angle to the first and to each other.

These canals are membranous tubes and each contains an enlargement called an *ampulla*, where are the sensory cells which are stimulated by changes in the position of the head (or body). Information borne to the brain from these organs over other neurons of the eighth nerve gives the animal knowledge of its special position. The cochlea is the sense organ of *hearing* and the semicircular canals of *equilibrium*. As long as animals are immersed in water, sound is of minor importance, but not so in the case of equilibrium. Impulses to the ear of fishes must come through the skull.

The spiracular cleft of Elasmobranchs is homologous with the tympanic cavity or middle ear, between the surface of the skull and the inner ear of land forms. In the land Vertebrate the Eustachian tube, from the mouth to the mid-ear, is a part of it. Between the inner and the middle ear a little window, *fenestra vestibuli* or *fenestra ovalis*, develops. Stretched across the external opening of the middle ear is the ear drum or tympanic membrane. This is flush with the surface of the head in Amphibia. In higher forms it lies at the inner end of a small passageway — the external canal. Surrounding its external opening in many Mammals is the external ear. Stretching across the middle ear from tympanum to fenestra ovalis in Amphibia, is a single little bone, the *columella*. Sound waves in air vibrate the tympanum. These vibrations are conveyed by the columella to the inner ear drum stretched across the fenestra vestibuli. Vibrations in this, set up vibrations in the liquid in the cochlea which stimulate the sensory cells of hearing. In Mammals, the columella is replaced by a chain of three little levers of bone: *outer, malleus; middle, incus; inner, stapes,* by which the vibrations are more effectively transmitted. These structures are special modifications of parts used for other purposes in lower Vertebrates.

Sight. Special sense organs of vision appear as animals become more specialized. The eyes of all Vertebrates are surprisingly similar in structure. In cave animals and deep-sea forms, the eye is degenerate. The eye is a hollow globe (Fig. 338) or rather parts of two globes. The wall is of tough, resistant material. There is an outer *sclerotic* coat. It has a transparent front, known as the *cornea.* Inside the sclerotic is the vascular and pigmented *choroid* coat. In front, it does not lie close to the cornea but close to the front of the lens and contains an aperture, the *pupil.* The disc around the pupil is called the *iris*. The third or inner coat of the eyeball is the *retina* which contains the special sensory cells of vision. These are connected to the brain by the nerve cells of the optic nerve. The lens is located just behind the iris and is biconvex and transparent. It is held in place to the choroid coat by the suspensory ligament and, unlike a camera lens, its convexity can be changed and so adjust the eye to different focal distances automatically. Between the lens and cornea is fluid aqueous humor and behind the lens is the thicker vitreous humor. Light waves, reflected from external objects, pass through the lens, forming images, and stimulate sensory cells in the retina behind it. Impulses are then carried over the optic nerve to the visual center in the brain.

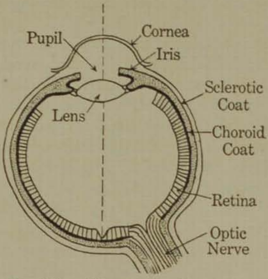


FIG. 338. — Diagram showing anatomy of vertebrate eye.

The eye is moved by six muscles in each eye which raise the eyes, lower them, turn them to the left, to the right, or roll them. Usually these muscles work harmoniously. It is not necessary to dissect a *human* eye to get a general idea of its structure. The eye of the *ox* or the *dogfish* will give about the same information. In land Vertebrates, lachrymal glands near the eye keep the eyeball moist and clean with their secretions.

The living Protozoan successfully adjusts itself to its changing world. The Amoeba exhibits but few structures enabling it to accomplish this. Some Protozoa however possess intracellular specialized structures. As we study higher and higher forms we note an increase in the complexity of special organs. Insects are highly organized animals, but a study of the comparative anatomy of the various classes of Vertebrates reveals evidence of evolution of greater specialization. The comparative anatomy of any taxonomic group reveals evidence of a type plan of structure common to all members of the group and this is interpreted as indication of common ancestry.

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