CHAPTER XX

HISTOLOGY

Introduction. Bichat in his " General Anatomy," published in 1801, pointed out that not only were structural similarities true of the organs of animals, but also of their tissues such as muscles and nerves. In 1838–39, Schleiden and Schwann advanced the analysis of organs when they announced the cell theory according to which the tissues of organs are composed of cells. In 1858, Virchow extended the application of the cell theory to diseased tissues.

Many individual Protozoa are single cells. Free single cells are also found in higher organisms. Examples are amoeboid white-blood cells, red-blood cells or erythrocytes, spermatazoa and ova. Colonial Protozoa are aggregations of similar cells which form a single organism. The Metazoa as a rule begin life as a single cell.

The gastrula stage in development establishes two principal embryonic tissues, namely, ectoderm and endoderm. The special tissues of Coelenterates consist of modifications of these two types of embryonic tissue. In our study of Hydra, we called attention, for example, to the (*a*) epithelio-muscular cell, (*b*) sensory cell, (*c*) nerve cell, and (*d*) cnidoblast cell — all of which are specialized, originating from simple embryonic ectoderm.

In the Platyhelminthes and higher Metazoa, a new embryonic tissue, the mesoderm, appears between the ectoderm and endoderm in the late gastrula stage. It is the purpose of the present chapter to present an account of the histological structure of the principal tissues of a vertebrate animal. It should be remembered that the tissues reviewed develop from the three primary germ layers as indicated. Histologists usually *classify* tissues, however, from a *physiological* rather than from an *embryological* point of view. We shall study tissues from the structural and functional point of view. Histologists divide the tissues of the body into five main types, namely, (*a*) Epithelium; (*b*) Connective; (*c*) Muscular; (*d*) Nerve; (*e*) Blood and Lymph.

A. Epithelium (Fig. 313 *A*). Some varieties of this tissue are similar to embryonic ectoderm and endoderm. It is derived, however, from all three embryonic tissues. Epithelium forms membranes covering the external surface of the body or forms a lining of cavities or tubes within the body. In Invertebrates the "skin," or epithelium covering the surface of the body, consists of one layer of cells. In the earthworm, these form a non-cellular external layer called the *cuticle*. In Mollusca, this epithelial layer secretes the *calcareous shell* and in Arthropoda, it forms the *chitinous* exoskeleton. The following types of epithelial cells occur in the Vertebrates but are not necessarily limited to them.

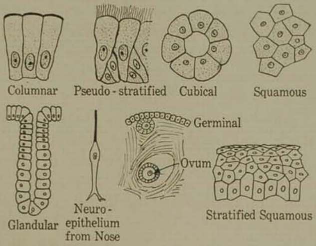

Fig. 313 *A*. — Types of epithelial cells.

1. *Columnar*. These cells are tall and columnar in shape. They are located side by side, forming one layer, the long axis of the cell being perpendicular to the surface of the membrane. This type of epithelium forms the lining of the stomach, small and large intestines. Absorption of digested food compounds by the columnar epithelium of the intestine is one of the functions of this epithelium.

2. *Cubical*. This cell is about as tall as it is wide and thick, or, in other words, it is cubical in shape. Portions of the tubules of the kidney and the vesicles of the thyroid gland and parts of the ducts of glands are composed of cubical cells.

3. *Squamous*. These cells are flat or scaly in form. The nucleus may appear as a slight bulge in the center of the flat cell. Squamous cells form the coelomic surface lining of the peritoneum and the exposed surface membranes of the mesentery and the lining membrane of the heart and blood vessels. These cells form the walls of capillaries and also the surface membrane on the outside of the digestive tract and are well adapted to the gentle movements of the viscera against one another since they are well lubri-

cated. In the blood vessels they are adapted to the smooth flowing of blood. They also form the walls of the air sacs of the lung, where they are adapted to diffusion of respiratory gases.

4. *Glandular.* In the intestinal tract, some of the columnar cells are specialized to form goblet-shaped accumulations of mucus which swell the cells. The secretion is discharged from the free surface into the lumen of the intestine. Such *goblet cells* are *unicellular* glands. On the other hand, the *glands* connected with the digestive tract are formed by evaginations of the intestinal endoderm during embryonic development. These glands vary in complexity from simple to compound types. In the mucous membrane of the small and large intestine are simple tubular glands; in the skin of the frog are simple alveolar glands; in the mucous membrane of the stomach the simple tubular excretory ducts receive secretions from several glandular branches. The kidney is an exceedingly complex compound-tubular gland as are also the salivary glands and pancreas. The mammary gland and the lungs are compound alveolar glands. The secreting cells of many glands are *polyhedral* in form although they were derived from an embryological columnar type. The cells of the gland ducts retain the original form, being cubical or columnar in type, or the larger ducts may possess a few layers of epithelial cells.

5. *Neuro-epithelium.* The rods and cones of the retina are sensory cells derived from embryonic ectoderm and are modified columnar cells. In the epithelium of the mucous membrane of the nose are found modified columnar epithelial cells which are the sensory cells of smell. Somewhat similar shaped cells occur in *taste buds*, the sensory end-organs of taste, located in the epithelium of the tongue. The sensory cells described are connected with the peripheral ends of afferent (sensory) nerve cells.

6. *Germinal.* The surface of the ovary is covered with a layer of cubical-shaped cells. From this layer, the ova are derived. The testis consists of tubules which contain cells from which, by a complicated process of spermatogenesis, the spermatozoa are produced.

7. *Stratified Squamous.* Not all epithelium consists of but one layer of cells, as indicated in the above types. The *epidermis* of the skin and the lining of the mouth, covering of the tongue, lining of the oesophagus and of the anus possess a many-layered epithelium, called *stratified squamous.* The deepest layer consists of

living cells somewhat columnar in shape. These cells possess the power of division. At each division, one of the daughter cells remains in the basal layer and grows to adult size and will later divide again. The other cell is pushed out of the basal layer into the next outer layer. Continued division, growth and migration of basal cells results in cells being constantly pushed out further and further from the basal layer, so forming the *strata* which vary in number in different localities. The outer and older cells gradually lose their vitality and become horny and mere scales (squamous) at the surface, where contact with external objects frees them. Callous skin formed on the hands as a result of physical labor is a number of layers of dead outer epidermal cells which protect the softer tissues within. Stratified squamous epithelium is always forming and always being worn away. It is one of the most important protective tissues of the body. With intact epidermis we can walk or can lift objects without pain. The accidental removal of a portion of epidermis reveals the degree with which healthful epidermis serves its purpose. It keeps out pathogenic Bacteria with which the surface of the body, and especially the hands, is constantly coming in contact. It prevents the rapid loss of water from the connective tissues beneath it. It contains no blood vessels although these are present in the connective tissue on which it rests.


FIG. 313 *B*.—Pseudo-stratified epithelium. Photomicrograph by Cooper.

8. *Pseudo-stratified.* The superficial cells of this epithelium are columnar in type. The free surfaces are usually ciliated. The inner ends taper to a narrow process which extends to the basement membrane. Between the narrow basal ends of these long cells are smaller tapering cells of varying length, but *their* inner ends also extend below to the basement membrane. This type of epithelium has a stratified appearance but differs from stratified squamous in that *all* cells extend to the basement membrane. Ciliated pseudo-stratified epithelium forms the lining membrane of the trachea and its larger branches (Fig. 313 *B*).

Attention has already been called to the importance of an intact epithelium. Accidental destruction of a small area of stratified-squamous epithelium is usually easily repaired, due to formation of new cells from the basal layer — a process which goes on at all times. But when the simple columnar epithelium of the intestine or the squamous epithelium of the air sacs of the lung is injured to any extent, its repair takes place slowly and with difficulty because replacement is dependent upon division of cells on the borders of the lesion, and cell division in this type of epithelium is normally not so active as in the first case mentioned.

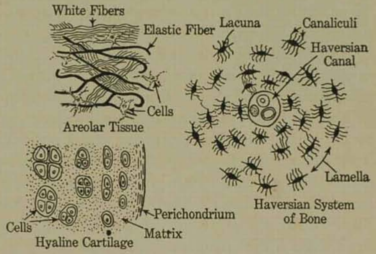

FIG. 314. — Connective tissues.

B. Connective Tissue (Fig. 314). Such a variety of tissues is found in this group that only a brief characterization is possible. Epithelium consists chiefly of cells, but in connective tissues the cells are few and often widely separated, and produce a great amount of intercellular substance which is the predominant part of connective tissue, and the connective or sustentative function of this type is served by the intercellular material. These tissues develop from mesoderm.

1. *Loose Fibro-elastic* or *Areolar Connective* tissue is one of the most common types. It consists of four structures. (*a*) *White fibers* are fine tissue threads arranged side by side in *bundles* which present a wavy appearance. The bundles branch, thus forming a network. They consist of an albuminous-like compound which when boiled yields *gelatin.* They are easily digested and are soluble in weak acids and alkalis. They are non-elastic. (*b*) *Elastic fibers* are fine, isolated branching tissue threads. They appear to be always somewhat stretched because on breaking the ends curl up and the pieces recoil. They are not readily digested by gastric juice and are not soluble in dilute acids or alkalis nor do they yield gelatin on boiling. They confer elasticity to areolar

tissue while the white fibers contribute strength to it. (*c*) In between the meshes of areolar fibers is *tissue juice*. This is a watery, colorless fluid or lymph. It consists of material derived from capillaries and from the cells of neighboring tissues. (*d*) *Connective tissue cells*. There are several varieties of these. Blood leucocytes are also present. (See Lymph, p. 371.) Areolar tissue connects the skin to the structures beneath it; it forms the supporting framework of the muscles, digestive tract, blood vessels, glands and other organs. If all the other tissues of the body were dissolved, leaving only the areolar tissue framework, there would still be left quite a complete model of the body and all its organs.

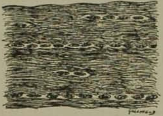

Fig. 315. — Longitudinal section of tendon.

2. *Dense Fibrous Tissue* (Fig. 315). A tendon is a strong cord of connective tissue connecting a muscle to a bone. Bundles of white fibers are arranged longitudinally and packed *closely together* with flat cells between the parallel bundles. A tendon is almost entirely dense white fibrous tissue. Thin *sheaths* of dense white fibrous tissue also form the covering of such organs as the liver, kidney and testis.

3. *Dense Elastic Tissue.* The principal unit of this tissue is the elastic fiber noted above. These form long, parallel, compact bundles separated from each other by thin investments of white fibrous tissue. They form a strong elastic cord such as the *ligamentum nuchae*, which is an important structure of support for the heavy head of a quadruped.

4. *Adipose Tissue* (Fig. 316). This is popularly known as 'fat.' The word 'fat' should be used to designate the principal chemical compound of adipose tissue. Adipose tissue consists of groups of fat cells which are held together by fibrous tissue. Fat droplets appear in connective tissue cells. The droplets increase in number, fuse and form a large globule of fat, which distends the cytoplasm so that it is but a mere film with the nucleus at some point in it. Adipose tissue commonly accompanies areolar tissue and is noted in the subcutaneous tissue, and around the mesentery, kidneys, adrenals and heart. When fat is used up in

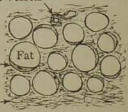

Fig. 316. — Adipose tissue.

the metabolism of starvation, the cells resume an appearance much like that of the original connective tissue cell from which they originated. Osmic acid stains fat black.

5. *Cartilage* (Fig. 314) is a firm, supporting, connective tissue. It has a solid ground substance called the matrix in which the cells are distributed. Cartilage has no blood vessels or nerves. There are three varieties: (*a*) Hyaline cartilage is found in the trachea and larger bronchial tubes, and at the ends of long bones. It forms the cartilaginous part of the nose and larynx and connects the ribs to the breastbone. The matrix is a clear, translucent, intercellular ground substance. The cells occur in little spaces called lacunae. A single cell in a lacuna may divide, forming two daughter cells in the same lacuna. Each daughter cell may then form matrix so that the two gradually grow apart. Sections of hyaline cartilage show single separate cells and cells in groups of two to eight. Cartilage is surrounded by a special dense-fibrous membrane called *perichondrium.* The side of the perichondrium next the cartilage plate has many small cells from which new superficial matrix is developed. (*b*) Elastic cartilage. This is hyaline cartilage in which the matrix is further specialized by the inclusion in it of elastic fibers, although the superficial layer is purely hyaline in character. Around it is a fibrous perichondrium. It forms the skeleton of the external ear. (*c*) Fibrocartilage. This type is a combination of hyaline cartilage and dense white-fibrous tissue. It has no perichondrium. It forms buffer-like pads between the vertebrae of the backbone and is found elsewhere.

Perichondrium connects cartilages to the surrounding connective tissues. It contains blood vessels, lymphatics and nerves. The nourishment of cartilage is derived from the blood vessels of the perichondrium.

The skeleton of Elasmobranchs is entirely of cartilage. Many of the bones of the higher vertebrates are preformed in cartilage, which is replaced by bone during development.

6. *Bone* (Fig. 314). This is a more rigid connective or supporting tissue than cartilage, which is not firm enough to be the skeletal framework of animals moving about on the land. However, transition from water to terrestrial life did not cause the change from cartilage to bone since the latter forms the skeleton of teleost fishes.

Flat bones, such as those of the face and top of the skull, are formed from embryonic membranes and hence are called *membrane bones.* The bones of the limbs, on the other hand, and many other bones of the skeleton are preformed in cartilage and hence are known as *cartilage bones.*

Flat bones present an outer and inner superficial layer of compact bone. The narrow region between is occupied by spongy bone, the spaces of which are occupied by marrow. The *long bones* possess a cylindrical shaft of compact bone surrounding a marrow cavity. At either end of such a long bone are the *epiphyses* or ends, each of which has a superficial thin layer of compact bone and an internal portion composed of spongy bone, the spaces of which are filled with red marrow. The epiphyses of long bones are capped with hyaline cartilage forming the *articular cartilages.*

The shaft of a long bone consists of a series of *lamellae* or bony layers. Four types of these are present. (*a*) The greater part of the substance of the shaft consists of several *Haversian systems* running lengthwise of the shaft. Each Haversian system consists of several concentric *lamellae.* In the center of each system is an Haversian canal about 0.07 mm. in diameter. In life it is occupied by blood vessels, nerves, lymphatics, marrow cells and connective tissue. Surrounding the central canal are concentric Haversian lamellae. Within and between each lamella are many small spaces called *lacunae.* From each lacuna, microscopic canals called *canaliculi* radiate out in all directions and communicate with canaliculi of lacunae of adjacent lamellae. In life each lacuna is occupied by a bone cell which has fine processes, each of which projects into a canaliculus. The Haversian canals extend parallel with each other lengthwise of the shaft, but also branch to connect with neighboring Haversian canals. Branches extend to the outer surface of the shaft and also to the marrow cavity so as to permit the entrance of blood vessels and nerves, which extend throughout the entire system of Haversian canals. (*b*) The spaces between adjacent Haversian systems are occupied by *interstitial lamellae,* which are incomplete Haversian lamellae but similar in structure. (*c*) Adjacent to the marrow cavity are *internal circumferential lamellae.* (*d*) Externally just within the outer surface are a few *external circumferential lamellae* which are also similar in structure to the Haversian lamellae.

The surfaces of bones, with the exception of the epiphyses which are capped with articular cartilages, are covered with a close-fitting, dense, fibrous sheath called the *periosteum.* It supports blood vessels and nerves. In young and growing bones, in the inner portion of the periosteum are many small bone-forming cells called osteoblasts. In older bone this inner portion contains less of these cells. However, if a portion of bone is destroyed, sufficient bone-forming cells are present in the periosteum to repair the loss. Lining the marrow cavity is a delicate fibrous layer similar to the periosteum.

Bone marrow consists of a very fine fibrous connective tissue containing fat cells, blood vessels, bone-forming cells and special marrow cells. There are two varieties of marrow, *yellow* and *red.* The yellow marrow is largely fat tissue. The red marrow contains a small amount of fat but more blood vessels, blood cells and marrow cells. In older bones, the shaft is occupied by yellow marrow but the red or embryonic type of marrow persists in the epiphysial portions and possesses the cells from which the blood cells are formed in adult life.

C. Muscle Tissue. This is the special contractile tissue of animals. It is derived from mesoderm. The following types of muscle tissues are distinguished.

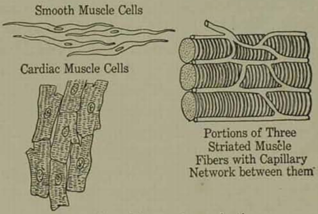

FIG. 317. — Types of muscle tissue.

(1) *Smooth* or *Plain Muscle* (Fig. 317). It is composed of long, tapering cells each possessing an elongated nucleus in the middle and thicker portion of the cell. These cells are arranged alongside one another. In vertebrates the cells are closely connected with one another and masses of them are held together by a delicate fibrous connective tissue. The cells are from 50 μ to 500 μ in length. When contracted, they are shorter and thicker. In the vertebrate they are involuntary. In the vertebrate intestine there is a cylindrical layer of smooth muscle cells arranged lengthwise of the tube. Toward the lumen is a second cylindrical layer whose cells are arranged at right angles to the length of the tube. Contraction of the first or outer layer causes a shortening of the intestine

at the point of contraction. Contraction of the inner muscle layer causes a decrease in the size of the lumen of the intestine at that point. But both layers contract in concert, and moreover, contraction at any point initiates a contraction in the region just beyond. The result is a contraction wave preceded by and followed by a local relaxation. Wave after wave succeed each other, constituting what is known as *peristaltic contraction.* In the intestine, this movement mixes food and enzymes, aids chemical action in digestion, aids absorption and keeps the contents of the intestine moving. The walls of arteries and veins, vas deferens, oviducts, ureters and bladder all possess layers of smooth muscle compounded with connective tissue.

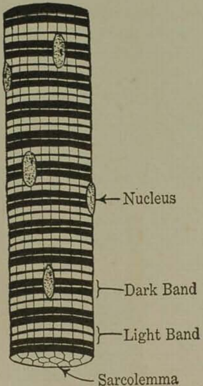

FIG. 318. — Portion of a striated muscle fiber.

(2) *Striated* or *Voluntary Muscle.* This forms the greater part of skeletal muscles which, with the skeleton, forms a great part of the locomotor mechanism. The histological unit of striated muscle is not a single cell, but a syncytium of cells forming a long, slender, microscopical rod-like unit called a muscle fiber. It is from 50 mm. to 130 mm. in length and from 10 μ to 100 μ in diameter. The striated muscle fiber (Figs. 317 and 318) is so-called because of the *alternating light* and *dark* transverse bands to be observed even in living muscle. There is an outer delicate sheath called the sarcolemma, the representative of the original cell membrane of the myoblast or embryonic cell from which the fiber developed. Within the fiber are long thread-like elements called *sarcofibrils,* imbedded in a more fluid *sarcoplasm.* Many nuclei occur along the fiber toward the surface. Capillaries occur between adjacent fibers, these being connected by branches to form a network. Finger-like peripheral ends of motor nerves terminate among striated muscle fibers, forming *motor end plates.* The peripheral ends of sensory (afferent) nerve also end around smaller, modified muscle fibers constituting sensory end organs of the

muscle sense. When a muscle fiber contracts, it becomes shorter and thicker and the differences in length of all the fibers are evident in the contraction of the muscle as a whole.

(3) *Cardiac Muscle* (Fig. 317). This type of muscle tissue is restricted to the heart. The vertebrate heart is composed of oblong-shaped cells whose ends branch, and these connect with other cells forming a network of interconnected parallel fibers, contain long fibrils and are also cross striated. The cell membranes are not present, so that cardiac muscle is a *syncytium.* A nucleus is in the center of each cytoplasmic cell mass. By the contraction of cardiac muscle the chambers of the heart are decreased in size and due to the presence of valves, blood is effectively *pumped* from auricles to ventricles and from the latter to the great aorta and pulmonary artery. The action of cardiac muscle is rhythmical, vigorous, powerful, up to the mark and unceasingly at work as long as life lasts. Its intrinsic action does not appear to be dependent upon motor nerve impulses, which is true of voluntary muscle.

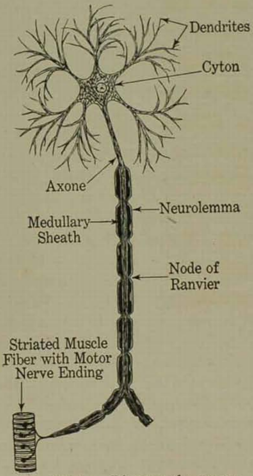

FIG. 319 *A*. — Diagram of a neuron.

D. **Nerve Tissue.** The general function of nerve tissue is to conduct impulses from sense organs to muscles or glands and its importance as an agent of adjustment has been emphasized. Nerves, spinal cord and brain are derived from ectoderm.

The Neuron. The histological unit of nerve tissue is called a neuron (Fig. 319 *A*). It is a highly specialized cell of which there are many varieties. A typical nerve cell or neuron possesses (*a*) a cell body containing a nucleus surrounded by cytoplasm. This portion of the neuron is called the *cyton.* (*b*) Extending from it are short, thick, irregular and branching processes called *dendrites* and (*c*) a long, single, thread-like process or *axone*. In general, the function of the dendrites is to pick up nerve impulses from the terminals of another neuron. The cell body is the center of metabolic activities of the entire neuron and probably amplifies impulses aroused in it by impulses from a connecting cell. The axone conducts these impulses to another neuron or possibly to a motor end plate in a muscle. The cytoplasm of the cell body contains a network of fine fibers imbedded in a more fluid neuroplasm. Mitochondria are present in it also. In addition, other bodies called Nissl granules are present. They exhibit modifications in different physiological and pathological conditions more than any other neuron structures. The dendrites resemble the cytoplasm of the cyton in structure. The axone consists of long fine neurofibrils arranged parallel with one another and imbedded in a fluid neuroplasm. The neurofibrils are continuations of the fibril system of the cyton.

Medullary Sheath. Within the brain and spinal cord, the axones are invested with a *medullary sheath* composed of a fatty substance called *myelin*. If the axones pass out from the central system to form a nerve, they possess a thin nucleated sheath called the *neurolemma,* which is outside the myelin. At regular intervals along the axone, the medullary sheath is constricted, forming the nodes of Ranvier. It is suggested that the axone is nourished from the outside at these points, some of which are at a comparatively long distance from the cyton.

Nerve Fiber. The axone and its covering is called a nerve fiber. Medullated axones vary in diameter from 2 μ to 20 μ. Some are very long. For example, cytons located in the spinal cord in the lumbo-sacral region have axones extending in nerves down the legs to the toes, *i.e.*, over 1,000,000 μ long. It is difficult to realize that such exceedingly fine thread-like processes are parts of a single cell, the nucleus of which is *far away* from the end portions of the axone. The proof of this required long, patient research, of which two contributions will be noted.

Golgi devised a method of technic in which silver chromate or some other silver salt forms a precipitate in the nerve cell, coloring all parts of the neurons black but not staining other substance. When rather thick sections are thus prepared, nerve cells or portions of them are clearly and definitely visible (Fig. 319 *B*). The study of successive sections indicates the connection between cyton and axone.

More recent than the work of Golgi is that of Harrison, who demonstrated that axones and dendrites *grow out* of the nucleated portion of an embryonic nerve cell. Near the peripheral end, the axone branches, and thus forms its terminal arborization. If this is within the brain or spinal cord, it is in contact with the dendrites of another neuron into which it conveys its impulse. The connection between the two cells is one of *contact* and is called a *synapse*. Impulses pass over neurons in one direction, *i.e.*, dendrites to cyton and from cyton to axone. The nervous system is an orderly but exceedingly complex organization of connecting neurons.

FIG. 319 *B*. — Photomicrograph of a pyramidal (motor) cell in cerebral cortex— Golgi technic. The triangular body is the cyton, branches are dendrites, — axone not shown. Photo by Cooper.

Divisions of Nervous System. The nervous system is divided into (*a*) the central system, composed of the brain and spinal cord; (*b*) the peripheral system, composed of the cranial and spinal nerves; and (*c*) the sympathetic system. Peripheral nerves are white cords containing nerve fibers (*i.e.*, axones with their sheaths) and bound together and covered with connective tissue. Their cytons are for the most part within the brain and spinal cord. The sympathetic system consists of a set of fine nerves supplying especially the organs of the abdominal and thoracic cavities. Associated with these nerves are ganglia. These are small enlargements containing cytons and so are locations where synapses of neurons occur outside the central system. The brain and spinal cord are composed of gray and white matter. The gray matter contains cytons, dendrites and portions of axones originating in the cytons present in it. White matter consists of masses of medullated axones. The gray matter of the cerebellum and cerebrum forms a thin external layer or cortex, while most of the body of these two parts of the brain consists of white matter. The cortex is about 2.5 mm. thick and that of the cerebrum contains several zones of cytons distributed at different levels throughout its thickness. Strong says that there are probably ten billion cytons in the cortex of the cerebrum alone. The cortex of the human brain has an area of over 200,000 sq. mm. Such a great expanse can be accommodated within the confines of the skull, because the cortex is arranged in a series of foldings or convolutions. The indicated connections between neurons is more marvelous than their numbers.

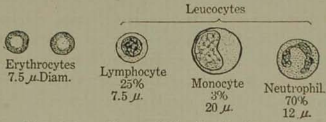

Fig. 320. — Types of blood cells (human).

E. Blood (Fig. 320) has often been called a tissue. It originates from embryonic mesoderm and consists of plasma and cells.

Plasma. This is a fluid, which is studied by chemical rather than by histological technic because it consists of water, salts, respiratory gases, sugars, fats, proteins, enzymes, hormones, vitamins as well as urea and other wastes of metabolism.

Cells. Blood transports special and unique cells. There are two kinds.

(*a*) *Erythrocytes, or Red Blood Cells.* The red blood cells of Vertebrates, except Mammals, are flat, oval-shaped and nucleated discs. The blood cells of Mammals are not nucleated although they arise from cells that are nucleated. Human red blood cells are thin biconcave discs about 7.5 μ in diameter. Each cubic centimeter of male human blood contains in health about 5,000,000 erythrocytes per cu. mm. and female human blood contains about 4,500,000 per cu. mm. In the adult, erythrocytes are formed by a series of mitoses from cells in the red marrow of flat bones and at the ends of long bones. Each red blood cell has a somewhat greasy external membrane inclosing the substance of the corpuscle. One of the important compounds of this is hemoglobin, a protein-iron compound having a chemical affinity for oxygen. The function of red blood cells is to carry oxygen from the lungs to the tissues. They also probably carry a certain amount of carbon dioxide back to the lung membranes. Normal plasma has a concentration equivalent to a 0.9% solution of sodium chloride and is *isotonic* with the saline concentration of the corpuscle. Ashby states that red blood cells have an average life of about thirty days. After they are produced in the red marrow, erythrocytes enter the blood stream, where they remain until functionless. It is thought that one function of the spleen is to remove these worn-out red cells from circulation and to destroy them. It is also believed that their iron is conserved.

(*b*) *Leucocytes, or White Blood Cells.* They are fewer than erythrocytes, averaging about 8,000 per cu. mm. of blood. There are several varieties of these cells. (1) Lymphocytes. These are round cells about the size of an erythrocyte or a little larger. They have a very large nucleus with a small outer ' rind ' of cytoplasm. They form about 20% of the leucocytes, are amoeboid but are not phagocytic. They are formed in lymph glands, spleen and red bone marrow. (2) Monocytes. These are large cells about 18 μ in diameter, have a large kidney or horseshoe-shaped nucleus, are remarkably phagocytic and constitute about 5% of the leucocytes. (3) Neutrophils. They are about 10 μ in diameter. The finely granular cytoplasm stains lilac color with a combination of eosin and methylene blue dyes. They are amoeboid and actively phagocytic. They make powerful proteolytic enzymes which act inside or outside them. They are chemotactically attracted to injured or infected tissues and are found in pus. The nucleus occurs in sausage-like links. They are the most numerous of the leucocytes, constituting between 60% and 70% of these cells. (4) Eosinophils form about 3% of the leucocytes and are about 12 μ in diameter. They are amoeboid but not phagocytic. The coarse granules have an affinity for eosin (acid dye). (5) Basophils are about 10 μ in diameter and are very few in number (0.5%). The nucleus has a variety of shapes. The coarse granules stain with basic (methylene blue) dyes. (6) Platelets. These are very small bodies about 3 μ in diameter. The presence of a nucleus is problematical as is also the question of their origin. It is thought that in cases of bleeding they liberate *thrombin,* the enzyme so essential to the clotting of blood. (7) Megakaryocytes. Although not found in circulating blood, they should be considered in the study of blood. They are giant cells, being from 30 μ to 100 μ in diameter. They are not found, therefore, in circulation, but are found in the blood of red bone marrow. They are regarded as large lymphocytes but non-phagocytic. They may have a very large nucleus, having sausage-like pieces, or these may occur separately. Some of the cells have pseudopodia-like processes.

Lymph. This is a colorless fluid present in tissues. Physiologically it is the middleman between blood vessels and tissue cells.

Water, salts, foods, etc., pass out from blood vessels into it and cells absorb these as needed from it. Cells discharge their wastes of metabolism into it. It is chiefly returned to the large veins in the neck by a special system of lymphatic vessels. From the veins, it again enters the general circulation. The chemical nature of lymph will not be considered here. A histological study of lymph involves a study of its special cells. These are lymph corpuscles and are recognized as blood leucocytes. Most of the cells are *lymphocytes* which are formed in the many lymph glands through which lymph flows in its circulation in the lymphatic vessels on its way to the heart. Lymph contains fat droplets and animal starch, glycogen. When an animal is fed on fat, the latter is absorbed from the intestine a few hours later. If the abdominal cavity is then opened, the lymph channels in the mesentery appear as milky cords because they contain so many droplets of fat. The circulation of lymph is in one direction, namely, *toward the heart.* In order to return from the tissue spaces, it enters the peripheral ends of small lymphatic vessels.

Tissue Construction of Organs

The various organs of the body are constructed of the different tissues just described. Some organs contain a predominance of some *one* of the five enumerated. In some organs all kinds of tissues are represented more or less equally. The following examples illustrate this organization.

(1) **Blood Vessels.** (*a*) Capillaries. These are minute tubes forming a network. The walls are composed of flat, squamous, epithelial cells. (*b*) Arteries vary in size but are larger than capillaries. They are lined with the same type of squamous epithelium that forms the entire capillary wall but have in addition outer layers of smooth muscle and fibro-elastic connective tissue. The walls of the larger branches have blood vessels of their own, and nerves. (*c*) Veins are similar in tissue composition to arteries, but the amount of smooth muscle and connective tissue is less. In veins and arteries, therefore, we find represented epithelium, connective tissue, muscle tissue, nerve tissue and blood.

(2) **Oesophagus** (Fig. 321). The histologic structure of the entire gastro-intestinal tract is similar in general but differs in details. The oesophagus, for example, is connected to the adjacent structures of the neck by fibrous connective tissue. Within this

is a zone of muscle. In the upper part of the oesophagus this is striated, while toward the stomach it is smooth muscle. Within the zone of muscle is a zone of fibro-elastic connective tissue forming the submucous coat, and within this is the mucous membrane. The mucous membrane consists first of an external thin coat of smooth muscle, then a *tunica propria* of fibro-elastic tissue, and on this is stratified squamous epithelium, forming the lining coat, *i.e.*, the internal wall of the lumen. Connective tissue and muscle are quite equally distributed in the oesophagus and the epithelium is prominent.

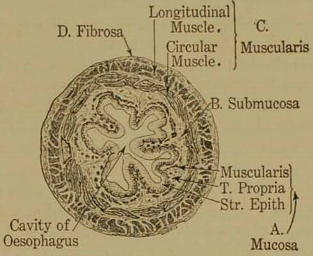

FIG. 321. — Cross-section, oesophagus of cat.

(3) **Pancreas.** The location of the pancreas has already been indicated. (*a*) The pancreas is a compound tubular-alveolar gland that secretes enzymes concerned in digestion of food in the digestive tract. All the cells concerned in producing and discharging the secretions are epithelial cells. The secretions formed pass through the duct system into the duodenum. (*b*) The pancreas also contains patches of modified epithelial cells forming the Islands of Langerhans. These are surrounded by capillaries. The Islet cells secrete a hormone into the blood. This hormone governs the metabolism of sugar elsewhere. Connective tissue sheaths support the lobes and lobules of the pancreas. The connective tissues support nerves, blood vessels and lymphatics. The pancreas is predominantly epithelial.

(4) **The bony framework** of the body is chiefly connective tissue, namely, bone. But many of the bones are covered with a fibrous periosteum and the ends of long bones are covered with hyaline cartilage. Moreover, bones are penetrated by blood vessels and nerves. So all types of tissues are present in bones.

(5) **Skeletal muscles** are anatomical organs. The chief tissue composing them is striated (voluntary) muscle fibers. But these are *harnessed* in sheaths of fibro-elastic connective tissue. There is first an external covering sheath of this called the epimysium.

Extensions of this pass within, forming bundles of fibers separated from each other by similar connective tissue sheaths called *perimysium.* Finer extensions of the *perimysial* tissue pass in between the individual fibers. The connective tissues support blood vessels and nerves.

(6) **Spinal Cord** (Fig. 322). It is located in the spinal canal of the vertebral column. It is *almost* divided into two lateral halves by a *dorsal septum* and a *ventral fissure.* The two halves are united by a commissure. In this commissure is located the spinal canal which communicates with the ventricles of the brain. A

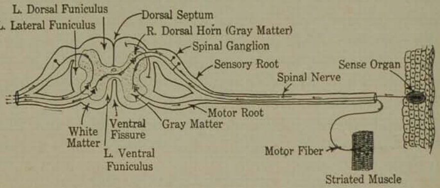

FIG. 322. — Diagram showing structure of spinal cord and connection of a spinal nerve with it. Structures involved in a simple reflex also shown.

study of a typical cross-section of the cord shows the above features. In addition we can see the central or inner *gray matter* surrounded by *white matter.* The gray matter has the appearance of a broad letter " H " or " X." The two dorsal expansions of gray matter are the *dorsal horns* and the two ventral expansions are the *ventral horns.* Tissue from each horn extends beyond the cord at intervals to form the *dorsal* and *ventral roots* of the spinal nerves originating at that level. On the dorsal root is a *spinal ganglion.*

The white matter occurs in three masses or *funiculi* on either side. (1) The (two) *dorsal funiculi* are located on either side of the dorsal septum and medial to the dorsal horns. (2) There is a *ventral funiculus* on *either side* of the ventral fissure and medial to the ventral horns. (3) There is a *lateral funiculus* on either side of the cord between the dorsal and ventral horn of that side. The funiculi are composed of nerve fibers extending lengthwise of the cord. The fibers of the dorsal funiculi carry afferent impulses up the cord, while the ventral fibers carry efferent impulses down the cord. The lateral funiculi contain groups of afferent fibers and groups of efferent fibers. It has been ascertained that the fibers of the funiculi are arranged in well-defined fiber tracts, carrying certain groups of impulses from certain stations to certain other stations. The nerve fibers involved are chiefly the axones of neurons and are parts of pathways extending from peripheral sense organs to the cord and up this to the brain and from this back down the cord and out to muscles or glands.

The gray matter of the cord contains cytons, their dendrites and axones arising from cytons. Let us consider some of these. Cytons located in the ventral horns have axones which pass out via the ventral nerve roots into the spinal nerve. Other cytons in the gray matter have axones which turn out into the funiculi and extend up or down the cord. Axones extend from one horn across the commissure to the horn on the other side. Some neurons are confined entirely to the gray matter. Axones from the dorsal roots extend into the dorsal horns.

(7) **Spinal Nerve.** Let us now study the histology of a spinal nerve. The dorsal and ventral roots meet just outside the cord (Fig. 322). The ventral root contains only motor fibers. The dorsal root contains sensory or afferent fibers. But there is an enlargement on the dorsal root called a *spinal ganglion*. This is chiefly an assemblage of somewhat pear-shaped cytons from which one process arises. But this process almost immediately divides into two. One of these, the *peripheral* process, extends out into the spinal nerve, while the other *central* process extends into the dorsal horn. (*a*) The central process within the dorsal horn has a branch which continues in the gray matter and forms a synapse with a motor cell in the ventral horn. Another branch may connect with a cyton whose axone extends across the commissure and out into the lateral funiculus of the cord and up in this to higher neurons. Another branch may enter the dorsal funiculus. (*b*) The peripheral branch of the ganglion cell extends out in the spinal nerve and ends, for

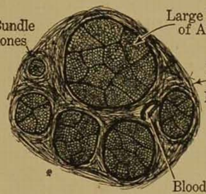

Fig. 323. — Cross-section of a small nerve.

example, in a peripheral sense organ of touch. The roots form the nerve.

The spinal nerve (Fig. 323) is a cable whose component elements are afferent *and* efferent nerve fibers. The entire nerve, its roots and the spinal ganglion are invested with a fibrous connective tissue sheath called the *epineurium*. From this extensions pass into the nerve, forming bundles of nerve fibers separated from each other by connective tissue sheaths (*perineurium*). The connective tissue extends also in between the individual fibers. The supporting connective tissue contains blood vessels and even nerves.

(8) **Brain.** We shall discuss this in general terms only. From a histological point of view it contains internal nerve centers which resemble ganglia in being assemblages of cytons and their processes, where connections are made with neurons carrying impulses from above or from below. The greater mass of the brain is composed of *white matter* or, in other words, conducting fibers. In the cerebrum and cerebellum, the *gray matter* forms an external rind or *cortex*, which has already been explained. The entire nervous system is a very complicated system of pathways, forming many simple reflex mechanisms, many complex reflex mechanisms and many more so complicated or involved that they can hardly be called reflex mechanisms. The number of neurons involved in a reflex varies. One of the simplest involving the cerebrum, consists of three neurons between the peripheral sense organ and the cortex of the cerebrum, one or more association neurons conducting the impulse to a motor neuron in the cortex; and this cell carries the impulse down the cord, where its end branches form a synapse with a motor cell of a spinal nerve.

The brain and spinal cord are inclosed in the *meninges*, which are three membranes of connective tissues, namely (*a*) dura mater; (*b*) arachnoid membrane; (*c*) pia mater.

(*a*) The *dura mater* is the outermost of these coats. Its outer face is in close contact with the inner face of the bony cavities in which the brain and cord are located. The outer part of the dura is similar to periosteum. The dura is composed of fibrous connective tissue and is richly supplied with lymphatic vessels but not many blood vessels.

(*b*) The *arachnoid* is a thin membrane between the dura and pia. It is delicate areolar tissue. Between the arachnoid and the pia is the subarachnoid space filled with lymph-like cerebro-spinal fluid.

(c) The *pia mater* closely invests the cord and brain, entering all the fissures, and extends even into the substance of these organs, carrying blood vessels with which it is well supplied.

It is evident therefore that although the nervous system is composed chiefly of nerve tissue, nevertheless the other types of tissue are present.

Selected References

Böhm, A. A., and von Davidoff, M. A. *Text Book of Histology.* W. B. Saunders, Phila.

Bremer, J. L. *Text Book of Histology* (Lewis and Stöhr). P. Blakiston's Son and Co., Phila.

Dahlgren and Kepner. *Principles of Animal Histology.* Macmillan Co., N. Y.

Jordan, H. E. *Text Book of Histology.* D. Appleton & Co., N. Y.

Piersol, G. *Text Book of Normal Histology.* Lippincott, Phila.

Schäfer, Sir E. *Essentials of Histology.* Lea and Febiger, N. Y. and Phila.

Bailey, Strong and Elwyn. *Text Book of Histology.* William Wood & Co., N. Y.